5.2.1 Pressure Regulating Control

Pressure regulating is the process of maintaining a difference of pressure between two points in a system. One type of pressure regulating maintains a definite pressure in one part of the system, while the other part fluctuates or changes within certain limits. An example of this type of control is a pressure-regulator valve that maintains a definite pressure on the discharge side of the valve by controlling the flow of steam, air, or gas through the valve (*Figure 9-19*).

A second type of regulator maintains a definite difference in pressure between two points and also controls the flow. This type of regulator is often applied to a boiler feeding to maintain a fixed difference between the pressure of water supplied at the feed valve and the pressure in the boiler steam drum. The pressure regulator may consist of a self-contained device that operates the regulating valve directly, or it may consist of a pressure-measuring device, such as a Bourdon-tube gauge, that operates a pilot or relay valve. The valve positions the regulating valve or mechanism to maintain the desired conditions.

Figure 9-19 — Pressure regulator.

Pressure controls are designed primarily for steam-heating systems but are also available for controlling air, liquids, or gases that are not chemically injurious to the control (*Figure 9-20*). The function of the pressure control is as follows:

- To control the pressure in the boiler.
- To secure the fuel-burning equipment when the pressure reaches a predetermined cutout.
- To start the fuel-burning equipment when the pressure drops to the cut-in point.

Figure 9-20 — Pressure control.

There are two settings on the pressure control—the cut-in point and the differential. To find the cut-out point, you add the differential to the cut-in pressure;

Cut-in point + Differential = Cut-out point

for example, when you are operating a boiler with a cut-in pressure of 90 pounds and a differential of 13 pounds, the cut-out pressure should be 103 pounds. When you encounter excessive vibrations, mount the pressure control remotely from the boiler on a solid mounting with a suitable piping connection between them. When you use a mercury type of switch control, be sure that it is mounted level and that the siphon (pigtail) has the loop extending in the direction of the back of the control and at a 90 degree angle to the front, as shown in *Figure 9-18*. This position prevents expansion and contraction of the siphon from affecting the mercury level and accuracy of the control. Additionally, when you install any pigtail, ensure the tube is filled with water. The water will prevent hot steam from contacting the control.

The pressure control can be mounted either on a tee along with the pressure gauge on the pressure-gauge tapping, as shown in *Figure 9-21*, or it can be mounted on the low-water cutout provided by some manufacturers. In either case, be sure that the pipe dope does NOT enter the control. The procedure you should follow is to apply the dope to the male threads, leaving the first two threads bare.

Figure 9-21 — Typical steam gauge installation.

5.3.0 Combustion Control

Combustion control is the process of regulating the mixed flow of air and fuel to a furnace as necessary to supply the demand for steam. A modulating pressuretrol controls the movement of the modutrol motor which in turn opens or closes the oil valve and air shutters to adjust the rate of firing to suit the demands of the boiler.

A modulating motor consists of the motor windings, a balancing relay, and a balancing potentiometer (*Figure 9-22*). The loading is transmitted to the winding through an oil-immersed gear train from

Figure 9-22 — Modulating motor.

the crank arm. The crankshaft is the double-ended type, and the crank arm may be mounted on either end of the motor. The motor works with the potentiometer coil in the modulating pressuretrol. An electrical imbalance is created by pressure change signals to the pressuretrol. This causes the motor to rotate in an attempt to rebalance the circuit. The crank arm, through linkage, positions the burner air louvers and the oil regulating valve, maintaining a balanced flow of air and oil throughout the burner firing range.

Another process of controlling combustion air is to use a manually adjusted air damper. A centrifugal blower, mounted on the boiler head and driven by the blower motor, furnishes combustion air. A definite amount of air must be forced into the combustion chamber to mix with the atomized oil to obtain efficient combustion. In operation, a pressure is built up in the entire head and the secondary air is forced through a diffuser to mix thoroughly with the atomized oil as combustion takes place.

The combustion airflow diagram in *Figure 9-23* shows a cutaway view of those components that influence most the path of the air through the burner assembly. Air is drawn into the motor-driven blower through the adjustable air damper at (A) and forced through openings (B) into the air box. Sufficient pressure is built up to force the air through openings (C) and the diffuser (D). In the area immediately beyond the diffuser (D), combustion is completed. The hot gaseous products of combustion are forced on through the remaining three passes, where they give up a large portion of the contained heat to the water which completely envelopes the passes.

Figure 9-23 — Airflow diagram.

The rate at which combustion air is delivered can be changed by throttling the intake to the blower by opening or closing the air damper to obtain the exact rate of airflow required for complete combustion. Since the rate at which fuel is delivered is predetermined by the design and is not readily adjustable, setting of the air damper is the only means of obtaining the correct ratio of fuel to air to ensure the most efficient combustion.

A pressure-regulating valve is built into the pump that controls the fuel. The fuel pump contains a two-stage gear-type pump, a suction strainer, a pressure-regulating valve, and a nozzle cutoff valve, all assembled in a single housing (*Figure 9-24*). There are many other types of fuel pumps, this is just one example.

Figure 9-24 — Fuel oil pump.

You can gain knowledge of the functional relationship of the component parts by studying the internal oil flow diagram shown in *Figure 9-25*.

Figure 9-25 — Internal oil flow diagram.

Observe that the two-stage fuel unit consists essentially of two pumps operating in tandem and arranged in a common housing. The first stage develops a pressure below the atmospheric pressure level at its inlet that causes the oil to flow from storage or supply to the strainer chamber reservoir. All air drawn into the unit rises to the top of this chamber. This air and excess oil are drawn into the first-stage-pumping element and pumped back to the fuel oil storage tank. The second stage withdraws air-free oil from the strainer chamber reservoir and raises the oil pressure to that required for proper atomization at the burner nozzles. The second stage, operating against a combination pressure regulating and nozzle cutoff valve, develops atomizing pressure because of the flow restriction imposed by this valve. The pressure-regulating valve also bypasses excess second-stage oil back to the bottom of the strainer chamber reservoir. The atomizing pressure can be varied within a restricted range by adjustment of the spring-loaded pressure-regulating valve. Normal atomizing pressures generally range between 95 and 120 pounds per square inch.

An orifice is included in the fuel line to the main oil burner (*Figure 9-25*). The orifice serves to keep the oil pressure from experiencing a sudden drop when the solenoid oil valve in that line opens. The orifice is commonly built into the solenoid oil valve (*Figure 9-25*, Item 1). Included in the schematic diagram is a photocell (3) which, if it sights no flame, reacts to cause a switching action that results in shutting down the burner.

5.4.0 Flame Failure and Operational Controls

Frequently on fully automatic boilers, you will find an electronic type of device provided for the control of flame failure. The device provides automatic start and operation of the main burner equipment. Some controls are designed to close all fuel valves, shut down the burner equipment within 4 seconds after a flame failure, and actuate an alarm. Some controls also create a safety shutdown within 4 seconds after de-energization of ignition equipment when the main burner flame is not properly established or fails during the normal starting sequence. These controls must create a safety shutdown when the pilot flame is not established and confirmed within 7 seconds after lighting. A safety shutdown requires manual reset before operation can be resumed and prevents recycling of the burner equipment.

6.0.0 INSTRUMENTS and METERS

A pressure gauge is essential for safe operation of a boiler plant. However, the use of additional instruments, such as flowmeters and draft gauges, increases safety and promotes efficiency. All of these instruments may be either indicating or recording.

6.1.1 Steam Flowmeters

A UT must be able to identify the different types of monitoring instruments and understand their operation and use. Meters used to measure quantities are divided into two general types:

1. Those indicating rate, such as flowmeters
2. Those indicating the total, such as scales

Many devices are designed to measure and indicate the pressure of steam flow. One of these devices is shown in *Figure 9-26*. This meter uses a weighted inverted bell (called a Ledoux bell) sealed with mercury. The bell moves up and down as the rate of flow changes. The movement is transmitted to a pen that records the flow.

Figure 9-26 — Flowmeter.

6.2.0 Steam and Air Flowmeters

A combustion air and steam flowmeter is shown in *Figure 9-27*. This meter is used as a guide in controlling the relationship between air required and air actually supplied to burn the fuel. The rate of steam generation is used as a measure of air necessary to burn the required amount of fuel. The flow of gases through the boiler setting is used as a measure of air supplied.

The essential parts of the meter are two airflow bells supported from knife-edges on a beam, which is supported by other knife-edges, and a mercury displacer assembly supported by a knife-edge on the beam. The bottoms of the bells are sealed with oil, and the spaces under the bells are connected to two points of the boiler setting.

Figure 9-27 — Airflow mechanism of a boiler air flowmeter.

6.3.0 Draft Gauges

A draft gauge is a form of pressure gauge. In boiler practice, the term “draft” usually refers to the pressure difference producing the flow. Drafts are pressures below atmospheric pressure. They are measured in inches of water. A draft gauge is essential to boiler operation. Its use increases the safety of operation.

A simple type of draft gauge is the U-tube gauge. The source of draft is connected to one leg of the U and the other end is left open. The difference between the levels of the liquid in the two legs is a measure of the draft. Water is generally used in this type of gauge. Take a close look at *Figure 9-28*, which shows a comparison of an inclined-draft gauge and a U-tube gauge.

When one leg of the U tube is arranged on an incline, the distance moved by the liquid in the inclined portion is increased for a given draft change, which makes more accurate reading possible.

Two or more draft gauges are required for economical boiler operation. The gauges inform the operator of the relative amount of air being supplied to burn the fuel and the condition of the gas passages. Draft gauges are made as indicators, recorders, or both. The measuring element uses a column of liquid, a diaphragm, or a ***bellows***. The liquids used are oil, water, or mercury.

Figure 9-28 — Comparison of inclined-draft gauge and U-tube gauge.

The gauge shown in *Figure 9-29* is an indicating type that operates on the same principle as the U tube (the difference between the levels of the liquid in the two legs is a measure of the draft).

Figure 9-29 — Liquid sealed draft gauge.

The bottom of the inverted bell is sealed with oil or mercury, depending on the magnitude of the draft or pressure to be measured. It is supported by knife-edges on the beam to reduce friction as much as possible. The weights counterbalance the weight of the bell, and the pointer is returned to zero. The source of draft is connected to the tube, which projects into the inverted bell, so an increase in draft causes the pointer to move down.

6.4.0 CO2 Meters (Analyzers)

Figure 9-30 shows one type of carbon dioxide meter. The meters are also known as analyzers and are designed for determining, indicating, and recording the percentage of CO_2 (carbon dioxide) in the products of combustion. The principle of this instrument is based on the fact that the specific weight of flue gas varies in proportion to its CO_2 content (CO_2 being considerably heavier than the remaining parts of the flue gas).

Figure 9-30 — CO2 meter (analyzer).

Test your Knowledge (Select the Correct Response)

3. The bottom of the inverted bell of the liquid sealed draft gauge is sealed with which substance?

   A. Water
   B. Sand
   C. Oil
   D. Steam

7.0.0 BOILER WATER TREATMENT and CLEANING

A UT must understand the methods, tests, and safety precautions involved in boiler water treatment and the procedures for cleaning boiler firesides and watersides. To ensure a boiler operates at peak efficiency, you must treat and clean it. Water testing, treatment, and cleaning go hand-in-hand. The reason for this is because the effect of the impurities in the water on interior surfaces determines the method and frequency of boiler cleaning. In this section, we will discuss the relationships between water testing, treatment, and cleaning, and the procedures for each.

7.1.0 Water Impurities

All natural waters contain acid materials and scale-forming compounds of calcium and magnesium that attack ***ferrous*** metals. Some water sources contain more scale-forming compounds than others; therefore, some waters are more corrosive than others. Subsurface or well waters are generally more scale-forming, while surface waters are usually more corrosive. To prevent scale formation on the internal water-contacted surfaces of a boiler and to prevent destruction of the boiler metal by corrosion, chemically treat feedwater and boiler water. This chemical treatment prolongs the useful life of the boiler and results in appreciable savings in fuel, since maximum heat transfer is possible with no ***scale*** deposits.

7.2.0 Scale

Crystal clear water, satisfactory for domestic use, may contain enough scale-forming elements to render it harmful and dangerous in boilers. Two such scale-forming elements are ***precipitates*** of hardness and silica.

Scale deposited on the metal surfaces of boilers and auxiliary water heat- exchange equipment consists largely of precipitates of the hardness ingredients—calcium and magnesium and their compounds. Calcium sulfate scale is, next to silica, the most adherent and difficult to remove. Calcium and magnesium carbonates are the most common. Their removal requires tedious hand scraping and internal cleaning by power-driven wire brushes. When deposits are thick and hard, the more costly and hazardous method of inhibited acid cleaning must be used. Scale deposits are prevented by the following methods: removal of calcium and magnesium in the feedwater to the boiler (external treatment); chemical treatment of boiler water (phosphate, organic extracts, etc.); and changing scale-forming compounds to form soft non-adherent sludge instead of scale that can be easily removed from the boiler by blowdown (internal treatment).

Silica in boiler feedwater precipitates and forms a hard, glossy coating on the internal surfaces. In the feedwater of high-pressure boilers, such as those used in electric generating plants, a certain amount of silica vaporizes under the influence of high pressure and temperature. The vapor is carried over with steam and silica deposits on the intermediate and low-pressure blading of turbines. In boilers operating in the range of 10- to 125-psig pressure, the silica problem is not so troublesome. When the water is low in hardness, contains phosphate that prevents calcium silicate scale from forming, or has enough alkalinity to keep the silica soluble, no great difficulty is encountered. The amount of soluble silica can be limited by continuous or routine boiler blowdown to prevent buildup of excessive concentrations.

7.3.0 Corrosion

Corrosion control occurs with the problem of scale control. Boilers, feedwater heaters, and associated piping must be protected against corrosion. Corrosion results from water that is acidic (contains dissolved oxygen and carbon dioxide). Corrosion is prevented by removing these dissolved gases by ***deaeration*** of feedwater, by neutralizing traces of dissolved gases in effluent of the deaerating heater by use of suitable chemicals, and by neutralizing acidity in water with an alkali.

7.4.0 Methods of Treatment

The specific method of chemical treatment used varies with the type of boiler and the specific properties of the water from which the boiler feed is derived. In general, however, the chemical treatment of feedwater and boiler water is divided into two broad types or methods--external treatment and internal treatment of makeup water for alkalinity control and for removal of scale-forming materials and dissolved gases (oxygen and carbon dioxide) before the water enters the boiler. Internal treatment means that chemicals are put directly into the boiler feedwater or the boiler water inside the boiler. Frequently, both external and internal chemical treatments are used.

External treatment, frequently followed by some internal treatment, often provides better boiler water conditions than internal treatment alone. However, external treatment requires the use of considerable equipment, such as chemical tanks, softening tanks, filters, or beds of minerals, and the installation costs are high. Such treatment is therefore used only when the makeup water is very hard or very high in dissolved minerals, or when internal treatment by itself does not maintain the desired boiler water conditions. The dividing line between the hardness and the concentration of dissolved matter in water are factors that are taken into consideration when you look at the physical makeup of the plant, the type and design of the boilers used, the percentage of makeup water being used, the amount of sludge the boiler can handle, the space available, and the adaptability of the operators. Many methods of internal treatment are in use. Most of these treatments use carefully controlled boiler water alkalinity, an alkaline phosphate, and organic material. One of the organic materials used is tannin. Tannin is a boiler water sludge ***dispersant***, that is, it makes precipitates more fluid and prevents their jelling into masses that are difficult to remove by blowdown. Because of treatment costs and simplicity of chemical concentration control, the alkaline phosphate-tannin method of internal treatment is perhaps the most widely used. When properly applied and controlled, this treatment prevents formation of scale on internal boiler surfaces and prevents corrosion of the boiler tubes and shell.

7.5.0 Boiler Water Testing

As we have just seen, boiler water must be treated with chemicals to prevent the formation of scale on the internal surface of the boiler and to prevent deterioration of the boiler metal by corrosion. Boiler water must be tested to determine the sufficiency of chemical residuals to maintain clean boiler surfaces. As a UT, you should be able to make various boiler water tests. The procedures for a few types of tests that you may have to make are given here—tests for hardness, phosphate, tannin, caustic alkalinity (with and without tannin), sodium sulfite, and pH. A test kit is provided for the different tests. Each test kit contains the equipment and materials for the specified test. If a kit is not available, you have to use the laboratory equipment provided in the boiler or water treatment plants (*Figures 9-31* and *9-32*).

Figure 9-31 — General laboratory equipment.

Figure 9-32 — General laboratory equipment.

CAUTION

The following caution applies to each test that is discussed: If the testing procedures of the equipment and/or reagent supplier differs from that prescribed in this text, the supplier's procedure should be used.

7.5.1 Test for Hardness

Boilers operating at pressures of 15 psi and less are normally used for space heating and hot-water generation. Practically all the condensate is returned to the plant. Only a small amount of makeup is required, and secondary feedwater treatment usually is sufficient. When appreciable quantities of steam are used in process work and not returned as condensate to the plant, the problem of scaling and corrosion arises, and more complete treatment of feedwater must be considered. The ideal water for boilers does not form scale or deposits, does not pit feedwater systems and boiler surfaces, and does not generate appreciable CO_2 in steam. However, such raw makeup water is impossible to get in the natural state from wells or surface sources. Does the advantage of treatment make up for the cost of treatment?

Feedwater of 20- to 25-ppm hardness as calcium carbonate ($CaCO_3$) need not be treated externally to reduce hardness if enough alkalinity is present to precipitate the hardness in the boiler as $CaCO_3$, or if hardness reducers, such as phosphates, are introduced to combine with and precipitate the hardness. Precipitation of this hardness in a low- or medium-pressure boiler generally does not cause wasteful blowdown. When the mixture of condensate and makeup in a medium-pressure steam plant has a hardness greater than 20 to 25 ppm as $CaCO_3$, the hardness should be reduced to a level of 0 to 2 ppm as $CaCO_3$.

Feedwater of a hardness in excess of 2 ppm as $CaCO_3$ should be treated to bring it within the range of 0 to 2 ppm as $CaCO_3$. This small remaining hardness can be precipitated in the boiler by secondary treatment and removed by continuous blow-off equipment.

The test for hardness, as presented here, uses the calorimetric titration method. This test is based on finding the total calcium and magnesium content of a sample by titration with a sequestering agent in the presence of an organic dye sensitive to calcium and magnesium ions. The end point is a color change from red to blue, which occurs when all the calcium and magnesium ions are separated.

The following equipment is used for the hardness test:

- One 25-ml buret, automatic, complete
- One 210-ml casserole, porcelain
- One 50-ml cylinder, graduated
- One stirring rod, glass

The ***reagents*** for the test are as follows:

- Hardness indicator
- Hardness buffer
- Hardness titrating solution

The steps of the hardness test are as follows:

1. Measure 50 ml of the sample in the graduated cylinder and transfer it to the casserole.
2. With the calibrated dropper, add 0.5 ml of the hardness buffer reagent to the sample, and stir.
3. Add 4 to 6 drops of hardness indicator. If hardness is present, the sample will turn red.
4. Add the hardness titrating solution slowly from the burette, and stir continually. When approaching the end point, note that the sample begins to turn blue, although you can still see a definite reddish tinge. The end point is the final discharge of the reddish tinge. Adding more hardness titrate solution does not produce further color change.

In using this procedure, add the hardness titrating solution slowly because the end point is sharp and rapid. For routine hardness determination, measure 50 ml of the sample, but add only approximately 40 to 45 ml to the casserole at the start of the test. The hardness buffer reagent and the hardness indicator should then be added as directed and the mixture titrated rapidly to the end point. The remaining portion of the sample should then be added. The hardness in the remainder of the sample will turn the contents of the casserole red again. Titrating is continued slowly until the final end point is reached. A record should be kept of the total milliliters of hardness titrating solution used.

To calculate the results in ppm hardness, use the following equation:

$$\text{ppm hardness} = \text{ml titrating solution x 1,000 } (CaCO_3)\ (\text{ml sample})$$

With a 50-ml sample, the hardness in ppm as $CaCO_3$ is equal to the ml of titrating solution used, multiplied by 20.

7.5.2 Test for Phosphate

The calorimetric test for phosphate uses a decolorizing carbon to remove tannin. Carbon absorbs the tannin, and the carbon and tannin are then filtered out. When tannin is not present, carbon improves the test for residual phosphate by making the tricalcium phosphate sludge more filterable.

The equipment required for the phosphate test is as follows:

- One phosphate color comparator block of two standards—30 ppm and 60 ppm of phosphate as PO_4. (The Taylor high-phosphate slide comparator may be used instead.)
- Four combination comparator mixing tubes, each marked 5, 15, and 17.5 ml, with stoppers
- One filter funnel, 65-mm diameter
- One package of filter paper, 11 cm in diameter
- One 20-ml bottle
- One 0.5-ml dropper
- One 1/4-tsp measuring spoon or spatula
- Two plain test tubes, 22 mm by 175 mm (about 50 ml)
- Two rubber stoppers, No. 3 flask
- One 250-ml glass-stoppered bottle or flask, labeled comparator molybdate reagent

The reagents you need are as follows:

- One 32-oz comparator molybdate
- One 2-oz concentrated stannous chloride
- One 32-oz standard phosphate test solution (45 ppm of phosphate, PO_4)

One pound decolorizing carbon. (This is a special grade of decolorizing carbon tested to make sure it does not affect the phosphate concentration in the sample.)

For test purposes, the stannous chloride is supplied in concentrated form. The reagent must be diluted and should be prepared from the concentrated stannous chloride on the day it is to be used, because the diluted solution deteriorates too rapidly for supply by a central laboratory. If not fresh, diluted stannous chloride gives low test results. Concentrated stannous chloride also deteriorates and should not be used if more than 2 months old.

The procedure for making diluted stannous chloride is as follows:

1. Fill the 1/2-ml dropper up to the mark with the concentrated stannous chloride.
2. Transfer it to a clean 20-ml bottle.
3. Add distilled water up to the shoulder of the bottle, then stopper and mix by shaking.

CAUTION

Any diluted stannous chloride not used the day it is made should be discarded.

The following procedure is used to make the test for phosphate:

1. Without disturbing any settled sludge, transfer enough of the sample to the test tube to till it about half full.
2. Add 1/4 tsp of decolorizing carbon. Stopper the tube and shake vigorously for about 1 minute. The carbon absorbs the tannin so it can be filtered out.
3. Fold a filter paper and place it in the filter funnel. Do not wet down the filter paper with water. Filter the shaken sample, using a combination mixing tube as a receiver. The carbon absorbs tannin, and the tannin and sludge present are filtered out more rapidly. Avoid jiggling the funnel, as unfiltered boiler water may overflow the edge of the filter paper into the tube. You have to support the funnel.
4. After 5 ml of the sample has filtered through, as indicated by the level in the tube, discard it. Continue filtering to bring the level in the test tube again up to the 5-ml mark. The sample should come through clear and free, or nearly free, of any color from the tannin. If it is not nearly free of tannin color, repeat the test using 1/2 tsp of carbon, adding it in two 1/4-tsp portions, and shaking it for 1 minute after each addition.
5. Add the comparator molybdate reagent to bring the level up to the second mark (15 ml). Stopper and mix by inverting the tube several times.
6. Add fresh diluted stannous chloride up to the third mark (17.5 ml). Stopper and mix by inverting. If phosphate is present, the solution in the mixing tube turns blue.
7. Place the tube in the comparator block. Compare the color of the solution in the tube with the standard colors of the phosphate color block. Colors between the two standard colors may be estimated. Take the reading within 1 minute after adding the stannous chloride, because the color fades quickly.
8. Record the results as LOW, if below 30 ppm; HIGH, if above 60 ppm, or OK, if between 30 and 60 ppm.

7.5.3 Test for Tannin

The purpose of the tannin test is to determine the amount of tannin in the boiler water. Tannin holds sludge in suspension. In treating boiler water with tannin, control the dosage by the depth of brown formed in the boiler water by the tannin. To estimate the depth of the color, which is necessary in adjusting tannin dosages, compare a sample of the boiler water with a series of brown color standards of successively increased depths of color. A tannin color comparator, which is used for the comparison, has five glass color standards: No. 1, very light; No. 2, light; No. 3, medium; No. 4, dark; and No. 5, very dark.

The kit for the tannin test contains the following:

- One tannin color comparator
- Two square tubes, 13-mm viewing depth
- One plain test tube, 22 mm by 175 mm
- One filter funnel, 65 mm by 65 mm

- One package of filter paper, 11 cm in diameter

You first fill a plain test tube almost to the top with cool boiler water. Then place a square test tube in the slot of the comparator, and insert the filter funnel in it. Fold a filter paper and place it in the funnel without wetting it down. Filter water from the plain test tube into the square tube until the tube is neatly full. Remove the square tube from the comparator and hold it up to a good source of natural light. Note the appearance of the filtered boiler water. Is it free of suspended solids and sludge? If not, refilter the sample, using the same funnel and filter paper. Repeat, using a double filter paper if necessary, until the sample does come through free of suspended solids and sludge.

To complete the test, place the square tube of filtered sample in the middle slot of the comparator. Then compare the color of the sample with the five standards, viewing it against a good source of natural light. The color standard most closely matching the color of the filtered sample gives the tannin concentration of the boiler water. For a number of boiler water conditions, the tannin dosage is usually satisfactory if it maintains a medium (No. 3) tannin color. If the tannin color is too high, blow down; if too low, add tannin.

7.5.4 Test for Caustic Alkalinity (OH) without Tannin

The boiler water sample for this test is collected at a temperature of 70°F or below.

The equipment required is as follows:

- Two 8-in. droppers with bulbs
- Two 250-ml glass-stoppered bottles or flasks labeled ***causticity*** No. 1 and causticity No. 2
- Four marked test tubes, 22 mm by 185 mm
- Three plain test tubes, 22 mm by 175 mm
- Three rubber stoppers, No. 2
- One 14-in. test-tube brush
- One test-tube clamp
- Two 9-in. stirring rods
- One 1-oz indicator dropping bottle for phenolphthalein
- One test-tube rack

The following reagents also are required:

- One 24-oz bottle or flask causticity reagent No. 1
- One 24-oz bottle or flask causticity reagent No. 2
- One 4-oz bottle phenolphthalein indicator

The following are the steps to follow in conducting a test for causticity when tannin is not used:

⚠ CAUTION ⚠

Avoid exposure of the sample to the air as much as possible to reduce absorption of the CO_2.

1. Without disturbing the settled sludge, fill a marked test tube exactly to the first mark (25 ml) with some of the original boiler water sample.

2. Shake causticity reagent No. 1 (barium chloride solution saturated with phenolphthalein) thoroughly and add enough to the graduated tube to bring the level exactly to the second, or long, mark (30 ml).
3. Stir the solution with the 9-inch stirring rod, which must be kept clean and reserved for the causticity test only. When the mixture remains colorless or does not turn pink, the causticity in the boiler water is zero and the test is finished. When the mixture turns pink, causticity is present. (If the pink color is not deep, intensify it by adding two drops of phenolphthalein indicator to the mixture in the tube.) Add causticity reagent No. 2 (standard one-thirtieth normal acid), using the 8-inch dropper; thatch must be kept clean and reserved for the causticity test only. Causticity reagent No. 2 is sucked from the reagent bottle into the dropper by its rubber bulb and added, drop by drop, to the test tube. After each addition, stir the mixture with a stirring rod. After sufficient reagent has been added, the pink color disappears; the change point is usually sharp. As soon as the pink color just fades out, stop adding the reagent.
4. The amount of causticity reagent No. 2 required to make the pink color disappear shows the concentration of hydroxide (OH) or causticity in the boiler water. The amount of reagent used is shown by the marks on the test tube above the long mark (30 ml). The distance between any two marks on the test tube equals 5 ml, and readings less than 5 ml can be estimated. For example, when only three fifths of the distance between the long mark and the next mark above were filled, then 3 ml was added. When the distance filled was past one mark plus three fifths of the distance to the next, then 5 + 3 = 8 ml was used. To obtain the actual ppm of hydroxide or causticity shown by the test, multiply the number of ml by 23. This constant number, 23, represents the amount of sodium hydroxide in the boiler water by volume. Thus, for 8 ml of causticity reagent No. 2, there are 8 x 23 = 184 ppm hydroxide or causticity in the water.
5. Record the results of the test in a boiler log or chemical log and adjust the range to meet requirements. When causticity is too high, blow down; if too low, add sodium hydroxide (caustic soda).

7.5.5 Test for Caustic Alkalinity (OH) with Tannin

For this test, start with a warm sample of about 160°F. It may be reheated by placing the sample-collecting container in a stream of hot boiler water drawn through the boiler water cooler connection. In a test for causticity when tannin is used, make sure you observe the same precautions as carefully as when tannin is not used.

CAUTION

Avoid exposure of the sample to the air as much as possible to reduce absorption of the CO_2.

The equipment and reagents required for this test are the same as those listed in the preceding section where tannin was not used.

The procedure for conducting a test for causticity with tannin is as follows:

1. Fill two test tubes to the first mark (25 ml) with some of the original boiler water sample, taking care not to disturb the settled sludge in the container. (Transfer as little sludge as possible from the sample-collecting container to the test tubes.)
2. Shake causticity reagent No. 1 thoroughly and add enough to each of the two marked tubes to bring the levels up to the second, or long, mark (30 ml). Stir both

with the stirring rod, which must be kept clean and reserved for the causticity test only.

3. Stopper both tubes and let them stand until any sludge formed has settled to the bottom. The sludge carries down with it much of the tannin or other colored matter in the solution; settling takes a few minutes if the sample is warm.
4. Without disturbing the sludge at the bottom, pour enough solution from the tubes into the third marked tube to fill it to the second, or long, mark. Discard the mixture left in the first two. When the sample in the third tube is still warm, cool it by letting cold water run on the outside of the tube. It is sometimes possible to intensify the pink color by adding two drops of phenolphthalein from the indicator-dropping bottle to the sample in the tube. Stir the solution. When it is not pink, the causticity in the boiler water is zero.
5. When the sample is not pink, the test is finished. But if the mixture turns pink, proceed in the same manner as directed in Steps 3, 4,and 5 when no tannin is used.

Here is a brief explanation of an alternate procedure for making the test for causticity when tannin is used. In this procedure any glass container, such as a large test tube or graduated cylinder, marked for 50 to 60 ml can be used instead of the two standard marked test tubes used in Steps 1 and 2 above. With the large test tube or graduated cylinder, the warm (160°F) sample is added up to the 50-ml mark and causticity reagent No. 1 up to the 60-ml mark. Stir the mixture and stopper the tube, or graduate. After the sludge settles, pour off enough of the solution into one of the standard marked test tubes to fill it to the long mark (30 ml). When the sample is warm, cool it by letting cold water run on the outside of the tube. Adding two drops of phenolphthalein may intensify the pink color. When the solution is not pink, the causticity in the boiler water is zero. But if it turns pink, proceed in the same manner as in Steps 3, 4, and 5 when no tannin is used.

7.5.6 Test for Sodium Sulfite

The sample for this test should be cooled to 70°F, or below, and exposed to the air as little as possible, because oxygen in the air combines with sodium sulfite in the sample and causes low readings. Collect a separate sample, using the boiler water sample cooler, with the line reading to the bottom of the sampling bottle. Allow the boiler water to run until a few bottlefuls overflow to waste.

The equipment necessary to make the sodium sulfite test is as follows:

- One 30-ml acid-dropping bottle, with dropper marked at 0.5 ml for hydrochloric acid 3N
- One 30-ml starch-dropping bottle, with dropper marked at 0.5 ml for starch indicator
- One 150-ml beaker
- One stopper for plain test tube
- One stirring rod
- One 8-in. dropper
- One 1/4-tsp measuring spoon
- One 50-ml beaker

- Two plain test tubes
- Two marked test tubes

The reagents required are as follows:

- One 2-oz bottle of potato or arrowroot starch
- One 8-ml vial of thymol
- One 24-oz bottle of hydrochloric acid 3N
- One 1-pt amber bottle of standard potassium iodate-iodide reagent

The starch indicator for this test must be prepared locally. The procedure to adhere to for good results is as follows:

1. Measure out a level 1/4 tsp of potato or arrowroot starch and transfer it to the 50-ml beaker.
2. Add a few milliliters of distilled water and stir the starch into a thick paste, using the end of the stirring rod.
3. Put 50 ml of distilled water into the 150-ml beaker. (It is convenient in this step to have the 150-ml beaker marked at the point where it holds 50 ml, or one of the marked test tubes can be used by filling it with distilled water to the fourth mark above the long mark.)
4. Bring the water in the 150-ml beaker to a boil by any convenient method.
5. Remove the source of heat and immediately pour the starch paste into the boiling water while stirring the solution.
6. Put a crystal of thymol into the starch solution and stir. After the solution has cooled, pour off any scum on the surface and transfer 30 ml to the indicator-dropping bottle.
7. The starch solution loses its sensitivity as an indicator after a time. Addition of the thymol preserves it for about 2 weeks. The starch should be dated when prepared.

In making the sodium sulfite test, proceed as follows:

1. Transfer 1 ml of hydrochloric acid 3N to a clean, marked test tube by measuring out 0.5-ml portions with the dropper of the acid-dropping bottle.
2. From the starch-dropping bottle, transfer 0.5 ml of starch to the marked test tube.
3. Without disturbing any settled sludge in the sample, pour enough of the sample into the marked test tube to bring the level up to the first mark (25-ml). Stir the mixture in the tube with the plunger end of the stirring rod.
4. To add the standard potassium iodate-iodide reagent to the mixture in the marked test tube, have the marked test tube supported and the stirring rod placed in the tube, so the reagent can be added with one hand while the mixture is stirred with the other. Fill the 8-inch dropper with standard potassium iodate-iodide reagent from the stock bottle by sucking it up with the rubber bulb. (The dropper must be kept clean and reserved for this test only.)
5. Add the reagent to the mixture in the marked test tube, one drop at a time, counting the number of drops and stirring after each is added until a permanent blue color, which is not removed by stirring, is obtained. The standard iodate-iodide reagent reacts with sodium sulfite in the mixture, and the formation of the

permanent blue color from the action of excess reagent with the starch shows that the iodate-iodide reagent has consumed all the sodium sulfite in the mixture.

6. Each drop of iodate-iodide reagent used (except the last one) indicates 5 ppm of sodium sulfite in the boiler water sample. To figure the concentration of sodium sulfite in the boiler water, multiply the total number of drops of the standard iodate-iodide reagent used, less one, by 5. For example, when 5 drops were used, subtract 1 from 5 = 4, 5 x 4 = 20 ppm.
7. Record the results of the test as ppm.

7.5.7 Test for pH

The value of pH indicates the degree of acidity or alkalinity of a sample. A pH of 7.0 represents the neutral point; the lesser values denote acidity; the greater values denote alkalinity. The test is made as soon as possible after you take the sample. Avoid exposure to the air as much as possible to reduce absorption of CO_2.

The following equipment is used in making the pH test of boiler water:

- Two vials of indicator paper, hydrions pH 10 to 20
- Two vials of indicator paper, hydrions C pH 11 to 12
- One 50-ml beaker
- One 2-oz bottle

In conducting the test for pH of boiler water, remove a strip of pH 10 to 12 indicator paper from the vial and dip it into the sample in the beaker. Keep the paper immersed for 30 seconds; then remove it. When the sample does not change the color of the paper or colors it yellow or light orange, the pH of the sample is too low and the test is finished. When the paper turns orange or red, the pH is either satisfactory or too high.

In that case, remove a strip of paper of pH 11 to 12 from the vial and dip it into the sample in the beaker. Keep the paper immersed for 30 seconds; then remove it. When the sample does not change the color of the paper or colors it a light blue, the pH is satisfactory. When the paper turns deep blue, the pH is higher than necessary. Blow down or reduce the dosage of caustic soda (NaOH).

7.5.8 Test for pH of Treated Condensate

In making a test for pH of treated condensate, take the sample from a point in the return piping near which condensation takes place, such as after a trap, or preferably where the return-line corrosion is known to occur. The sample must represent water flowing in the return lines. Water taken from the return tank, especially of large installations, generally shows a higher pH. A sample should not be taken from a collecting tank if other water, such as makeup, is received in the tank.

The equipment required for this test is as follows:

- One 4-oz brown bottle of condensate pH indicator
- One 1-oz indicator bottle, with dropper marked at 0.5 ml
- One 100-ml beaker, marked at 50 ml
- One 9-inch stirring rod, glass

In making a test for pH of treated condensate, proceed as follows:

1. Pour a freshly drawn sample into the testing beaker until it is filled to the 50-ml mark. You do not have to cool the sample.
2. Transfer 0.5 ml of indicator solution to the 50-ml testing beaker, using the marked dropper. Stir the solution in the beaker. If the color of the solution changes to light pink, the sample is NEUTRAL, or slightly alkaline; therefore, the condensate pH is satisfactory and the test is over.
3. Record in a log that the pH range is between 7 and 7.5.
4. When the color change is green, the sample is in the acid range and the boiler water must be treated with Amines. Treat the boiler water with Amines gradually (in small amounts at a time), and retest after each treatment. Amines are the only chemicals used to treat boiler water that will vaporize and leave with the steam and thereby protect the return system.

WARNING

Permission to treat with Amines must be obtained from your supervisor. Amines are volatile, poisonous, and in the alkaline range.

5. When the color change is red or purple, the sample is in an excessive alkaline (pH) range. In that case, reduce the Amines treatment gradually (in small amounts at a single time), and retest after each treatment. Remember, the condensate pH normal acceptable range is between 7 and 7.5.

7.5.9 Test for Total Dissolved Solids

The solu-bridge method is a simple and rapid way to determine the total dissolved solids (TDS) content. Ionizable solids in water make the solution conduct electricity. The higher the concentration of ionizable salts, the greater the conductance of the sample. Pure water, free from ionizable solids, has low conductance and thus high resistance. The solu-bridge instrument measures the total ionic concentration of a water sample, the value of which is then converted to parts per million. The solu-bridge test equipment and reagent are furnished by the supplier in a kit.

CAUTION

The model of the solu-bridge given below is not suitable for measuring solids in condensed steam samples or an effluent of the de-mineralizing process. A low conductivity meter is necessary because of the extremely low solids content of condensed steam and de-mineralized water.

The equipment and reagent are as follows:

- One solu-bridge, Model RD-P4 or equivalent, for a 105 to 120-volt, 50- to 60-cycle ac outlet. (This model has a range of 500 to 7,000 micromhos/cm.)
- One polystyrene dip cell, Model CEL-S2.
- One thermometer, 0°F to 200°F.
- One 0.1-g dipper for gallic acid.
- One cylinder, marked at the 50-ml level.
- Gallic acid powder, 1 lb.
- Calibration test solution, 1 qt.

The test is made as follows:

1. Without shaking, pour 50 ml of the sample into the cylinder. Add 2 dippers of gallic acid powder and mix thoroughly with a stirring rod.
2. Connect the dip-cell leads to the terminals of the solu-bridge and plug the line cord into a 110-volt AC outlet. Turn the switch ON and allow the instrument to warm up for 1 minute.
3. Clean the cell by moving it up and down several times in distilled water. Measure the temperature of the sample to be tested; then set the point of the solu-bridge temperature dial to correspond to the thermometer reading.
4. Place the cell in the cylinder containing the 50-ml sample. Move the cell up and down several times under the surface to remove air bubbles inside the cell shield. Immerse the cell until the air vents on the cell shield are submerged.
5. Turn the pointer of the solu-bridge upper dial until the dark segment of the tube reaches its widest opening.
6. Calculate the result in ppm by multiplying the dial reading either by 0.9 or by a factor recommended by local instructions. For example, when the dial reading is 4,000 micromhos and the factor used is 0.9, then 4,000 x 0.9 = 3,600 ppm.
7. Record the results of the test in ppm.

8.0.0 CLEANING BOILER FIRESIDES and WATERSIDES

Boiler heat transfer surfaces must be kept clean to provide for safe and economical boiler operation. In this section we will describe the methods and procedures involved in fireside and waterside cleaning.

8.1.0 Cleaning Boiler Firesides

Excessive fireside deposits of soot, scale, and ***slag*** cause the following conditions: reduced boiler efficiency, corrosion failure of tubes and parts, reduced heat transfer rates and boiler capacity, blocking of gas passages with high draft loss and excessive fan power consumption, and fire hazards.

Methods for cleaning boiler firesides include wire brush and scraper cleaning, hot-water washing, wet-steam lancing, and sweating.

8.1.1 Wire Brush and Scraper Cleaning

When too much soot is deposited and the passages become plugged, hand lancing, scraping, and brushing are generally used. Special tools required for reaching between the lanes of tubes may be made from flat bars, sheet metal strips cut with a saw-toothed edge, rods, and similar equipment. Some boilers have different sizes of tubes, so you need various sizes of brushes and scrapers to clean the boiler tubes. The brushes or scrapers are fastened to a long handle, usually a piece of pipe, inserted and pushed through the tubes. When you are cleaning the passages, be very careful not to score or gouge the tubes because it can lead to weakening and rupturing of tubes under pressure.

8.1.2 Hot-Water Washing

This method of cleaning is often used to clean super heaters, economizers, and other sections of the steam generator that are difficult or impossible to reach by brushing or scraping. The water may be applied with hand lances and/or boiler soot blowers. Dry out the boiler setting immediately after water washing to reduce damage to the refractory and other parts of the setting.

Safety is always paramount; therefore, always be cautious when washing boiler firesides. Some precautions you should observe are as follows:

- Wet the boiler refractory and insulation as little as possible. Install canvas shields or gutters where possible to reduce wetting of refractories.
- Protect electrical equipment from water damage.
- Provide all necessary instructions and protective equipment for workers.
- Provide a compressed air lance to loosen scale after water washing.
- Provide adequate equipment to heat and pump the hot water. The water should be heated and maintained at a temperature close to about 150°F, because water exceeding this temperature cannot be handled safely and efficiently. However, because cold water does not clean satisfactorily, you have to maintain the water temperature as close as 150 degrees as possible. A water pressure of 200 to 250 psig should be provided at the cleaning lances or soot blowers. The water jets must penetrate the tube banks and strike with enough force to break up the slag accumulations.
- Start the water washing at the top of the unit and work down.
- The unit must be dried out immediately after washing.

8.1.3 Wet-Steam Lancing

The wet-steam lancing method is similar to the hot-water method except that wet steam is used instead of hot water. The steam should be wet and at a pressure of 70 to 150 psig. The unit must be dried out immediately after lancing is completed.

8.1.4 Sweating

Fireside slag can be removed from the convection super heaters by forming a sweat on the outside of the tubes. Cold water is circulated through the tubes, and moisture from the air condenses on the tubes to produce sweat. The hard slag is changed into mud by the sweat, and the mud can be blown off by an air or a steam lance. A large tank filled with water and ice can be used as the cold-water source. Steam can be blown into the area around the tubes during the cold-water circulating period to provide adequate moisture in the air.

8.1.5 eaning Procedures

The procedures for cleaning boiler firesides are as follows:

WARNING

You must wear proper protective equipment when cleaning a boiler. For example, Tyvek ® suits, Eye protection, Respirator, and check with your safety department before entering a boiler.

1. Remove the boiler from service and allow it to cool. Make sure the boiler is cool enough for a person to enter. Someone must be standing by whenever a person is in the boiler. DO NOT force-cool the boiler.

2. Disconnect the fuel line openings. Secure all valves, and chain, lock, and tag all fuel lines to the burner and install pipe caps.
3. Disconnect the electrical wiring. Secure and tag the electrical power to the boiler. Disconnect the burner conduit and wiring. Mark and tag all electrical wiring to ensure proper reinstallation.
4. Open the boiler access doors by loosening all nuts and dogs and swing the door open. Be careful not to damage the refractory door lining.
5. Remove the burner from the boiler openings. Follow the manufacturer's instructions for specified burners. Wrap this equipment with plastic, rags, or other suitable protective coverings. Remember, soot and loose carbon particles must be kept out of the moving parts of the burner because they can cause the burner to malfunction.
6. Provide all spaces with free-air circulation by opening doors and windows, or provide fresh air by mechanical means. An assistant should be stationed outside the opening and be ready at all times to lend a hand or to be of service in case of a mishap.
7. Cover the floor area around the tube ends with drop cloths to catch soot. Position a vacuum cleaner hose at the end of the tube being cleaned. Keep soot from contacting wet areas because soot and water form carbonic acid.
8. Remove tube baffles where possible and pass a hand lance or rotating power cleaner brush through each tube slowly and carefully so no damage occurs to personnel or equipment.
9. Inspect tube surfaces for satisfactory condition before continuing on to the nest tube. Use a drop cord or flashlight for viewing through the entire length of a tube. Wire brush all tube baffles either by hand or use of power tools.
10. Apply a light coat of mineral oil to all cleaned surfaces. To do this, fix an oil-soaked rag to the end of a brush or rod long enough to extend through the tubes, and thoroughly swab each surface, including baffles. Mineral oil is the only lubricant that prevents rusting and also burns off freely without leaving a carbon deposit.
11. Clean all flat surfaces by brushing with the hand or power tools. Make sure that powered equipment is grounded.
12. Use an industrial vacuum cleaner to remove loose soot.

8.2.0 Cleaning Boiler Watersides

Any waterside deposit interferes with heat transfer and can cause overheating of the boiler metal. Where waterside deposit exists, the metal tube cannot transfer the heat as rapidly as it receives it. This causes metal to become overheated so that it becomes plastic in nature which commonly results in bubbles, blisters or ruptures to tube walls.

Waterside deposits include sludge, oil, scale, corrosion deposits, and high-temperature oxide. Except for oil, these deposits are not usually soluble enough to be removed by washing or boiling out the boiler.

The term "waterside corrosion" is used to include both localized pitting and general corrosion. Most, if not all, is probably electrochemical. There are always some slight variations (both chemical and physical) in the surface of boiler metal. These variations in the metal surface cause slight differences in the electric potential between one area of a tube and another area. Some areas are anodes (positive terminals).

Iron from the boiler tube tends to go into solution more rapidly in the anode areas than at other points on the boiler tube. This electrolytic action cannot be completely prevented in any boiler. However, it can be reduced by maintaining the boiler water at the proper alkalinity and by keeping the dissolved oxygen content of the boiler water as low as possible.

The watersides of naval boilers may be cleaned in two ways—mechanically, by thorough wire brushing of all drums, headers, and tubes, and chemically by circulating chemical cleaning solutions through the boiler.

8.2.1 Mechanical Cleaning

Before mechanical cleaning of watersides is begun, the internal fittings must be removed from the steam drum. The fittings (particularly the steam separators and apron plates) must be marked or otherwise identified as to position in the steam drum to ensure their correct reinstallation. All internal fittings must be wire brushed and cleaned before they are reinstalled.

Cleaning the watersides of the generating tubes requires a special tube cleaner. There are several types available, but perhaps one of the most common is the pneumatic turbine-driven tube cleaner shown in *Figure 9-33*.

Figure 9-33 — Boiler tube cleaner (pneumatic turbine-driven type).

This type of cleaner consists of a flexible hose, an air-driven motor, a flexible brush holder, and an expanding wire bristle brush. The turbine-driven motor consists of a set of turbine blades made to revolve when compressed air is admitted through the hose. The turbine-driven motor, in turn, drives the wire brush. There are several sizes of brushes available, *Figure 9-34* shows two views of a brush and a refill.

Before you start cleaning tubes, be sure that adequate ventilation and lighting have been arranged. Someone should also be stationed outside the drum to act as tender and to assist whoever is working in the drum. Keep a written checkoff list of all tools and equipment taken into the watersides and be sure that the same tools and equipment are removed.

With the air shut off, insert the tube cleaner in the tube until the brush is about even with the far end of the tube. Wrap friction tape, a rag, or some other marking material around the hose to show how far the tube cleaner can be inserted without having the brush protrude beyond the far end of the tube. Then remove the cleaner from the tube. Remember that the tubes in each row are the same length; however, the tube lengths vary from row to row. Therefore, separate markings have to be made on the hose for each row of tubes.

Figure 9-34 — Various wire brush sizes.

After the hose has been marked, insert the brush in the tube and turn on the air to start the brush rotating. Pass the brush slowly along the length of the tube until the identifying mark has been reached. Then slowly draw the brush back, withdrawing the cleaner from the tube. You do not have to shut off the air to the tube cleaner each time the cleaner is withdrawn from the tube. However, be sure to steady the brush assembly with your hand to keep the cleaner from whipping. Allowing the brush to whip at either end of the tube is the most common cause of broken tubes.

Establish a new mark for the next row and proceed with the cleaning. Make as many passes as necessary through each tube to ensure adequate cleaning. Be careful not to stop the tube cleaner in any one place in the tube, as the continued rotation of the brush in one place might damage the tube. Be careful, also, to see that the brush and the flexible shaft do not protrude from the other end of the tube, as this may result in a broken shaft.

The tube is most easily cleaned from the steam drum. However, some rows of tubes are not accessible from the steam drum and must be cleaned from the water drum or header. The lower ends of ALL tubes must be cleaned from the water drum or header. You may also find tubes bent so that brushes cannot be forced around the bend without breaking the tube cleaner. These tubes must be cleaned from both ends. Tube cleaners must be kept in good operating condition. The rotor and blades of the air motor should be kept clean and well lubricated. The hose connections should be kept tight and free from leaks. The flexible shafts should be inspected frequently and renewed when they show signs of wear or damage. When the brushes become too worn to work efficiently, a new set of brush refills should be inserted into the brush body. Store tube cleaners in a clean, dry container.

After all tubes, drums, and headers have been cleaned and after all tools and equipment have been removed from the watersides, blow through the tubes with air; then wash out the drums, tubes, and headers with fresh water. Ensure all dirt is removed from the handhole seats. Then examine the seats for scars, pits, or other defects that might cause leakage. All bottom blow, header blow, and test cock valves should be inspected and repaired under the manufacturer's instructions during each waterside cleaning.

After washing, thoroughly dry out the boiler watersides. Inspect the watersides to determine the condition of the metal to see if the cleaning was satisfactory. Also, inspect the boiler to be sure that all the parts are tight. Be sure that all openings between drums and gauge glasses, blow valves, and safety valves are clean and free of foreign matter. These openings are sometimes overlooked.

8.2.2 Chemical Cleaning

In most cases mechanical cleaning is the preferred method for cleaning watersides. Chemical (acid) cleaning requires special authorization since it requires elaborate and costly equipment and rather extensive safety precautions. However, you may have to use the chemical method, so a limited discussion on it is given here.

Inhibited acid cleaning is used to remove mill scale from the watersides of new or recently serviced boilers. When compared with mechanical cleaning, acid cleaning of boilers has the following advantages:

- Less outage time is required
- Less dismantling of the unit
- Lower cost and labor
- More through job accomplished because the acid reaches areas inaccessible to mechanical cleaners
- Increased ability to examine the unit thoroughly for defects, such as cracks and corrosion pitting, because the cleaning is more complete

8.2.2.1 Acids for Cleaning

The following acids are used to clean boilers: hydrocholoric acid, phosphoric acid, sulfamic acid, citric acid, and sulfuric acid.

8.2.2.1.1 Hydrochloric Acid

Hydrochloric acid is most frequently used for boiler cleaning because it has a relatively low cost, and satisfactory inhibitors are available. Also, the chemical reactions of the hydrochloric acid with the boiler deposits usually result in soluble chlorides.

8.2.2.1.2 Phosphoric Acid

Phosphoric acid can remove mill scale from new boilers. With this acid, the boiler can be fired directly without producing noxious or corrosive fumes. Direct firing produces good circulation and distribution of the cleaning solution. Another advantage of phosphoric acid cleaning is that the metal surfaces resist corrosion after cleaning. When cleaned with phosphoric acid, you must protect metal surfaces from surface corrosion during draining and before neutralization.

8.2.2.1.3 Sulfamic Acid

Sulfamic acid is available in a powder that must be placed in solution. The powdered acid is easier and safer to handle than liquid acids in carbons. It does not produce noxious fumes as it dissolves and it is less corrosive than hydrochloric acid, especially at higher concentrations and temperatures.

8.2.2.1.4 Citric Acid and Sulfuric Acid

Citric acid and sulfuric acid are used for removing boiler waterside deposits. Sulfuric acid is economical and easily inhibited. However, a danger is that the sulfuric acid can form insoluble salts such as calcium sulfate.

8.2.2.2 Inhibitors

Without inhibitors, acid solutions attack the boiler metal as readily as they attack the deposits. With the addition of suitable inhibitors, the reaction with the boiler metal is greatly reduced. Inhibitors used include arsenic compounds, barium salts, starch, quinolin, and pyridin. Commercial inhibitors are sold under trade names by various chemical concerns. Other inhibitors are manufactured by companies that furnish complete acid cleaning services.

8.2.2.3 Safety Precautions

When acid cleaning a boiler installation, you must observe safety precautions as follows:

- Before acid cleaning, replace all brass or bronze parts temporarily with steel or steel alloy parts.
- Provide adequate venting for safe release of acid vapors.
- Close all valves connecting the boiler with other piping or equipment.
- Provide competent chemical supervision for the cleaning process.
- Do not exceed the specified acid and inhibitor allowable temperature. The inhibiting effect decreases with the temperature rise and the probability of acid attack of the boiler metal increases.
- After acid cleaning, be sure to thoroughly flush out all of the tubes that are horizontal or slightly sloping. Obstructions in these tubes can cause poor circulation, overheating, and failure of tubes when the unit is placed in service.
- Use goggles, rubber gloves, and rubber aprons when handling acids.
- Slowly pour the acid into the water when mixing the solutions.

⚠ CAUTION ⚠

Never pour water into acid.

- Do not chemically clean boilers with riveted joints.
- During acid cleaning, hydrogen gas can develop through the reaction of the acid on the boiler metal. Some of the generated gas becomes part of the atmosphere inside the boiler, and the remainder is absorbed by the boiler metal, then liberated gradually. Because hydrogen air mixtures are potentially explosive, be careful when opening a unit for inspection after acid cleaning. Until the atmosphere within the boiler pressure parts has been definitely cleared of explosive gases, do NOT use open flames, flashlights, lighting equipment, or anything that might produce a spark near the openings to the pressure parts. Do NOT enter the boiler. The unit can be cleared of explosive gases by thoroughly flushing the unit with warm water with a positive overflow from the highest vent openings. The water temperature should be as near to 212°F as possible to accelerate the liberation of hydrogen absorbed in the metal. After opening the unit, place air blowers at the open drum manholes to circulate air through the

unit. Use a reliable combustible gas indicator to test the boiler atmosphere for explosive mixtures.

8.2.2.4 Acid Cleaning Procedures

Boiler units can be acid cleaned by either the "circulation" or "fill and soak" method. The circulation method can be used to clean units with positive liquid flow paths, such as forced circulation boilers (*Figure 9-35*). The inhibited acid solution is circulated through the unit at the correct temperature until test analyses of samples from the return line indicate that the acid strength has reached a balance and no further reaction with the deposits is taking place. Because the strength of the acid solution can be determined frequently during the cleaning process, this method can be more accurately controlled and can use lower strength solutions than the fill-and-soak method.

Figure 9-35 — Acid cleaning by circulation method.

The fill-and-soak method is used for cleaning units with natural circulation (*Figure 9-36*). The boiler unit is filled with the inhibited acid solution at the correct temperature and allowed to soak for the estimated time. It is not possible to obtain accurate representative samples of the cleaning solution during the soaking period.

8.2.2.5 Flushing and Neutralizing

After acid cleaning, drain and then flush the unit with clean, warm water until the flushing water effluent is free of acid and soluble iron salts.

Figure 9-36 — Acid cleaning by fill-and-soak method.

Next, circulate a neutralizing solution through the unit until the effluent shows a definite alkaline reaction. The types of neutralizing solutions used are as follows: soda ash, trisodium phosphate, sodium tripolyphosphate, or other nontoxic chemicals. After circulation of the neutralizing solution, you can drop the water level to the normal level and fire the boiler at 50 psig with open vents to permit the escape of liberated gases. Finally, drain the boiler again and flush it with clean, warm water.

8.2.3 Boiling Out

New boilers, or boilers that have been fouled with grease or scale, should be boiled out with a solution of boiler compound. New boilers must be washed out thoroughly. The steps required for one method of boiling out are as follows:

1. Dissolve 5 pounds of caustic soda and 1 1/2 pounds of sodium nitrate or 10 pounds of trisodium phosphate for each 1,000 gallons of water the boiler holds at steaming level. Put the mixture into the boiler as a solution. In multiple-drum boilers, divide the charge and put equal amounts in each of the lower drums.
2. Fill the boiler with hot feedwater to the level of the bottom of the steam drum. Turn the steam into the boiler through the usual boiling out connections, or bottom blow, and allow the boiler to fill gradually to the top of the gauge glass.
3. Steam pressure in the boiler should be kept between 5 and 10 pounds. The boiling out should continue for 48 hours. Immediately after boiling out, give a series of bottom blows to remove the bulk of the sludge. The boiler should be cooled, washed out immediately, and given the usual mechanical cleaning.

You may not always want to use the above method for boiling out. The steps for a second satisfactory method for boiling out are as follows:

1. Clean out all loose scale and any scale adhering to the boiler that can be removed manually.
2. Place about 15 pounds of caustic soda or soda ash and 10 pounds of metaphosphate for each 100-boiler horsepower (hp) of the boiler.
3. Seal the boiler openings but open all vents. Fill the boiler about three-quarters full with water.
4. Start the burner and raise the temperature of the water in the boiler to about 200°F. Maintain this temperature for about 24 to 48 hours. Add makeup water as required during this period to fill the boiler to the base of the safety valve.
5. Analyze the boiler water during the boiling out period and add enough caustic soda and metaphosphate to maintain the following concentrations:

   Causticity as ppm OH 300 to 500

   Phosphate as ppm PO_3 100 to 150

6. Open the boiler at the end of the boiling-out period and clean out the sludge and loose scale. Pay particular attention to removing scale and sludge from water legs in fire-tube boilers.
7. Flush the boiler thoroughly.
8. If a lot of corrosion is exposed when the scale is removed, notify your superior so a boiler inspection can be made.

When the boiler is operated, any residual scale may cause faulty operation. The boiler should be taken out of service at frequent intervals to remove sludge formed from disintegrated scale. As soon as personnel can work in the boilers, wire brush the drums and ends of all tubes.

Then clean the interior of all tubes, using the approved style of boiler tube cleaning brushes.

You should operate all cleaners in the same way. After cleaning all the tubes, follow up by blowing them out thoroughly with a strong air jet. Then inspect to see if replacement of any of the tubes is necessary.

Test your Knowledge (Select the Correct Response)

4. Which method is used to clean out a boiler fouled with grease?

   A. Fill-and-soak
   B. Circulation
   C. Percolation
   D. Boiling out

9.0.0 BOILER MAINTENANCE

As a UT, it is your responsibility to operate, maintain, and repair boilers. You can perform operator maintenance on shore-based boilers; perform preventive maintenance and minor repairs on boilers and associated equipment; complete chemical tests on boiler water and feedwater; replace defective boiler tubes; and test, adjust, and recalibrate boiler gauges and other accessories.

This section provides information on some of the methods, procedures, and techniques used to operate, maintain, and repair boilers and associated equipment safely under typical conditions. Because of the broad scope of tasks involved in operating and servicing boilers, this section does not tell you all you need to know about the subject. Learning how to accomplish the procedures given in the following sections can help you acquire a basis on which to develop more advanced skills. While the procedures given in this section are typical, you should always follow the manufacturer’s instructions for the equipment.

9.1.0 Maintenance of Auxiliary Equipment

A well-planned maintenance program is the key to avoiding unnecessary downtime or costly repairs, promoting safety, and aiding local inspection. An inspection schedule listing the procedures should be established. It is recommended that a boiler room log or record be maintained for recording the daily, weekly, monthly, and yearly maintenance activities. This provides a valuable guide and aids in the operational efficiency, length of service, and safe operation of a boiler. It is also important to remember that improperly performed maintenance is just as damaging to a boiler as no maintenance at all.

9.1.1 Maintenance Requirements for Control of Water Level

The need to check water level controls and the waterside of the pressure vessel periodically cannot be overemphasized. Most instances of major boiler damage are the result of operating with low water or using untreated (or incorrectly) treated water. Always be sure of the boiler water level and blow down the water column routinely. Check samples of boiler water and condensate according to procedures recommended by your water consultant.

Since the manufacturer generally sets low water cutoff devices, do not attempt to alter or adjust these controls. If a low water device should become erratic in operation or if the setting changes from previously established levels, check for reasons and correct it by repair or replacement.

Figure 9-34 is a replica of the low water cutoff plate attached to a steam boiler. These instructions should be followed on a definite schedule. These controls normally function for long periods of time and may lead to laxity in testing on the assumption that normal operation will continue indefinitely.

On a steam boiler, the head mechanism of the low water cutoff devices should be removed from the bowl at least once a month to check and clean the float ball, the internal moving parts, and the bowl or water column. Remove the pipe plugs from the tees or crosses, and make certain the cross-connecting piping is clean and free of obstructions. Controls must be mounted in a plumb position for proper performance.

A scheduled blowdown of the water controls on a steam boiler should be maintained. It is impractical to blow down the low water cutoff devices on a hot-water boiler since the entire water content of the system would be involved. Many hot-water systems are fully closed and any loss of water would require makeup and additional feedwater treatment that might not otherwise be necessary. Since the boiler and system arrangements usually make it impractical to perform daily and monthly maintenance of the low water cutoff devices, it is essential to remove the operating mechanism from the bowl annually or more frequently if possible, to check and clean the float ball, the internal moving parts, and the bowl housing. Also, check the cross-connecting piping to make certain that it is clean and free of obstructions.

9.1.2 Gauge Glass Replacement

A broken or discolored gauge glass should be replaced at once. Always use new gaskets when replacing a gauge glass. Use the proper size rubber packing. Do not use "loose packing" that could be forced below the glass and possibly plug the valve opening.

Close the valves when replacing the glass. Slip a packing nut, a packing washer, and a packing ring onto each end of the glass. Insert one end of the glass into the upper gauge valve body far enough to allow the lower end to be dropped into the lower body. Slide the packing nuts onto each valve and tighten.

If the glass is replaced while the boiler is in service, open the blowdown valve and slowly bring the glass to operating temperature by cracking the gauge valves slightly. After the glass is warmed up, close the blowdown valve and open the gauge valves completely. Check the try cocks and gauge cocks for freedom of operation and clean them as required. It is imperative for the gauge cocks to be mounted in exact alignment. If they are not, the glass will be strained and may fail prematurely.

9.1.3 Feedwater Regulator Maintenance

Proper control of the water level requires that the feedwater regulator be maintained. Here are a few pointers for regulators.

If the water level changes from its normal position, make sure you adjust the bypass to manual operation and check promptly for the source failure. If leaks develop around the packed stems, see that they are stopped immediately. If the boiler is off line, close the hand valve in the feed line. Bear in mind that the regulator is not designed for use as a stop valve. About once every 3 months, you will probably be called on to assist in blowing down the steam and water connections separately.

9.1.4 Valve Maintenance

Valves require special care and attention if they are to work as intended. There may be variations among activities in the type and frequency of valve inspection and servicing requirements. Therefore, follow instructions issued by your activity when they differ from those outlined here.

Types of valves that you may be responsible for helping service and maintain at regular intervals include (1) stop valves of the globe or gate type and (2) stop-and-check valves, which combine in one tray and angle or stop valve of the globe type and a check valve. At least once every 3 months, valves that have not been operated for some time should be operated to prevent sticking. Make sure that you also check for leaks, bent stems, or a missing or broken handle, and lubricate the exposed threads and gearing of the valve stem.

Loosen and lift the packing follower about once every 3 months or more often if possible. Lubricate the packing with graphite bearing oil or graphite bearing grease. Replace the packing followers and tighten sufficiently to ensure against leaks.

Blowoff or blowdown valves should be opened at least once a day. There are four reasons for using these valves:

1. Controlling high water
2. Removing sludge and sediment
3. Controlling chemical concentrations in the water
4. Dumping a boiler for cleaning or inspection

The amount and frequency of blowing down depends on a chemical analysis of the water in the boiler and operating conditions.

On a quarterly basis, inspect the blowoff valves when the boiler is washed out and an internal inspection is made. Check the valves for leaks, and inspect the pipe and fittings between the blowoff valves and the boilers. If repairs are needed, see that they are made promptly. In making a quarterly check on the blowoff valves, do not overlook the insulation, bearing in mind that it should be kept dry. Another item is the discharge piping leaking from the valves. Make sure the discharge piping is not mounted so rigidly that proper expansion and contraction are affected.

Keep safety valves in top working order (*Figure 9-37*). At regular intervals, depending upon operating conditions, the safety valves must be lifted manually. At least once each year the valves should be tested by raising steam pressure to popping pressure of the respective

Figure 9-37 — Typical spring loaded safety valve.

valve. If safety valves function improperly, promptly report the matter to your immediate supervisor. For detailed information on the maintenance of safety valves, refer to manufacturer's manual.

9.1.5 Steam Injector Maintenance

With injectors, little maintenance is required. At times you will have to reseat the overflow and ring valve. Lime deposits also can reduce the operation by closing down the size of the combining and delivery tubes. A good way to remove lime deposits is to place the injector in a tube of muriatic acid for several hours.

To clean the injector, remove the bottom plug (*Figure 9-38*). The delivery tube and ring valve drop out. Examine and clean all passages and holes. After cleaning, replace them in the plug (which acts as a guide) and screw tightly in place.

Figure 9-38 — Cross-sectional view of an injector.

9.1.6 Steam Trap Maintenance

Once each month, see that steam traps are tested for correct operation.

Once a year, or more often if required, dismantle and clean all traps. Inspect for the following:

1. Accumulation of foreign matter
2. Plugging of orifices, valves, and vents
3. Cracked, corroded, broken, loose, worn, or defective parts
4. Excessive wear, grooving, and wire drawing of valves and seats
5. Defective bellows, buckets, or floats
6. Leaky vessels and pipes
7. Defective bypass valves

Repair or replace defective parts as required following yearly inspection. Replace or repair all defective gaskets, bellows, valves, valve seats, floats, buckets, linkages, and orifices. Use only matched sets of replacement valves and seats. Make certain all replacement parts are of the correct size. Do not change the weight of floats or buckets when repairing traps, or operation may be affected. Often, it is more economical to purchase and install new parts than to recondition defective elements. Repair or replace leaking bypass valves. Repack valve stems.

9.1.7 Fan Maintenance

The forced-draft fan should be checked daily to prevent an accumulation of dust in or around the fan. Keep the fan clean! Also, check daily on the sound of the fan. If it is not normal, report the matter promptly to your supervisor.

A daily check should also be made to ensure adequate lubrication of the fan. The temperature is another item that should not be overlooked. This you can test by feel. In case of excessive temperature, notify your supervisor immediately.

Because induced-draft fans are exposed to hot, dirty gases, they must be observed closely to prevent operating difficulty. Taking proper care of the fan requires daily attention to ensure that the following conditions are met:

1. Bearings are kept cool and well lubricated.
2. Fan is kept clean. Also, see that any change from the normal in sound is reported promptly to your supervisor.

9.1.8 Handhole and Manhole Gasket Maintenance

At each regular boiler overhaul, all handhole and manhole fittings and gasket seating surfaces on the drums and headers must be cleaned, inspected, repaired, or renewed if necessary. If the plates are warped, distorted, or otherwise damaged, they must be repaired or renewed.

Whenever handholes and manholes are opened, new gaskets must be fitted. After a gasket has once been compressed, it must be discarded, as it will not provide a seal. Be sure to use the correct size and type of gasket. Never use any makeup compound on the seating surfaces when installing the gaskets. Graphite may be used on the threads of the stud to prevent seizure of the nut.

Before installing a new gasket, thoroughly clean the two gasket seating surfaces (one on the drum or header and one on the plate). Be sure you remove all the corrosion or other surface deposits and all adhering pieces of the old gasket. It is impossible to obtain a tight joint as long as any foreign matter remains on either seating surface or in the corners of the fitting. Be sure to water-soak the new gasket for 24 hours before installation.

Power-driven wire brushes are best for cleaning the seating surfaces. Scrapers should be used only when wire brushes are not enough to clean the surface. Scrapers must be used with great care, if they are used at all, since they tend to remove too much metal from the seating surfaces.

If the gasket seating surfaces show a lot of pitting, you may have to get these surfaces machined or reground. If the seating surface on a handhole or manhole plate is badly pitted or damaged, discard the plate and replace it with a new one or one that has been machined to blueprint specifications.

The clearance between the shoulder of a manhole plate and the manhole must not exceed 1/16 inch when the plate is centered accurately. *Figure 9-39* shows where the clearance is

Figure 9-39 — Manhole plate clearance.

measured. If the clearance is greater than 1/16 inch, the plate should be built up by electric welding at the inner edge of the shoulder. Steelworkers should do the welding, so the manhole plate may be stress-relieved after it is welded and the welded surface may be re-machined.

To position a manhole gasket properly, fit it on the long axis until the inner edge of the gasket fits the shoulder snugly at the ends of the long axis of the manhole plate. The clearance between the gasket and the shoulder should be equalized at the top and bottom of the short axis. Do NOT allow the outer edge of the gasket to protrude at any point beyond the gasket-seating surface in the drumhead. If an edge protrudes, the gasket may unravel when it is compressed by the tightening of the manhole cover. Discard any gasket that protrudes beyond the edge of the gasket-seating surface.

To install a manhole or handhole plate, first center the fitting in the opening. Make sure the shoulder does not bind on the edges of the opening. Then slip the yoke on and start the stud nut. Run the nut on the stud until it is hand tight; then give the nut one-quarter of a turn with a wrench. Do NOT tighten the nut enough to compress the gasket.

When the boiler is given a hydrostatic test, the pressure of the water usually forces the manhole and handhole gaskets into place and thus ensures proper seating. The plates are first set up lightly. When the boiler is ready for testing, the pressure should be pumped up to within 50 psi of the hydrostatic test pressure, regardless of any leakage from the manhole or handhole plates. Leakage is likely to be general at first, but it decreases as the pressure is increased. When the pressure is within 50 psi of the test pressure, most of the leakage stops although the nuts are still loose.

If some plates are leaking badly, the trouble is probably caused by improper seating of the gaskets. As a rule, the gasket is caught on the outer edge between the edge of the plate and the edge of the counter-bore for the seat. A light blow with a hammer on the outside of the plate usually relieves the tension on the gasket and allows it to seat properly.

After leaky gaskets have been adjusted and while full test pressure is on the boiler, tighten up all plates firmly. Use only the wrenches specified for this purpose.

Some economizer headers and a few super heater headers are fitted with handhole plugs instead of handhole plates. Also, some economizers have bayonet types of cleanout plugs on the front ends of the tube loops to allow access to the tubes at the return bend end. Detailed instructions for installing and removing the plug type of manhole fittings and the return bend cleanout fittings are given in appropriate manufacturer's technical manuals.

9.1.9 Hydrostatic Tests

The boiler should be given a hydrostatic test annually or whenever the operator doubts the boiler strength. The purpose of the test is to prove the tightness of all the parts of the boiler or the strength of the boiler and its parts.

In preparing the boiler for a test, rinse it out with fresh water. Then check carefully to see that no loose scale or tools are left in any part of the boiler.

WARNING

Do NOT exceed the test pressure. NEVER apply more than 10 pounds of pressure above the maximum working pressure on a low-pressure boiler. Consult the ASME code for testing procedures for other than welded steel boilers. In case of unusual conditions, discontinue the test immediately and notify your supervisor.

The procedures for making boiler hydrostatic tests are as follows:

1. Close all openings and "gag" (clamp down) all safety valves. Gags should be only hand tight and straight. Do NOT use a wrench; it will bend the valve stem and possibly damage the seat. Remember that valves are easily damaged if lifted by water pressure. Close all connections on the boiler except air cocks, test pressure gauge, and valves of the line through which pressure is to be applied.
2. Reduce the water level in the boiler by opening an air cock, and blow down the boiler until the water level is below the feedwater inlet connection. Clear the blowdown area before blowdown.
3. Connect a hydrostatic pump between the boiler and water service connection. Install all pipe and fittings between the pump and the boiler. Remember, the pipe and fittings must be able to withstand test pressures. Install a hose between the pump and the chosen water service. Ensure the chosen water service supplies ample water pressure to conduct the test.
4. Remove the plug from the feedwater inlet cross by turning it in a counterclockwise direction.
5. Open the boiler casing access doors or plates so tube ends can be inspected during the test.
6. Install a wedge between the control switch and the pressure-actuating platform. Also, install a stop valve before the control switch to protect the control so hydrostatic pressure will not actuate or damage the control. The range of the pressure control is usually less than the hydrostatic pressure being applied. Do NOT bend or damage the actuating parts.
7. Fill the boiler with water until water discharges out of the air cock; then close the air cock. Ensure all the air is expelled from the boiler before closing the air cock. Turn on the water service valve. The water temperature should be the same as the surrounding atmosphere. The minimum water temperature must be 70°F.
8. Check the boiler steam pressure gauge in-line cock to ensure that it is open. Ensure the butterfly handle is in line (parallel) with the tubing.
9. Apply water pressure of 1 1/2 times the maximum allowable working pressure. To avoid rapid shock and strain, bring this pressure up in 10 equal increments, inspecting for leaks and deformities at each increase.
10. Inspect tube ends, boiler seams, pressure fittings, and connections. Make the corrections and repairs wherever possible.
11. Secure pressurizing connections at the required test pressure. Continually inspect the boiler tubes, seams, fittings, and connections. If the boiler and fittings are tight, the pressure should NOT drop more than 1.5 percent in 4 hours. If loss of pressure is over 1.5 percent, find the leak(s) and make the repairs.

Following all hydrostatic testing, steam pressure is raised to lift safety valves and to determine the fitness of the boiler for use.

9.2.0 Boiler Tubes

For any boiler re-tubing job, it is absolutely essential to use tubes that conform in every way to the tube requirements of the particular boiler. Boiler tubes are NOT identical. They differ in such important characteristics as composition of the metal, outside diameter, wall thickness, length, and curvature.

Much of the required information on sizes, thickness, and number of tubes per boiler is given in the manufacturer's technical manual. Some of the information is under the heading of "Tube Data." More detailed information is usually given on the drawings included in the manual.

9.2.1 omposition of Boiler Tubes

Generating tubes are usually made of low carbon steel. They may be either seamless or resistance-welded. Seamless tubes were once definitely preferred for naval use. However, improved methods of manufacturing the welded tubes have led to an increased use of welded tubes in naval boilers. Repair ships, tenders, and other naval activities that use, handle, or issue plain carbon steel tubes have been instructed to make no distinction between the seamless and the welded tubes, but to stock, issue, and install them interchangeably without regard to the method of manufacture.

Super heater tubes usually are not made of plain low carbon steel. On boilers where the superheated steam temperature reaches 850°F or higher, the super heater tubes may be made of carbonmolybdenum steel, chromium-molybdenum steel, or an 18-8 chromium-nickel (stainless) steel.

To find detailed information on the composition of the metals used for generating tubes and super heater tubes in any particular boiler, check the manufacturer's technical manual. The information may be given on the drawings, or it may be included in the text.

Although we all have a general idea of what we mean by the word metal it is not easy to give a simple, accurate definition. Chemical elements are metals if they are lustrous, hard, good conductors of heat and electricity, malleable, ductile, and heavy. In general, these properties of hardness, conductivity, malleability, and so forth are known as metallic properties, and chemical elements that possess these properties are generally called metals. Chemical elements that do not possess these properties are called nonmetals. Oxygen, hydrogen, chlorine, and iodine are a few examples of nonmetallic chemical elements. A few chemical elements behave sometimes like metals and sometimes like nonmetals. These elements are often called metalloids. Carbon, phosphorus, sulfur, and silicon are examples of metalloids.

Most types of steel look quite a lot alike, so you cannot go by appearances. On Navy blueprints and on drawings furnished in the manufacturer's technical manuals, materials are usually specified by federal or military specification numbers. In addition, the blueprints and drawings may refer to a commercial classification system, such as the Society of Automotive Engineers (SAE) system or the American Iron and Steel Institute (AISI) system.

Federal or military specifications usually require the tubes to be identified by some marking system. For example, one specification for boiler tubes requires that boiler tubes 1 1/4 inches or greater in diameter and 3 feet in length be legibly marked by paint stenciling, while smaller or shorter tubes may be bundled and tagged. Another boiler tube specification requires the tubes to be marked by ink stenciling approximately 3 inches from each end and again in the middle of the tube. As a general rule, boiler tube identification markings must include (1) the name or trademark of the manufacturer, (2) the heat number, (3) the class letter, (4) the specification number, and (5) the outside diameter, the wall thickness, and the length.

9.2.2 newing Tubes

Boiler tubes should be replaced when they cannot be made tight, or when they are warped, or otherwise seriously damaged. As a general rule, boiler tubes should not be straightened in place; leaks may develop that could cause permanent damage to other parts of the boiler. Occasionally, however, you may find a screen tube or a wall tube that has bowed out of position for no apparent reason; you can straighten the tube in place and re-roll it if a replacement tube is not available. Tubes that have bowed out of position because of low water should not be straightened.

To renew tubes in the A row, the corresponding tubes in the B row must also be renewed, regardless of their condition. Similarly, whenever superheated tubes are renewed, remove the super heater support tubes when they are not accessible without removal of the super heater tubes.

General renewal of tubes in a boiler should not be undertaken without approval of the Chain of Command. The commander's decision as to whether to approve a general renewal of the tubes will be based on the results of inspection and examination of tube samples.

Before beginning to renew tubes, be sure all preparations have been made. Be sure the right types of replacement tubes are available and that all tools and equipment required for the job are on hand and in good working order. Check the cutters, the air hoses, and the fittings for the pneumatic tools, the tube benders, the electric equipment, and the staging.

The steam drum must be opened and some fittings removed to allow access to the ends of the tubes. Also, the water drums and headers must be opened. Any fittings removed from the drums should be carefully set aside and marked, if necessary, to ensure correct replacement.

Before allowing a person to enter the boiler, be sure all safety precautions are observed. Make it your personal responsibility to see that all cross-connecting valves between the boiler being re-tubed and any steaming boiler are closed and locked or wired shut and are tagged DANGER. DO NOT OPEN. Be sure, also, that the control valves of the steam-smothering system are locked in the CLOSED position. See that enough ventilation is provided; keep portable blowers running at all times while people are working in the boiler. Do not allow unauthorized types of lights in the boiler. Flashlights are preferred for boiler work. If portable lights are used, the electric leads must be thoroughly insulated and the portable fixture itself must be the grounded, watertight type. Before use, portable lights should be checked by an electrician to ensure they are safe.

9.2.3 oving Tubes

Using an air-powered side-cutting chisel to cut the old tube flush with the drum or header (*Figure 9-40*) is one method of removing tubes. Carefully work the cutter so as not to damage the surface of the drum or header. When you are removing super heater tubes, it will be impossible to cut the tube flush with the header with a side-cutting chisel. An expandable fly cutter must then be used to cut out the tubes.

Figure 9-40 — Side-cutting chisel.

After removing the main part of the tube from the boiler, use a safety ripping chisel of the type shown in *Figure 9-41* to make a cut on the inside of the remaining portion of the tube. The safety ripping chisel is designed so it cannot cut entirely through the tube; therefore, it cannot score the tube sheet.

After cutting the tube approximately three-fourths of the way along the tube sheet, crimp the edges of the tube and drive out the stub with a blunt chisel. If the tube is a large one, you may have to make two cuts with the safety ripping chisel instead of one; the cuts should be about an inch apart.

If a safety ripping chisel is not available, you can remove the tube by the following method:

1. Split the ends of the tube with a flat chisel from the end of the tube to the drum or header at two places about ¾ inch apart.
2. Force the 3/4-inch piece upward with a bar until it has been raised off its seat and has curled into the tube.
3. Split the tube to a point beyond the other side of the tube seat with a tool ground to conform to the tube hole. Be careful not to damage the tube hole.
4. Break in the ends of the tube with a crimping tool, and then drive out the stub.

Figure 9-41 —Safety ripping chisel.

Arc welding equipment can be used as an aid to the tube removal on some boilers. This procedure requires running two beads, ¾ inch apart, through the entire tube sheet, quenching with water, and then using a backing-out tool. Do NOT use this method of tube removal if the drums or headers are made of 4-6 chromium steel.

Technology updates have made the removal of tubes much easier since the invention of the chisel. Figure 9-42 shows one option, the tube tugger. It is the simplest one to operate and will make this job easier for the UT. Be sure to follow the manufacturer's instructions as to the use of the tool. The basic operation of the tool is as follows:

1. Thread the spear into the tube using an impact drive or by hand.

Figure 9-42 —Tube tugger in operation.

2. Secure the tube tugger to the counter balance.
3. Position the tugger over the spear and hold against the tube sheet.
4. Initiate the stroke of the tugger, when it has reached its maximum stroke; initiate the return stroke, keeping the tugger in contact with the tube sheet. Repeat until the tube end is visible from the back of the collet holder.
5. Once the spear has passed through the collet jaws, stop the tugger and remove the spear from the tube.
6. Continue the extraction until the tube is fully extracted from the vessel.

9.2.4 eaning Tubes

Replacement tubes must be thoroughly cleaned to remove all scale, dirt, and preservatives. One way of cleaning a tube is to push a kerosene-soaked rag through it and wipe the outside of the tube with a similar rag. Diesel oil may also be used. If a large enough tank is available, boiler tubes may be cleaned by immersing them in an approved cleaning solution, such as a saturated solution of boiler compound in hot water, to which a small amount of kerosene has been added. Boiler tubes may also be cleaned with steam jets.

9.2.5 Preparing Tube Sheets

The tube sheet holes must be prepared before replacement tubes are inserted. The best way is to use a piece of hardwood turned to a diameter slightly less than the diameter of the hole and covered with a medium fine-grit emery cloth. Pass the wooden piece in a circular motion, back and forth through the tube sheet or header holes to smooth the surface. Finish the job by using a fine emery cloth wrapped around your finger. Keep working until the hole is clean and smooth.

When preparing tube seats, check the size and trueness of the tube holes; use a tube nipple of corresponding size as a template. It is impossible to make tube seats tight if the tube holes are much enlarged or if they are too elliptical (out-of-round). To ensure the tightness of the tube seats, be sure that the maximum enlargement and the maximum ellipticity of the tube holes do not exceed known values.

9.2.6 Repairing Tube Sheets

Out-of-round tube holes, small steam cuts, and other minor defects may, in some cases, be corrected by welding. NAVFAC approval is not required for this type of welding repair on drums and headers made of low carbon steel, carbon-molybdenum steel, or steel containing less than 1 percent chromium if a qualified welder uses approved welding procedures for the welding, filler metal, and position of welding under MIL-STD-248. Always check the blueprints for the material of the drums and headers before welding.

9.2.7 Preparing Tube Ends

After the tubes have been thoroughly cleaned, prepare the tube ends inside and outside. Clean the ends with a wire brush and polish them with abrasive paper and a liquid cleaner until the tube ends are completely clean, free of burrs and mill scale, and thoroughly polished. Clean and polish the tube ends for a distance equal to the thickness of the tube seat plus 2 or 3 inches.

Round off the tube ends with a file so no square or sharp edges remain. If the tubes are not rounded off at the ends, the tubes may split when they are belled.

9.2.8 Fitting Tubes

When installing tubes, always fit the tubes into the steam drum before inserting the other end in the water drum or header. Inserting the tubes into drums and headers is not particularly difficult since all tube holes are drilled normal to the tube sheet.

If you are renewing a complete row of tubes, fit a tube at each end of the row and then work toward the middle. You may find slight differences in the lengths of tubes required if the boiler has been in service for some years. These differences are more likely to show up at the ends of the rows than in the middle.

When fitting tubes into drums or headers, be sure each tube extends far enough into the header or drum. Tubes up to (but not including) 2 inches in outside diameter (OD) should project 3/16 to 5/16 inch into the drum or header. Tubes 2 inches OD and larger should project 5/16 to 7/16 inch into the drum or header.

After you have fitted a tube and allowed for the amount it must project into the steam drum and into the water drum or header, remove the tube and cut off the excess. One of the tools you may use to cut the tube is the boiler tube cutter (*Figure 9-43*).You may be able to use one tube as a guide for cutting off the excess on several other tubes; if you recall, the tubes may vary slightly in length, particularly in older boilers. Do NOT use one tube to measure the rest of the tubes in a row if you believe there are big differences in tube lengths in the row. If your sample tube happened to be a little on the short side, you would end up with a whole row of tubes that were too short, and therefore could not be used.

Figure 9-43 — Tubing cutter.

Each tube must be carefully aligned with the other tubes. Use a plywood batten about 1/2 inch thick, 3 feet long, and 3 inches wide to align tubes in the generating bank. After positioning the tubes, check them with the batten. Then place small, wooden wedges to hold the tubes in place until they have been expanded into the tube sheets. Be sure to remove the batten and the wedges before starting work on the next row. These wooden pieces cannot be left in the boiler. You will have a real job on your hands if, after installing five or six more rows of tubes, you suddenly discover that you have overlooked the batten or one of the wedges.

9.2.9 Expanding Tubes

The basic joint in boiler construction is an expanded joint that must not leak or lack holding power. Leakage, if permitted to go uncorrected, leads to deficiency of holding power because of deterioration of the tube seat. Slight leakage itself should not be taken as cause for alarm, but rather as evidence to correct the fault as soon as possible. Deficiency of holding power causes the tube to pull out of its seat. In most cases, the tubes are installed within the furnace of the boiler, and any danger to personnel, if the tubes pull out of the seat, is reduced since the steam will be discharged up the stack. For this reason, tubes 1 inch outside diameter (OD) up to and including 2 inches OD are expanded by "boilerman's feet," as only a small amount of expansion is required to hold the tubes firmly in place. With tubes 3 inches OD and larger and all external downcomers, special precautions must be taken to ensure the tubes are properly expanded in the tube seat. Through a series of tests, the point of maximum holding power for various sizes of tubes has been found and is expressed in terms of standard diameters that should be measured after the tube has been expanded in place. In new construction or replacement of tubes where the tube and hole measurements can be obtained, the correct amount of expansion can be found by using the following formulas:

For tubes in drums: Diameter of tube hole minus OD of tube, plus 0.012 inch per inch OD of tube.

For tubes in headers for boiler design pressure under 500 psi: Diameter of tube hole minus OD of tube, plus 0.015 inch per inch OD of tube.

For tubes in headers for boiler design pressure over 500 psi: Diameter of tube hole minus OD of tube, plus 0.020 inch per inch OD of tube.

The figure arrived at by using the above formulas should be added to the OD of the tube as measured to give the required OD of the tube after rolling.

If it is impossible to reach the outside of the tubes in drums to gauge them, the inside diameter (ID) of the tube must be measured. Since the plastic deformation of the tube wall varies with tube wall thickness, the ID of the tube for different wall thickness will vary. Where the outside of the tube is inaccessible, the following formula is used in the expansion of a tube:

- The ID of the tube, plus the tube hole diameter minus the OD of the tube plus the expansion increase factor.

Boiler tubes should be expanded with the expanding equipment furnished to the shop. Select expanders of the proper size for the tube size and the seat thickness and expanders proper for the operation to be performed. There are two types of expanders: roller-type and ball-drift type. Roller-type expanders are furnished for use by the shop labor force. Roller-type expanders are shown in *Figure 9-44*. A series of adapters are furnished for use if tube holes are not readily accessible. Some of these adapters are shown in *Figure 9-45*.

Figure 9-44 — Roller type tube extenders.

Figure 9-45 — Adapters for tube expanders.

Tube expanders are operated by air motors. The air, at about 100 psi, enters through a controlling handle and goes into the motor housing where it drives an air turbine. The turbine is attached to the shaft of the motor. The controlling handle can be turned clockwise or counterclockwise. A chuck with a tapered shank engages the shaft of the air motor, thus transmitting the power of the motor to the rollers used for expanding tubes into the tube sheet.

Both the air motors and the chucks are available in various sizes. The large sizes of motors and chucks are used for expanding the larger sizes of tubes. *Figure 9-46* shows a tube expander in use.

Figure 9-46 —Expanding a tube.

Tube expanders must be used carefully to avoid damage to the expanders and to prevent injury to personnel. The centrifugal force developed by the air turbine is great, so the air motor must be gripped firmly with both hands. If the roller-mandrel combination should bind, the force of the air motor could break the mandrel and quite possibly cause injury to the operator. Always have a person stationed nearby to give immediate assistance if necessary. If you run into any trouble, your safety person may be able to crimp the hose quickly and thus keep the mandrel from breaking.

9.2.10 elling Tubes

Most tubes are expanded and belled. However, check the drawing to determine if any specific instructions are shown. Some tubes in 1,200 psi boilers are lightly expanded or belled before welding; some are directly butt-welded to the studs. A roller-type or a drift-type belling tool is used. The drift-type tool is shown in *Figure 9-47.*

When belling a tube, be careful not to overdo the operation. Tubes up to, but not including 2 inches OD should be belled at least 1-15 inch but no more than 1/8 inch. Tubes 2 inches OD and larger should be belled at least 1/8 inch, but no more than 3/16 inch. The increase is to be measured over the outside tube diameter at the end of the tube. *Figure 9-48* shows the process of belling a tube.

Figure 9-47 — Belling tool.

Figure 9-48 — Belling a tube.

Some expanders are fitted with belling rolls. When these expanders are used, the tubes are expanded and belled at the same time; thus, there is no need for a separate belling job.

9.2.11 newing Welded Tubes

In some boilers of recent design, the super heater tubes and the economizer tubes are welded after they have been expanded. The renewal of these tubes is more complicated than the renewal of ordinary tubes. Procedures for renewing welding tubes are given in the appropriate manufacturer's technical manual.

9.2.12 Plugging Boiler Tubes

As an emergency measure, it is sometimes necessary to plug defective boiler tubes until they can be replaced.

CAUTION

Any tube that is plugged must have a hole drilled in it to prevent pressure buildup in the tube when the boiler is steamed.

Various sizes of tube plugs are carried in the supply system. The plugs are tapered to the required shape and are usually drilled and threaded at the larger end so they may be removed with a tube plug extractor.

Tubes must be plugged at each end. Before driving a tube plug into position, be sure the plug and the inside of the tube are absolutely clean so the plug makes good metal-to-metal contact with the tube. Drive the plug far enough in to ensure it will hold, but do not drive it so far in that it damages the tube sheet.

In plugging super heater tubes, use an offset driver to drive in the plugs when the tube holes do not fall in line with the handhole opening. When a super heater tube is plugged, it will eventually burn away after a period of service. When tubes have burned away (or when they have been removed) so much that they leave a gas lane more than three tube rows wide through the entire super heater tube bank, plug the gas lane with a plastic or castable refractory. If the lane cannot be plugged, the firing rate of the boiler must be restricted to avoid overheating the super heater tubes next to the gas lane.

When a sidewall tube needs to be plugged, cut the tube 3 to 4 inches above the sidewall heater and 3 to 4 inches below the steam drum. The space left exposed after removal of the tube should be packed with plastic refractory to protect the pressure parts previously cooled by the plugged tube. Do not plug more than two tubes next to each other since an exposed area wider than this cannot be effectively protected for an extended operation. Sidewall tubes that have been plugged should be replaced at the earliest opportunity.

When a rear wall tube needs to be plugged, cut the tube 3 to 4 inches from the headers or at other cutoff points specified in the manufacturer's technical manual. Use a plastic refractory to plug casing openings in order to cover exposed areas not protected by firebrick or high-temperature castable refractory, and to cover the exposed pressure parts previously cooled by the plugged tube. Rear wall tubes that have been plugged should be replaced at the earliest opportunity.

Super heater screen 1 1/2 and 2 inches in outside diameter should, in general, be replaced, rather than plugged, when tube failure occurs.

In plugging generating tubes 1 inch and 1 1/4 inches in outside diameter behind the super heater tube bank (in single-furnace boilers) and behind the 2-inch tubes (in double-furnace boilers), consider gas laning and drum protection. Any complete lane through the tube bank more than three tube rows wide should be re-tubed, especially if such a lane is bounded by the boiler casing. Any drum area greater than 4 inches square should have refractory protection over the drum or, if this is not practicable, have blind nipples replace the failed tubes instead of just plugging the failed tubes. The blind nipples give greater protection to the drum than plugged tubes.

If an economizer element develops a leak, the ends of the element should be plugged at the inlet header and at the outlet header. To install a tapered plug in an economizer element, screw the plug extractor into the plug and insert the plug into the tube. Unscrew and remove the extractor from the plug. Drive the plug securely into position by holding one end of a piece of pipe against the plug and striking the pipe on the other end.

Figure 9-49 shows how to remove a plug from an

Figure 9-49 — Removing plug from economizer element.

economizer element. Screw the plug extractor into the plug. Place the handhole plate binder in position over the extractor, and then thread on the handhole fitting nut. As you tighten the handhole fitting nut, the plug pulls out.

Some activities using boilers of recent design are furnished with expandable gasketed plugs for plugging economizer elements. One of these plugs is shown in *Figure 9-50*.

The installation of the expandable plug is shown in *Figure 9-51*. After inserting the plug assembly into the tube, hold a screwdriver in the slot of the retainer stem to keep the plug from turning as you tighten the nut. As you tighten the nut using an open-end wrench or a socket wrench, the gaskets expand radially as they are compressed axially.

Figure 9-50 — Expandable gasketed plug.

Figure 9-51 — Installing expandable plug in economizer element.

The removal of an expandable plug is shown in *Figure 9-52*. Insert a socket wrench or an open-end wrench through the handhole and remove the retainer nut. Insert the economizer plug extractor and then thread it onto the retainer. Place the handhole plate binder in position over the extractor and the thread on the handhole fitting nut. As you tighten the nut, the plug pulls out.

Figure 9-52 — Removing expandable plug.

9.3.1 Repairing Boiler Refractories

Furnaces are built with high-grade, fire-resistant materials that take a lot of punishment. Sooner or later, however, repairs become necessary. Furnace walls or floor may need repairing. The procedure for this repair is as follows:

First, mix the mortar, using a Navy-recommended fire clay or fire cement and fresh water. Do not add anything else. Make the mortar rather thin and free of lumps.

Inspect the bricks for flaws and evenness. Choose the best edge for the furnace side. Dip the brick in fresh water and allow the excess water to drip off.

Now, dip one end and side of the brick into the mortar, using an edgewise motion to prevent air bubbles from forming. Lift the brick from the mortar and allow the excess mortar to drip off. Do not place any mortar on the wall or brick with a trowel. The mortar sticking to the brick is all that is used.

If the mortar is too thick, you will not get the thin joints that you want. The mortar should be a little thinner than the usual wall plaster. You can feel the proper thickness with your hand. Some mortar will stick to your hand as you lift it away from the mortar. Add more clay or water as necessary, and stir the batch often to keep the mortar at the desired consistency.

Place the brick quickly in position in the wall and pound it in place with a wooden mallet until no mortar can be forced out of the joints. With high-grade brick, joints can be made less than 1/32 inch thick. Joints should never exceed 1/16 inch.

With a small trowel, fill in any unevenness in the furnace side of the seam and bead over the joints (*Figure 9-53*). Be sure that no edges of the brick are exposed. The wall should be laid up evenly and smoothly. Any excess mortar that protrudes from the joints should be smoothed off with a small trowel so the corners of the brick are protected.

Figure 9-53 — Cementing block.

Allow the wall to dry for about 12 hours with the burner shutters open to allow circulation of air, which permits the escape of some of the water added to the mortar. As soon thereafter as practicable, light the burner under the boiler and slowly bring the furnace up to operating temperature to bond the mortar to the adjacent brickwork.

When inspecting the boiler, you may find cracks or holes in the furnace lining. To make necessary repairs, mix some of the fire clay you used for brick mortar into a thick mixture. Use more mortar than you used for the brick mortar mix. Use a trowel to apply this wash.

While standard firebrick generally is used for normal refractory work, plastic firebrick is recommended for emergency patches and for building up furnace openings. Plastic firebrick is unfired firebrick in a stiff plastic condition. It offers a particular advantage in that, because of its plastic nature, it can be pounded into places where otherwise a firebrick of special shape would be required. The fusion point of plastic firebrick is practically equal to that of standard firebrick. Because of the moisture in the plastic material, however, a greater degree of shrinkage takes place. This factor prevents its general use for sidewalls. It provides an excellent material, though, for repairing brickwork, topping off side and back walls, repairing and constructing the burner openings and, in general, for any part of the furnace not exposed to temperatures in excess of 2000°F. It is particularly adapted for use in place of specially formed brick of complicated shapes.

Plastic firebrick material, as received from the factory, ordinarily contains enough moisture for working. Avoid the addition of water or any foreign material. In laying up, chunks of plastic just as taken from the can should be rammed tightly into place (preferably in horizontal layers). In general, the more solidly the section of plastic is rammed up, the better it will be.

As the next step, the plastic section should be vented with 3/16-inch holes. Ensure that the holes extend clear through the plastic and are not more than 2 inches apart. This positioning allows deeper heat penetration during the baking-out process. It also permits ready escape of the steam formed from the moisture in the plastic. Do NOT trowel the surface of a new plastic section. This tends to prevent the escape of steam during baking out.

The plastic section should be held in place with as many anchor bolts as would have been provided had standard firebrick been used instead of plastic. The plastic section should be air-dried. This takes from 48 to 72 hours, depending upon the atmosphere. As soon as practicable after air drying, the furnace should be fired with a small fire and gradually brought up to operating temperature to complete baking out. Plastic requires a temperature of about 2900°F to 3000°F for baking out. If small shrinkage cracks open up, they should be filled with fire clay. If large cracks occur, they should be filled with plastic.

When used for patches, as in the case of brick falling out, the hole should be cleaned out to give at least 4 inches of body thickness to the plastic brick. In building up furnace openings, the use of a metal form is desirable. However, it is not absolutely necessary if care is exercised in making openings of the proper shape and concentric with the atomizer at every point. If furnace openings, as built, have a smooth surface, they should be roughened with a stiff wire brush before baking out.

The following ways to maintain newer boilers are recommended. The boiler is normally shipped with a completely installed refractory. This consists of the rear head, the inner door, and the furnace liner (*Figure 9-54*). Follow the instructions in the manufacturer's manual for the boiler you are maintaining. Where specific directions or requirements are furnished, follow them.

Normal maintenance requires little time and expense and prolongs the operating life of the refractory. Preventive maintenance through periodic inspection keeps the operator informed of the condition of the refractory and helps guard against unexpected downtime and major repairs.

Frequent wash coating of refractory surfaces is recommended. A high-temperature bonding, air-dry type of mortar diluted with water to the consistency of light cream is used for this purpose. Recoating intervals vary with operating loads and are best determined by the operator when the heads are opened for inspection.

Maintenance consists of occasional wash coating of the entire liner. Face all joints or cracks by applying high-temperature bonding mortar with a trowel or use your fingertips. This should be done as soon as the cracks are detected. Should segments of the liner become burned out or broken, replace the entire refractory. Any refractory that may

Figure 9-54 — Front and rear doors open on a gas-fired boiler.

break out should be removed as soon as detected so it will not fuse to the bottom of the furnace and obstruct the burner flame.

Remove the existing refractory and thoroughly clean that portion of the furnace covered by the liner to remove all old refractory cement or other foreign material to ensure the new liner seats firmly to the steel. Inspect all furnace metal for soundness. There may be metal clips welded in the furnace at the extreme end of the liner. These clips were installed to prevent shifting during original shipment and serve no other purpose. They are tack-welded in place and can be removed when you are installing the new liner. If they are not removed, make sure the liner has clearance between this clip and the end of the refractory to allow for expansion in this direction.

Depending upon the design pressure of the boiler, the furnace may be of the corrugated type. Although it is not necessary to fill in the depressions for convenience of installation, some or all of the corrugation valleys may be filled with insulating cement. The liner tile should be fitted tightly against the crown of the corrugations.

The furnace extension of the boiler or a dry oven is shown in *Figure 9-55*. The throat tile should be installed flush with the front of the oven and should fit tightly against its sides. The two rows of furnace tile should be fitted tightly against the furnace wall. It is not necessary to allow for expansion.

Figure 9-55 — Furnace liner refractory.

It is recommended that the tile be dry fitted, match marked, removed, and then reinstalled with the proper amount of refractory cement. Thin joints are desirable. Generally, it is necessary to shave a portion from one or more tiles to obtain a fit. If a fill piece is required, cut it to fit and install this piece at the bottom of the furnace. It is important to have a good seal between the burner housing and the throat tile. Liberally coat the sealing area with an insulating pulp cement or equivalent mixed with water before swinging the burner housing into place.

The rear door is a steel shell containing horizontal baffle tiles and lined with insulation material and a castable refractory (*Figure 9-54*).

Burned or discolored paint on the outer surface of the door does not necessarily indicate refractory trouble but may be an indication of other conditions such as the following:

- Leaking gaskets
- Improper seal
- Door-retaining bolts insufficiently or unevenly tightened
- Air line to the rear sight tube is blocked or loose
- Repainted with other than heat-resistant paint

Therefore, before you assume the refractory requires re-working, check the following:

- Condition of the tadpole gasket
- Condition of the insulating cement protecting the tadpole gasket.
- Horizontal baffle tile for large cracks, breaks, chipped corners, and so forth

- Cracks in the castable refractory at the ends of the baffle tile
- Tightness of door bolts
- Air line to the sight tube to ensure it is clear and all connections are tight. If necessary, blow it clear with an air hose.

It is normal for refractories exposed to hot gases to develop thin "hairline" cracks. This by no means indicates improper design or workmanship. Since refractory materials expand and contract to some degree with changes in temperature, they should be expected to show minor cracks because of contraction when examined at low temperature. Cracks up to approximately 1/8 inch across may be expected to close at high temperature. If there are any cracks that are relatively large (1/8-inch to 1/4-inch width), clean and fill them with high-temperature bonding mortar. Any gap that shows between the castable refractory and the baffle tile should be filled in a similar fashion.

After opening the rear door, clean off the flange surface of the door with a scraper or wire brush. Clean the surface of the refractory carefully with a fiber brush to avoid damaging the surface. Clean the mating surfaces of the baffle tile and the boiler shell. Remove all dried-out sealing material. Wash coat the lower half of the rear door refractory before closing it. The upper half of the door contains a lightweight insulating material similar to that used in the inner door. A thin wash coat mixture applied gently with a brush is helpful in maintaining a hard surface.

The front inner door is lined with a lightweight castable insulation material. Thin "hairline" cracks may develop after a period of time; however, these cracks generally tend to close because of expansion when the boiler is fired. Here again, a thin wash coat mixture is helpful in maintaining a hard surface. Minor repairs can be accomplished by enlarging or cutting out affected areas, making certain they are clean, and then patching as required.

Should the entire installation require replacement, remove existing material and clean to the bare metal. Inspect the retaining pins and replace if necessary. Reinforcing wire suitably attached may also be used. The recommended insulation is known as Vee Block Mix and is available in 50-pound bags. Mix the material with water to a troweling consistency. Mixing should be completely uniform with no portion either wetter or drier than another. Trowel this mixture into any areas that are being patched. If replacing complete insulation, begin at the bottom of the door and apply the mixture to a thickness equal to the protecting shroud. With a trowel, apply the mixture horizontally back and forth across the door in layers until the required thickness is reached. Allow the mixture to air-dry as long as possible. If immediate use of the boiler is required, fire as slowly as possible to avoid rapid drying of the material.

Whenever the front or rear door is opened for inspection, the head gasket should be checked for hardening and brittleness. Doubtful gaskets should be replaced. Coat the gasket with an oil and graphite mixture before closing the door. Make certain all gaskets retaining rivets are in place. The flange of the door should be clean and free of any hardened cement, scale, and so forth. Check the condition of the rope gasket used as a baffle seal. Replace if necessary. If the rope is in good condition, liberally coat it with an insulating pulp before closing. Make sure the rope is properly positioned.

If it is necessary to replace the rope, wire brush the tube sheet area to remove all of the old sealing material. Place a new piece of 1 1/2-inch-diameter rope gasket on the lip of the baffle tile. Hold it in place with furnace cement or an adhesive.

NOTE

Earlier models have several steel bar segments tack-welded across the tube sheet to serve as a gasket retainer for 5/8-inch-diameter rope. It is suggested that these bars are removed and 1 1/2-inch-diameter rope be used.

Generously apply a seal, consisting of a pulp mixture of insulating cement and water, around the entire rear door circumference. Place the pulp around the inside diameter of the head gasket. Also coat the tube sheet area adjacent to the baffle tile. When the door is closed, the pulp compresses to protect the tadpole gasket and to form a seal between the refractory surface and the tube sheet. The insulating pulp seal is not needed or used on the front head. Make sure the gaskets are in position when closing.

When you are closing the door, bolts should be snug and tightened evenly to avoid cocking the door and damaging the gasket. Start tightening at the top center bolt and alternate between the top center bolt and the bottom center bolt until both are drawn-up tight. Do not over-tighten. Continue the tightening sequence along top and bottom, tightening the bolts alternately until the door is secured and gas-tight. After the boiler is back in operation, retighten the bolts to compensate for any expansion.

NOTE

Proper sealing of the doors is essential to avoid leakage of combustion gases and loss of heat and operating efficiency.

9.4.0 Boiler Operation

The operation of a boiler consists of seven major phases: (1) pre-watch assumption checks, (2) pre-operating checks, (3) lining up of systems, (4) operating procedures, (5) operating checks, (6) securing procedures, and (7) boiler emergencies.

9.4.1 Pre-Watch Assumption Checks

The pre-watch assumption checks are often neglected by boiler watch standers. Before you assume the responsibility of a boiler watch stander, you must complete specified checking procedures to ensure that the equipment in service is in sound operating condition and is functioning satisfactorily. When the watch is relieved, the watch stander coming on duty inspects the instrument readings and charts, visually inspects all equipment, and exchanges information with off-going watch standers. Oncoming watch standers should complete the following inspections and tests before assuming duty:

- Visually inspect the setting and casting.
- Observe the furnace and firing conditions.
- Inspect the charts, logs, controls, and so forth on equipment performance during previous watch.
- Inspect the fans, dampers, damper drives, and other driven auxiliaries.
- Test the water columns and gauge glasses.
- Obtain information from the watch standers on duty on the boiler operating condition and any unusual event or trouble that occurred during the previous watch.

Immediately after accepting the operational responsibility, you should make a complete inspection of all auxiliary equipment as follows:

- Inspect all electric motor drives for abnormal temperature, condition of bearings, and so forth.
- Inspect the fan and pump bearings for overheating and adequacy of lubrication.
- Visually inspect the boiler and all associated equipment; listen for unusual sounds, friction, vibration, and other abnormal conditions.
- Inspect the burners, fuel supply, pilot systems, and other fuel supply components.
- Review the log sheets to obtain information on past operating conditions and unusual events.

9.4.2 Pre-Operating Checks

The pre-operating checks should be completed before lining up and lighting off a boiler. These checks are performed to ensure that the plant and associated equipment are in a safe and efficient operable condition. The major pre-operating procedures applicable to boilers in general, as well as additional procedures for gas-fired and oil-fired boilers, are shown in *Tables 9-4*, *9-5*, and *9-6* below.

Table 9-4 — Pre-operating checks for boilers.

Equipment	Check/Action
Boiler room	Remove rags, paint cans, oil spots from deck.
	Stow tools and equipment.
Furnace/Gas passages	Must clean and clear; all doors must fit tight.
	Must be in good repair and purged.
	No oil/tools in combustion chamber.
Valves	Good operating condition.
	Missing/broken handwheels or bent stems.
Piping	Inspect piping for leaks.
	Check for proper support.
Electrical systems	Oil-soaked or frayed wiring.
	Damaged or loose conduit.
	Improperly secured control boxes.
Guards	Tight and in proper position.
Water gauge glass	Well lighted and not stained.

Table 9-5 — Additional pre-operating checks for gas-fired boilers.

Equipment	Checks
Pilot and main gas cock	Operate smoothly.
Copper tubing	Has no restrictions, such as kinks or flat spots.
Air shutters	Operate freely.
	Linkage must not have too much loose motion.
Burner and main gas valve	Must be firmly supported.
Boiler room	Has no free gas. Ventilate if present and test all piping with soap solution.

Table 9-6 — Additional pre-operating checks for oil-fired boilers.

Equipment	Checks
Strainers	Inspect and clean.
Burners	Must be clean.
	Nozzle must be clean.
	Inspect and test electrodes.
	Check all fittings for leaks.
	Check operation of burner safety switch.
Oil system	Inspect for leaks, and repair.

9.4.3 Lining Up Systems

After you have completed the pre-operating checks, your next job is to line up the boiler systems. The procedure used in lining up boiler systems (fuel, water, steam, and electrical) vary with different types and kinds of boilers. Always follow the manufacturer's instructions for the boiler being used. Before lining up a boiler, complete the following basic tasks:

1. Fuel oil
   a. Measure with a stick or gauge.
   b. See that the proper valves are open.
   c. Remove any excess accumulation of water in the tank.
2. Gas
   a. Check the pressure.
   b. Check for leaks.

3. Gas-fired unit
    a. Check and regulate the water level and line up the feed system.
    b. Examine the burner, control valves, and safety shutouts for proper working condition before lighting off.
    c. Purge air out of the gas lines by external vents before lighting off.
    d. Check the draft devices and purge the combustion chamber.
    e. Light the pilot and set the flame.
    f. Open the main gas cock.
    g. Close the burner controls switches to light the burner.
    h. Maintain the fuel-air ratio for complete combustion.
4. Oil-fired unit
    a. Check and regulate the water level. Line up the feedwater system. Check the operation of the feed pump.
    b. Line up the fuel oil system.
    c. Purge the combustion chamber.
    d. Close the burner control switch; if automatic, the burner should light off.
    e. Should ignition fail, the furnace must be purged before a second attempt is made.
    f. Do not allow oil to impinge on brickwork or part of the boiler.
    g. Maintain the proper air-fuel ratio.

In general, the basic lighting off procedures for most boilers are as follows:

1. Close the following valves:
    a. All blowdown valves and boiler drains
    b. Chemical feed valves
    c. Boiler non-return
    d. Main steam stops
    e. Soot blower header (steam system) and all soot blowers
    f. All burner fuel valves
    g. Water column and feedwater regulator drains
    h. Auxiliary valves, as necessary
2. Open the following valves:
    a. Vent valves on boiler drums and super heaters
    b. Super heater drain valves
    c. Recirculating line valves in economizer, if so fitted
    d. Feedwater stop and check
    e. Drum steam gauge connection
    f. Water column gauge connections

g. Water column gauge glass valves

h. Auxiliary valves, as necessary

3. Start filling the boiler with properly treated water at a temperature close to the temperature of the pressure parts. The temperature difference should not be greater than 50°F to avoid severe temperature stresses. Fill the boiler to level just below the middle of the glass on the water column.
4. Close the induced draft fan dampers (or other flue gas control dampers).
5. Start the induced draft fan.
6. Close the forced draft fan dampers (or other air control dampers).
7. Start the forced draft fan.
8. Start the air heater rotor if a regenerative type of air heater is installed.
9. Light off the boiler under the manufacturer's instructions and maintain a firing rate so the water temperature in the boiler is raised 100°F per hour until operating pressure is reached. On new boilers, check expansion movement to see that no binding or interference occurs.
10. When burning oil, prevent incomplete combustion in the furnace: Unburned oil is deposited on the cooler surfaces in the back of the unit, such as the economizer and air heater, and this creates a potentially dangerous condition.
11. When the steam drum reaches about 25 psig, close the vent valves on the boiler drum. Check the steam pressure gauge now to be sure that it is registering.
12. Ease up on the stem of the main steam stop valve to prevent any serious expansion stresses. If there is no steam on either side of the main steam stop valve, gently lift and reseat it to make sure that it is not stuck. Open the drain valve on the boiler side of the main steam stop valve.
13. Observe the water level carefully to ensure that no water is carried over into the super heater. Maintain a normal water level in the drum by blowing down or feeding water as may be required.
14. Operate the vent and drain valves in the super heater headers and economizer by following the manufacturer's instructions. In general, drain valves in the super heater inlet header are closed first, followed by the drains in the super heater outlet header. In any case, the super heater outlet header drain and vent valves must not be completely closed until enough steam flow through the boiler outlet valve is assured.
15. Check for leaking gasket joints. If a leaking gasket is discovered, shut down the boiler and tighten the joints.
16. If the gasket still leaks, drop the pressure again, replace the gasket, and repeat the lighting off sequence.

Before cutting in the boiler, proceed as follows:

1. Open all drain valves between the boiler and the header, especially the drains between the boiler and the two stop valves.
2. Warm up the steam line between the boiler and the header by back feed through the drip line or by means of the bypass valve.

3. When the steam line is thoroughly heated and at header pressure, open the bypass valve.
4. When the boiler pressure almost reaches line pressure, open the bypass line around the main steam stop valve to equalize pressures and temperatures in the piping; then slowly open the main steam stop valve. As the boiler reaches line pressure and is actually steaming, slowly raise the non-return valve stem to the full open position.
5. After the boiler is on line, close all super heater drains.
6. Inspect the entire boiler, and close any drain valves that are not discharging condensate.
7. Close the economizer-recirculating valve when an adequate continuous feedwater flow is established.
8. Close the drain valve at the non-return valve.
9. Close the bypass valve around the non-return valve.
10. A boiler with a pendant (non-drainable) super heater has a slightly different operation. Super heaters of this type trap condensate in the loops that must be boiled off before the firing rate can be increased and the steam flow started.
11. Maintain a constant firing rate. The strength of thick steam drums may be impaired by excessive temperature differentials between the top and the bottom of the drum if the proper firing rate is not maintained. Tubes may start leaking at rolled seats and the super heater tubes may overheat.
12. On boilers generating saturated steam, follow the above instructions for removing air and condensate.

9.4.4 Operating Procedures

Success in operating boilers depends largely upon the operator’s performance. No fixed set of rules can be established to fit all conditions. Consequently, the operator must see and interpret all prevailing operating conditions and, if necessary, take action to control, modify, or correct them. To be able to do this, the operator must be thoroughly familiar with the characteristics and standard operating procedures for the boiler for which the operator is responsible. This section acquaints you with some of the basic operating procedures that generally apply to most, if not all, boilers you will be assigned to operate. For specific operating instructions, consult the manufacturer’s manual for the boiler concerned.

9.4.4.1 Normal Operation

During normal operation of boilers, the operators have two major responsibilities. The first is to maintain proper water level at all times. If the water level is too low, tubes may overheat, blister, and rupture. If water level is too high, carry-over of water to the super heater tubes may damage the super heater elements and the turbine. The second is to prevent loss of ignition when burning fuel is in suspension. Maintain safe and efficient combustion conditions in the furnace and correct fuel-air ratios.

9.4.4.2 Blowdown

Establish definite intervals for blowing down the boiler, depending on the type of operation and chemical analysis of the boiler water. During regular operation, never blow down economizers or water-cooled furnace walls. Blowdown valves on this type of equipment serve only as drain valves.

Blowdown should be at reduced or moderate rates of steam for low point drains or blowdown valves. When the water glass is not in full view of the operator blowing down a boiler, another operator should be temporarily assigned to observe the water glass and signal the operator handing the valves. For control of water conditions when working, use continuous blowdown to maintain the proper concentration at all times and to prevent blowing down large quantities of water while the boiler is operating at a high capacity.

9.4.4.3 Boiler Makeup Water

Use only properly treated water for makeup, and maintain the boiler water conditions as specified in water treatment instructions. Make an accurate water analysis at specified intervals. Carefully control the blowdown and the addition of treatment chemicals to meet the manufacturer's specifications.

9.4.4.5 Soot Removal

Remove soot from hoppers and pits at definitely established intervals, as necessary.

9.4.4.6 Instrument Readings

Establish definite intervals for observing and recording the readings on all important instruments and controls. Be sure you obtain accurate readings and see that the readings are recorded properly on the log sheet or other required record.

9.4.5 Operating Checks

To help ensure efficient operation of the boiler, operators should ensure that proper operating checks are done during boiler operations. Operating checks, as shown in *Table 9-7*, apply to most, if not all boilers.

Table 9-7 — Operational checks for boilers.

Equipment	Action/Check
Water level	Check frequently; water expands during the heating up period.
Main steam stop bypass (if installed)	Open if the boiler is to be cut in on a cold line.
	Main steam stop can be opened when there is no other boiler on the same steam line.
Air cock	Close after steam has formed and has blown all air from the boiler.
Steam pressure	Raise slowly, usually 1/2 to 2 1/2 hours, depending upon type and size.
	Temperature of water should be raised at a rate of 100°F per hour.
Safety valve	Manually lifts when pressure is at least 75% of the valve setting.
	Make sure valves reseat properly; if valves fail to reseat, lift them a second time.
Boiler feedwater	Commence feeding boiler.
Firing	Gas: Maintain ignition; maintain air-fuel ratio; there should be no soot formation.
	Oil: Maintain ignition; observe flame and adjust dampers; check accuracy by flue-gas analysis.
Water level	Blow down gauge glass and water column.
	Keep at proper level.
	Determine true level of water frequently.
Boiler blowdown	Watch and monitor gauge glass.
	Frequency depends on water tests.
Cutting in boiler	If closed, open main steam stop valve.

Keys to efficient boiler operation and performance are as follows:

1. Flue-gas temperature
   a. Keep the temperature low.
   b. Temperature should be about 150 degrees higher than temperature of steam produced.
2. Flue-gas analysis
   a. Take periodically.

   b. Maintain proper CO^2 level for fuel used.

3. Flame
   a. Should be long and lazy.
   b. Must not enter the tubes.
   c. Should not be dark and smoky.
   d. Have a light brown haze from stack, except gas.
   e. When the fuel is oil, have a yellow flame with dark or almost smoky tips.
4. Draft
   a. Usually 0.03 to 0.06 inches of water.
   b. Check the manufacturer's recommendations.
5. Makeup feed
   a. Maintain low rate.
   b. Avoid excessive boiler blowdown.
6. Insulation
   a. Ensure boiler and lines are well insulated.
7. Water treatment
   a. Carry out prescribed treatment of boiler water.

9.4.6 Securing Procedures

The recommended procedures for securing boilers are as follows:

1. Reduce the load on the boiler slowly, cutting out the fuel supply by proper operation of the fuel-burning equipment.
2. Maintain normal water level.
3. When the boiler load is reduced to about 20% of rating, change the combustion control and the feedwater control to manual operation.
4. Before securing the final fuel burner, open the drain valves at the steam and non-return valve and the drain valve on the super heater outlet header. Be sure the bypass valve around the non-return valve is closed.
5. Secure the final fuel burner when the load has been reduced sufficiently.
6. Continue operating the draft fans until the boiler and the furnace have been completely purged.
7. Shut down the draft fans.
8. Close the dampers, including the air heater and super heater bypass dampers, when provided.
9. Follow the manufacturer's instructions for the rate of cooling the boiler. A thermal strain may occur if the change is too fast.
10. When the boiler pressure has started to drop, close the steam stop and non-return valve.
11. When the boiler no longer requires any feed and the non-return valve is closed, open the valve in the recirculating connection of the economizer, if provided.

12. Let the boiler pressure drop by relieving steam through the super heater drain valve and the drain valve at the non-return valve. If the boiler is losing pressure at a rate faster than specified by the manufacturer, throttle the drain valves as necessary to get the proper rate. Do not close the valves completely
13. When the drum pressure drops to 25 psig, open the drum vent valves.
14. If a regenerative type of air heater is used, the rotor may be stopped when the boiler exit gas temperature is reduced to 200°F.
15. The boiler can be emptied when the temperature of the boiler is below 200°F. Before sending someone into any part of the boiler, close and properly tag all controls, valves, and drains or blow down valves connected with similar parts of other units under pressure at the time. This move prevents any steam or hot water from entering the unit. The tags are to be removed only by the authorized person who tagged out the boiler and must remain in place until the work is completed. Ventilate the boiler thoroughly and station a person outside. Inside, use only low voltage portable lamps provided with suitable insulation and guards. Even 110 volts can kill under the conduction conditions inside a boiler. All portable electrical equipment should be grounded; electric extension cords should be well insulated, designed to withstand rough usage, and maintained in good condition.

9.4.7 Boiler Emergencies

Typical emergency situations encountered with the operation of boilers are (1) low water, (2) high water, (3) serious tube failure, (4) flarebacks, (5) minor tube failure, and (6) broken gauge glass. *Table 9-8*, lists the safe procedures to follow.

Table 9-8 — Procedures for Boiler Emergencies.

EMERGENCY	TASK	KEY POINTS
Emergency One: Low water condition indicated by no water level in the gauge glass.	Secure the boiler; secure electrical switches, steam stop, and feed stop. Provide water level by opening try cocks. Cool the boiler until the water temperature is 200°F. Secure all sources of draft. Check controls. Find out the cause for failure. Correct the trouble. After correction, add water to correct water level.	Do NOT add water to the boiler to raise the water level in the gauge glass column. Stay away from the discharge. Do not force cool.
Emergency Two: High water condition indicated by gauge glass full of water.	Prove water level by opening the try cocks. Blowdown the boiler by opening the blowdown valves. Find cause of failure. Correct the trouble. Secure the boiler if pump controls operate improperly.	Stay away from discharge. Check blowdown pit. Watch the gauge glass until normal level is reached. If control operates properly, continue to operate the boiler.
Emergency Three: Serious tube failure making it impossible to maintain water level.	Secure the boiler by securing the electrical, steam, and fired systems. Add water to the boiler until the ruptured tube level is reached and the boiler is cooled to a temperature of 200°F. Open boiler to replace the tube.	For large boilers: Water should be fed to the boiler until properly cooled. Mark the gauge glass if within its range. Observe level by whatever means available.
Emergency Four: Flareback caused by an explosion within the combustion chamber.	Secure the boiler. Find the cause of flareback and correct. Check for sufficient fuel and type of fuel contamination. Check the burner.	Ensure that a slug of water did not interrupt flame with a refire before pre-purge.
Emergency Five: Minor tube failures indicated by trouble maintaining water level under normal steam demand.	Secure the boiler if it is possible to remove it from the line for sufficient time to make necessary repairs. Secure electrical switches. Open the steam stop and feed stop if additional water is not needed.	If unable to secure boiler because of steaming requirements and you can maintain the water level, continue to operate. If unable to maintain the water level and/or supply, secure the boiler.
Emergency Six: Broken gauge glass on water column.	Secure top and bottom valves. Replace gauge glass. Use chains to prevent injury to personnel.	Boiler may be kept on line. Check the boiler water level by using the try cocks.

9.4.8 Boiler Operating Logs

The main purpose of boiler operating logs is to record continuous data on boiler plant performance. Logs become a source of information for analyzing the operation of the boiler for maintenance and repair. The daily operating log sheets provide the basic information around which maintenance programs are developed. The log is arranged for use over a 24-hour period divided into three 8-hour shifts. Log sheets vary among different activities, but you should have no difficulty in making log entries once you understand what information is required. The types of information to be entered in the appropriate column of the log are as follows:

- Steam pressure. Based on steam gauge readings and indicates the performance of the boiler.
- Steam flow. Actual output of the plant, in pounds per hour, to obtain steam flow. The data from these entries are used to determine the number of boilers to operate for greatest efficiency.
- Feedwater heater pressure. Indicates whether the proper deaerating temperature can be maintained in the heater.
- Feedwater heater temperature. Shows the effectiveness of the feedwater heater. A drop in steam-supply pressure or insufficient venting may cause low heater temperature.
- Feed pump pressure. Indicates the effectiveness of the boiler feed pumps. If the feedwater supply fails, the pressure reading enables the operator to determine whether the trouble is in the feed pumps. Pumps are defective when the feed pump pressure reading is below normal.
- Last-pass draft. Indicates the actual draft produced by the stack or the induced-draft fan. A decrease in the last-pass draft with other conditions constant indicates leaking baffles. An increase shows gas passages are becoming clogged.
- Percent CO_2 flue gas. This value is a measure of relative quantities of air supplied with fuel. It is kept at a value that has been established as most satisfactory for the plant, fuel, firing rate, and other related factors. In plants not equipped with CO_2-recording meters, this value is determined with a hand gas analyzer.
- Flue gas temperature. Shows the quantity of heat leaving the boiler with flue gases. This heat represents a direct energy loss in fuel. Dirty heating surfaces or leakage of baffles causes high flue gas temperatures. Excessive fouling of firesides of boilers increases draft loss, while leaking baffles decrease draft loss. Either condition raises the temperature of flue gas above normal.
- Fuel. Fuel oil quantities are determined by the use of a measuring stick and tables supplied with a given tank. Some tanks are equipped with gauges to show the fuel volume. Always determine the quantity of fuel used, as this represents a major operating cost.
- Outside temperature. The load on a heating plant is greatly influenced by outside temperature. Record this temperature for comparison with steam generated and fuel used. These comparative values are useful in finding abnormal fuel consumption and in estimating future requirements.
- Makeup water. Record the quantity of makeup water used to enable the operator to note an abnormal increase before a dangerous condition develops. Return all possible condensate to the boiler plant to save water and chemicals used to treat water.
- Water pressure. Indicates whether water is sufficient.
- Hot-water supply temperature. Insufficiently heated water can cause scaling or deposits in a boiler.

- Water softeners. Where softeners are used, a decrease in the quantity of time used for runs between regeneration indicates either an increase in hardness of incoming water or a deterioration of softening material.
- Total and average. Space is provided for recording the total and average quantities per shift. Steam flowmeter. The steam flowmeter integrator reading at the end of a shift and multiplied by the meter constant gives the quantity of steam generated. Dividing steam generated by fuel burned (gallons of oil) yields a quantity that shows the economy obtained. If a plant does not have a steam flowmeter, pumps can be calibrated for flow and a record kept of their operating time, or condensate and makeup water can be metered.
- Boiler feed pumps in service. Makes it possible to determine operating hours and to ensure that various pumps are used for equal lengths of service.
- Phosphate, caustic soda, and tannin added. Is valuable in keeping the correct boiler water analysis and in determining total chemicals used.
- Remarks. The Remarks column is used to record various types of information for which space is not provided elsewhere on the log sheet. Note irregularities that are found during inspections, dates boilers are drained and washed out, equipment to be checked daily, and so forth.
- Other personnel. Names of personnel responsible for specific tasks and data must be entered on the log sheet, if required.

9.5.1 Safety

In servicing boilers, the need for safety cannot be overemphasized. Much progress has been made over the years in the development of safety devices for boilers. There are still many ways, however, in which serious accidents can happen around boilers. A boiler operator or serviceman who is careless on the job threatens the safety of everyone. Accidents somehow have a way of happening at a moment we least expect. All the more reason, therefore, for constant alertness and close attention to detail. Do not take chances! Be safety conscious!

Some of the major safety precautions to be observed by Utilitiesmen engaged in boiler operation and servicing are presented below.

As protection against toxic or explosive gases, boiler settings must be ventilated completely and tested for toxic or explosive gases before crews are permitted to enter.

The covers of manholes must be removed for ventilation before people enter the drum.

Before anyone enters a steam drum, mud drum, or other waterside enclosure, steam and feed lines connected to the headers under pressure should be isolated by a stop valve and a blank with an open telltale valve in between, or by two stop valves with a telltale valve opened in between.

A ventilating fan should be operating in the drum when someone is working in the boiler.

Workers should not be inside the waterside of the boiler when pressure is being applied to test a valve that has not been under pressure.

Workers should wear protective clothing when making boiler water tests.

Boiler settings must be examined daily for external air leaks. Cracks, blisters, or other dangerous conditions in joints, tubes, seams, or blowoff connections are to be reported to your supervisor immediately.

Boilers should also be examined regularly for deposits on their heating surfaces and for grease or other foreign matter in the water. Boilers showing any such faults should be cleared at the first opportunity and should not be used until cleared.

Performing certain adjustments and repairs while pressure is up is prohibited. A complete absence of pressure is to be ensured by opening the air cock or test and water gauge cocks connecting with the steam space before fittings or parts subject to pressure are removed or tightened, and before manhole or handhole plate fittings are loosened on a boiler that has been under pressure.

Combustion control, feed control, and burner, stoker, or similar adjustments are permitted with the boiler steaming, since many adjustments can be made only when pressure is up.

When cleaning operations are performed, workers should wear the proper personal protective equipment. The following requirements apply:

- Hard hats and goggles must be worn.
- When a worker is chopping slag inside a furnace, a respirator must be worn.
- Safety-toed shoes or toe guards must be worn to prevent injuries from falling slag.
- When someone is working inside the furnace, a large warning sign, such as Caution-Man Working Inside, should be placed near the furnace entrance.
- The use of open-flame lights is prohibited in boilers. When cleaning where flammable vapors and gases may be present, workers are to use only explosion-proof portable lamps equipped with heavily insulated three-wire conductors, with one conductor connecting the guard to ground.
- Oil accumulated on furnace bottoms should be cleaned out immediately.
- The fuel-oil suction and discharge strainers should be cleaned at least every 8 hours and more frequently if necessary.
- Condensate pits in boiler rooms should have metal covers. If the pits must be opened for maintenance, adequate guards should be placed around them and warning signs posted.
- Wear goggles with dark lenses, Number 1.5 to 3 shade, and suitable fireproof face shields when working near or looking through furnace doors of boilers in operation.
- When firing a cold boiler, be sure that the air vents are open on the boiler proper and that the drains are open on the super heater; keep these open until steam is liberated from the openings. Super heater vents must remain open until the boiler is on the line.
- Be sure gas-fired and oil-fired boilers, whether manual or automatic, are cleared of combustible gases after each false start.

All semiautomatic (multi-burner) boilers and all fully automatic boilers should be equipped with a manually activated switch for pilot ignition and a control device to prove the pilot flame is on before the main fuel valve is opened. Do NOT use a hand torch to light off a boiler. If a hand torch is applied to a firebox filled with vaporized oil, a severe boiler explosion is likely to occur.

Prevent overheating of boilers equipped with super heaters by firing at a slow rate during the warm-up period and by allowing a small amount of steam to flow through the super heater.

When taking over a watch, blow the water gauges and note the return of the water in the glass. Be certain of the water level at all times. Do NOT be misled by a dirt marking on the gauge that may look like the surface of the water. Do NOT depend entirely upon automatic alarm devices and automatic feedwater regulators.

If the water goes out of sight in the bottom of the gauge glass, kill the fire with the quickest means available; immediately close the steam stop valve, and allow the boiler to cool slowly; then, drain the boiler completely and open it for inspection. Do NOT feed cold water to a boiler that has had low water until the boiler has cooled.

Check the water on steaming boilers by try cocks at least once each watch and before connecting a boiler to the line.

Check safety valves often to be sure they will pop at the correct pressure, as marked on the nameplate. Do NOT break the seal of a safety valve or change its adjustment, unless such action has been authorized. NEVER weight pop valves, relief valves, and so on, to increase the recommended steam pressure for which the boiler is approved.

Do not use oil from a tank in which a lot of water is mixed with oil unless a high suction connection is provided. When an atomizer sputters, shift the suction to the standby tank or another storage tank. A sputtering atomizer indicates water in the oil.

Reduce the fouling of oil heaters by using as few heaters as possible. Recirculate the oil through the used heaters for a short time after securing the burners. Maintain the prescribed fuel-oil temperature; do NOT exceed it.

If a large steam leak occurs in a boiler, shut off the burners, continue to feed water until the fire is out, close the steam stop valve, ease the safety valves, clear the furnace of gases, close the registers, and cool the boiler slowly.

Do NOT tighten a nut, bolt, or pipe thread, nor strike any part, nor attempt other adjustments to parts while the boiler is under steam or air pressure.

Take care to prevent lubricating oil, soap, or other foreign substances from getting into the boiler. Condensate from cleaning vats should be drained to waste and not returned to the boiler.

Close the furnace openings as soon as all fires have been put out and the furnace has been cleared of gases.

At shore installations, the handles on pull chains to boiler water-gauge cocks and water-gauge glass stop valves should be painted the following colors:

Opening water-gauge glass stop valves WHITE

Closing water-gauge glass stop valves RED

Top gauge cock YELLOW

Center gauge cock GREEN

Bottom gauge cock BLUE

Do NOT use water to put out an oil fire in the furnace.

When fires are banked, make certain the draft is enough to carry off flammable gas accumulations.

The following lists contain a number of actions to which you should ALWAYS be alert and a number of actions you should NEVER perform.

9.5.1 Safety Precautions

Always study every conceivable emergency and know exactly what action to take.

Always proceed to proper valves or switches rapidly but without confusion in time of emergency. You can think better walking than running.

Always check the water level in the gauge glass with the gauge cocks at least daily—also at any other time you doubt the accuracy of the glass indication.

Always accompany orders for important operations with a written memorandum. Use a logbook to record every important fact or unusual event.

Always have at least one gauge of water before lighting off. The gauge cocks should check the level.

Always be sure the blowdown valves are closed, and proper vents, water-column valves, and pressure-gauge cocks are open.

Always use the bypass if one is provided. Crack the valve from its seat slightly and await pressure equalization. Then open it slowly.

Always watch the steam gauge closely and be prepared to cut the boiler in, opening the stop valve only when the pressures are nearly equal.

Always lift the valve from its seat by the hand lever when the pressure reaches about three quarters of popping pressure.

Always consult the officer in charge of the plant, your CPO, or other proper superior and accept his/her recommendations before increasing the safety-valve setting.

Never fail to anticipate emergencies. Do not wait until something happens before you start thinking.

Never start work on a new job without tracing every pipeline in the plant and learning the location and purpose of each and every valve regardless of size. Know your job!

Never leave an open blowdown valve unattended when a boiler is under pressure or has a fire in it. Play safe--your memory can fail.

Never give verbal orders for important operations or report such operations verbally with no record. Have something to back you up when needed.

Never light a fire under a boiler without checking all valves. Why take a chance?

Never open a valve under pressure quickly. The sudden change in pressure, or resulting water hammer, may cause piping failure.

Never cut a boiler in on the line unless its pressure is within a few pounds of header pressure. Sudden stressing of a boiler under pressure is dangerous.

Never bring a boiler up to pressure without trying the safety valve. A boiler with its safety valve stuck is the same as playing with dynamite.

Never increase the setting of a safety valve without authority. Serious accidents have occurred from failure to observe this rule.

In case of an oil fire in the boiler room, close the master fuel-oil valve and stop the oil pump.

Other than the above precautions, the following list contains a number of safe practices that you should try to follow in your work. It also contains a number of unsafe practices that you must avoid.

9.5.2 Safe Practices

Always have the valve fitted with a new spring and re-stamped by the manufacturer for changes over 10 percent.

Always keep out loiterers, and place plant operation in the hands of proper persons. A boiler room is not a safe place for a meeting.

Always consult the officer in charge of the plant, your CPO, or other proper superior before making any major repair to a boiler.

Always allow the draft to clear the furnace of gas and dust for several minutes. Change draft conditions slowly.

Always consult someone in authority. Two heads are better than one.

9.5.3 Unsafe Practices

Never allow unauthorized persons to tamper with steam plant equipment. If they don't injure themselves, they may injure you.

Never allow major repairs to a boiler without authorization.

Never attempt to light a burner without venting the furnace until clear. Burns could occur.

Never fail to report unusual behavior of a boiler or other equipment. It may be a warning of danger.

9.5.4 Lockout Devices

A lockout device is a mechanism or arrangement that allows the use of key or combination locks (most commonly padlocks) to hold a switch lever or valve handle in the OFF position. Some switches and valves have lockout devices built in; others must be changed before locks can be used. As a UT, you may use lockout devices when working on potentially hazardous equipment, such as high-pressure steam lines, electrically operated equipment, and boilers. The use of a lockout device is a great advantage since the machine or equipment cannot be started up, energized, or activated while you are working on it. The examples in *Figure 9-56* will give you an idea of how devices may be used in locking out valves.

Figure 9-56 — Locking out valves.

9.5.4.1 Multiple Lock Adapter

It is often an advantage for a lockout device to accommodate more than one padlock. In this way, when you are working on a machine or an item of equipment with the valve locked off, another person can come along and use the padlock to do other hazardous work on the machine or equipment at the same time, rather than wait until you are finished.

Since most controls are not designed to accommodate more than one padlock at a time, multiple lock adapters, called lockout clamps or tongs, may be used (*Figure 9-57*). These adapters should be permanently chained to the control, or alternately, issued to all people with padlocks.

Figure 9-57 — Multiple lock adapters.

9.5.4.2 Locks

Perhaps you are wondering what kind of lock should be used—key or combination. What person should have a lock? Who should be in possession of the keys or combinations? How should the lock be identified? The answers to these questions may vary from one activity to another, but some guidelines are as follows:

1. Key-operated padlocks are more commonly used than combination locks. Supervisors can control keys easier than combinations.
2. Locks should be issued to every person who works on closed-down equipment. No key (or combination) should fit more than one lock.
3. Only one key should be issued to a person authorized to use the lock. At some activities, the supervisor may be permitted to maintain a duplicate set of keys for locks under his/her control, or a master key. Some activities, however, may have only one lock-one key. In an emergency, bolt cutters may be used to remove a lock. As a word of caution: Keys and locks should never be loaned.

4. Locks should identify the user by name, rate, and shop. This information can be stamped into the lock case, stenciled on, or carried on a metal tag fixed to the shackle of the lock. In addition, locks may be color coded to identify the skill or rating of the lock folder, such as UT, Construction Electrician (CE), or Construction Mechanic (CM). The colors could also follow the hard hat color code.

9.5.4.3 Lockout Procedures

If locks, lockout devices, and multiple lock adapters are to be effective, they must be used properly on every occasion where they are needed. Make sure that you follow the steps of the lockout procedure below.

1. Before any equipment is locked out, there should be agreement as to the specific machine or unit to be taken out of operation. The supervisor should oversee lockout procedures.
2. Turn off the point-of-operation controls. (Remember that disconnect switches should never be pulled while under load because of the possibility of arcing or even explosion.)
3. See that the main power controls (switch, breaker, or valve) are turned OFF. Where electrical voltages are involved, do NOT attempt this yourself but have it done by a CE.
4. After the switch has been opened or the valve closed, the person who will be doing the work should snap the locks on the control lever or multiple lock adapter. At this point, tag the switch, valve, or device being locked. Tags should indicate the type of work being done, approximately how long the job will take, and the name of the supervisor.
5. Try the disconnect or valve to make sure it cannot be moved to ON.
6. Try the machine controls as a test to ensure the main controls are really off.
7. As each person completes work, only that person should remove the lock and supplemental tag. The person removing the last lock should notify the supervisor that the work is finished and the equipment is ready to be placed back in operation.

Test your Knowledge (Select the Correct Response)

5. What color should the pull chain handle be painted for the center gauge cock?

   A. White
   B. Red
   C. Yellow
   D. Green

Summary

As a UT, you will be involved with the installation, operation, and maintenance of various types of boilers such as water-tube or fire-tube. You must understand the basic theory and operation of steam generation. You must have the understanding of the purpose, use, interface, and control of boiler fittings, automatic control mechanisms, instruments and meters associated with boilers. You also must be capable of identifying and correcting water impurities problems associated with boilers by utilizing various water treatment and boiler cleaning procedures.

You will also be involved in the maintenance and repair of auxiliary equipment, boiler tubes, and refractories. As a UT, you will be responsible for the detailed boiler operations including pre-watch tours, pre-operating checks, operating procedures, operating checks, securing procedures, and the recording and upkeep of boiler operating logs. You will also be responsible for the immediate and effective casualty control over any type of boiler emergencies encountered. You must know and understand the numerous safe and unsafe practices associated with boiler operations including the use of local lockout procedures. Remember, you will be the first line of defense in the prevention against accidents and mishaps from occurring.

Review Questions (Select the Correct Response)

1. An increase in pressure results in what effect on the boiling point temperature of water?

   A. Increase
   B. Decrease
   C. Sharp decrease, then gradually increasing
   D. No effect on temperature

2. What is the difference between dry saturated steam and wet statured steam?

   A. Temperature
   B. Water particles in suspension
   C. Condensation level
   D. Absence of water particles in suspension

3. Which description identifies a water-tube boiler?

   A. Products of combustion pass through the tubes and the water surrounds them.
   B. Only water and diesel fuel are used to generate steam.
   C. Products of combustion surround the tubes through which the water flows.
   D. Only vertical tubing for water passage is found in fire-tube boilers.

4. In a water-tube boiler, how are baffles usually arranged?

   A. Directly across the tubes twice prior to being discharged from the boiler.
   B. Directly parallel with the tubes three times prior to being discharged from the boiler.
   C. Directly parallel with the tubes twice prior to being discharged from the boiler.
   D. Directly across the tubes three times prior to being discharged from the boiler.

5. Which is NOT a type of fire-tube boiler?

   A. Horizontal supply tubular
   B. Firebox
   C. Scotch marine
   D. Vertical tube

6. Which safety device provides added protection against low-water conditions?

   A. Ball limit switch
   B. Fusible plug
   C. Low level transducer
   D. Over-temperature rheostat

7. Which type of fire-tube boiler are UTs assigned to operate and maintain more often than any other type?

   A. Vertical tube
   B. Scotch marine
   C. Horizontal fire-tube
   D. Firebox

8. Where is the blowdown pipe of a vertical tube boiler attached on the water leg?

   A. Uppermost part
   B. Midway point of pipe
   C. Upper and lower parts of pipe
   D. Lowest part

9. Gas flows into the horizontal return tubular boiler from what component?

   A. Firebox
   B. Drum
   C. Shell
   D. Breaching

10. Where are the manholes located on a horizontal return tubular boiler?

   A. Upper part of shell
   B. Upper and lower part of the shell
   C. Lower part of shell
   D. No manholes associated with this type of boiler

11. What is the position of the air cock prior to firing a cold boiler with no steam pressure?

   A. Shut
   B. Open bleed position
   C. Open
   D. Bypass

12. Which piece of equipment facilitates the removal of gases through the stack?

   A. Excavation blower
   B. Forced raft fan
   C. Air cock
   D. Induced draft fan

13. Which blowdown valve permits the removal of scale and sediments from the water column?

   A. Water column blowdown
   B. Drum water blowdown
   C. Water leg blowdown
   D. Sump water blowdown

14. The fire-actuated plug has a melting point of how many degrees Fahrenheit?

- A. 435
- B. 445
- C. 455
- D. 465

15. Which equipment steadies the water level in the gauge glass through the reservoir capacity of the column?

- A. Fusible plug
- B. Breaching
- C. Water column
- D. Blowdown valves

16. What are the three lengths associated with the electrode assembly?

- A. Maximum, Minimum, and Burner cutout
- B. High, Low, and Burner shutdown
- C. Open, Shut, and Burner shutdown
- D. High, Low, and Burner cutout

17. What is the purpose of try cocks?

- A. To prove the water level in the boiler.
- B. To increase water level in the boiler.
- C. To decrease water level in the boiler.
- D. To release excess steam from the boiler.

18. How many safety valves are required on a boiler that has more than 500 square feet of heating surface?

- A. 1
- B. 2
- C. 3
- D. 4

19. What device on the safety valve is provided to lift the valve from its seat?

- A. Vent port
- B. Lifting lever
- C. Lifting switch
- D. Vent bonnet

20. A steam injector can lift a stream of water at a temperature of 120°F how many feet?

- A. 10
- B. 12
- C. 14
- D. 16

21. **(True or False)** The water supply should not be hotter than 120°F for the injector to operate.

A. True
B. False

22. What is known as the process of maintaining a difference of pressure between two points in a system?

A. Pressure regulating
B. Pressure maintaining
C. Pressure differential
D. Pressure building

23. Which is NOT a function of the pressure control?

A. To control the pressure in the boiler.
B. To secure water flow when temperature reaches 500°F.
C. To secure the fuel burning equipment when the pressure reaches a predetermined cutout.
D. To start fuel burning equipment when the pressure drops to the cut-in point.

24. What are the two settings on the pressure control?

A. Cut-out point and differential
B. Cut-in point and stabilization
C. Cut-in point and differential
D. Cut-out and cut-in points

25. Which method is used to controlling combustion air?

A. Automatically adjusted air cock
B. Automatically adjusted air damper
C. Manually adjusted air cock
D. Manually adjusted air damper

26. What is the only means of obtaining the correct ratio of fuel to air?

A. Setting of air damper
B. Setting of air transducer
C. Setting of air cock
D. Setting of differential

27. In combustion control, what is the normal atomizing pressures in pounds per square inch?

A. 50 to 95
B. 95 to 120
C. 110 to 130
D. 150 to 220

28. How many seconds after flame failure will the burner equipment be secured?

A. 2
B. 3
C. 4
D. 5

29. Safety shutdown sequence will commence after how many seconds after pilot flame is not established and confirmed?

A. 2
B. 4
C. 6
D. 7

30. Which meter is used as a guide in controlling the relationship between air required and air actually supplied to burn the fuel?

A. Combustion air and steam flowmeter
B. Steam flowmeter
C. Combustion air flowmeter
D. Combustion air and water flowmeter

31. What unit of measurement is associated with drafts?

A. Pounds per square inch
B. Inches of water
C. Microns
D. Gallons per minute

32. Which are scale-forming elements?

A. Silicon and calcium
B. Calcium sulfate and precipitates of hardness
C. Precipitates of hardness and silica
D. Magnesium and iron

33. What type of coating does silica leave behind when it precipitates in boiler feedwater?

A. Soft clear
B. Hard milky
C. Soft opaque
D. Hard glossy

34. What is the most widely used method of treatment of scale?

A. Alkaline phosphate-tannin
B. Softening tanks
C. Bed of carbon minerals on inlet line
D. Dissolving of oxygen and carbon dioxide

35. Boilers operating at what pressure are normally used for hot-water generation?

A. 20 psi or more
B. 15 psi or less
C. 15 psi or more
D. 25 psi or more

36. Which reagent is NOT used in the test for hardness?

A. Hardness indicator
B. Hardness buffer
C. Hardness filter
D. Hardness titrating solution

37. What function does carbon play in the test for phosphates?

A. Sifts out the phosphate chemical
B. Makes the tricalcium sludge less filterable
C. Breaks up the feedwater
D. Absorbs the tannin

38. Concentrated stannous chloride should be discarded after how many months after preparation?

A. 2
B. 3
C. 4
D. 5

39. At what temperature, in degrees Farhenheit, should the boiler water sample be for the conduct of the caustic alkalinity without tannin test?

A. 70
B. 80
C. 120
D. 140

40. At what temperature, in degrees Fahrenheit, should the boiler water sample be for the conduct of the caustic alkalinity with tannin test?

A. 120
B. 140
C. 160
D. 180

41. Prior to conducting the sodium sulfite test, to what temperature, in degrees Fahrenheit, should the boiler water sample be cooled?

A. 40
B. 50
C. 60
D. 70

42. When the paper turns orange in the conduct of the pH test, what does this indicate to the operator?

A. pH is too high.
B. pH is too low.
C. Increase of caustic soda dosage is required.
D. Retest is required.

43. **(True or False)** The lower the concentration of ionizable salts, the greater the conductance of the sample.

A. True
B. False

44. Which cleaning method for fire-side boilers is NOT recommended?

A. Scraper cleaning
B. Wet steam sweating
C. Dry steam lancing
D. Hot-water washing

45. When utilizing the hot-water washing method, at what temperature, in degrees Fahrenheit, should the water be?

A. 120
B. 130
C. 140
D. 150

46. How is fireside slag removed from the convection super heaters?

A. By circulating cold water through the tubes.
B. By using a high pressure hot-water washer.
C. By increasing output boiler temperature.
D. By using a wire brush on the interior side of tubes.

47. How is water corrosion reduced?

A. Keeping dissolved oxygen levels high.
B. Maintaining the boiler water alkalinity at proper levels.
C. Replacing cathodic anodes monthly.
D. Maintaining the boiler water acidity at proper levels.

48. After a safe shutdown of the boiler, what is required prior to commencing tube cleaning?

A. Boiler water temperature to 65°F
B. Tube clearance tolerances verified
C. Adequate ventilation
D. Blowdown of internal components

49. **(True or False)** The lower ends of all tubes must be cleaned from the water drum or header.

A. True
B. False

50. Which acid is NOT required in chemical cleaning of boilers?

A. Boric
B. Sulfuric
C. Citric
D. Sulfamic

51. What is the purpose of citric acid?

A. Removal of all conductance properties from tube.
B. Removal of boiler waterside deposits.
C. Formation of corrosion-eating organisms.
D. Removal of boiler fireside deposits.

52. What are the two methods of boiler acid treatments?

A. Circulation or soak
B. Inhibited or fill-and-soak
C. Circulation or fill-and-soak
D. Reactive and fill

53. Which is NOT a neutralizing solution?

A. Soda ash
B. Trisodium phosphate
C. Sodium tripolyphosphate
D. Calcium sulfate

54. When conducting the boiling out method, the temperature of the water in the boiler needs to be at what degree Fahrenheit for at least 24 to 48 hours?

A. 180
B. 190
C. 200
D. 210

55. What is the most common cause of major boiler damage?

A. Bent tubes
B. Low water
C. Warped water columns
D. High sludge buildup

56. How often are blowdown valves opened?

A. Once a watch
B. Once daily
C. Twice a watch
D. Twice daily

57. How often are steam traps tested for correct operation?

A. Once a watch
B. Once a day
C. Once a week
D. Once a month

58. The clearance between the shoulder of a manhole plate and the manhole must not exceed what value?

A. 1/16 inch
B. 1/8 inch
C. 1/4 inch
D. 5/8 inch

59. How often is a hydrostatic test performed on a boiler?

A. Weekly
B. Monthly
C. Quarterly
D. Annually

60. In a hydrostatic test, what is the minimum water temperature of the boiler, in degrees Fahrenheit?

A. 50
B. 60
C. 70
D. 80

61. On boilers where the superheated steam reaches 850°F or higher, what material is the super heater tubes constructed out of?

A. Chromium-molybdenum iron
B. Carbonmolybdenum brass
C. Chromium-nickel copper
D. Carbonmolybdenum steel

62. What tool is used to remove tubes?

A. Air-powered side-cutting chisel
B. Arc welding equipment
C. Engineer’s hammer
D. Carbonate tip chainsaw

63. Tubes of 2 inches outside diameter are belled to what minimum distance, in inches?

A. 5/8
B. 7/16
C. 1/8
D. 7/8

64. What is the maximum projection into the drum or header for tubes of 2 inches outside diameter?

A. 5/8
B. 7/16
C. 3/4
D. 7/8

65. After the repair of boiler refractories, how many hours must the wall dry with the burner shutters open?

A. 4
B. 6
C. 8
D. 12

66. Plastic requires a baking-out temperature range of what value, in degrees Fahrenheit?

A. 2900 to 3000
B. 3000 to 3100
C. 3200 to 3300
D. 3300 to 3400

67. When should the head gasket be inspected?

A. Whenever front door is opened.
B. Whenever rear door is opened.
C. Whenever both front and rear doors are opened.
D. Whenever bottom door is opened.

68. How many phases of operation are associated with boiler operation?

A. 1
B. 3
C. 5
D. 7

69. Pre-operating checks are performed at what time of boiler operation?

A. Before lining up and lighting off
B. Before lining up
C. Before lighting off
D. Before fuel onload

70. During normal operation of the boiler, how many responsibilities does the operator have?

A. 1
B. 2
C. 3
D. 4

71. At what temperature, in degrees Fahrenheit, should the flue-gas temperature be above the steam-produced temperature?

A. 120
B. 130
C. 150
D. 170

72. How many inches of water should the draft be under normal operating conditions?

A. 0.01 to 0.03
B. 0.02 to 0.04
C. 0.03 to 0.06
D. 0.05 to 0.08

73. When should the drum vent valve be opened during normal operations?

A. Drum pressure drops to 25 psig.
B. Drum pressure rises to 50 psig.
C. Drum pressure drops to 15 psig.
D. Drum pressure rises to 25 psig.

74. At what temperature, in degrees Fahrenheit, can the boiler be emptied?

A. Below 200
B. Below 300
C. Below 400
D. Below 500

75. How many emergency situations should the operator be aware of when running a boiler?

A. 2
B. 4
C. 6
D. 8

76. The boiler operating log is set up on what frequency for logkeeping?

A. 12-hour period divided into three 4-hour shifts
B. 12-hour period divided into four 3-hour shifts
C. 24-hour period divided into three 3-hour shifts
D. 24-hour period divided into four 6-hour shifts

77. At shore installations, the handles on pull chains to boiler water gauge cocks are colored; which color is associated with opening water-gauge glass stop valve?

    A. White
    B. Yellow
    C. Red
    D. Green

78. What device is used to hold a switch lever in the off position?

    A. Tagout
    B. Lockout
    C. Stark
    D. Bendel

Trade Terms Introduced in this Chapter

British Thermal Unit (BTU)	The amount of heat required to raise the temperature of 1 lb. of water 1°F.
Saturated	Soaked, impregnated, or imbued thoroughly; charged thoroughly or completely.
Baffles	An artificial obstruction for checking or deflecting the flow of gases.
Water leg	The tubing in which water flows through a boiler.
Sediment	The matter that settles to the bottom of a liquid.
Flue	Any duct or passage for air or gas.
Bellows	A device for producing a strong current of air, consisting of a chamber that can be expanded to draw in air through a valve and contracted to expel it through a tube.
Ferrous	Of or containing iron.
Scale	A coating or incrustation, as on the inside of a boiler, formed by the precipitation of salts from the water.
Deaeration	To remove bubbles from a liquid, as boiler feedwater, as by mechanical agitation in a vacuum or by heating at atmospheric pressure.
Dispersant	A liquid or gas added to a mixture to promote dispersion or to maintain dispersed particles in suspension.
Precipitates	A solid that is separated from a solution by chemical or physical changes.
Reagents	A substance used in a chemical reaction to detect, measure, examine, or produce other substances.
Causticity	Capable of burning, corroding, dissolving, or eating away by chemical action.
Slag	The glassy mass left as a residue by the smelting of metallic ore.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Basic Machines, NAVEDTRA 12199, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

OSHA Regulations (Standards – 29 CFR)

Naval Construction Force Manual, *NAVFAC P-315*, Naval Facilities Engineering Command, Washington, D.C., 1985.

Facilities Planning Guide, NAVFAC P-437, Volumes 1 and 2, Naval Facilities Engineering Command, Alexandria, VA, 1982.

Fluid Power, NAVEDTRA 12964, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

National Standard Plumbing Code-Illustrated, National Association of Plumbing- Heating-Cooling Contractors, Washington, DC, 2006.

Safety and Health Requirements Manual, EM-385-1-1, Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 1992.

MIL-STD-17-1, Mechanical Symbols

International Plumbing Code 2009, International Code Council

International Mechanical Code 2009, International Code Council

R. Dodge Woodson, *Plumber's Quick-Reference Manual Tables, Charts, and Calculations,* 1st edition, McGraw-Hill, NY, 1996.

Water Testing Kit, Chemical Agent: M272, Technical Operations Manual, TM 3- 6665-319-10, Department of the Army, Washington, DC, 1983

Boiler Care Handbook, Cleaver-Brooks Division of Aqua-Chem. Inc., Milwaukee, WI, 1985.

COMFIRSTNCDINST 3500.1, Operational Risk Management (ORM).

COMFIRSTNCDINST 5100.2, Naval Construction Force Occupational Safety and Health Program.

UFC 3-430-07, Inspection and Certification of Boilers and Unfired Pressure Vessels.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 10

Steam Distribution Systems

Topics

1.0.0 Exterior Steam Distribution Systems

2.0.0 Interior Steam Distribution Systems

3.0.0 Steam Distribution System Components

To hear audio, click on the box.

Overview

As a UT you may have questions about delivering steam from the steam plant to the user. You will find information in this chapter that answer questions about steam distribution systems. A steam boiler is virtually useless for heating without a good distribution system for taking the steam to the areas to be heated.

The term distribution system, as used in this chapter, refers to the network of piping required to distribute steam from a boiler room or a boiler plant through the steam pipes to the equipment using it. In this chapter, both exterior and interior steam distribution systems are discussed, including their maintenance requirements, various components and purposes in the distribution system.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of exterior steam distribution systems.
2. Describe the different types of interior steam distribution systems.
3. Describe the components of a steam distribution system.

Prerequisites

None

This course map shows all of the chapters in Utilitiesman Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Utilities Equipment and Maintenance	↑	
Air Conditioning		
Refrigeration		
Heating Systems		U
Steam Distribution Systems		T
Boilers		
Sewage Disposal, Field Sanitation, and Water Treatment		B
Prime Movers, Pumps, and Compressors		A
Plumbing Fixtures		S
Piping System Layout and Plumbing Accessories		I
Structural Openings and Pipe Material		C
Fundamentals of Water Distribution		
Basic Math, Electrical, and Plumbing Operations		
Plans, Specifications, and Color Coding		

Features of this Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 EXTERIOR STEAM DISTRIBUTION SYSTEMS

The exterior distribution system is divided into underground and aboveground systems. The following topics discuss these two systems in detail.

1.1.0 Underground Systems

The major underground systems are the conduit and the ***utilidor*** types of systems. These systems are normally installed only in permanent heating installations because of their high cost of installation.

1.1.1 onduit Type

In the conduit type of steam distribution system, the pipe is installed inside a conduit that is usually buried in the ground below the frost line. The frost line is the lowest depth that the ground freezes during the coldest part of the winter. The pipe commonly used for steam is black steel pipe, which is not as strong as that required for condensate return lines. The conduit and insulation serve to protect and insulate the steam pipe. One type of conduit is shown in *Figure 10-1*. The conduit must be strong enough to withstand the pressure of the earth and the usual additional loads imposed upon it.

Figure 10-1 — One type of steam distribution conduit.

Several types of materials and various designs are used in the manufacture of conduit. Common types of conduit are constructed of masonry cement, galvanized iron, and steel. The conduit is usually sealed with asphaltic tar or some other type of sealer to prevent water from getting into the insulation and deteriorating it. Insulation may be attached directly to the pipe, attached to the inner surface of the conduit, or in loose form and packed between the pipe and the conduit.

The bottom of the trench for the conduit should be filled with coarse gravel or broken rock to provide support and adequate water drainage. When water is allowed to collect, it seeps into the conduit through porous openings in the sealer. This wets the

Figure 10-2 — Typical manhole for distribution system.

insulation and causes it to lose much of its insulating value.

Manholes are required at intervals along the line to give access to the necessary valves, traps, and expansion joints. A typical manhole is shown in *Figure 10-2*.

1.1.2 Utilidor Type

The utilidors, or tunnels, of the utilidor type of system are constructed of brick or concrete. The size and shape of the utilidor usually depend upon the number of distribution pipes to be accommodated and the depth the utilidor must go into the ground. Manholes, sometimes doors, are installed to provide access to the utilidor. A typical utilidor is shown in *Figure 10-3*. The utilidor is usually constructed so the steam and condensate return lines can be laid along one side of the tunnel on pipe hangers or anchors. This is usually done with the type of hanger with rollers that provides for free movement required by the expansion of the pipe. The other side of the utilidor should be a walkway that provides easy access to lines when you are inspecting and doing maintenance.

Figure 10-3 — Typical utilidor.

1.2.0 Aboveground Systems

Aboveground steam distribution systems are further divided into overhead and surface systems:

1.2.1 Overhead Distribution Systems

Overhead distribution systems are often used in temporary installations and sometimes in permanent installations. The main drawback to this type of distribution system is the high cost of maintaining it. These overhead systems are similar in many respects to underground distribution systems. They require valves, traps, provision for pipe expansion, and insulated pipes. The main difference is that the steam distribution and condensate return piping are supported on pipe hangers from poles instead of being buried underground (*Figure 10-4*).

Figure 10-4 — Steam and condensate lines supported by poles.

1.2.2 Surface Distribution Systems

In some cases, you will find that steam and condensate lines are laid in a conduit along the surface of the ground. These systems, however, are not as common as overhead and underground systems. Surface systems require about the same components as the overhead and the underground systems—traps, valves, pipe hangers to hold the pipes in place, and provision for pipe expansion. Sometimes an expansion loop, formed by a loop of pipe, is used instead of an expansion joint to provide for pipe expansion.

1.2.3 Maintenance

The maintenance required for exterior distribution systems normally consists of inspecting, repairing, and replacing insulation, traps, valves, pipe hangers, expansion joints, conduit, utilidors, and aluminum or distribution systems. The maintenance required on conduit and utilidors consists of keeping the materials of which they are constructed from being damaged and of ensuring that water is kept out of the tunnels and pipes. The maintenance required on outside metal coverings is about the same as that for the conduit and utilidors.

2.0.0 INTERIOR STEAM DISTRIBUTION SYSTEMS

Interior steam distribution systems may be classified according to pipe arrangement, accessories used, method of returning condensate to the boiler, method of expelling air from the system, or the type of control used. The interior steam systems discussed in this section are classified by pipe arrangement; they include but are not limited to: Gravity, One-Pipe, and Air-Vent System.

Steam may be fed to interior steam distribution systems from a boiler in the same building or from the exterior distribution system of a central plant.

2.1.0 Gravity, One-Pipe, Air-Vent System

The gravity, one-pipe, air-vent system is one of the oldest types of internal distribution systems (*Figure 10-5*). Its capacity is usually ample, and its installation cost is low. Because the condensate is returned to the boiler by gravity, this system is usually confined to one building and is seldom used as a central plant distribution system. The steam is supplied by the boiler and is carried by a single system of piping to the radiators. The return of condensate depends upon the hydrostatic head. Therefore, the end of the steam main, where the main is drained to the wet return, should be high enough above the waterline to provide the required hydrostatic head above the entrance to the boiler. The radiators in the system are equipped with an inlet valve and an air valve. The inlet valve is the radiator shutoff valve, while the air valve permits the venting of air from the radiators. Condensate is drained from the radiators through the same pipe that supplies the steam; they flow in opposite directions, however, which is a disadvantage. Under certain conditions, the condensate is held in the radiators. This causes noisy operation and a fluctuating water level in the boiler. Water hammer and slow heating are characteristic of this system when the pipe sizing, pitch, and general design are inadequate.

Figure 10-5 — Gravity, one-pipe, air-vent system.

2.1.1 Installation

Although all gravity, one-pipe, air-vent systems are alike in design, two installations are seldom alike in detail. Since the details differ with the make and model of equipment, the manufacturer's installation procedures should be followed. Also, you should follow the mechanical blueprints for a particular installation. There is some general information in this section that applies to most heating systems of this type.

To prevent water hammer and re-evaporation of the water, drain all condensate from the lines. The necessary internal drainage can be obtained by sloping the lines down in the direction of condensate flow, at least one-fourth of an inch for every 10 feet of pipe. The radiators must also be tilted so the condensate flows out of them into the same pipe through which the steam is entering.

Air vents are installed in the steam lines and radiators to eliminate air in the system. Air in the system tends to block the flow of steam, and it consequently acts as an insulator by preventing the emission of heat from the heating surface. Therefore, the air must be quickly and effectively vented from the heating equipment and steam lines to get quick and even heating from the steam-heating system. Most steam distribution systems are now fitted with automatic vents that permit the air to pass but which block the passage of steam. *Figure 10-5* shows air vents in the radiator and the distribution system.

2.1.2 Operation

The operating instructions for gravity, one-pipe, air-vent systems vary from one installation to another. The manufacturer of the equipment usually furnishes the specific operating instructions for the equipment.

Generally speaking, most steam systems have a main steam stop valve located on the top of the boiler. The purpose of this valve is to hold the steam in the boiler until you are ready to let it out. When you are ready to turn the steam into the distribution system, you should only crack (open very little) the valve. The reason for doing this is to allow the system to warm up slowly and avoid any thermal shock to the lines and fittings. After the system has warmed up, open the main steam stop valve slowly. While opening the valve, check often to ensure that the proper water level is maintained in the boiler.

You will also note that the radiator valves in one-pipe steam distribution systems should be either completely open or completely closed. Partial opening of the valve interferes with the proper drainage of water from the radiator.

2.1.3 Maintenance

This section covers the problems you are most likely to encounter in the field when maintaining a gravity, one-pipe distribution system. The most probable causes of these problems and the remedies for them are also addressed.

When a radiator fails to heat or water hammer occurs, there are several probable causes. One is the failure of the air vents to function, thereby causing the radiator to become air bound. A second cause is that the radiator valves are not completely open. Another cause is that the radiators and lines are not correctly pitched. To remedy these causes of heat failure, inspect the operation of the air vents and the positions of the radiator valves to make sure they are open. Then check and correct, if necessary, the pitch of the radiators and lines when the other checks do not correct the trouble.

A fluctuating waterline in the boiler can be caused by an excessive pressure drop in the supply lines, which in turn is usually caused by partial stoppage in the pipes. This, of course, can be remedied only by removing the cause of the stoppage. Uneven heat distribution is another trouble that you may encounter. This can be caused by inoperative radiator vents, improperly vented steam mains, or incorrectly pitched mains. To eliminate this uneven heat distribution, check and clean the air vents at the radiator and those in the steam mains. Then check and correct, as required, the pitch of the steam lines if the other remedies have not corrected the trouble.

2.2.0 Two-Pipe Vapor System with a Return Trap

The two-pipe vapor system with an alternating return trap is an improvement over the one-pipe system (*Figure 10-6*).

Figure 10-6 — Two-pipe vapor system with a return trap.

The return from the radiator has a thermostatic trap that permits the flow of condensate and air from the radiator. It also prevents steam from leaving the radiator. Because the return mains are at atmospheric pressure or less, a mechanical return trap is installed in the system to equalize the condensate return pressure with the boiler pressure. The mechanical return trap is primarily a double-valve float mechanism which permits equalization of the boiler pressure and the pressure within the return trap.

2.2.1 Installation

Vapor-steam systems with return traps are similar in design. However, two installations are seldom alike. Since the details differ with the type of heating equipment, the manufacturer's installation instructions should be followed.

However, the mechanical return trap should be installed on a vertical pipe in the return system that is adjacent to the boiler. The top of the trap should be level with or below the bottom of the dry return main. The bottom of the trap should be approximately 18 inches above the boiler waterline to provide a sufficient hydrostatic head to overcome friction in the return piping to the boiler.

2.2.2 Operation

The two-pipe vapor system with a return trap alternately fills and dumps. It returns condensate to the boiler by a mechanical alternating-return trap instead of by gravity. The alternating-return trap consists of a vessel with a float that, by linkage, controls two valves simultaneously so that one is closed when the other is open. One valve opens to the atmosphere; the other is connected to the steam header. The bottom of the vessel is connected to the wet return.

In operation, when the float is down, the valve connected to the steam header is closed and the other is open. As the condensate returns, it goes through the first check valve and rises into the return trap, which is normally located 18 inches above the boiler waterline. The float starts to rise when the water reaches a certain level in the trap, the air vent closes, and the steam valve opens. This action equalizes the trap and boiler pressures and permits the water to flow by gravity from the trap, move through the boiler check valve, and go into the boiler. The float then returns the trap to its normal vented condition, ready for the next flow of returning water.

2.2.3 Maintenance

The problems you are likely to encounter in maintaining the two-pipe vapor system with a return trap will differ with each system. Some of the more common troubles are discussed here. For specific instructions, you should refer to the manufacturer's manual or pamphlet pertinent to each piece of equipment.

When a radiator fails to heat, the air vent being plugged or the radiator being waterlogged because of a plugged or defective trap can cause the condition. In case there is a plugged air vent, all you need to do is clean it. When there is a waterlogged radiator, check the trap to determine if it is plugged; also check to see if the bellows is serviceable. If the trap is plugged, then cleaning it should solve your problem. However, if the trap is damaged, the damaged part, or the whole trap, must be replaced.

When the entire steam distribution system fails, the trouble can be caused by inoperative return traps or inoperative check valves. Clean and inspect the return traps and the check valves, and replace the defective parts or the whole unit if necessary.

2.3.0 Two-Pipe Vapor System With a Condensate Pump

The two-pipe vapor system with a condensate pump is similar to the two-pipe vapor system with the return trap, except that the condensate is returned to the boiler by a power-driven centrifugal pump instead of by a return trap (*Figure 10-7*).

Figure 10-7 — Two-pipe vapor system with a condensate pump.

This system includes a separate main, a radiator feed at the top, and a return system with thermostatically trapped outlets located at the bottom of the radiators opposite to the feed end. The return main terminates at the receiver of the condensate pump, where all of the air in the system is discharged to a vent on the receiver. With the use of a condensate pump, all of the returns to the pump are kept dry and the radiators can be located below the boiler waterline. This is not possible with the steam distribution systems previously described. The radiators should be installed above the return main to permit gravity flow of the condensate from the radiator, and the return main should pitch downward to the pump receiver.

2.3.1 Installation

Two-pipe vapor systems with condensate pumps are basically alike in design. However, since two installations are seldom alike, it is necessary to install each system according to the mechanical blueprints furnished by the civil engineer and the instructions of the manufacturer of the equipment.

2.3.2 Operation

The two-pipe vapor steam distribution system can be operated at the pressure limit of the steam plant boiler, provided the condensate pump is designed for sufficient discharge head necessary to overcome discharge pipe friction loss, boiler pressure, and the hydrostatic head between the pump outlet and the waterline of the boiler. The ends of the steam mains are drained and vented into the dry return main through a combination float and thermostatic trap.

The two-pipe system with a condensate pump is adapted to relatively large installations and is probably the most practical and trouble-free system. Most vapor systems differ somewhat with each installation. For specific instructions for the correct operating procedures, refer to the manufacturer's instructions for the specific type of equipment installed.

2.3.3 Maintenance

Most of the two-pipe vapor steam distribution systems differ from one system to another. Therefore, you will encounter different maintenance problems with each system. It is not feasible to try and cover all of the problems you might encounter with different systems of this type. However, the more common ones are discussed.

When you find that the individual radiator fails to heat, either an inoperative steam trap or a radiator that is not installed correctly can cause the trouble. Repairing or replacing the steam trap or correcting the improper installation of the radiator can eliminate these troubles.

When it is the whole distribution system that fails to heat, the causes include clogged or closed receiver vents, a flooded return line, the lack of pump capacity, or air binding the system. These troubles can be remedied by opening the vents, checking and adjusting the pump cut-in, replacing the pump, or repairing inoperative rerun traps.

One common trouble that occurs in this type of distribution system is the overflow of water from the receiver vent, usually caused by an inoperative pump. The pump may be causing the flooding because of its inadequate capacity or because it is unable to handle the volume of condensate required. This condition can be corrected by either repairing or replacing the pump.

Another cause of overflow of water from the receiver vents is an obstruction in the line between the condensate receiver and the boiler. The trouble can be remedied by eliminating the obstruction, regardless of whether it is a closed valve or a clogged line.

2.4.0 Two-Pipe Vapor System with a Vacuum Pump and a Condensate Return

The two-pipe vapor distribution system with a vacuum pump and a condensate return is similar to the two-pipe vapor system with a condensate pump (*Figure 10-8*). The piping in this system includes separate steam and return mains.

Figure 10-8 — Two-pipe vapor system with a vacuum pump.

2.4.1 Installation

Most vapor distribution systems with vacuum pumps and condensate returns are similar. However, two steam distribution installations are seldom alike in detail. When installing vapor-heating distribution systems, refer to the manufacturer's recommendations, civil engineer's mechanical drawings, and specifications for the proper installation procedures.

2.4.2 Operation

When this type of distribution system is operated, the steam is supplied at the top of the radiator and the air and condensate discharged through a thermostatic trap from the bottom of the opposite end of the boiler. All returns are dry and terminate at the vacuum pump. The vacuum pump is usually a motor-driven unit, although low-pressure steam turbines have been successfully used to a limited extent. The vacuum pump returns the condensate to the boiler and maintains the vacuum or sub-atmospheric pressure in the return system. The maintenance of a vacuum in the return system (3 to 10 inches of water) enables almost instantaneous filling of the heating units at low steam pressure (0 to 2 psi) since air removal is not dependent upon steam pressure.

The vacuum pump withdraws the air and water from the system, separates the air from the water, expels the air to the atmosphere, and pumps the water to the boiler, feedwater heater, or surge tank. Usually, the vacuum pump is supplied with a float switch as well as a vacuum switch, and it can be operated as a condensate pump unit. The float switch should be used only when the vacuum switch is defective, and then only until the defects can be repaired or corrected.

This system can be used in all types of buildings, and it is of particular advantage for the satisfactory operation of indirect radiation units, heating coils, and ventilating units, and for other units that requires close automatic control. Indirect radiation is a term applied to warm-air heating systems that receive their heat from steam supplied to their heat exchanger coils.

2.4.3 Maintenance

When considering the subject of maintenance on a two-pipe vapor distribution system having a vacuum pump, you will find that most of the troubles that have previously been discussed also apply to this system. In this distribution system, however, keeping air from leaking into the system is more of a problem than in the other distribution systems. Excessive air leakage often causes the pump to run all the time, or the leakage can cause the system to fail to heat altogether. To eliminate air leakage, you must find the point where air is leaking and repair it, so air cannot get into the system. Rusty spots and water seepage usually indicate the points at which air is leaking into the system.

Test your Knowledge (Select the Correct Response)

1. In a two-pipe vapor system with a return trap, the bottom of the trap should be how many inches above the boiler waterline?

   A. 12
   B. 14
   C. 16
   D. 18

3.0.0 STEAM DISTRIBUTION SYSTEM COMPONENTS

In previous sections of this chapter, you read about various components as you studied the various distribution systems. The components were only mentioned, however, and not explained in detail. Therefore, in this section, we are going to discuss these components, their purpose, operation, and maintenance.

3.1.0 Radiators

Steam radiators are normally classified into two categories. One is the fin-tube radiator, which consists of a metal tube that has metal fins attached on the outside to increase its total heating surface. It generally has a valve at one end and a trap at the other end. This radiator has been used more extensively in the past 15 years. It is readily adaptable to areas where floor space is limited, since the radiator is normally mounted on the walls. The second category is the cast-iron radiator, which is made in sections. A typical cast-iron radiator is shown in *Figure 10-9*. These radiators are similar to those used in hot-water heating systems. The cast-iron radiator is generally used in the one-pipe distribution system. In this system, there is only one distribution pipe connected to the radiator. This pipe delivers steam to the radiators, and it also returns water from the condensed steam to the boiler. For this reason, the radiators must be tilted slightly toward the distribution pipe.

Figure 10-9 — Cast-iron radiator.

The radiators in a two-pipe steam distribution system are connected to the boiler by means of a distribution pipe as well as by a condensate return pipe. Since the steam and condensate in the system flow in separate pipes, the pipes are smaller than those required for the same size radiator in a one-pipe system. The radiator outlet is usually equipped with a steam trap that prevents steam from leaving the radiator until it condenses into water.

3.2.0 Radiator Air Vents

There are two types of radiator air vents: automatic and manually operated. A typical automatic air vent is shown in *Figure 10-10*. Air vents are installed to remove air from the radiators because air keeps the radiator from heating properly.

The type of air vent shown consists of a hermetically sealed bellows, a valve disk and seal, and a vent body. The bellows contains a ***volatile*** liquid with a boiling point 10°F or lower than that of water. So, when this liquid is heated to a temperature 10°F below the steam and

Figure 10-10 — Automatic air vent.

water temperature, the liquid volatilizes, expands, and closes the valve. When air surrounds the bellows, the air is cooler than the steam. This causes the bellows to contract, to open the valve, and to allow the air to escape. This cycle then starts over again.

The type that is operated manually is usually a small valve that has a slotted screw incorporated in the stem and a little spout on one side for the discharged air. These manual vents are normally installed in the same place in the distribution system as automatic vents.

3.3.0 Steam Traps

Steam traps are designed to retain the steam in a radiator or other using device until it changes into condensate. After the steam has turned into condensate, the trap releases the water so it can enter the return lines. However, it keeps the steam coming into the radiator from escaping. The trap performs an important function since the excessive accumulation of water prevents the proper heating of the radiator or other steam equipment. Also, steam that is permitted to blow through a defective trap results in heat loss.

3.3.1 Types of Traps

Traps are generally classified according to their operation. The most common types of traps are float, bucket thermostatic, float thermostatic, impulse, thermodynamic, throttling, and bimetallic element.

3.3.1.1 Float Trap

The float trap normally consists of a body, float, linkage, seat, and valve. A typical float trap is shown in *Figure 10-11*. As water enters the trap, the float rises, opens the valve, and allows the accumulation of water to flow into the return lines that take it to the boiler. When the water has run out, the float falls, closes the valve, and traps the steam.

The maintenance to be done on a float trap is simple. One of the most common difficulties is that the float gets water in it and does not rise. In this case, the float must be replaced. The valve sometimes gets plugged or worn and has to be cleaned or replaced.

Figure 10-11 — Float trap.

3.3.1.2 Ball-Float Trap

In a ball-float trap, the valve of the trap is connected to the float so the valve opens when the float rises. When the trap is in operation, the steam and water that may be mixed with it flow into the float chamber. As the water level rises, the float is lifted, thereby lifting the valve plug and opening the valve.

The condensate drains out and the float moves down to a lower position, then closes the valve. The condensate that passes out of the trap is returned to the feed system.

3.3.1.3 Bucket Trap

There are two types of bucket traps: the upright and the inverted. An example of the inverted bucket trap is shown in *Figure 10-12*.

During operation of the upright bucket trap, the steam and water both enter the trap body. As the water enters, it causes the bucket to float and the valve to close. The water continues to rise; it overflows into the bucket, which sinks. When the bucket sinks, the trap valve is opened and the steam pressure forces the water out. When all of the water is expelled from the bucket, the bucket again floats, the valve closes, and the cycle starts again.

Figure 10-12 — Inverted bucket trap.

During the operation of the inverted bucket trap, the steam and water both enter under the bucket. The steam makes the bucket buoyant, causes it to rise, and closes the valve. When the steam condenses, the bucket drops, opens the valve, and the steam blows the water out of the trap.

Maintenance on bucket traps consists mainly of cleaning and inspecting them periodically. If the trap begins to leak steam, replace the valve disk and seat. However, if the bucket fails to open the valve, the trap usually becomes waterlogged. When a valve disk or seat becomes damaged, the trap allows steam to leak through. The condensate return line becomes excessively hot when the trap is leaking steam. Bucket traps contain some water at all times. Therefore, they must be drained when the system is to be off during freezing weather.

3.3.1.4 Thermostatic Trap

The thermostatic trap is often used on radiators and is commonly known as a radiator trap. It has a bellows that contains volatile fluid that expands and vaporizes when heated. Pressure builds up inside the bellows and causes it to lengthen and close the valve. A typical thermostatic trap is shown in *Figure 10-13.*

When water collects around and cools the bellows, the bellows contracts. This action opens the valve and permits water to escape. As the water goes out, the steam that enters contacts the bellows and

Figure 10-13 — Thermostatic trap.

causes it to expand, closing the valve and preventing the steam from escaping.

The most common trouble with the thermostatic trap is that the bellows develops holes, fails to work, and has to be replaced. The bellows and lower valve seat can be removed for repair without disconnecting any of the piping.

3.3.1.5 Float Thermostatic Trap

The float thermostatic trap operates on the principle of the float trap and the thermostatic trap. Practically the same maintenance is required. A typical example of the float thermostatic trap is shown in *Figure 10-14*. The thermostatic bellows acts as an air eliminator.

Figure 10-14 — Float thermostatic trap.

3.3.1.6 Impulse Trap

The operation of the impulse trap is based on the principle that a portion of hot water, under pressure, flashes into steam when its pressure is reduced (*Figure 10-15*). The trap is operated by a moving valve impelled by changes of pressure in a control chamber. The valve has tiny orifices drilled through its center that allow the continuous bypassing of condensate from the inlet of the trap to the control chamber. This bypassing reduces the chamber pressure below the inlet pressure so the valve opens and allows free discharge of the condensate. The temperature of the remaining condensate rises and flashes back to steam. The flow through the valve orifice is choked and pressure builds up in the control chamber, closing the valve.

About 5 percent of the rated capacity of the trap flows through the valve orifice. The pressure on the discharge side of the trap should not be over 25 percent of the inlet pressure if the trap is to function properly. Very little maintenance, except some periodic cleaning, is required for the impulse trap. The trap may be disassembled for cleaning or repairing without disturbing any of the piping.

Figure 10-15 — Impulse trap.

3.3.1.7 Thermodynamic Trap

A typical thermodynamic trap is shown in *Figure 10-16*. It contains only one moving part—a disk. This disk is operated by changes in steam pressure. Pressure under the disk raises it to allow the condensate to be discharged. Droplets of condensate form on top of the disk. Then steam enters at high velocity and creates a low pressure under the disk; the droplets of water above the disk then flash into steam and create a high pressure above the disk. (Water expands to as much as 1,728 times its volume when it changes to steam.) The high pressure against the top of the disk overcomes the lower pressure of the incoming steam, so the trap closes. As more condensate collects in the trap, the steam above the disk condenses and relieves the high pressure and the cycle is repeated.

Figure 10-16 — Thermodynamic steam trap.

The most common trouble is that the trap becomes plugged and has to be disassembled and cleaned. The thermodynamic trap can be cleaned or repaired without disturbing any of the piping. Very little other maintenance is required for this trap because of its simple construction. Also, the trap is usually constructed of stainless steel.

3.3.1.8 Throttling Trap

The operation of the throttling trap is based on the principle that the flow of water through an orifice decreases as its temperature approaches that of the steam used (*Figure 10-17*). The rate of flow of the condensate may be adjusted by raising or lowering a stem (needle valve) that fits into a tapered seat. This throttling trap has no moving parts.

Condensate that is slightly cooler

Figure 10-17 — Throttling trap.

than steam enters the trap, travels up through a baffle arrangement, and is discharged through an orifice. If the condensate discharge rate is higher than the inlet rate, the water (condensate) level in the chamber drops. This allows steam to enter the baffle passage and heat the condensate. The amount of water flashing into steam increases, so the volume of steam-water mixture handled by the orifice increases and thereby reduces the capacity of the orifice. The reduced flow through the orifice permits the level of condensate in the chamber to rise until the heater water in the baffle passage has been completely discharged and replaced with water that is slightly cooler. Then the cycle is repeated. Air is vented from this trap through the same passage as the condensate. The throttling trap can be replaced without disturbing any of the piping.

3.3.1.9 Bimetallic-Element Trap

The bimetallic-element trap contains bimetallic elements that bend when heated (*Figure 10-18*). The metals in the bimetallic strip generally are Emvar and copper. The copper expands rapidly when heated, but Emvar expands very little. Therefore, the bimetallic strip bends when it is heated. This trap may be used for higher or lower steam pressure by increasing or decreasing the number of bimetallic leaves in the trap.

Figure 10-18—Bimetallic-element steam trap.

This trap works basically the same as the thermostatic trap. When steam enters the trap, the element is heated and bends, thus closing the valve. As steam condenses, the elements cool and straighten out to allow the valve to open and let the condensate escape. The bimetallic trap can be repaired without disturbing any of the piping.

3.3.2 Pointers on Operating Procedures

To help ensure trouble-free service of steam traps, follow the proper operating procedures carefully. Some important factors involving operating procedures are furnished below.

- Steam traps should be operated within the capacity rating and pressure differentials recommended by the manufacturer. Use traps for the correct pressure and temperature. If operating pressures change, it may be necessary to change trap sizes, or internal parts, to fit the new pressure conditions.
- Traps should be insulated where heat must be conserved. Some types of traps which depend on the cooling effect of the condensate for operation should be left bare. Check the manufacturer's instructions regarding insulation.
- Where continuity of service is a requirement, a three-valve bypass is usually provided to permit drainage while the trap is being overhauled. Bypasses are also used to speed up the discharge of condensate and air when you are starting a system. In normal operation, however, the bypass valve should be kept closed to prevent steam from being wasted.
- Check valves, located in the discharge line, are important in parallel installations to prevent the discharge of one trap from backing up into that of another. Also, when condensate from the trap must discharge to a higher elevation, a check valve prevents backflow of condensate.
- Inverted bucket traps must be primed for operation by providing a condensate seal in the bottom of the trap. Prime the trap before starting operation by removing the test plug on top of the trap and filling the trap with water. If no test plug is available, the trap can be primed by closing the discharge valve and opening the steam supply valve slowly until the steam is condensed and the trap is filled with condensate.
- Blow down steam traps periodically to rid them of dirt and sediment. Blow down and clean strainers as required.
- When overhauling traps, do not remove thermostatic elements while hot. This practice may result in expansion beyond the stroke range of the bellows or diaphragm.
- Periodically, open the air vents of float traps not provided with thermostatic air vents to vent out accumulated air.

3.3.3 Steam Trap Tests

Methods for testing traps without breaking the installation are stated below.

3.3.3.1 Test Valve Method

Close the discharge valve and open the test valve. Observe discharge characteristics. Intermittent discharge, dribble, or semi-continuous discharge indicates correct operation. A continuous steam blow indicates loss of prime, defective valve operation, or foreign matter embedded in the valve seat. A continuous condensate flow may indicate that the trap is too small, the amount of condensate is abnormally high, or a pressure differential that is too low.

3.3.3.2 Glove Test Method

Grab inlet and outlet pipes simultaneously, using a canvas glove on each hand for protection. A slight temperature difference indicates that no condensate is passing.

3.3.3.3 Pyrometer Test Method

This method is more accurate than the previous one, as it uses a surface contact ***pyrometer*** to check inlet and outlet temperatures. File a clean spot on both pipes before taking readings.

3.3.3.4 Pyrometric Crayon Test Method

Temperature-indicating crayons can be used when no pyrometer is available. Select crayons of proper temperature ratings and mark the required pipe spots. When the crayon marks melt, the temperature of the test spots corresponds to those of the crayon ratings.

3.3.3.5 Ear Test Method

Hold one end of a metal rod to the trap body and place the other end in your ear, or use an engineer's stethoscope. If the trap is operating properly, you will hear the regular opening and closing of the valve. If operation is defective, you will hear considerable rattling or the continuous flow of steam.

3.3.3.6 Protection Against Freezing

Protect traps from freezing in cold weather. If the steam is shut off during freezing weather, drain the traps and piping of all condensate. Make certain insulation is in good condition. The inverted bucket is especially prone to freezing because, in normal operation, it is half filled with water.

3.4.0 Water Tanks

It is virtually impossible to operate a boiler plant and heating system in perfect balance. The demand for water by the boiler may exceed the rate at which water is being returned from the heating system, or the water may be returning at a rate that is greater than the requirements of the boiler. One or more tanks can be installed to compensate for uneven flows and for differences between the demand and supply of water. These vessels are called surge tanks *(Figure 10-19)*.

Sudden reductions in pressure may lead to violent steam formation. Flash tanks help eliminate disturbances in the

Figure 10-19 — Surge tank.

piping system caused by this process. These tanks are usually small and are located near the traps where the pressure release occurs.

When the steam condenses, the steam trap, usually a float thermostatic type, allows the condensate to drain into the condensate return line. A strainer is installed just ahead of the trap to keep foreign matter out of the trap.

3.5.0 Water Heaters

Steam-operated water heaters are used to supply hot water for laundries, dining halls, latrines, and other facilities. There are two general types of these heaters: storage and instantaneous.

3.5.1 Storage Type

The storage type of water heater is used to provide potable (drinking) water. The steam-operated storage type of water heater consists of a steel tank that contains a steam coil like that shown in *Figure 10-20*. The hot-water tank is connected to the base water supply system and remains full of water at all times.

Figure 10-20 — Storage-type water heater.

The steam is circulated through the heating coil or "bundle," as it is sometimes called. The heat from the steam is transferred through the walls of the coil to the water in the tank. Because of the difference in weight between hot and cold water, the hot water rises and the cold water goes to the bottom of the tank where the steam coil is located. Here the water is heated and begins to circulate. Eventually, all of the water in the tank becomes heated. When hot water is drawn, more cold water enters the tank and this heating process repeats itself. This action maintains a full tank of hot water for use whenever hot water is needed. According to safety regulations, the hot water should not exceed 180°F. The storage type of water heater may be constructed to be installed in either the horizontal or the vertical position.

Tappings are usually provided in the tank for a thermometer—a thermostatic element for a temperature-regulating valve (which will be discussed later in this section) and a safety valve. The tube coil should be inspected annually to make sure steam is not leaking into the water. The chemicals that are sometimes used in the steam may make the people who use the water sick if they drink it.

3.5.2 Instantaneous Type

Instantaneous heaters are used primarily as boiler feedwater heaters; however, they are sometimes used to provide potable (drinking) water at some installations. The operation of the instantaneous-type heater is basically the same as the storage-type heater; their construction, however, is quite different. The diameter of the instantaneous heater is small in comparison to the storage-type heater. The outer shell of the instantaneous heater is small in comparison to the storage-type heater. The outer shell of the instantaneous heater barely covers the tube coil, as you can see in *Figure 10-21*. In some makes, the water is circulated through the coil, and the steam is released in the shell and surrounds the coil. A temperature-regulating valve controls the water temperature for both types of heaters.

Figure 10-21 — Instantaneous-type water heater.

3.6.0 Temperature Regulators

The temperature regulator is used to regulate the quantity of steam necessary to maintain the hot water at the desired temperature. The unit consists of a temperature bulb, copper line, diaphragm, spring and temperature adjustment, and steam valve. A typical temperature-regulating valve is shown in *Figure 10-22.*

Figure 10-22 — Temperature-regulating valve.

The bulb and copper tube are called the capsule and capillary tube. They contain a gas that expands or contracts with a change in temperature. The capillary tube is connected to the top of the temperature regulator which contains a diaphragm (bellows). The diaphragm (bellows) is connected to the valve stem. A spring holds the valve open at low temperatures. When the temperature rises in the water tank, the gas in the temperature bulb expands and forces the diaphragm down, closing the steam valve. Adjusting the tension of the spring can control the water temperature. A steam trap in the steam-heating system returns the condensed steam to the condensate tank.

The hot-water tank accessories consist of a temperature gauge that has a range of 40°F to 210°F and a safety valve or pressure relief valve. The relief valve is set at a pressure that is 10 pounds higher than the operating pressure, and both the setting and the valve must comply with current American Society of Mechanical Engineers (ASME) code specifications.

3.7.0 Condensate Pump Return

Condensate return pumps move the water that has condensed from the steam in radiators, heating coils, convectors, and unit heaters to circulate back to the boiler. One type of condensation return pump is shown in *Figure 10-23*. Units of this type normally consist of a receiver or condensate tank and pump independently controlled by float switches. A check valve and a vent on the receiver allow the receiver to fill and empty as the need arises.

Condensate return pumps are maintained as prescribed by the manufacturer of the unit. Usually, the motor should be oiled, the check valves and vents cleaned, the float switches adjusted, the pump repacked, and the tank cleaned at least once each year.

Figure 10-23 — Condensate return pump.

3.8.0 Expansion Joints

Expansion joints and expansion loops in long heating lines are convenient devices for handling the pipe elongation caused by expansion. The five major types of expansion joints are as follows: slip joint, bellows joint, swing joint, expansion loop, and ball joint.

The slip joint is shown in *Figure 10-24*. The female part of the joint is placed over the male part and the joint is held tight by the packing that permits expansion. The kind of packing used determines the temperature to which the joint can be subjected.

The bellows joint has a metal bellows that flexes as expansion occurs (*Figure 10-25*). The joint consists of a thin-walled corrugated copper stainless steel tube clamped between flanges. Rings help to keep the corrugations under relatively high pressure. The steam pipe and joint should be supported and guided to keep misalignment to a minimum.

Figure 10-24 — Slip-type expansion joint.

Figure 10-25 — Bellows-type expansion joint.

The swing, or swivel, joint is most often used to allow expansion to occur naturally in a system that has threaded joints. When it is used with welded elbows, the swing joint introduces torsional strains in the elbows and in the swing piece.

The expansion loop absorbs expansion through the formation of U- or Z-loops in the pipeline.

The ball joint is often used instead of the expansion loop because it requires less space and material. A ball joint consists of four basic parts. The joint has a casing or body to hold the gaskets and a ball. The ball is a hollow fitting shaped externally like a ball at one end (inside the casing) and is threaded, flanged, or adapted for welding to the pipe at the other end. There are two gaskets that hold the ball and provide the seat. There is also a retaining nut or flange that holds the ball and gaskets in the casing. The end of the two pipes being coupled is connected to the joint casing; the end of the other pipe is connected to the ball. In operation, the ball joint allows the movement of the pipe with 30° to 40° of flexibility, plus a rotating or swivel motion of 360°.

The slip-type joint must be kept properly aligned, adequately packed, within the proper limit of travel, and thoroughly cleaned and lubricated. You should adjust or replace the packing, as required, to prevent leaks and assure a free-working joint. It is necessary to lubricate every 6 months with the proper grease for this type of joint and the service conditions. Once a year, you should check the flange-to-flange distance of the slip joints. You should check the flanges first when they are cold and next when they are hot. Measuring makes sure that the travel is within the limits shown in the manufacturer's data. A change in slip travel usually indicates a shift in anchorage of a pipe guide, so you must locate and correct the difficulty. You should also inspect annually for signs of erosion, corrosion, wear, deposits, and binding. Then you should repair or replace the defective parts, as required.

Check the bellows-type joint annually for misalignment, metal fatigue, corrosion, and erosion. You should note the amount of travel between cold and hot conditions. If the joint fails, you should replace the bellows section of the joint.

Expansion loops require little specific maintenance except inspection for alignment and leaks.

The ball joint must be kept adequately packed. You should adjust or replace the gaskets, as required, to correct leaks and obtain a free-working joint. Always refer to the manufacturer’s instructions for doing maintenance work.

The swing joint requires the same typical maintenance for pipe fittings.

Summary

As a UT, you will be involved with the installation, operation, and maintenance of various types of steam distribution systems such as exterior and interior steam distribution systems. You must understand the purpose and equipment associated with underground and aboveground systems.

You will also be involved in the installation, operation, and maintenance of several interior steam distribution systems such as gravity, one-pipe, air-vent, two-pipe vapor system with a return trap, two-pipe vapor system with a condensate pump, and two-pipe vapor system with a vacuum pump and condensate return. As a UT you will be responsible for the upkeep and maintenance of several steam distribution components such as radiators, radiator air vents, steam traps, water tanks, water heaters, temperature regulators, condensate pump returns, and expansion joints. The information presented in this chapter will help you perform your duties with confidence and accuracy.

Review Questions (Select the Correct Response)

1. The exterior distribution system is divided into what two systems?

   A. Underground and aboveground
   B. Trench laid and overhead
   C. Sloping and aboveground
   D. Underground and surface

2. The utilidor type of steam distribution system is part of what distribution system?

   A. Aboveground
   B. Underground
   C. Overhead
   D. Surface

3. **(True or False)** The frost line is the lowest depth that the ground freezes during the coldest part of winter.

   A. True
   B. False

4. Insulation associated with the conduit type of steam distribution CANNOT be installed in which manner?

   A. Directly to the pipe
   B. Attached to the inner surface of the conduit
   C. Packed between the pipe and conduit
   D. Directly to the conduit

5. Why is the bottom of the trench filled with broken rock when dealing with the conduit type distribution system?

   A. Adequate water drainage
   B. Allowance for pipe expansion
   C. Adequate heat release
   D. Allowance for water hammer dispersal

6. What material is used to construct the utilidor type distribution system?

   A. Steel
   B. Brick
   C. Cast iron
   D. Vitrified clay

7. What is the main drawback of an overhead distribution system?

   A. High cost of installation
   B. Lack of adequate erection space
   C. High cost of maintenance
   D. Interference with electrical lines

8. Which of the following is NOT a classification factor when considering an interior steam distribution system?

   A. Pipe arrangement
   B. Accessories used
   C. Air expulsion method
   D. Pipe size

9. In a gravity, one-pipe, air-vent system, the return of condensate depends on what factor?

   A. Hydrostatic head
   B. Pipe diameter
   C. Boiler baffle arrangement
   D. Air vent location

10. The necessary internal drainage in a gravity, one-pipe, and air-vent system can be obtained by sloping the piping in what manner?

   A. 1/2 of an inch for every 10 feet of pipe.
   B. 1/4 of an inch for every 10 feet of pipe.
   C. 1/4 of an inch for every 20 feet of pipe.
   D. 1/2 of an inch for every 20 feet of pipe.

11. What interferes with the proper drainage of water from a radiator that is part of a gravity, one-pipe, and air-vent system?

   A. Completely closed main steam stop valve
   B. Check valve failure
   C. Partial opening of main steam stop valve
   D. Completely open main steam stop valve

12. Incorrectly pitched mains located in gravity, one-pipe, and air-vent systems cause what condition?

   A. Improper condensate drainage
   B. Forced mixing of feedwater and condensate
   C. Excessive water hammers
   D. Uneven heat distribution

13. What trap permits the flow of condensate and air from the radiator installed in a two-pipe vapor system with a return trap?

   A. Thermostatic
   B. Impulse
   C. Float
   D. Bucket

14. Which valves shut and open when the return trap float starts to rise?

    A. Condensate valve opens and feedwater valve shuts.
    B. Air vent shuts and steam valve opens.
    C. Condensate valve shuts and feedwater valve opens.
    D. Air vent opens and steam valve shuts.

15. What type of pump is used in the two-pipe vapor system with a condensate pump?

    A. Rotary
    B. Submersible
    C. Centrifugal
    D. Jet

16. At what section of a condensate pump does the return main terminate in a two-pipe vapor system?

    A. Vent valve
    B. Supply end
    C. Bypass valve
    D. Receiver end

17. Which system is the most practical and trouble-free?

    A. Two-pipe vapor system with condensate pump
    B. Two-pipe vapor system with a return trap
    C. Two-pipe vapor system with a vacuum pump and condensate return
    D. Gravity, one-pipe, and air-vent

18. Which is NOT a possible cause of an entire distribution system’s failure to heat in a two-pipe vapor system with a condensate pump?

    A. Flooded return line
    B. Open receiver vents
    C. Lack of pump capacity
    D. Air binding the system

19. How many inches of water must be maintained in the vacuum pump in a two-pipe vapor system with a vacuum pump and condensate return line?

    A. 1 to 5
    B. 2 to 11
    C. 3 to 10
    D. 9 to 13

20. Steam radiators are classified into how many categories?

    A. 1
    B. 2
    C. 3
    D. 4

21. **(True or False)** Cast iron radiators are similar to those used in hot-water heating systems.

A. True
B. False

22. Where is the manual vent installed on a cast iron radiator?

A. Opposite end of automatic vent location
B. Same spot as an automatic vent
C. Above the automatic vent
D. Downstream of automatic vent

23. How many steam traps are associated with steam distribution systems utilized by the Seabees?

A. 3
B. 5
C. 7
D. 9

24. When using a ball-float trap, where is the condensate returned to?

A. Condensate pump
B. Surge tank
C. Air vent
D. Feedwater system

25. Which indication identifies a bucket trap leaking steam?

A. Excessively hot condensate return line
B. Continuous venting of trap
C. Cycling of condensate pump
D. Water hammers

26. What is another term used for the thermostatic trap?

A. Stark relief
B. Radiator trap
C. Air cock
D. Radiator vent

27. The pressure on the discharge side of the impulse trap should not be over what percentage of the inlet pressure of the trap?

A. 5
B. 15
C. 25
D. 35

28. Thermodynamic traps are constructed out of what material?

A. Brass
B. Vitrified clay
C. Cast iron
D. Stainless steel

29. How is the rate of flow of the condensate adjusted when using a throttling trap device?

A. Raising or lowering needle valve.
B. Turning stem valve clockwise or counterclockwise.
C. Decreasing the boiler feedwater input level.
D. Increasing the condensate pump capacity.

30. What happens when the bimetallic strip in the bimetallic-element trap is heated?

A. Contracts
B. Bends
C. Expands
D. Straightens

31. How are dirt and sediment removed from traps?

A. Lubrication of trap stem valves
B. Increase of boiler feedwater output
C. Blowdown of traps is conducted
D. Decrease of condensate flow rate to boiler

32. Which condition indicates a defective valve operation?

A. Intermittent discharge
B. Semi-continuous discharge
C. Dribble
D. Continuous steam blow

33. What can be installed to compensate for differences between the demand and supply of water?

A. One or more water tanks
B. Vacuum pump
C. Pyrometer
D. Condensate return trap

34. What type of trap is usually installed inside a water tank to allow condensate to drain into the return line?

A. Bucket
B. Float thermostatic
C. Thermodynamic
D. Bimetallic-element

35. What two types of steam-operated water heaters are utilized?

A. Storage and delayed
B. Continuous and delayed
C. Storage and instantaneous
D. Continuous and instantaneous

36. According to safety regulations, the hot water in steam heaters will not exceed how many degrees?

A. 120
B. 140
C. 160
D. 180

37. What temperature-regulating element controls the temperature in steam water heaters?

A. Valve
B. Transducer
C. Trap
D. Sensor

38. What is the bulb and copper tube assembly called in a temperature- regulating device?

A. Bellows and capillary tube
B. Capsule and capillary tube
C. Baffles and branching line
D. Capsule and branching line

39. What is the temperature range on a gauge installed on a hot-water tank?

A. 50°F to 150°F
B. 200°F to 500°F
C. 40°F to 210°F
D. 140°F to 675°F

40. At what pressure is the relief valve set at on a hot-water heater?

A. 10 pounds higher than input pressure
B. 20 pounds higher than input pressure
C. 10 pounds higher than operating pressure
D. 20 pounds higher than operating pressure

41. How many expansion joints are associated with steam distribution systems?

A. 3
B. 5
C. 7
D. 9

42. Ball joint expansion type joint allows for how many degrees of flexibility?

A. 10 to 20
B. 20 to 30
C. 30 to 40
D. 40 to 50

43. **(True or False)** Expansion loops require little maintenance except inspection for alignments and leaks.

A. True
B. False

Trade Terms Introduced in this Chapter

Utilidor	An aboveground, insulated network of pipes and cables, used to convey water and electricity in communities situated in areas of permafrost.
Volatile	Evaporating rapidly; passing off readily in the form of vapor.
Pyrometer	An apparatus for measuring high temperatures that uses the radiation emitted by a hot body as a basis for measurement.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Basic Machines, NAVEDTRA 12199, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

OSHA Regulations (Standards – 29 CFR)

Naval Construction Force Manual, *NAVFAC P-315*, Naval Facilities Engineering Command, Washington, D.C., 1985.

Facilities Planning Guide, NAVFAC P-437, Volumes 1 and 2, Naval Facilities Engineering Command, Alexandria, VA, 1982.

Fluid Power, NAVEDTRA 12964, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

National Standard Plumbing Code-Illustrated, National Association of Plumbing-Heating-Cooling Contractors, Washington, DC, 2006.

Safety and Health Requirements Manual, EM-385-1-1, Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 1992.

International Plumbing Code 2009, International Code Council

International Mechanical Code 2009, International Code Council

R. Dodge Woodson, *Plumber's Quick-Reference Manual Tables, Charts, and Calculations,* 1st edition, McGraw-Hill, NY, 1996.

Water Testing Kit, Chemical Agent: M272, Technical Operations Manual, TM 3- 6665-319-10, Department of the Army, Washington, DC, 1983

Boiler Care Handbook, Cleaver-Brooks Division of Aqua-Chem. Inc., Milwaukee, WI, 1985.

COMFIRSTNCDINST 3500.1, Operational Risk Management (ORM).

COMFIRSTNCDINST 5100.2, Naval Construction Force Occupational Safety and Health Program.

UFC 3-430-07, Inspection and Certification of Boilers and Unfired Pressure Vessels.

Maintenance of Steam, Hot Water and Compressed Air Distribution Systems, NAVFAC MO - 209, Naval Facilities Engineering Command, Alexandria, VA, 1989.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate__ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 11

Heating Systems

Topics

1.0.0	Principles of Heating
2.0.0	Combustible Fuels
3.0.0	Warm-Air Heating Equipment
4.0.0	Warm-Air Heating Systems
5.0.0	Low-Temperature Hot Water Systems
6.0.0	Low-Temperature Hot Water Distribution Systems
7.0.0	High-Temperature Hot Water Systems

To hear audio, click on the box.

Overview

Heat is one of the prime necessities of life, as essential as food, clothing, and shelter. You can have a very good shelter, but you still need heat to be comfortable in it. By studying this chapter, you will start to gain knowledge of what you will be required to know to become a proficient Utilitiesman in the operation of a heating plant.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the principles of heating.
2. Identify the different types of combustible fuels.
3. Describe warm-air heating equipment.
4. Describe the different types of warm-air heating systems.
5. Describe the purpose and operation of low-temperature hot water systems.
6. Describe the different types of low-temperature hot water distribution systems.
7. Describe the different types of high-temperature hot water systems.

Prerequisites

None

This course map shows all of the chapters in Utilitiesman Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Utilities Equipment and Maintenance	↑	
Air Conditioning		
Refrigeration		
Heating Systems		U
Steam Distribution Systems		T
Boilers		
Sewage Disposal, Field Sanitation, and Water Treatment		B
Prime Movers, Pumps, and Compressors		A
Plumbing Fixtures		S
Piping System Layout and Plumbing Accessories		I
Structural Openings and Pipe Material		C
Fundamentals of Water Distribution		
Basic Math, Electrical, and Plumbing Operations		
Plans, Specifications, and Color Coding		

Features of this Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PRINCIPLES of HEATING

Long after people had advanced to the stage of house building, heating methods had not improved much. For centuries, fires for heating and lighting were contained in ***braziers*** or confined to an unused corner of a room. The smoke was supposed to escape through a hole left in the roof of the building during construction of course, a considerable amount of rain and snow entered the room during bad weather. During the twelfth century, however, the people in the northern part of Europe started using crude fireplaces and flues to replace the brazier and hole-in-the-roof method of heating. Some of these rudimentary heating systems still exist in Europe.

In the thirteenth and fourteenth centuries, round, hollow stone chimneys began to be used. At the end of the fourteenth century, people were using a number of fireplaces in their homes and grouping the chimneys together in a vertical, rectangular mass of masonry with decorative effect. By the end of the Italian renaissance period, chimneys were in common use.

During colonial days in America, the fireplace chimneys were a large masonry mass projected through the center of the roof, or were an important feature of the gable end walls. This general trend of using chimneys is often followed in architecture today because central heating, required in places where fires are required 5 or 6 months of the year, makes the chimney an important feature of a heating plant. There are heating installations, however, that do not make use of the masonry chimney and have substituted an inconspicuous metal smoke pipe. Other types of heating, such as electrical heating, require no chimney. Methods and equipment used for heating the places we live and work have progressed quickly in the last 100 years. This quick advance is due to our understanding of the principles and theory of heat, which in earlier times was not yet understood.

1.1.0 Theory of Heat

Heat is a form of energy that is known for its effect. Heat can be produced or generated by the combustion of fuels, by friction, by chemical action, and by the resistance offered to the flow of electricity in a circuit. However, the particular form of generated heat with which the Utilitiesman (UT) will be dealing is produced by combustion. Generated heat is obtained by burning common types of fuels, such as coal, oil, and gas.

1.2.1 Measurement

To operate a heating plant efficiently, you must be familiar with the measurement of heat and the method of transferring this heat from the plant to the space being heated. The first part of this section is devoted to measuring temperature; the second part is concerned with the transfer of heat from the plant to the space being heated.

Measurements of temperature and pressure, which are obtained continuously, are very important factors in the operation of a heating plant. The degree of correctness of these measurements directly affects the safety, efficiency, and reliability of the operation of the heating plant. Although heat and temperature have a direct relationship, there is also a distinction between them. For example, a burning match develops a much higher temperature than a steam radiator, but the match does not give off enough heat to warm a room. Another example tells us that 10 pounds of water at 80°F will melt more ice in a given length of time than 1 pound of water at 100°F. The former has more heat, but the latter has a higher temperature. Temperature is the measurement of heat intensity in degrees Fahrenheit or Celsius. Therefore, temperature measurements can be made by using a glass thermometer calibrated either in degrees Fahrenheit or Celsius. The generally accepted way of stating measurements of temperature in English-speaking countries is in degrees Fahrenheit.

The thermometer measures the degree of sensible heat of different bodies. The thermometer can make a comparison only between the temperature of a body and some definitely known temperature, such as the melting point of ice or the boiling point of water. *Figure 11-1* shows a comparison of the scales of Fahrenheit and Celsius thermometers. It also shows the marking of the freezing and boiling points of pure water at sea level. The range of the Fahrenheit thermometer between the freezing point and the boiling point is 180° (32° to 212° = 180°). On the Celsius thermometer, the range is 100° (0° to 100° = 100°) from the freezing point to the boiling point.

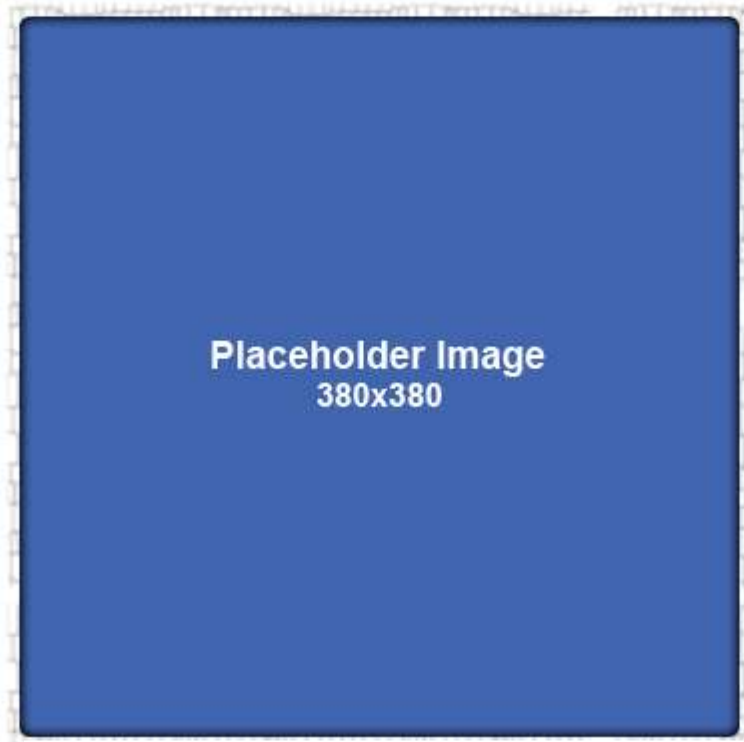


Figure 11-1 — Comparison of Fahrenheit and Celsius thermometers.

To convert Fahrenheit readings to Celsius:

$$(°F - 32°) \div 1.8 = °C$$

To convert Celsius readings to Fahrenheit:

$$(°C \times 1.8) + 32° = °F$$

The heat that can be measured by a thermometer and sensed or felt is referred to as "sensible heat." An example of sensible heat is presented by placing a small vessel of cold water over a gas flame and putting a thermometer in the water. Upon observation, you note that the thermometer indicates a rise in temperature. Also, if you place your finger in the water several times, you will feel (or sense) the change in temperature that has taken place.

The unit of measurement for a given quantity of heat is the ***British Thermal Unit*** (BTU). One BTU is the amount of heat needed to change the temperature of 1 pound of water 1° Fahrenheit at sea level. If one BTU is added to 1 pound at 50°F, the temperature of that pound of water will be raised to 51°F.

All substances above absolute zero contain heat. There is heat even in ice, and its melting point is fixed at 32°F. Because of a fundamental law of nature, when ice at 32°F melts into water at 32°F, a change of state takes place. The ice (solid) has turned into water (liquid). A certain amount of heat is required during this change of state. This heat is known as latent heat. Latent heat is the amount of heat required to change the state of a substance without a measurable change in temperature.

There are other types of heat that you will encounter in heating:

- Specific heat–The ratio between the quantity of heat required to raise 1 pound of any substance 1°F and the amount of heat required to raise the temperature of 1 pound of water 1°F.
- Superheat–The amount of heat added to a substance above its boiling point.
- Total heat–The sum of sensible heat plus latent heat.

We previously mentioned absolute zero. Scientists have determined that when the temperature of a substance has been reduced to -460°F, all the heat has been removed from a substance. At this point all the molecules cease to have motion. Absolute zero is the lowest temperature obtainable. Heat is present in all substances when the temperature is above absolute zero.

1.3.0 Heat Transfer

The transfer of heat is the next problem to consider after the heat has been produced. It must be moved to the space where it is to be used. Heat naturally flows from a warmer to a cooler substance; consequently, there must be a temperature difference before heat can flow. Naturally, the greater the temperature difference, the faster the heat flow. When placed together, two objects that have different temperatures tend to equalize their temperature. Heat travels in heating systems from one place to another by three different methods. All three of these methods are used in most heating systems. They are discussed in the paragraphs that follow.

1.3.1 onduction

Conduction is the flow of heat from one part of a substance to another part of the same substance, or from one substance to another when they are in direct contact.

When one end of a stove poker is held in a flame, the other end will soon be too hot to hold. This indicates that the heat is being conducted, or transferred, from one end of the poker to the other end. Such a transfer of heat is called conduction. Conduction is used to transfer heat through the walls of a stove, furnace, or radiator so that the warmth can be used for heating. Some materials do not conduct heat as well as others. For example, if a piece of wood had been used instead of the poker, the end of the wood away from the fire would have remained cool. Those materials that offer considerable resistance to heat flow are referred to as insulators or poor conductors.

1.3.2 Convection

Convection is the transfer of heat by means of mediums, such as water, air, and steam. When air is heated, it expands, becomes lighter in weight, and rises. The cooler air, which is heavier, then flows in to replace the warm air. Thus a convection current is set up. Water, when heated, acts in the same way as air. The water next to the heating surface becomes warmer, lighter, and rises. This action allows the cooler water to flow in next to the heating surface and become heated. Convection is a very important factor in a heating system. It is this force, developed by heating the medium, which circulates that medium to the space to be heated.

1.3.3 Radiation

Radiation is the transfer of heat through space. When a hand is held in front of a stove, it is quickly warmed by means of radiation. In this same manner, the earth receives its heat from the sun.

Radiated heat is transferred by heat waves, similar to radio waves. Heat waves do not warm the air through which they pass, but they must be absorbed by some substance to produce heat. For example, when you stand in the shade of a tree, you feel cool because the leaves and limbs are absorbing the heat waves before they reach you.

When heat waves strike an object, some are reflected, some may pass through, and the object absorbs the rest. Polished metals are the best reflectors known; therefore, they are poor absorbers of heat. A poor absorber is also a good radiator. Rough metal absorbs heat more readily than a highly polished metal, and it also loses heat faster by radiation.

The color of a substance also affects its absorbing power. A black surface absorbs heat faster than a white one. That is why light-colored clothes are cooler in summer than are dark-colored clothes.

2.0.0 COMBUSTIBLE FUELS

If electricity and coal are disregarded, the fuels most commonly used with heating equipment are either gas or petroleum. Next, we will take a brief look at the types and characteristics of combustible gases and fuel oils used for heating.

2.1.0 Types of Gases

Gaseous fuels are usually classified according to their source that, in turn, determines their chemical composition. The heat valve (BTU per cubic foot) varies with the types of gas and determines the quantity required for a specific heating requirement. The types principally in use are natural gas, manufactured gas, and liquid petroleum gas (*Table 11-1*).

Table 11-1 — Fuel Gases

Fuel	Source	Heating Value Maximum (BTU per cu ft)	Remarks
Natural gas	Gas wells	700 – 1300 Average 1000	Ideal fuel. It is pumped to point of use.
Manufactured Gas			
Carbureted Water Gas	Manufactured from coal enriched with oil vapors	520 – 540	Costly good fuel that is part of most city gas systems.
Oil gas	Manufactured from petroleum	520 – 540	Used on U.S. west coast; is often mixed with coke oven gas.
Producer gas	Manufactured from coal, ***coke***, and wood	135 – 165	Requires cleaning.
Liquefied/Petroleum gas			
Propane	By-product of gasoline	2500	Boiling point: -44°F. Liquefies under slight pressure.
Butane	By-product of gasoline	3200 – 3260	Boiling point: 32°F. Liquefies under slight pressure.

2.1.1 Natural Gas

Natural gas is a mixture of combustible gases and usually small amounts of inert gases obtained from geologic formations. While the composition of natural gas varies with the source, methane (CH_4) is always the major constituent. Most natural gases also contain some ethane (C_2H_6) along with small amounts of nitrogen and carbon dioxide (CO_2). Natural gas is colorless and odorless in its natural form; however; a distinctive odor is usually added as a safety factor for detecting leaks. Natural gas mixes readily and completely with combustion air and thus is substantially free from ash and practically smokeless. These characteristics contribute to good environmental pollution control. From a standpoint of trouble-free performance, ease of handling, and control, natural gas offers many advantages that make it the most desirable of all heating fuels.

2.1.2 Manufactured Gas

The common manufactured gases are carbureted water gas, oil gas, and producer gas. These gases are roughly one-half hydrogen and one-third methane, plus small amounts of carbon dioxide, nitrogen, and oxygen. They are made by converting low-grade liquid or solid fuels to the gaseous form by destructive distillation (cracking) of oil or coal, by the steam-carbon reaction, or by a combination of both processes. These gases are ordinarily used at or near the production point because high manufacturing costs rule out the added expense of distribution.

2.1.3 Liquefied Petroleum Gas

Liquefied petroleum gases (LPG) are hydrocarbon gases normally obtained as a by-product of oil refineries or by stripping natural gas. These compounds are normally gaseous under atmospheric conditions; however, they can be liquefied by moderate pressure at normal temperatures.

The principal LPG products are propane (C_3H_8) and butane (C_4H_{10}). Propane, the most common, is available by the bottle or cylinder and in bulk form. Its boiling point is -44°F (note that this is very close to that of refrigerant R-22).

Butane is generally available in bulk form. It boils or vaporizes at 32°F. In other words, if the temperature of butane is 32°F or lower, at atmospheric pressure, it remains a liquid, and heat must be applied to bring it to the gaseous state. Note in *Table 11-1*, the high heating values of propane and butane.

2.1.4 Fuel Oils

Fuel oils are derived from crude oil, which consists primarily of compounds of hydrogen and carbon (hydrocarbons), and smaller amounts of oxygen, nitrogen, and depending on the source, sulfur. Practically all fuel oil is either a product or a by-product of refining crude oil by the fractional distillation process or by cracking.

The Bureau of Standards, United States Department of Commerce, standardizes commercially used fuel oils. The oils are numbered in grades 1, 2, 4, 5, and 6 and are titled commercial standard grades (CSG). These grades are identified in the Navy by military specifications and are intended for use in oil-burning equipment for the generation of heat in furnaces for heating buildings, for the generation of steam, and for other purposes. A more in-depth discussion of fuels and their characteristics is contained in *Fundamentals of Petroleum*, NAVEDTRA 10883. A comparison of fuel oils by grade is given in *Table 11-2*.

Table 11-2 — Comparison of Fuel Oils

Grade Number	Approximate weight/gallon	Heating value (BTU per gallon)	Type Fuel
1	6.92	136,000	Volatile distillate oil for use in burners that prepare fuel for burning solely by vaporization.
2	7.08	138,500	A moderately volatile distillate oil for use in burners which prepare fuel for burning by a combination of vaporization and atomization.
4	7.58	145,000	A residual oil for burner installations not equipped with pre-heaters.
5 (Light)	7.83	148,500	A residual oil of intermediate viscosity for use in burners equipped with pre-heaters; however, preheating may or may not be required depending on climate and equipment.
5 (Heavy)	Greater than 5 Light	Greater than 5 Light	A residual oil of greater viscosity than 5 light. Preheating may be required before burning this oil; and in cold climates, preheating may be required before handling as well.
6	8.16	152,000	A residual oil of high viscosity for which preheating is always required.

Test your Knowledge (Select the Correct Response)

1. Which metal is the best reflector of heat?

   A. Polished
   B. Concaved
   C. Rough
   D. Convexed

3.0.0 WARM-AIR HEATING EQUIPMENT

Advances in the field of warm-air heating have made it one of the most popular and widespread forms of heating in use today. It has the advantage of adaptability with various fuels and can be used in a variety of buildings, including barracks, hangars, personnel housing, schools, and theaters. It is likely, therefore, that at one time or another you will be responsible for performing technical maintenance and repair and installation of warm-air heating equipment and systems.

The different types of heating equipment that will be discussed include unit heaters, electric and gas- and oil-fired space heaters, and gas-fired and oil-fired furnaces.

3.1.0 Unit Heaters

In this chapter the term unit heater is defined as an installed equipment item and a component of a system consisting of an extended finned heat transfer surface (coil) and a propeller or blower fan to create airflow through it. Unit heaters are indirect units that differ from space heaters because they generate heat indirectly from a medium of steam or hot water piped through a central distribution system. Space heaters are direct-fired units that generate heat directly by the use of an electrical coil or by a combustible fuel.

Unit heaters can be used for many heating requirements, the major limiting factor being the availability of a steam or hot-water system. They are commonly used with heating systems in shops, offices, dining halls, and warehouses. There are three basic types: (1) suspended horizontal discharge, (2) suspended vertical discharge, and (3) floor-mounted or horizontal type of blower unit (*Figure 11-2, Views A* and *B*).

The units are rated in BTU or equivalent direct radiation heat output and cubic feet per minute (cfpm) air discharge capacity at a given fan or motor speed. These ratings are important in the application of unit heaters.

Manufacturers furnish information regarding the area effectively heated by units to enable proper planning and location of the units. Generally, units under 50,000 BTU per hour are designated to operate on low-pressure steam or high-temperature hot water.

Figure 11-2 — Types of unit heaters.

3.1.1 Space Heaters

Space heaters are used for heating rooms and similarly enclosed spaces, either in addition to, or in place of, a central heating system. They are desirable as a means of providing heat to a small space because of their simplicity of construction, low initial cost, and reasonable fuel consumption. They may be placed directly in the space or at such a location where heat can be delivered through a single register into the space.

Space heaters are sometimes classified by the manner in which they transfer heat to the space to be heated, for example, by radiation and/or convection. The terms direct-fired and indirect-fired are also used to identify such heaters. In this chapter, space heaters are identified as direct-fired units and by their heat source or fuel. This discussion will include electric, gas-fired, coal-fired, and oil-fired units.

3.1.1.1 Electric Heaters and Installation

Space heaters with electrically powered heating elements are used in spaces where it is desired to eliminate cold spots and maintain uniform temperatures, whereas other fuels are useful as portable units on the floor to overcome floor drafts, and as fixed units mounted in or to walls or ceilings. They are generally rated in kilowatts (kW). One kW (1,000 watts) is equal to 3,415 BTU per hour.

Electric space heaters are available in two general types—the radiant and natural convection type and the forced warm-air (fan) type. In the radiant and natural convection type, heat from electric elements rises and strikes parabolic (bowl-shaped) reflectors. The reflectors are highly polished curved metal surfaces, which deflect the heat outward into the place where heat is desired (*Figure 11-3*).

Some radiant heat units have no deflectors but provide a combination of radiant and natural convection heat, which rises from the coils into a chamber open on the side where heat is required. The electric baseboard convection heater is an example of this type. The forced warm-air type uses a motorized fan to circulate heat from the heating element outward into the space (*Figure 11-4*). The electric units are operated manually with an ON-OFF switch or automatically with a thermostat.

In the selection and installation of electrical space heaters, safety must be assured. Units that are to be installed should bear the label of the Underwriter’s Laboratories (UL). They should also conform to the safety standards outlined in space heating equipment UL-573. All electrical work required for an installation should be done according to the manufacturer’s instructions and by a qualified Construction Electrician (CE).

Figure 11-3 — Electric space heaters.

Figure 11-4 — Forced warm-air electric space heaters.

3.1.1.2 Gas Heaters and Installation

Gas-fired space heaters are clean in operation; they are also easily operated and require no fuel handling. They are adaptable for use with natural gas, manufactured gas, or liquefied petroleum gas. Their construction features are similar regardless of the type of gas used. Basically, there are two types—the vented and the unvented.

Vented units are enclosed metal cabinets with either top or bottom, or front and rear grilles for warm-air circulation. The flame burns in a closed combustion chamber, and the heater vent carries away the gases (*Figure 11-5*).

The flow of heat is maintained by a motor-driven fan and is controlled by vanes, fins, louvers, or ***diffusers***. This type of unit is more satisfactory than the unvented type because there is less danger of carbon monoxide poisoning.

Figure 11-5 — Rear view of vented gas-fired space heater.

A panel unit is one type of vented unit (*Figure 11-6*). It may be recessed or surface-mounted in either an interior or exterior wall with a vent properly insulated and run up through the wall. This type of unit has the advantage of requiring less floor or ceiling space.

Unvented units are usually the open-flame type where the gas burns in an open combustion chamber. These heaters should be used in a well ventilated area. Ventilation ensures that the carbon monoxide produced by the gas flame is removed.

Gas-fired space heaters and their connections must be of the type approved by the American Gas Association (AGA). They must also be installed according to AGA specifications. Installation factors, such as the type of gas, the capacity of the heater, and the line pressure drops, must be known to ensure proper plumbing procedures with respect to the gas service line. All newly installed piping should be tested for gas leaks. These tests should comply with NAVFAC DM3.

Figure 11-6 — Gas-fired panel space heaters.

On vented gas units, be careful to install the venting system properly to minimize the harmful effects of condensation and to ensure that the combustion products are carried away. During operation, the inner surface of the vent must be heated above the dew point of the combustion products. This prevents water from forming in the ***flue*** pipe. Vent sections must be installed with the male ends of the inner liner down to allow any condensation that forms to return. This is important since the burning of 1,000 cubic feet of natural gas produces approximately 12 gallons of water. For the same reason, horizontal flue pipes should have an upward pitch of at least 1 inch per running foot.

Vent pipes should be equipped with draft diverters. A diverter is a type of inverted cone through which the flue gases must pass on their way to discharge. It allows air from the heated room to be drawn into the flue pipe joining the combustion-gases. This action prevents excessive downdrafts or updrafts that are apt to extinguish the pilot light or possibly the main burner.

3.1.1.3 Oil-Fired Space Heaters

In areas where oil is the principal fuel, oil-fired space heaters are used for many space heating requirements. Oil-fired space heaters are very simple in construction. They consist of a burner, a combustion chamber and outer casing, a fuel tank, and fuel control valve. An air space is provided between the combustion chamber and the outer casing. Air enters through grilles in the bottom of the heater, is heated, and passes out through grilles in the top of the unit. Some oil-burning heaters are equipped with a blower and electric motor to force the heated air out into the room. They turn at slow speed and may be either direct drive or belt driven.

Oil-fired space heaters have atmospheric vaporizing-type burners. The burners require a light grade of fuel oil that vaporizes readily at low temperatures and leaves only small amounts of carbon and ash. Number 1 fuel oil is generally used. The two types of burners that will be discussed are the natural draft pot and the perforated sleeve.

Natural draft pot distillate burners are widely used for space heaters, room heaters, and water heaters. A cutaway view of a natural draft pot type of burner is shown in *Figure 11-7*. In operation, the distillate (oil) is fed at the bottom of the burner, either at the center or on the sides, and is vaporized at this point by radiant heat from above. The vapors rise and mix with the air drawn through the perforated holes in the burner.

During high fire conditions, the flame burns above the top combustion ring (*Figure 11-8*), and under low fire conditions, the flame burns in the lower portion or pilot ring of the burner (*Figure 11-9*).

Figure 11-7 — Cutaway view of a natural draft pot type of burner.

Figure 11-8 — High fire flame.

Figure 11-9 — Low fire flame.

The perforated sleeve burner consists of a metal base formed of two or more circular fuel vaporizing grooves and alternate air channels (*Figure 11-10*). Several pairs of perforated sleeves or cylinders force the air through the perforations into the oil vapor chamber. In this way a large number of jets of air are introduced into the oil vapor, bringing about a good mixture. This mixture burns with a blue flame and is clean and odorless.

These burners usually have a short kindling wick. Some burners have a cup below the base in which alcohol is burned to provide heat for starting. The wick and alcohol are used only for lighting.

Figure 11-10 — Perforated sleeve burner.

3.1.1.3.1 Installation

Oil-burning heaters are portable and are easily moved from one location to another. For satisfactory operation, follow the installation procedures supplied by the manufacturer. In both pot type and perforated sleeve burners, oil is fed to the burner under control of a float-operated metering valve (*Figure 11-11*). Set the unit level so the oil can be properly distributed in the burner.

NOTE

The fuel level control valve is the only safety device on the oil-fired space heater.

When several space heaters are installed in a building, an oil supply from an outside tank to all of the heaters is often desirable. This eliminates frequent filling of individual tanks and reduces waste from spilling. *Figure 11-12* shows the principal elements of such a system and important points to consider during installation.

Figure 11-11 — Oil-controlled metering valve.

Figure 11-12 — Space heaters installed in series.

Be sure that the space heater is placed a safe distance from the wall. You also need a metal pan for it to sit in. This pan catches the oil if a leak occurs. Do not use a sandbox or cement, as both absorb oil and create a fire hazard. In case of wood floors, place a piece of fire-retardant material, such as Gypsum board (Sheetrock), on the floor underneath the metal pan. It may also be needed on the wall behind the heater if the wall is made of wood.

Since the flow of air to a vaporizing type of burner is induced by a chimney draft, pay careful attention to this feature. The draft produced by any chimney depends upon the height of the chimney and the difference in temperature between the flue gas and outside air. The cross-sectional area required depends upon the volume of flue gas to be carried. Since outside air temperature varies during the heating season, arrange the chimney or flue to produce the necessary draft under the most unfavorable conditions likely to be encountered, usually an outside temperature of 60°F. Above this temperature, heat is not usually required, and below this temperature, draft would be increased.

Install the draft regulator to maintain a constant draft adjustment for the rate at which the heaters are fired. The regulator is a swinging damper or gate with provision for adjustment. Since balance and free action are the fundamentals on which its operation depends, be sure the installation provides for these features. Install the damper section with the word “top” at the true top position. Make sure the face is plumb. When the damper regulator is installed in a horizontal run of pipe, do not use a counterweight on the damper.

A downdraft may seriously interfere with proper functioning of these burners. Downdraft may result when the chimney is not high enough above the roof line or is too close to other high buildings, trees, or terrain features. The chimney top must be at least 3 feet above the highest point of the building roof. If the difficulty is caused by other factors, a downdraft hood may prove effective. There are several successful designs; a simple constructed type is shown in *Figure 11-13*.

Figure 11-13 — H-type downdraft hood.

Copper tubing is often used in an oil supply system to burners because of its high resistance to corrosion and ease of installation. The use of compression fittings or flair fittings is best for fuel supply applications. A major advantage in using copper tubing is that it can be bent easily without collapsing the tube, especially if a tubing bender is used; this cuts down on the number of fittings required for installation.

3.2.0 Unit Heater Maintenance

Oil-fired space heaters require periodic cleaning. You must make frequent checks to ensure that equipment is kept clean because accumulations of carbon and soot can cause disastrous fires. Move units when they are cleaned, so they can be cleaned inside and out. You must remove accumulations of soot from inside the fuel pipe. Ensure that all piping and tubing are kept clean and free of oil drippings.

The pot or burner assembly may be cleaned without removing the heater. When cleaning this component, remove it through the front door opening and clean all the air holes using a soft copper wire. Do not remove all the carbon from the bottom because a small accumulation of carbon at the bottom acts as a wick and helps maintain the pilot light. In replacing the burner assembly, make sure both sides of the burner are tightened equally so the top of the burner and the fire-retardant gasket are set firmly against the flue projection.

In checking the constant-level control valve, check the operation of the heater through a complete cycle of operation from the pilot fire position to the main fire position, and then back to the pilot fire position. Set the control valve, if it is the manual type, to high fire; if equipped with a thermostatic device, set the thermostat above room temperature. If the heater fails to operate properly through the cycle, check the constant-level control valve and follow the manufacturer's instructions for disassembly and cleaning. A parts breakdown of the valve is shown in *Figure 11-14*.

Figure 11-14 — Constant-level control valve.

Some of the common problems with pot and sleeve oil burners, gas-fired space heaters, their causes, and possible remedies are listed in *Table 11-3* and *Table 11-4.*

Table 11-3 — Troubleshooting Chart for Pot and Sleeve Oil Burners

Problem	Probable Cause	Possible Remedy
Burner smokes	Improper fuel	Use recommended fuel
	Insufficient oil flow	Troubleshoot low flow
	Excessive chimney draft	Check draft regulator
	Pilot casing is poorly fitted	Remove/Install correctly
	Dirty burner	Clean burner
Burner goes out	Low oil supply	Add oil
	Plugged vent on supply line	Clean vent
	Insufficient oil flow	Troubleshoot low flow
	Improper fuel	Use recommended fuel
	Fuel inlet plugged with carbon	Clean
	Dirt in oil control valve	Clean valve
	Oil valve is not level	Level valve
	Filter cartridge plugged	Clean filter
	Excessive chimney draft	Check draft regulator
	Excessive flue downdraft	Install downdraft hood
Burner flooded	Dirty float valve	Remove/Clean valve
	Improper operation	Perform proper procedures
	Needle valve stuck	Clean/Replace valve
	Dirty burner	Clean burner
	Excessive flue downdraft	Install downdraft hood
Low oil flow	Air trapped in supply line	Eliminate high points
	Oil control valve not level	Level valve
	Oil too heavy	Use recommended oil
	Dirt in supply line	Clean line and components
	Clogged oil strainer	Clean strainer
	Flue inlet clogged with carbon	Remove carbon
High fuel consumption	Improper fuel	Use recommended fuel
	Heat loss	Reduce air supply
	Excessive chimney draft	Check draft regulator
	Heat exchanger caked with ***slag***	Clean affected areas

Table 11-4 — Troubleshooting Chart for Gas-fired Space Heaters

Problem	Probable Cause	Possible Remedy
Motor does not run	Incorrect current	Check and correct
	Faulty wiring	Rewire
	Defective wiring	Replace/Lubricate
Motor runs intermittently	Thermal overload cuts out	Replace motor
Excessive fan and motor noise	Bent fan blade	Straighten/Replace
	Excessive end play in shaft	Exceeds 1/32, Repair/Replace
Solenoid valve hums or flutters	Installed backwards	Check arrow and correct
	Poor electrical connection	Check/Correct/Replace
Burner does not ignite	Faulty pilot burner	Check/Correct/Replace
	Inoperable solenoid valve	Replace solenoid
Delay in main burner ops	Malfunctioning limit switch	Replace limit switch
Improper burning	Primary air not set	Adjust primary air
	Incorrect ***orifice*** size	Check specs and replace
	Incorrect gas pressure	Check specs and adjust
Pilot fails to light	Stopped pilot line	Clean line or replace
	Excessive draft	Eliminate draft
	Low gas pressure	Check pressure regulator

4.0.0 WARM-AIR HEATING SYSTEMS

Heating equipment for complete air-conditioning systems is classified according to the type of fuel burned, the BTU capacity of the furnace, and the method of circulating the warm air. Warm-air systems are generally identified as either a gravity-type or a forced-air type system.

4.1.0 Gravity System

Gravity furnaces are often installed at floor level. These are really oversized, jacketed space heaters. The most common difficulty experienced with this type of furnace is a return-air opening of insufficient size at the floor. Make the return-air opening on two or three sides of the furnace wherever possible. Provide heat insulation above the furnace top to avoid a possible fire hazard.

Gravity warm-air heating systems operate because of the difference in specific gravity (weight) of warm air and cold air. Warm air is lighter than cold air and rises when cold air is available to replace it.

4.2.0 Forced-Air System

The majority of the furnaces produced today are of the forced warm-air type. This type of furnace includes the elements of a gravity warm-air system plus a fan to ensure adequate air distribution. It may include filters and a humidifier to add moisture to the air. The inclusion of a positive pressure fan makes possible the use of smaller ducts and the extension of the system to heat larger areas without the need for sloping ducts. It is possible to heat rooms located on floors below the furnace if necessary. Forced-air furnaces are manufactured in a variety of designs. A typical oil-fired furnace is shown in *Figures 11-15* and *11-16*.

Figure 11-15 — Oil furnace.

Figure 11-16 — Horizontal stowaway oil furnace.

A typical gas-fired furnace is shown in *Figure 11-17*.

In a forced-air system, the fan or blower is turned on and off by a blower control which is actuated by the air temperature in the bonnet or plenum. The plenum is that part of the furnace where it joins the main trunk duct. The blower control starts the fan or blower when the temperature of the heated air rises to a set value, and turns the fan or blower off when the temperature drops to a predetermined point. Thus the blower circulates only air of the proper temperature.

4.3.0 Air Distribution

A knowledge of air distribution principles is important when dealing with central warm-air heating systems. Satisfactory heating from warm-air systems is absolutely dependent upon proper distribution of warm air from the heat source to all portions of the space served. Warm air must be distributed in quantities that are required to offset the rate of heat released to each room. With radiator systems, distribution is primarily a problem of getting enough hot water or steam to each radiator to be sure the radiator heats to its rated capacity. It is not possible to deliver more heat through steam or hot water than the radiator is designed to transmit. With warm-air systems, however, the rate of air delivery and the temperature of the air delivered to the room determine the amount of heat reaching each room. Temperature balance, therefore, is primarily a problem of controlling air distribution.

Factors such as velocity, volume, temperature, and airflow direction play an important part in temperature balance. In addition, for human comfort, space-temperature variations and noise levels must also be considered. Convection currents result from the natural tendency of warm air to rise and cold air to fall. Examples are the temperature variations near doors and windows, and when dense, cool air is drawn away quicker than warm air. Objectionable noise will result at supply diffusers if room velocities exceed 25 to 35 feet per minute (fpm). Air stratification and cold floors may also result when supply diffusers are not properly located within the space.

Figure 11-17 — Gas-fired vertical warm-air furnace.

Patterns of air distribution vary with the positions of supply diffusers. A diffuser that discharges through the floor in an upward direction or downward through the ceiling provides a vertical distribution of air. On the other hand, a diffuser that discharges through a wall provides a horizontal distribution of air. The spread for either the horizontal or the vertical pattern depends on the setting of the diffuser vanes. A low horizontal discharge provides the most effective distribution. Air distribution that results from different diffuser locations is shown in *Figure 11-18*.

Figure 11-18 — Air diffuser distribution.

As previously mentioned, warm-air heating systems are generally identified as either the gravity type or the forced-air type. The type of duct distribution used further identifies these installations. There are two types of duct layouts: (1) the individual duct (*Figure 11-19, View A*), where each duct is connected directly to the furnace plenum, and (2) the trunk and branch duct (*Figure 11-19, View B*), where the trunk duct connects to the furnace plenum and then branches off to the outlets.

Figure 11-19—Types of duct layouts.

Gravity-type furnaces are rated in leader area capacity, the leaders being the warm-air pipes. With respect to return ducts, the register-free area and the return-air duct should not be less than 1 1/4 times the area of the leader serving a given area. Gravity-type installations, shown in *Figure 11-19*, *View A*, use the individual duct layout.

Forced warm-air systems usually have a register temperature range of 150°F to 180°F. Ducts can be in the form of a trunk with branches or with individual leaders from a plenum chamber. Furnaces used with forced-air installations must be equipped with automatic firing devices. Velocities usually are in the range of 750 to 900 fpm in trunks and approximately 600 fpm in branches. Outlet velocities at registers may be as high as 350 fpm.

4.4.0 Gas Fired Furnaces

In this section, construction features, basic components, gas burners, and controls of gas-fired furnaces are discussed.

4.4.1 Construction Features

The various gas-fired furnaces available today have similar basic components; however, there, are variations in design with respect only to dimensions and airflow. Unit features pertinent to dimensions and airflow are important when selecting a furnace for a particular space or application. A vertical counter-flow unit, for example, is normally used where supply ducts are located beneath the floor because it has the return in the top and the outlet in the bottom. The most commonly used unit is the upflow highboy which, as a rule, draws air from the side or bottom and discharges it from the top. It can be installed in small spaces. In the horizontal unit, the air flows in one side and out the other. This unit is suitable for installation in crawl spaces, attics, and basements. In another type, sometimes called a lowboy, both the return and the outlet are at the top. It is a shorter and wider version of the upflow unit. The different airflows are shown in *Figure 11-20*.

Figure 11-20 — Furnace airflow designs.

Another type of furnace is the duct furnace. It is designed for mounting in a duct system where air circulation is provided by an external fan. It is generally used with an air-conditioning system to supply heat during the heating season by using the same ductwork. This type can be installed as a single unit or in batteries for larger requirements. A typical gas-fired duct furnace is shown in *Figure 11-21*.

Figure 11-21 — Gas-fired duct furnace.

Gas-fired furnaces have three main parts—the return-air compartment that houses the blower and filter components, the warm-air compartment that includes the heat exchanger radiators and combustion enclosure, and the combustion air and fuel compartment. This arrangement is shown in *Figure 11-22.*

Figure 11-22 — Internal view of a furnace.

4.4.2 sic Components

The components and assemblies of a gas-fired furnace can be broken down into six units. Each unit is discussed briefly below. Refer to *Figure 11-21* and *Figure 11-22* as we go along to identify the location of individual parts.

The furnace casing, sometimes called the cabinet, along with the framework contains and supports the components of the unit. It also provides an insulating chamber for directing return air through the heat exchanger into the warm-air outlet.

The blower is a centrifugal fan that provides the circulation required to move warm air across the heated space. It also pulls the return air from the space back to the furnace.

The burners are usually the Bunsen type regardless of their size or shape. *Figure 11-23* shows Bunsen burners. The burner nourishes the flame as it provides the correct mixture of primary air and fuel gas to the combustion area.

The gas manifold assembly includes the gas valves, pressure regulator, and those components that automatically control the flow of gas to the pilot and main burner. It is directly connected to the burner.

4.4.3 Gas Burners and Controls

Figure 11-23 — Bunsen burners.

To use natural gas, a nearly ideal fuel, requires comparatively simple equipment and unskilled labor. This clean gas is almost free of noncombustibles and is therefore clean. However, it is relatively dangerous compared to coal or oil because it mixes easily with air and burns readily. Extreme care must be exercised to prevent or stop any leakage of gas into an unlighted furnace or into the boiler room. All gas burners should be approved by the AGA and installed according to the standards of the National Board of Fire Underwriters (NBFU).

The gas burners used in gas-fired furnaces usually have a non-luminous flame and are the Bunsen type, as shown in *Figure 11-23*. Part of the air needed for combustion is primary air that is drawn into the burner mixing tube or "venturi," where it mixes with the gas that burns at the burner ports. The secondary air is supplied around the base of each separate burner flame by natural draft or is induced by a draft fan.

The gas burner controls include the following units—manual gas valve, gas pressure regulator, solenoid gas valve, diaphragm valve, pilot light, thermocouple, thermocouple control relay limit control, heat exchanger, draft diverter, and humidifier (*Figure 11-24*). A manual gas cock or valve must be installed ahead of all the controls.

Figure 11-24 — Automatic gas burner control system.

4.4.3.1 Manual Gas Valve

The manual gas valve is installed on the heating unit next to the gas pressure regulator. It is used to shut off the gas to the heating unit in case some of the controls must be repaired or replaced.

4.4.3.2 Gas Pressure Regulator

The gas pressure regulators used in domestic gas-heating systems are usually of the diaphragm type (*Figure 11-25*). A gas pressure regulator maintains the desired pressure in the burner as long as the gas main pressure is above the desired pressure. When the gas pressure to the burner is low, the pressure-regulating spring pushes the diaphragm down, in turn pushing the pilot valve down. When the pilot valve opens, supply pressure is applied to the top of the operating piston. As the operating piston moves down, the main valve opens, admitting supply pressure to the burner. As burner pressure rises, the diaphragm is pushed up against the pressure-regulating spring, closing the pilot valve. This removes the supply pressure from the top of the operating piston, and the piston return spring pushes the piston up, closing the main valve. The regulator is thus closed every time the burner pressure gets above the desired amount. Turning the adjusting screw at the top can vary the setting of the regulator.

Figure 11-25 — Gas pressure regulator.

4.4.3.3 Solenoid Gas Valve

The basic principles of construction and operation applied in all solenoid gas valves are similar. However, the design of each individual unit differs somewhat from the others. The two most common types of solenoid gas valves are the standard solenoid valve and the recycling solenoid valve discussed in the following paragraphs.

The standard solenoid gas valve shown in *Figure 11-26* is of the electric type. It is suitable for use with gas furnaces, steam and hot-water boilers, conversion burners, and industrial furnaces. This valve operates when a thermostat, limit control, or other device closes a circuit to energize

Figure 11-26 — Standard gas solenoid valve.

the coil. The energized coil operates a plunger, causing the valve to open. When there is a current failure, the valve automatically closes because of the force of gravity on the plunger and valve stem. The gas pressure in the line holds the valve disk upon its seat. To open this valve during current failure, use the manual-opening device at the bottom of the valve. When the electric power is resumed, you should place the manual-opening device in its former position.

The recycling solenoid gas valve shown in *Figure 11-27* can be used with the same heating equipment as the standard solenoid gas valve. The design of this valve differs from that of the standard solenoid gas valve because it is equipped with an automatic recycling device that allows the valve to switch to manual operation during power failure. However, upon the resumption of power, the thermostat automatically resumes control of this valve.

Figure 11-27 — Recycling solenoid valve.

4.4.3.4 Diaphragm Valve

The diaphragm gas valve shown in *Figure 11-28* can be used interchangeably with a solenoid gas valve. Its main feature is the absence of valve noise when it is opening or closing. In this type of diaphragm valve, the relay energizes and opens the three-way valve so the gas pressure on the top of the diaphragm is released to the atmosphere. Reducing the pressure on the top of the diaphragm in this manner causes the gas supply pressure to flex the diaphragm upward, opening the main gas valve. When the relay is de-energized, the vent to the atmosphere is sealed and pressure from the gas supply is allowed to be applied to the top of the diaphragm, forcing it down and sealing the main valve.

Figure 11-28 — Diaphragm gas valve.

4.4.3.5 Pilot Light

The gas pilot light in a gas-heating unit is a small flame that burns continuously and lights the main burner during normal operation of the heating unit. It is located near the main burner (*Figure 11-24*).

The gas flow to the pilot light is, in some cases, supplied by a small, manually operated gas shutoff valve on the main gas line above the main gas valve. In other cases, the gas can be supplied from the pilot tapping on a solenoid gas valve, as shown in *Figure 11-26*. In more expensive heating units, the gas for the pilot light is often supplied by a thermocouple controlled relay.

4.4.3.6 Thermocouple

A thermocouple is probably the simplest unit in the electrical field that is used to produce an electric current by means of heat. It is constructed of two U-shaped conductors of unlike metals in the form of a circuit (*Figure 11-29*).

If these conductors were composed of copper and nickel, respectively, and were joined as shown in the figure, two junctions between the metals would exist. If a flame heated one of these junctions, a weak electric current would be produced in the circuit of these conductors. A series of junctions can be arranged to form a thermopile to increase the amount of current produced (*Figure 11-30*).

Figure 11-29 — Principle of a thermocouple.

In the heating field, thermocouples and thermopiles are used to produce the electrical current used to operate such units as gas valves, relays, and other safety devices.

Figure 11-30 — Thermopile.

The thermocouple is located next to the pilot light of the main gas burner, as shown in *Figure 11-24*. It generates the electric current (usually 50,000 microvolts) which holds open a main gas valve, a relay, or any other safety devices, permitting gas to flow to the main burner. Soon after the pilot light is extinguished, current ceases to flow to these safety devices, thus causing them to shut off the gas to the heating unit. These safety devices will not operate again until the pilot light is lighted and current is again generated by the thermocouple.

4.4.3.7 Thermocouple Control Relay

The thermocouple-operated relay shown in *Figure 11-31* is a safety device used on gas-fired heating equipment. The thermocouple, when placed in the gas pilot flame, generates electricity. The electric current energizes an electromagnet that holds a switch or valve in the open position as long as the pilot flame is burning. When the pilot flame goes out because of high drafts or fuel failure, the electromagnet is de-energized, thus closing and preventing the opening of the switch or valve. The closing of the valve or switch prevents the burner from filling the combustion chamber with unburned gases.

Figure 11-31 — Thermocouple and valve relay assembly.

To re-light the pilot light, push up the reset button at the bottom of the relay and allow the gas to flow to the pilot light. Since some heating units are not equipped with relays, the pilot light is not automatically shut off in case of gas supply failure.

The relay shown in *Figure 11-32* is an electrical switch type of relay. It is entirely electrical and can be used as a controlling unit for either the magnetic or diaphragm gas valves. This unit is actuated by the electric current generated by the thermocouple. It controls the operation of the gas valve in the magnetic and diaphragm valves. A relay of this type must also be reset manually for normal operation.

Figure 11-32 — Electric switch type of relay.

4.4.3.8 Limit Control

The limit control in a gas burner system is a safety device. It shuts off the gas supply when the temperature inside the heating unit becomes excessive. The limit control device can be adjusted to the desired setting. It exercises direct control on the gas or diaphragm valve.

4.4.3.9 Heat Exchanger

This unit or assembly may be either a single or sectional contoured steel shell. It extends vertically from the burner enclosure to the flue exit. Functionally, it transmits heat from the hot gases of combustion to the circulating warm air that passes the outer surfaces.

4.4.3.10 Draft Diverter

The diverter is simply a sheet metal chamber that encircles the flue. It has an opening at the bottom to allow air to be drawn in by the flue draft. Its purpose is to reduce the downdrafts and updrafts that are objectionable to pilot and burner operation.

4.4.3.11 Humidifiers

Humidifiers used with forced warm-air heating systems are usually of the pan type. Unless the water is relatively free of solids, these humidifiers require frequent attention, since the float may stick in the open position or the valve may clog. Overflowing of the pan may result in a cracked heating section, and a stopped-up inlet valve will make the humidifier inoperative.

The drum type of evaporative humidifier uses an evaporation pad in the shape of a wheel. The slow-turning wheel is submerged in the water in the lower pan where the sponge-like plastic foam material becomes ***saturated*** with water. The wheel lifts this portion of the pad and exposes it to the warm, dry air flowing through it. The air then absorbs more moisture because of lower relative humidity at a higher temperature.

4.5.0 Oil-Fired Furnaces

Oil-fired furnaces are similar to gas-fired units in physical arrangement. Internally, oil-fired units have three areas—the burner compartment, the combustion and radiating chamber, and the blower compartment. *Figure 11-33* shows a cutaway view of a typical oil-fired furnace.

Like gas-fired units, oil-fired units are also available with various airflow designs. The model shown in *Figure 11-15* is designed with both the return-air inlet and the warm-air outlet in the top. More compact models are available with the return-air inlet at the side or bottom below the radiating and combustion area (*Figure 11-33*). The warm-air outlet is at the top.

A floor furnace is shown in *Figure 11-34*. This type of oil-fired unit is smaller, lighter in construction, and designed to be hung from the floor of the space served. Only a minimum of clearance is required below the floor (check with manufacturer’s specifications).

Oil burners may be separated into various classes, such as domestic and industrial. Since domestic oil burners are used almost universally in warm-air furnaces, they are the only ones covered in detail in this section.

Figure 11-33 — Oil-fired furnace.

Figure 11-34 — Oil-fired floor furnace.

4.5.1 Domestic Oil Burners

Domestic oil burners atomize the oil and are usually electrically power driven. They are used in small central heating plants. They deliver a predetermined quantity of oil and air to the combustion chamber, ignite it, and automatically maintain the desired temperature.

Domestic oil burners are classified according to various methods, none of which is entirely satisfactory because of the overlapping among a great number of models. Classification may be by type of ignition, draft, operation, method of oil preparation, or features of design and construction.

4.5.1.1 Design and Construction

One of the most common types of domestic oil burners is the pressure-atomizing gun type of burner. Gun type burners atomize the oil by fuel-oil pressure. The fuel-oil system of a pressure-atomizing burner consists of a strainer, pump, pressure-regulating valve, shutoff

Figure 11-35 — High-pressure gun type of oil burner.

valve, and atomizing nozzle (*Figure 11-35*). The nozzle and electrode assembly includes the oil pipe, nozzle holder, nozzle, strainer, electrode insulators, electrodes, supporting clamp for all parts, and static disk. The oil pipe is a steel rod with a fine hole drilled through it. This hole reduces oil storage in the nozzle to a minimum that prevents squirting at the nozzle when the burner shuts off.

The air system consists of a power-driven blower with means to throttle the air inlet, an air tube that surrounds the nozzle and electrode assembly, and vanes or other means to provide turbulence for proper mixing of the air and oil. The blower and oil pump are generally connected by a flexible coupling to the burner motor. Atomizing nozzles can be furnished to suit both the angle of spray and the oil rate of a particular installation. Flame shape can also be varied by changing the design of the air exit at the end of the air tubes. Oil pressures are usually about 100 psi, but pressures considerably greater are sometimes used.

Electric ignition is almost exclusively used. Electrodes are located near the nozzle but must not be in the path of the fuel oil spray. The step-up transformer provides the high voltage (usually 10,000 volts) necessary to make an intense spark jump across the electrode tips.

4.5.1.2 Fuel Unit

There are many types of fuel units available for oil burners; however, the T-type, two-stage fuel unit is the most commonly used. *Figure 11-36* shows this type of unit. It is an oil pump with two strainers mounted on the body of the oil burner and operated by the blower motor shaft.

The T-type, two-stage fuel unit can be used on a single-line or on a two-line system. When Number 1 on the strainer cover is next to the letter marked on the body of the pump, it is correctly arranged for a single-line system. It is set up for a two-line system when the cover is turned so Number 2 is adjacent to the same letter.

Figure 11-36 — T-type, two-stage fuel pump.

A two-line system is necessary when the bottom of the fuel tank is below the level of the pump. The suction line from the tank is connected to the pump port marked "Inlet." The return line is connected to the pump bypass port and is directed back into the tank. With the one-line system, the return line is not used.

4.5.1.2.1 Ignition Electrodes

The heat of a spark jumping between two ignition electrodes ignites the fuel (*Figure 11-35*). The voltage necessary to cause the spark to jump is much more than the line voltage available. Therefore, an electric transformer is used to step up the line voltage to approximately 10,000 volts.

The wall flame burner has an oil distributor and fan blades mounted on a vertical shaft directly connected to the motor. The oil distributor projects the oil to a flame ring made of either ***refractory*** material or metal. *Figure 11-37* shows this type of burner. The hot flame ring vaporizes the oil, and the oil vapors mix with air and burn with a quiet blue flame that sweeps the walls of the furnace. Ignition may be electric, gas-electric, or gas. High-grade fuel oil is necessary for satisfactory performance.

Figure 11-37 — Vertical-rotary burner of the vaporizing or wall-flame type.

4.5.1.2.2 Horizontal Rotary Type

The horizontal rotary type was originally designed for industrial use; however, sizes are available for domestic use. It has a wider range of fuel-burning capacity than the high-pressure gun type and can accommodate heavier grades of fuel. *Figure 11-38* shows this type of burner.

The major parts of the burner are the housing, fan, motor, fuel tube, and rotating atomizing cup. The atomizing cup and fan are driven at the same speed by a directly connected electric motor. Oil is fed through the fuel tube to the inner surface of the atomizing cup. The oil spreads over the surface of the cup, which turns at 3,450 revolutions per minute (rpm). It then flows to the edge of the cup where it is thrown off. The whirling motion and the resulting centrifugal force separate the oil into fine particles as it leaves the cup. Primary air supplied by the fan is thrown in around the outer edge of the rotating cup and given a whirling motion in the direction opposite that of the oil. The streams of air and oil collide and thoroughly mix as they enter the combustion chamber.

Figure 11-38 — Horizontal-rotary oil burner.

4.5.1.3 Oil Burner Controls

The purpose of oil-burner controls is to provide automatic, safe, and convenient operation of the oil burner. The system is designed to maintain the desired room temperature, to start the burner as required, and to ignite the fuel to initiate combustion. However, in case trouble arises during operation, the burner must be stopped and further operation prevented until the trouble has been corrected.

Oil-burner controls are essentially the same as stoker or gas controls. The only difference is that the oil burner has, in addition, two ignition electrodes and a primary or safety control. A diagram of a typical forced warm-air control system is shown in *Figure 11-39*.

4.5.1.3.1 Primary Control

The burner primary control is electrically connected between the thermostat and the burner, as shown in *Figure 11-39*, and it performs several functions. The primary control closes the motor and ignition circuits when the thermostat calls for more heat. It breaks the motor circuit and stops the burner when the motor first starts if the fuel fails to ignite or if the flame goes out. The control prevents starting of the burner in case of electrical failure until all safety devices are in the normal starting position.

Figure 11-39 — Forced warm-air control system.

An interior view of a primary control is shown in *Figure 11-40*. This control device is also equipped with a high-temperature limit control. This control shuts down the heating plant whenever the temperature of the furnace becomes excessive. For example, if the thermostat is exposed to a blast of cold air for a long period of time, the heating plant could run long enough to become overheated to the point of severe

Figure 11-40 — Interior view of a primary control.

damage or external fire if it were not for this high-temperature limit control.

4.5.1.3.2 Limit Control

The limit control is a device that responds to changes in air temperature (in a warm-air heating system), to changes in water temperature (in a hot-water heating system), and to changes in steam pressure (in a steam-heating system). The limit control has two distinct functions. The first function is to control the operation of the fire so the temperature and pressure of the heating plant never exceed safe operating limits. This function is distinctly for safety control.

The second function of the limit control is to limit the temperature and pressure of the heating system for better temperature regulation in the building. This function is particularly useful in controlling coal-fired heating systems where the coal bed continues to give off heat when the stoker motor stops. By lowering the setting of the limit control, however, it is possible to prevent an excessively hot fire that would continue to throw off excessive amounts of heat after the thermostat has been satisfied.

4.5.1.3.3 Temperature-Responsive Devices

Many automatic control units, such as the thermostat, limit control, fan control, and many others, must respond to temperature changes. Actually, these are the instruments that use a temperature change to cause the electrical contacts inside each unit to open and close. The opening and closing is an indicating signal that is transmitted to the primary control for specific action, such as starting or stopping the operation of the heating plant.

4.5.1.3.4 Bimetallic Strip

Some automatic control units are equipped with a switch that contains a straight bimetallic strip to open and close electrical contacts. This actuating device is made by welding together two pieces of dissimilar metals, such as brass and Invar (*Figure 11-41, View A*). Below a certain predetermined temperature, this strip does not deflect or bend. However, when the strip is heated, it bends in the direction of the metal that expands the least (*Figure 11-41, View B*).

Figure 11-41 — Bimetallic strips.

Actually, this electrical switch is constructed by welding two electrical connections and contacts to the strip (*Figure 11-41, View C*). A switch of this type can then be used to control electrical circuits because the bimetallic strip responds to temperature changes. This is a basic example of how this principle of bimetallic strip operation is used in many temperature-responsive automatic units. Other control switches contain bimetallic strips that are spiral, U-shaped, Q-shaped, or even in the shape of a helix (*Figure 11-42*).

Figure 11-42 — Various types of bimetallic strips.

4.5.1.3.5 Vapor-Tension Device

The vapor-tension principle is also used to actuate some types of automatic control units. This is a common type of temperature-measuring device in which the effects of temperature changes are transmitted into motion by a highly volatile liquid. The most used vapor-tension device is the simple compressible bellows (*Figure 11-43, View A*).

The ***bellows*** is made of brass. It is partially filled with alcohol, ether, or other volatile liquid not corrosive to brass. When the temperature around the bellows increases, the heat gasifies the liquid inside and causes the bellows to extend. The extension closes a set of electrical contacts (*Figure 11-43, View B*). When the bellows cools again, it contracts. The contraction opens the electrical contacts.

Figure 11-43 — Tension devices.

4.5.1.3.6 Remote-Bulb Device

Liquid-filled devices are not always limited to the simple bellows. There are some remote-bulb devices that not only have a bellows but also have a capillary tube and a liquid-filled bulb (*Figure 11-44*).

When the liquid in the bulb is heated, part of it gasifies and forces its way through the capillary tube into the bellows. This increased pressure inside the bellows causes it to extend and open a set of electrical contacts (or open or close a valve). When the bulb cools, the gas liquefies and decreases pressure inside the bellows. This decreased pressure allows the bellows to contract and close the electrical contacts.

Pressure-responsive devices are actuating mechanisms installed in units such as steam-pressure controls, steam-pressure gauges, and pressure regulators.

Figure 11-44 — Remote-bulb device.

4.5.1.3.7 Bellows

One type of pressure-responsive actuating device uses bellows in a way similar to that of the remote-bulb type. In this application, the bellows extends and contracts in response to changes in steam pressure. The action caused by movement of the bellows opens or closes a set of electrical contacts.

4.5.1.3.8 ourdon Tube

Another type of pressure-responsive actuating device is found inside the pressure gauge (*Figure 11-45*). In this actuating device, the pressure is applied inside a hollow, partially flattened, bent tube called a Bourdon spring tube. The pressure inside this tube tends to straighten it, and in so doing, it moves the lever mechanism that turns the pointer. The pressure gauge measures the pressure in pounds per square inch (psi).

Figure 11-45 — Bourdon spring tube.

Humidity-responsive devices open or close solenoid or motorized valves which control the flow of water or steam to humidifying equipment. The sensitive element which actuates the motion in this device consists of a group of human hairs. These hairs lengthen when the humidity is high and shorten when the humidity is low.

Accumulation of dust and grease on these hairs, while not damaging, may decrease the sensitivity of the controller. Consequently, you should clean the element periodically with a camel's-hair brush and clean ether, and then a complete wetting with distilled water should follow this cleaning.

4.5.1.3.9 Electrical Switches

Electrical switches in heating-control equipment operate electrical circuits in response to signals from automatic control units. In other words, the actions initiated by devices responsive to temperature, pressure, and humidity changes open or close switch contacts. These in turn control the operation of the heating plant through electrical circuits. Switches may be either the snap-action type or the mercury type.

Snap-action switches vary in their designs. Some are constructed so they have an over-center spring arrangement designed so the movement of the actuating lever engages the spring and causes the switch to move with snap-action. The snap-action type of switch is shown in *Figure 11-46, View A*.

Another snap-action switch shown in *Figure 11-46, View A* has a small magnet that causes the electrical contacts to remain firmly closed. It also provides the switch with the snap-action effect. The contacts of this switch must open or close quickly to avoid excessive arcing across the points. Arcing burns the contacting surfaces, which eventually causes switch failure.

A mercury switch has the electrical contacts and a small amount of mercury in a hermetically sealed short glass tube (*Figure 11-46, View B*). Tilting the switch causes the mercury inside the tube to cover or uncover the contacts. When the contacts are covered, the electrical circuit is completed.

Figure 11-46 — Electrical switches.

Every electrical switch is designed so it has a specific rated capacity in amperes and volts, for example, a capacity of 8 amperes at 110 volts. An electrical switch should never be overloaded because overloading causes overheating, which eventually results in switch failure that can create a fire hazard.

The standard controls furnished for automatic fuel-burning equipment come in sets designed for warm-air, hot-water, and steam-heating systems. A standard set usually consists of a thermostat, limit control, primary control, and electric motor. Auxiliary controls are those designed for a specific function in a warm-air, hot-water, or steam-heating system. They are in addition to the standard controls.

4.5.1.3.10 Thermostat

The thermostat is the nerve center of the heating-control system. It is the sensitive unit that responds to changes in room temperature. It indicates whether more or less heat is required from the heating plant. It transmits the indicating signal to a primary control for action. This indicating signal is initiated by closing or opening electrical contacts in the thermostat.

Thermostats often differ in construction according to the type of primary control with which they are to be used. Probably the most used thermostats are the spiral-bimetallic type and the mercury-bulb type.

An electric clock thermostat has the additional features of an electric clock and an automatic mechanism that can be adjusted to change the thermostat setting at a desired time. For instance, it can be adjusted to reset the thermostat automatically from 80°F to 60°F at 11:00 p.m. (when 80°F heat is not needed). Then it will reset the thermostat to 80°F at 6:00 a.m. (when more than 60°F heat is needed).

The location for the thermostat should be representative of that part of the building in which heat is needed to maintain a comfortable temperature. The best location is on an inside wall, just a few feet from an outside wall and about 4 1/2 feet above the floor. The thermostat wiring must conform to local electrical ordinances.

To check the calibration of a thermostat, hang an accurate test thermometer within 2 inches of the device. Allow 15 to 30 minutes for the thermostat and thermometer to adjust themselves to room temperature. The thermostat contacts should close when the control knob or dial is set at the temperature indicated by the test thermometer. You should not try to recalibrate the thermostat if the closing point varies 1°F or less. When calibration is necessary, follow the manufacturer's instructions.

4.6.0 Furnace Installation

Since there are many types and makes of oil- and gas-fired warm-air furnaces on the market, detailed assembly instructions to suit all makes and types cannot be given in this manual. However, some general instructions which apply to both oil-fired and gas-fired furnaces, except as noted, are given below.

Carefully follow assembling instructions included with each furnace or blower shipment. Each piece or casting is manufactured to fit in its proper place. Parts are seldom interchangeable.

Install furnaces in a level position. If the floor is uneven, use a steel wedge, a cast iron wedge, or the leveling bolts provided on some equipment. Use a spirit level to make sure the unit is level.

Gas-fired and oil-fired forced-air units which have the blower below the heating element or combustion chamber should be set on masonry at least 3 inches thick and extending at least 12 inches beyond the casing wall. Install all other units on a cold masonry floor. Provide enough clearance to permit easy access for repairs. Make the clearance at least 18 inches from wood or other combustible material unless you install an asbestos board at least 1 inch from the combustible material. Units may be installed near masonry walls; however, leave ample room to permit proper servicing.

Furnace cement is furnished with each cast iron furnace. Seal all furnace joints with a liberal amount of furnace cement between sections to ensure the furnace is gastight. Asbestos rope is furnished with a number of furnaces; follow the manufacturer's instructions covering its use. See that projections from the furnace, such as the smoke pipe or clean-outdoors, extend through the outside of the casing.

In assembling a furnace, be sure to tighten all bolts. Draw each bolt until it is almost tight. Then, after all bolts have been installed, draw each one gradually until all are uniformly and properly tight. Avoid drawing bolts too tight, as this can crack or break a casting or buckle a steel plate.

After assembling the furnace, check all doors for free operation and tight fit.

Install the downdraft diverters furnished with the equipment on all gas-burning furnaces. Diverters are developed for individual furnaces.

Use a vent or smoke pipe that is at least as large as the smoke-pipe outlet of the furnace.

Securely fasten the vent or smoke pipe at each joint with a minimum of three sheet metal screws. Install horizontal pipe with a pitch upward of at least 1 inch per linear foot (*Figure 11-47*).

Ventilate the furnace room adequately to supply air for combustion. Provide an opening having 1 square inch of free-air area for each 1,000 BTU per hour of furnace input rating, with a minimum of 200 square inches. Locate the opening at or near the floor line whenever possible. In addition, provide two louvered openings, each having a free-air area of at least 200 square inches in it, at or near the ceiling as near opposite ends of the furnace room as possible.

Figure 11-47 — Smoke pipe (flue) installation.

Tank installation is largely governed by local conditions. Listed here are the principles of tank installation that give greatest freedom from service problems. Adhere as closely to these recommendations as local conditions permit.

When possible, install single-pipe gravity oil feed on inside tanks or elevated outside tanks (*Figure 11-48*). This type of installation is used for single-stage pumps. Use a 1/4-inch globe valve at the tank instead of a larger size. Larger valves sometimes cause tank hum.

Figure 11-48 — Diagram of piping for inside or outside elevated tank installations.

For all installations, use a continuous piece of 1/2-inch copper tubing from the oil tank or valve to the burner and a similar piece for the return when required. The principle is to minimize the number of joints and thus minimize the possibility of air or oil leaks.

For inside installations where it is necessary to run the piping overhead between the tank and burner, when the burner is either above or below the tank level, the two-pipe system is recommended. This requires the use of a two-stage pump.

A dual-stage pump may be changed from a single-stage to a two-stage pump to accommodate a single-pipe or two-pipe system. The stages on a Webster fuel pump can be changed by removing the four screws on the pressure side of the pump and lining the Number 1 up with the letter on the pump body for a one-pipe system. The Number 2 lined up with the letter is for a two-pipe system. Most Sunstrand fuel pumps are shipped from the factory set up for a one-pipe system. To change to a two-pipe system, remove the 3/8-inch pipe plug from the bottom of the pump housing. There you will find an Allen head plug. Remove this plug for a two-pipe system.

Install the outside tanks according to the instruction below (*Figure 11-49*).

Figure 11-49 — Diagram of piping for buried outside tank.

Normally, when you are installing an underground fuel tank, the suction and return lines are made of black iron from the tank to the inside of the building, and there the burner is connected by copper tubing with a coil in it to eliminate vibration.

The return line is usually installed in the opposite end of the tank. Carry it to within 5 inches of the bottom. This creates an oil seal in the two lines, and any agitation caused by return oil is safely away from the suction line.

A 1 1/2-inch fill line and a 1 1/2-inch vent line are recommended. Carry the vent well aboveground and put a weatherproof cap on it. Pitch the vent line down toward the tank.

Use special pipe ***dope*** on all iron pipe fittings that carry oil. Treat the underground outside tank and piping with a standard preparation or commercial corrosion-resistant paint.

4.7.0 Maintenance of Fuel Oil Systems

Among the major duties of the UT are troubleshooting and servicing oil burners. To keep the burner in good operating condition, you must be able to recognize the symptoms of various types of trouble and must know how to make various service and maintenance adjustments to the burner.

Before getting into a discussion on troubleshooting and servicing of oil burners, let's point out some information on fuel oil firing.

4.7.1 Fuel Oil Firing

Because fuel oils do not burn in the liquid state, several physical conditions must be attained to affect complete and efficient combustion.

1. Either the liquid must be thoroughly vaporized or gasified by heating within the burner, or the burner must atomize it so vaporization can occur in the combustion space.
2. The mist must be thoroughly mixed with sufficient combustion air.
3. Required excess air must be maintained at a minimum to reduce stack thermal loss.
4. Flame propagation temperature must be maintained.

Vaporization within the burner is generally confined to small domestic services, such as water heating, space heating, and cooking, and to some industrial processes. Burners for this purpose are usually of the pot type with natural or forced draft, gravity float-type feed control, and hand or electric ignition. Kerosene, diesel oils, and commercial oils of grades Nos. 1 and 2 are suitable fuels because they vaporize at relatively low temperatures.

If oil is to be vaporized in the combustion space in the instant of time available, it must be broken up into many small particles to expose as much surface as possible to the heat. This atomization is done in three basic ways:

1. By using steam or air under pressure to break the oil into droplets
2. By forcing oil under pressure through a suitable nozzle
3. By tearing an oil film into tiny drops by centrifugal force

Primary combustion air is usually admitted to the furnace through a casing surrounding the oil burner. The casing is spiral-vaned to impart a swirling motion to the air, opposite to the motion of the oil. Three types of burners used for atomization are the steam- or air-atomizing burner, the mechanical-atomizing burner, and the rotary-cup burner.

Burners should be piped with a circulating fuel line, including cutout, bypass, pressure-relief valves, and strainer ahead of the burner. Burners should be accessible and removable for cleaning, and the orifice nozzle plates should be exchangeable to compensate for a wide range in load demand.

4.7.2 Steam-Atomizing and Air-Atomizing Burners

The burners consist of a properly formed jet-mixing nozzle to which oil and steam or air is piped. The conveying medium mixes with fine particles of fuel passing through the nozzle, and the mixture is projected into the furnace. Nozzles may be of the external or internal mixing type, designed to project a flame that is flat or circular and long or short. A burner should be selected to give the form of flame that is most positioned so there is no flame impingement on the furnace walls and so combustion is completed before the flame contacts the boiler surfaces.

Steam-atomizing burners are simpler and less expensive than the air-atomizing type and are usually used for locomotive and small power plants. They handle commercial grade fuel oils Nos. 4, 5, and 6 and require a steam pressure varying from 75 to 150 psi. The oil pressure needs to be enough to carry oil to the burner tip, usually from 10 to 15 psi. Burners using air as the atomizing medium are designed for three air pressure ranges: low pressure to 2 psi, medium pressure to 25 psi, and high pressure to 100 psi.

Figure 11-50 shows a steam-atomizing burner of the external mixing type. In *View A,* the oil reaches the tip through a central passage and whirls against a sprayer plate to break up at right angles to the stream of steam (*View B*). The atomizing stream surrounds the oil chamber and receives a whirling motion from vanes in its path. When air is used as the atomizing medium in this burner, it should be at 10 psi for light oils and 20 psi for heavy oils. Combustion air enters through a register; vanes or shutters are adjustable to give control of excess air.

4.7.3 Mechanical-Atomizing Burner

The burner is universally used except in domestic or low-pressure service. Good atomization results when oil under high pressure (to 300 psi) passes through a small orifice and emerges as a conical mist. The orifice atomizing the fuel is often aided by a slotted disk that whirls the oil before it enters the nozzle.

Figure 11-50 — Steam-atomizing burner.

Figure 11-51 shows a mechanical-atomizing burner. *View A* is a cross section of the burner; *View B* shows the central movable control rod that varies, through a regulating pin, the area of tangential slots in the sprayer plate and the volume of oil passing through the orifice; *View C* shows a design with a wide-capacity range obtained by supplying oil to the burner tip at a constant rate in excess of demand. The amount of oil burned varies with the load; the excess is returned.

4.7.4 orizontal Rotary-Cup Burner

The burner atomizes fuel oil by tearing it into tiny drops (*Figure 11-52*). A conical or cylindrical cup rotates at high speed (about 3,450 rpm), if motor driven. Oil moving along this cup reaches the periphery where centrifugal force flings it into an airstream. It is suitable for small low-pressure boilers.

Figure 11-51 — Mechanical-atomizing burner.

Figure 11-52 — Rotary-cup oil burner.

4.8.0 Oil-Burner Maintenance

Before attempting to start or to service oil burners, see that you have the proper maintenance equipment available. One item of equipment needed is a pressure gauge set. This should consist of a 150 psi pressure gauge, fittings to connect it, and a ***petcock*** for removing the air from the oil line when starting the burner. You will need a full set of Allen setscrew wrenches for bypass plugs and for adjusting the nozzle holder and electrodes. Make sure you have a socket wrench of proper size for removing or replacing the nozzle, an open-end wrench as required for the nozzle holders, and a small thermostat wrench. This wrench comes packed with the thermostat and is used for adjusting the differential. A small screwdriver is required for adjusting pressure at the regulator and installing and servicing the thermostat. Another important item is pipe dope, and if available, use the oil-line type only. If in doubt, order a can of special oil-pipe dope for use on all pipe threads requiring dope. A nozzle assortment should also be kept on hand. It is cheaper to make a change, time considered, than to clean the nozzle on the job. When a few nozzles have accumulated, clean them in the shop.

When installing a nozzle, use a socket wrench for turning the nozzle. Be sure the nozzle seat is clean. Screw it on until it reaches the bottom, then back it off and retighten it several times to make sure of a tight oil seal. Do not over-tighten the nozzle or the brass threads will become deformed, making it difficult to remove the nozzle.

Clean the nozzles in the shop on a clean bench. A nozzle is a delicate device. Handle it with care. Use kerosene or safety solvent to cut the grease and gum; use compressed air, if available, to blow the dirt out. Use goggles for eye protection when blowing dirt out with compressed air. Never use a metal needle to clean the opening; it will ruin the nozzle. Sharpen the end of a match or use a nonmetallic bristle brush to clean the opening.

When you are checking the nozzle, you may have to make adjustments in the distance of the nozzle from the tube end, the distance of the ignition points ahead of and above the nozzle, and the distance or gap between the ignition points. *Figure 11-53* shows these nozzles adjustments. The nozzle tip is set 5/8 inch apart, 1/8 inch ahead of the nozzle, and 1/2 inch above the nozzle center line. These settings are given only for this particular illustration. Actual adjustments should always be made according to the specific settings in the manufacturer's instruction manual. Always tighten electrodes securely to ensure permanent adjustment.

Figure 11-53 — Setting of ignition points and nozzles.

4.8.1 Troubleshooting

When oil burners are operated, operating problems will occur. These problems can cause interruption of service, inefficiency, and damage to the equipment in the system. To ensure proper operation and efficiency, you will need to be able to identify and correct these difficulties. A list of common difficulties and their remedy are contained in *Table 11-5*.

Table 11-5 — Common Operating Difficulties for Oil Burners

Condition	Check for
Furnace pulsates on starting, stopping, or during operation.	Proper adjustment of the nozzle electrode assembly land blast tube.
	Improper draft. Leaks in chimney.
	Defective nozzle.
	Air in the line, between fuel unit and nozzle.
Flame is raw and stingy.	Too large an opening in the air adjustment.
	Partly plugged nozzle.
	Air in the pump.
Ignition points collect carbon.	Ignition points too close to nozzle.
	Nozzle loose in holder.
	Improper oil cutoff when burner is shutdown.
Oil pump is noisy.	Air in oil line.
	Leaks in suction line.
	Plugged strainer.
Burner starts and stops too frequently.	Thermostat is improperly wired.
	Thermostat is improperly adjusted.
	Drive arm adjustment is incorrect.
	Limit control is set too low.
	Plugged air filters.
	Nozzle is too large for unit.
Burner failsafe is activated.	Low voltage occurring at night.
	Incorrect polarity of wiring.
	Primary control or stack switch improperly adjusted.
No oil at the nozzle.	Fuel too low in the supply tank.
	Plugged nozzle.
	Leak in the suction line.
	Leak in the vacuum-gauge port.
	Pump failing to turn.
	Leaking strainer gasket.
	Leaking pump-shaft seal.
	Fuel unit not operating.

4.8.2 Flame Adjustment

After the burner has been visually adjusted and allowed to run about 30 minutes, reduce the stack draft until there is just enough over-fire draft in firebox to keep the pressure from increasing under unfavorable draft conditions. The draft regulator helps maintain a constant draft in the furnace regardless of outside weather conditions. Adjust the draft by properly setting the adjuster. Too little draft is likely to cause firebox pressure, odors in the building, and possible smoke or smothering of the flame. Too much draft accentuates the effect of a possible leak in the furnace, lowers the percentage of CO_2 in the flue gas, and in turn reduces the overall efficiency of the unit. After the burner flame and draft are properly adjusted, a flue-gas analysis should show a CO_2 content of approximately 10 percent. If it does not, recheck the burner air adjustment and inspect for air leaks. For best results, the flame should be just large enough to heat the building properly in cold weather.

Air supplied to the burner will then be the minimum for clean combustion. If the furnace is large enough and the burner has been set for correct oil flow and minimum amount of air, stack temperature should not exceed 600°F. Higher stack temperatures indicate that the fire is too large or the furnace too small, or that there is too much excess air.

4.8.3 Test Equipment

It is almost impossible to set and adjust a burner without instruments or test equipment. Proper instruments, in good working order, must be available in the heating shop for use by personnel who service this equipment.

The draft gauge, usually of the pointer-indicating type, is used to determine suction in the smoke pipe or combustion chamber. Suction is measured in inches of water. Carefully follow the instructions for operating the instrument.

The stack thermometer is used to indicate the temperature of gases in the smoke pipe. Insert the thermometer halfway between the center and outside of the smoke pipe and not more than 12 inches from the furnace between the smoke pipe connection and the draft regulator or barometric damper. Be careful to prevent the thermometer from being influenced by cold air taken in by the draft regulator.

The flue-gas analyzer is used to determine the percentage of CO_2 produced by combustion. The CO_2 reading shows how much excess air is being used. Along with the stack temperature, it denotes the efficiency of the furnace. If, despite a good flame setting, CO_2 readings are low, examine the furnace for air leaks.

4.9.0 Fuel Pump

Maintenance requirements include cleaning the strainer, servicing the valve seat and needle valve, and adjusting the pressure regulator. You must clean the strainers frequently to prevent the screen from clogging and causing a shutdown. A good test for valve operation consists of removing the nozzle line at the pump connection, starting and stopping the pump, and observing whether the valve cuts off sharp and lean. When necessary, you can easily service the valve by removing the valve chamber cover, holding spring, washer, adjusting spring, cap, and bellows assembly. Then, by taking off the nut that is marked "Nozzle," you can remove the valve, valve guide, and plug assembly.

You can adjust the pressure regulator by replacing the vent plug with a pressure gauge, removing the cover screw, and using an Allen wrench to turn the adjusting screw clockwise to increase the pressure or counterclockwise to decrease the pressure.

Burner failure or improper unit operation can be caused by various problems. Often you can pinpoint the problem by observing the type of failure and giving it some thought before attacking the problem. At other times, you can determine the cause only by a process of elimination. *Table 11-6* lists specific oil pump troubleshooting procedures, while *Table 11-7* and *Table 11-8* list general oil burner troubleshooting procedures. Check the simplest and more obvious items before progressing to the other checks and always refer to the manufacturer's instructions, here are some general trouble shooting steps that might be useful.

Table 11-6 — Oil Pump Troubleshooting

CONDITION	CAUSE	REMEDY
No oil flow at nozzle	Oil level below line in supply tank	Fill tank with oil.
	Clogged strainer or filter	Remove/clean strainer. Replace filter element.
	Clogged nozzle	Replace nozzle.
	Air leak in intake line	Tighten all fittings. Tighten unused intake port plug. Check filter cover and gasket.
	Restricted intake line	Replace any kinked tubing and check valves.
	Two-pipe system that becomes air bound	Check for and insert bypass plug. Make sure return line is below oil level.
	Single-pipe that becomes air bound	Loosen gauge port plug or easy flow valve and bleed oil for 15 secs after foam is gone in bleed hose. Check intake fitting for tightness. Check all pump plugs.
	Slipping or broken coupling	Tighten/replace coupling.
	Frozen pump shaft	Replace pump.
Oil Leak	Loose plugs or fittings	Dope with thread sealer.
	Leak at pressure adjuster screw or nozzle plug	Washer damaged. Replace the washer/O-ring.
	Blown seal (single-pipe system)	Check to see if bypass plug has been left in unit. Replace oil pump.
	Blown seal (two-pipe system)	Check for kinked tubing or obstructions in return line. Replace oil pump.
	Seal leaking	Replace oil pump.
	Cover	Tighten cover screws or

CONDITION	CAUSE	REMEDY
		replace damaged gasket.
Noisy operation	Bad coupling alignment	Loosen fuel unit mounting screws slightly and shift fuel unit in different positions until noise is eliminated, Retighten mounting screws.
	Air in inlet line	Check connections.
	Tank hum on two-pipe system and inside tank	Install return line hum eliminator in return line.
Pulsating pressure	Partially clogged strainer or filter	Remove/clean strainer. Replace filter element.
	Air leak in intake line	Tighten all fittings.
	Air leaking around cover	Be sure strainer cover screws are tight. Check for damaged cover gasket.
Improper nozzle cut-off	To determine the cause of improper cutoff, insert a pressure gauge in the nozzle port of the fuel unit. After a minute of operation, shut burner down. If the pressure drops from normal operating pressure and stabilizes, the fuel unit is good and air is the cause of cutoff. If, the pressure drops below 80 psig, replace oil pump.	
	Filter leaks	Check face of cover and gasket for damage.
	Strainer cover loose	Tighten four screws on cover.
	Air pocket between cutoff valve and nozzle.	Run burner, stopping and starting unit, until smoke and after-fire disappears.
	Air leak in intake line	Tighten intake fittings. Tighten unused intake port and return plug.
	Partially clogged nozzle strainer	Clean strainer or change nozzle.
	Leak at nozzle adapter	Change nozzle and adapter.

Table 11-7 — Oil Burner Troubleshooting

Burner Fails to Start			
Source	**Procedure**	**Causes**	**Correction**
Thermostat control	Check thermostat settings	Thermostat is in Off or Cool position	Switch to Heat
		Thermostat is set too low	Turn to higher setting
Safety overloads	Check burner motor, primary safety control, and auxiliary limit switch	Burner motor overload tripped	Push motor overload reset
		Primary control tripped on safety	Reset safety switch
		Auxiliary limit switch tripped on safety	Push auxiliary limit switch reset
Power	Check furnace disconnect switch and main disconnect switch	Switch open	Close switch
		Blown fuse or tripped breaker	Replace fuse or reset breaker
Thermostat unit	Touch jumper wire across thermostat terminals on primary control. If burner starts, then fault is in thermostat circuit	Loose thermostat screw connections	Tighten connection
		Dirty contacts	Clean contacts
		Thermostat not level	Level thermostat
		Faulty thermostat	Replace thermostat
Cad cell	Disconnect flame detector wires at primary control. If burner starts, fault is in the detector circuit	Flame detector leads shorted	Separate leads
		Flame detector exposed to light	Seal off false source of light
		Short circuit in flame detector	Replace detector

Burner Fails to Start			
Source	**Procedure**	**Causes**	**Correction**
Primary control (1)	Place trouble light between the black and white leads. No light indicates there is no power to the control.	Primary or auxiliary control switch open	Check dial adjustment. Set to maximum stop setting. Jumper terminals; if burner start switch is faulty, replace control
		Open circuit between disconnect switch and limit control	Trace wiring and repair or replace
		Low line voltage or power failure	Call CE
Primary control (2)	Place trouble light between the orange and black leads. No light indicates the control is faulty	Defective internal control circuit	Replace control
Burner (1)	Place trouble light between the black and white leads to burner motor. No light indicates no power to the burner motor.	Blown fuse	Replace fuse
Burner (2)	Place trouble light between the black and white leads to burner motor. Light indicates power to the motor and a burner fault	Binding burner blower wheel	Turn off power and rotate blower wheel by hand
		Seized fuel pump	If seized, free wheel from binding or replace fuel pump
		Defective burner motor	Replace motor
Burner Starts but NO Flame is Established			
Oil supply	Check gauge or use dip stick. Coat dipstick with litmus paper and insert to bottom of tank. Listen for pump whine.	No oil in tank	Fill tank
		Water in oil tank	Pump or drain the water out if greater than 1 inch in depth

Burner Fails to Start			
Source	**Procedure**	**Causes**	**Correction**
		Tank shutoff valve closed	Open valve
Oil filters and oil line	Listen for pump whine	Oil line filter plugged	Replace filter cartridge
		Kinks or restriction in oil line	Repair or replace oil line
		Plugged fuel pump strainer	Clean strainer or replace pump
	Open bleed valve or gauge port. Start burner. No oil or milky oil indicates loss of prime	Air leak in oil supply line	Locate and correct leak and tighten all connections
Oil pump	Install pressure gauge on pump and read pressure. Pressure should not be less than 100 psig	Pump partially or completely frozen; No pressure and motor locks out on control	Replace pump
		Coupling disengaged or broken; No pressure	Reengage or replace coupling
		Fuel pressure too low	Adjust pressure to 100 psig
Nozzle	Disconnect ignition leads. Observe oil spray (gun assembly must be removed from the unit). Inspect nozzle for plugged orifice or carbon buildup around orifice	Nozzle orifice plugged	Replace nozzle with same size, spray angle, and spray type
		Nozzle strainer plugged	Replace nozzle with same size, spray angle, and spray type
		Poor or off center spray	Replace nozzle with same size, spray angle, and spray type.

Burner Fails to Start			
Source	**Procedure**	**Causes**	**Correction**
Ignition electrodes	Remove gun assembly and inspect electrodes and leads	Fouled or shorted electrodes and leads; Eroded electrode tips; Improper position of electrode tips	Clean electrodes and leads. Dress up electrode tips and reset gap to 1/8 inch and correctly position the tips
		Bad buss bar connection	Retension and align
		Cracked or chipped insulators	Replace electrode
		Cracked or burned lead insulators	Replace electrode leads
Ignition transformer	Connect ignition leads to transformer. Start burner and observe spark. Check line voltage to transformer primary	Low line voltage	Check voltage at power source. Correct cause of voltage drop or call CE
		Burned out transformer windings	Replace transformer
		No spark or weak spark	Properly ground transformer case
Burner motor	Motor does not come up to speed and trips out on overload. Turn off power and rotate blower wheel by hand to check for binding or excessive drag	Low line voltage	Check voltage at power source. Correct cause of voltage drop or call CE
		Pump or blower overloading motor	Correct cause of overloading or replace motor
		Faulty motor	Replace motor

Table 11-8 — Oil Burner Troubleshooting

Burner Starts and Fires but Locks Out on Safety				
Source	**Procedure (1)**	**Procedure (2)**	**Cause**	**Correction**
Poor fire	After burner fires, immediately place jumper across flame detector terminals at primary control	If burner continues to run, fault may be due to poor fire. Inspect fire	Unbalanced fire	Replace nozzle
			Too much air; lean short fire	Reduce combustion air; check combustion
			Too little fire; long dirty fire	Increase combustion air; check combustion
			Excessive draft	Adjust barometric damper for correct draft
			Too little draft or restriction	Correct draft or remove restriction
Flame detector		If fire is good, fault is in flame detector. Check detector circuit.	Dirty cad cell face	Clean cad cell face
			Faulty cad cell; exceeds 1500 ohms	Replace cad cell
			Loose or defective cad cell wires	Secure connections or replace cad cell holder and wire leads
			Primary control circuit defective	Replace primary control
Oil supply (listen for pump whine)		If burner loses flame (does not lock out on safety), fault is in the fuel system	Air slug or leak in supply line	Check supply line and oil tank
			Restriction or plugged strainers	Remove restrictions or replace pump

Burner Runs Continuously (Too Little Heat)				
Combustion	Check burner combustion for CO_2 stack temperature and smoke.	If burner continues to run (does not lock out on safety), fault may be due to poor fire. Inspect fire.	Unbalanced fire	Replace nozzle
			Too much air; lean short fire	Reduce combustion air; check combustion.
			Too little fire; long dirty fire	Increase combustion air; check combustion.
			Excessive draft	Adjust barometric damper for correct draft.
			Too little draft or restriction	Correct draft or remove restriction.
Flame detector		If fire is good, fault is in flame detector. Check detector circuit.	Dirty cad cell face	Clean cad cell face.
			Faulty cad cell; exceeds 1500 ohms	Replace cad cell.
			Loose or defective cad cell wires	Secure connections or replace cad cell holder and wire leads.
			Primary control circuit defective	Replace primary control.
Oil supply (listen for pump whine)		If burner loses flame (does not lock out on safety), fault is in the fuel system	Air slug or leak in supply line	Check supply line and oil tank.
			Restriction or plugged strainers	Remove restrictions or replace pump.

Burner Starts and Fires but Short Cycles (Too Little Heat)			
Source	Procedure	Causes	Correction
Thermostat	Check thermostat.	Heat anticipator set too low	Correct heat anticipator setting.
		Vibration in thermostat	Correct source of vibration.
		Thermostat in warm-air draft	Shield thermostat from draft or relocate thermostat.
Limit control	Connect voltmeter between line voltage connections to primary control (black and white leads). If burner cycles due to power interruption, it is cycling off limit.	Dirty air filters (furnace)	Clean or replace filter.
		Blower running too slow	Speed up blower for 85 to 95 temperature rise.
		Blower motor seized or burned out	Replace motor.
		Blower bearings seized	Replace bearings and shaft.
		Blower wheel dirty	Clean blower wheel.
		Blower wheel in backwards	Reverse blower wheel.
Power	If voltage fluctuates, then fault is in power source. Recheck voltage at power source.	Wrong motor rotation	Replace with motor of correct rotation.
	Disconnect thermostat wires at primary control.	Restrictions in return air or supply air system	Correct cause of restriction.
	1. If burner turns off, fault is in thermostat circuit.	Adjust limit control set too low.	Rest limit to maximum stop setting.
	2. If burner does not turn off, fault is in primary control.	Loose wiring connection	Locate and secure connection.
		Low or fluctuating line voltage	Call CE.

Burner Starts and Fires but Locks Out on Safety.				
Source	**Procedure (1)**	**Procedure (2)**	**Cause**	**Correction**
Poor fire	After burner fires, immediately place jumper across flame detector terminals at primary control.	If burner continues to run, fault may be due to poor fire. Inspect fire.	Unbalanced fire	Replace nozzle.
			Too much air; lean short fire	Reduce combustion air; check combustion.
			Too little fire; long dirty fire	Increase combustion air; check combustion.
			Excessive draft	Adjust barometric damper for correct draft.
			Too little draft or restriction	Correct draft or remove restriction.
Flame detector		If fire is good, fault is in flame detector. Check detector circuit.	Dirty cad cell face	Clean cad cell face.
			Faulty cad cell; exceeds 1500 ohms	Replace cad cell.
			Loose or defective cad cell wires	Secure connections or replace cad cell holder and wire leads.
Primary control		If burner locks out on safety, fault is in primary control.	Primary control circuit defective	Replace primary control.

Burner Runs Continuously (Too Much Heat)			
Source	**Procedure**	**Cause**	**Correction**
Thermostat	Disconnect thermostat wires at primary control.	Shorted or welded thermostat contacts	Repair or replace thermostat.
	1. If burner turns off, fault is in the thermostat circuit.	Stuck thermostat bimetal	Clear obstruction or replace thermostat.
		Thermostat not level	Level thermostat.
		Shorted thermostat wires	Repair short or replace wires.
		Thermostat out of calibration	Replace thermostat.
		Thermostat in cold draft	Correct cause of draft or relocate thermostat.
	2. If burner does not turn off, the fault is in the primary.	Defective primary control	Replace primary control.

5.0.0 LOW-TEMPERATURE HOT WATER SYSTEMS

The Seabees use both the cast iron and steel hot-water type of boilers as sources of heat for domestic hot-water systems in residences and other buildings. Small hot-water heaters heat the hot water for domestic and for limited industrial uses.

Hot-water boilers come in many shapes and sizes. They are constructed with a firebox for burning fuel and have provisions for passing the hot gases over the heat-absorbing surfaces of the boiler. In most cases, ***baffles*** guide the gases over the most effective route. These baffles also retard the flow of the gases from the furnace so water can absorb as much of the heat as possible. Commonly both ends of the boiler have openings for cleaning the boiler tubes and for washing the interior of the boiler. Since most boilers are stationary units permanently installed at the site, they have specified fittings and accessories for a specific heating job. Some boilers, however, called package boilers, are complete units, including fittings and accessories. These boilers are normally mounted on skids so they can be moved to different sites.

This accounts for the term package boiler. Package boilers usually have the same accessories and controls as the comparable stationary type of hot-water or steam boiler. Cast iron boilers are seldom used as package boilers because of the danger of cracking the boiler sections during transportation.

Cast iron hot-water boilers vary in size from small domestic units to moderately sized units capable of developing 31 through 98 horsepower. These boilers are usually constructed of several sections joined together by push nipples (round pieces of metal pipe tapered at both ends). Pipes known as header connections ordinarily connect the boiler sections (*Figure 11-54*).

Figure 11-54 — Cast iron boiler castings.

Cast iron boilers normally do not have brick settings. Usually, the only bricks used with these boilers are those that are sometimes used as a base for the boilers. In most cases, the bases are made of cast iron. Square sectional cast iron boilers are similar to the typical unit shown in *Figure 11-55*. This boiler consists of a front and rear section and a number of intermediate sections, depending on the size of the boiler. The sections are connected on each side at the top and bottom either by push nipples or by an outside header. When nipples are used, these sections are held firmly together by rods and nuts.

The boiler has a separate base that does not contain water and, therefore, requires a floor of fireproof construction. Boilers that have water in their bases are referred to as wet-bottom boilers. These boilers are relatively small water units that may be installed on floors constructed of combustible materials. This method of installation, however, is not desirable.

Figure 11-55 — Cast iron boiler.

The construction of square sectional boilers is ordinarily such that the sections can be taken through regular-sized doors for assembly inside the boiler room. This is a distinct advantage from the standpoint of both installing new equipment and replacing broken sections. Cast iron boilers resist the chemical action of corrosive agents much better than steel boilers.

The disadvantage of cast iron hot-water heating boilers is the danger of the sections cracking or breaking when improperly handled or fired.

5.1.0 Steel Hot-Water Boilers

Most steel hot-water boilers are constructed in two sections. One section consists of the water jackets, combustion chamber, and smoke passages. These components are either welded or riveted together as a unit. The other section consists of the base and either the grates or burner, and is constructed according to the type of fuel used (*Figure 11-56*).

Figure 11-56 — Typical hot-water boiler--light oil- or gas-fired.

Another steel boiler is a horizontal unit of the portable type, having an internal firebox surrounded by water lanes. It rests either on a cast iron or a brick base. The front part of the boiler rests on a pedestal. A disadvantage of this one-piece steel boiler is that it is heavy and requires special equipment to lift it.

5.2.0 Installing Boilers for Low-Temperature Hot Water Systems

A boiler must have a good foundation. The top surface of the foundation should be level to ensure proper alignment of the boiler sections, and thus eliminate strain on the boiler castings. The furnace foundation should be poured separately from the finished floor. It should be of sufficient width and depth to support the boiler without any settling, and it should extend 2 inches above the finished floor. Assembly procedures vary in detail for various boilers. However, manufacturers furnish detailed procedures for the assembly of their boilers. Usually, the plans for the foundations can be procured from them.

5.3.0 Operation of Hot Water Boilers in a Low-Temperature Hot Water System

Hot-water boilers, regardless of their design and type, operate on the same basic principle. The fuel burns in the combustion chamber and produces heat. The resultant heat is radiated and conducted to the water in the water jackets surrounding the combustion chambers, and passes through the boiler tubes; heat is liberated by the flue gases and absorbed by the water surrounding the tubes. The amount of heat transferred into the water depends on the rate of heat conduction through the metal in the boiler tubes and the rate of water circulation in the boiler. For this reason, boilers are designed with baffles to hold the hot gases as long as possible. They give up maximum heat before passing into the chimney.

5.4.0 Boiler Fittings and Accessories

All boilers have certain accessories for safety and ease of operation. These accessories are pressure-relief valves, pressure gauges, water-level control valves, and automatic controls.

5.4.1 Pressure-Relief Valve

Figure 11-57 — Pressure-relief valve.

In a closed hot-water heating system, there is always the possibility of building up a dangerous pressure. Consequently, a pressure-relief valve is installed to allow this pressure to escape. A typical pressure-relief valve is shown in *Figure 11-57*. This valve is usually on the top of the boiler. It contains a spring-loaded valve that unseats when the pressure in the system increases to a predetermined value, thereby allowing water to escape until the pressure drops to a safe point. A valve of this type can be adjusted for different pressure.

Pressure-relief valves may eventually corrode and stick if they are not forced to operate occasionally. It is a good practice, once each month, to increase the pressure to a point that operates the valve. When the relief pressure on the gauge exceeds the setting of the valve, check the valve pressure with an accurate gauge and adjust it to the required amount. However, do not exceed the maximum safe pressure of the boiler.

5.4.2 Pressure Gauge

The operator must know the water pressure in the boiler at all times. A gauge is connected to the top of the boiler. It shows the water pressure in the boiler and in the system in pounds per square inch. This gauge is usually a combination gauge that also indicates boiler water temperature and altitude. The type shown in *Figure 11-58*, however, indicates pressure only.

Little maintenance is required for this unit other than to clean the glass so the gauge can be read. Some types of pressure gauges are constructed so they can be re-calibrated. However, the proper equipment to do this is not always available in the heating shop. To calibrate a pressure gauge properly, you must have either a master gauge set or a deadweight tester.

Figure 11-58 — Water pressure gauge.

5.4.3 Water-Level Control Valve

Water is added to a hot-water heating system by either a manually operated water valve or an automatic valve which is controlled by a float mechanism. Both valves are nearly identical to those used in the free-water system of a steam boiler.

5.4.4 Airflow Switch

The airflow switch, or "sail switch" as it is sometimes called, is in the stack, breeching, or the air inlet to the boiler. This switch shuts down the firing equipment in the event of an induced or forced draft failure. To check the operation of this switch, you restrict or shut off the draft. When you have done this, the switch should shut off the burning equipment.

6.0.0 LOW-TEMPERATURE HOT WATER DISTRIBUTION SYSTEMS

In hot-water heating systems, the water is heated at a central source and circulated through pipes to radiators, convectors, or unit heaters. There are two general types of low-temperature, hot-water heating systems. The first type is a gravity system in which water circulation depends upon the weight difference between the hot column of water leading to the radiators and the relatively cooler, heavier column of water returning from the radiators. The second type is the forced-circulation system in which water is circulated by a power-driven pump.

6.1.0 Gravity Systems

The distribution systems and piping for hot-water heating systems and for domestic hot-water supply systems are simpler in design than those for steam because there are no traps, drips, or reducing valves. Several items, such as supports, insulation, and some valves and fittings, are the same for steam and hot-water distribution.

Gravity hot-water distribution systems operate because of the gravitational pull on the heavier cool water, which sinks as the heated water becomes lighter and rises. At this point, let us discuss some of the types of gravity systems that are currently used.

6.1.1 One-Pipe, Open-Tank System

The one-pipe, open-tank gravity distribution system consists of a single distribution pipe that carries the hot water to all of the convectors or radiators and returns it to the boiler (*Figure 11-59*). This system is easy to install and moderate in cost.

The water that flows into the radiators at the end of the system has a lower temperature than the water entering the first radiators. A system of this type should be designed so the water reaching the last convector is not too much cooler than the water reaching the first convector. Because of this progressive temperature drop in the distribution system, convector radiators should be installed at the end of the system to equalize the amount of heat radiation per radiator. It is difficult to get enough circulation by gravity to give the system small convector temperature drops; consequently, we do not recommend the one-pipe, open-tank gravity system.

Figure 11-59 — One-pipe, open-tank gravity hot-water distribution system.

6.1.2 Two-Pipe, Open-Tank System

Many hot-water gravity distribution systems are two-pipe, open-tank systems (*Figure 11-60*). This heating system is constructed with separate water mains for supplying hot water and returning cold water. The radiators are connected in parallel between the two mains. In the two-pipe, open-tank gravity system, the distributing supply mains are either in the basement with upfeed to the radiators or in the attic. When the system is in

Figure 11-60 — Two-pipe, open-tank gravity hot-water distribution system.

the attic, it has overhead downfeed supply risers. The return mains are in the basement. Return connections for the two-pipe system are usually made into a gravity return which pitches downward to the return opening in the heating boiler. The water temperature is practically the same in all radiators, except for the allowance to be made for the temperature drop in the distribution supply mains occurring between the boiler and the end of the circuit. Water temperatures are the lowest at the end of the circuit. The amount of temperature drop between the beginning and the end of the line depends upon the length of the main and upon the heating load.

A tank with its vent open to the atmosphere is installed in the system above the highest radiator for water expansion. The water level in the expansion tank rises and falls as the system is heated and cooled, and the system is full of water and free from air at all times. In the open-tank gravity hot-water heating system, the expansion tank is installed on a riser directly above the boiler, so the air liberated from the boiler water enters the tank and is not retained in the system.

6.1.3 One-Pipe, Closed-Tank System

A one-pipe, closed-tank gravity hot-water distribution system is similar to the one-pipe, open-tank gravity hot-water heating system, except the expansion tank is a pneumatic compression tank not open to the atmosphere (*Figure 11-61*). When the water in a closed-tank system is heated, it expands into the pneumatic compression tank. This action permits system operation at a much higher water temperature, without boiling, than the temperature in the one-pipe, open-tank gravity system. This also results in higher heat emission from the radiators.

A gravity open-tank system with an average boiler water temperature of 170°F has a radiator emission rate of 150 BTU psi, whereas a gravity closed-tank system with an average boiler water temperature of 190°F has a radiator emission of 180 BTU per square foot (psf). Higher boiler water temperatures permit higher temperature drops through the radiators; consequently, smaller pipe sizes can be used. The closed pneumatic compression system requires a relief valve, usually set for the relief of water pressure over 30 psi, depending upon the height of the building. A pressure-regulating valve automatically maintains the system full of water. Installation of the radiators and piping for an equivalent two-pipe, closed-tank gravity upfeed or overhead downfeed system is the same as that for the open system, except the sizes of both the pipe and the radiators are uniform and can be smaller. The open-tank system may have a reversed return main that does not go directly back to the boiler.

Figure 11-61 — One-pipe, closed-tank distribution system.

It doubles back from the last radiator and parallels the supply main back to the boiler entrance. The reversed return system allows equal length of heating circuits for all radiators. Friction and temperature losses for all radiators are nearly equal. In most cases, the reversed return system involves no more piping than other piping arrangements. With the correct size of piping and radiator supply tappings, the reversed return system provides even heat and circulation to all radiators, even those near the end of the circuit.

6.1.4 Expansion in a Gravity Hot-Water Distribution System

In the gravity and forced-circulation systems, open and closed expansion tanks allow the water in the distribution system to expand as the temperature rises. An open tank must be mounted at the highest point in the system; a closed tank can be located at any point. If the air cushion leaks out of the closed expansion tank, it fills with water. At times, you must recharge the tank by draining part of the water out of the tank and allowing air to fill the space.

In the open system, an expansion tank open to the atmosphere allows the system to expand. The open system is normally designed to operate at the maximum boiler temperature of 180°F. This gives an average radiator temperature of 170°F or a radiator output of 150 BTU psf. The closed system, in which the expansion takes place against a cushion of air in the tank closed against the atmosphere, can be operated at temperatures above 212°F because the pressure built up in the system prevents the water from boiling. Radiator temperatures then become equal to those of low-pressure steam systems.

When a hot-water system is first filled with water, it is normally necessary to bleed the air out of the system at the same time. You can remove the air by opening an air vent on a radiator or by breaking a union near the end of the line. The temperature of the water distributed is from 150°F to 250°F. The higher temperatures are used with the forced-circulation systems.

6.2.0 Forced-Circulation Systems

Forced-circulation hot-water distribution systems have several advantages. They permit the use of smaller pipe sizes and allow the installation of radiators at the same level as the boiler, or below, without impairing water circulation. By using a circulation pump, a positive flow of water is assured throughout the system. In larger installations, especially where more than one building is served, forced circulation is almost invariably used. With the development of a circulation pump of moderate cost, the forced-circulation system is being used more in small heating installations.

As in gravity systems, forced-circulation systems can consist of a one-pipe or a two-pipe, upfeed or downfeed, and can be equipped with a direct or a reversed return. Although these systems usually have closed expansion tanks, they may have open tanks.

6.2.1 One-Pipe, Closed-Tank System

The general arrangement of a one-pipe, closed-tank, forced-circulation system is similar to the one-pipe gravity system, but with the addition of a circulating pump (*Figure 11-62*).

The circulation to individual radiators is improved by special supply and return connecting tees. These tees, by an ejecting action on the distribution supply main and an ejecting action on the return, combine to use a portion of the velocity head in the main to increase circulation through the radiators. Tees of this type also aid in stratification of hot and cold water within the distributing main. They are designed to take off the hot-test water from the top of the main and to deposit the colder water on the bottom of the main.

6.2.2 Two-Pipe, Closed-Tank System

The general arrangement of the piping and radiators for the two-pipe, forced-circulation distribution system is the same as that for the two-pipe gravity system. The relative locations of the compression tank relief valve and the circulating pump are shown in *Figure 11-63*.

6.3.0 Distribution System Components

The component parts of a hot-water distribution system include the following: pipelines, radiators, convectors, unit heaters, circulating pumps, reducing valves, flow-control valves, and special flow fittings.

Figure 11-62 — One-pipe, closed-tank distribution system with a circulating pump.

Figure 11-63 — Two-pipe, closed-tank, forced-circulation system.

6.3.1 Pipelines

The piping system constitutes the closed passageway for the delivery of hot water to the points where it is used. Pipelines are made of lengths of pipe fastened by screwed, flanged, or welded joints. They have valves and fittings, such as tees, unions, and elbows, according to the needs of the installation. Pipelines are supported by hangers and fastened by anchors. Expansion joints or loops allow for expansion.

Mains and branches of the pipeline should be pitched so the air in the system can be discharged through open expansion tanks, radiators, and relief valves. The pitch is generally not less than 1 inch for every 10 feet. The piping arrangements for a new system should provide for draining the entire system.

6.3.2 Radiators

The radiator transfers heat from the hot water in the pipes of a hot-water heating system into the surrounding air in a room. A radiator is usually of two types. Cast iron radiators are constructed and assembled in sections, as shown in *Figure 11-64, Views A* and *B*. Damaged radiator sections can be replaced without replacing the entire radiator assembly. Fin-tube radiators are constructed of steel pipe and fins, which are welded to the pipe (*Figure 11-64, Views C* and *D*).

Radiators usually rest on the floor. However, they can be either mounted on a wall or hung from the ceiling. The location of a radiator depends on the type of room to be heated and its location with respect to the location of the boiler. For instance, in a forced-circulation hot-water distribution system, the radiators may be on the same level with the boiler.

Figure 11-64 — Types of radiators.

6.3.2.1 Convectors

Convectors are supported on the wall much in the same way as a pipe. The convectors consist of a fin-tube radiator mounted in a metal cabinet and transfer heat much in the same way, although a damaged section must be welded or the entire convector must be replaced (*Figure 11-65*).

Figure 11-65 — Convector.

6.3.2.2 Radiator Vents and Shutoff Valves

Hot-water heating system radiators and high points in the distribution lines must have some type of vent that releases air from the system. Air trapped in the system prevents the circulation of water. For this purpose, a manually operated key-type air vent can be used (*Figure 11-66*).

Manually operated key-type air vents can be replaced by automatic air vents. One type of automatic air vent is shown in *Figure 11-67*. It automatically allows the air that forms in the system to escape. When air vents fail, replace them.

Figure 11-66 — Manually operated key-type air vent.

Radiators also have shutoff valves, which reduce or stop the flow of hot water through a radiator (*Figure 11-68*). They are installed in the piping next to the inlet side of the radiator. Occasionally, you must tighten the packing nut on these valves to prevent the water from leaking around the valve stem.

Figure 11-67 — Automatic air vent.

Figure 11-68 — Radiator shutoff valve.

6.3.3 Unit Heaters

Unit heaters are the same as those used in warm-air heating, except hot water is used vice coils for the heating medium. The heater consists of a heating coil supplied with hot water. The coil is usually of the finned type, and an electric fan circulates air over it. A unit heater installed in a distribution main is shown in *Figure 11-69*.

Servicing unit heaters is generally outlined in the NAVFAC instructions. In general you need to check for water leaks, cleanliness of the finned coils, and the operation of the fan motor. Other accessories which you also should inspect are traps, air vents, fan blades, and valves. Make any needed repairs. Lubricate the electric fan monthly.

6.3.4 ulating Pumps

A forced hot-water heating system has a water-circulating pump in the return line near the boiler. This pump ensures the positive flow of water regardless of the height of the system or the drop in the water temperature. Greater velocities of water flow are obtainable with forced circulation than with gravity circulation.

Figure 11-69 — Hot-water unit heater installation.

Circulating pumps are free of valves and float control elements. They are operated under a sufficiently high water inlet temperature to eliminate the difficulties caused by vapor binding. The pumps are usually operated by electric motors.

During maintenance servicing, check the pump carefully for proper rotation, and lubricate the electric motor and pump according to the manufacturer's instructions. Also, periodically clean the pump of sand, rust, and other foreign matter that has collected in the pump casing. Be sure the pump rotates freely and the shaft packing glands, if there are any, are not drawn up so tight that they score the shaft.

6.3.5 Reducing Valves

A reducing valve is normally installed in the cold-water line going to the boiler. It automatically keeps the closed system supplied with water at a predetermined safe system pressure. These valves are usually set at the factory, but you may adjust them in the shop to a desired pressure. You should install this valve at approximately the same level as the top of the boiler.

6.3.6 Flow-Control Valves

Forced hot-water circulating systems use the flow-control valve shown in *Figure 11-70.* It is normally installed in the distribution main. This valve prevents gravitational flow of water through the system. The valve does

Figure 11-70 — Flow-control valve.

not offer any serious resistance to the flow of water when the circulating pump is in operation. However, when the pump is not operating, the small gravitational head of water cannot open the valve. Each week you should check the flow-control valve for proper operational down-free movement. Examine the valve for water leaks and repair it when necessary.

6.3.7 Special Flow Fittings

Various types of special tees designed to deflect main-line water into the radiator branches are used in one-pipe and two-pipe forced-circulation systems. These fittings are designed and calibrated to the size of the radiator and system-operating temperature. Fittings of this type are required with one-pipe, forced-flow systems, and they do equally well for radiators above and below the distribution mains.

6.4.0 Maintaining and Troubleshooting Hot-Water Heating Systems

Hot-water heating systems require little maintenance other than periodic checks to make certain that all air is out of the system and all radiators are full of water. The circulating pumps should be oiled regularly according to the manufacturer's instructions, and the pressure-relief valves should be checked periodically.

Some of the common discrepancies encountered when troubleshooting hot-water heating systems are contained in *Table 11-9*.

Table 11-9 — Troubleshooting Hot-Water Heating Systems

SYMPTONS	REMEDY
Boiler smokes through the feed doors.	Clean the boiler flues and the flue pipes. Repair any chimney leaks.
Boiler heats slowly.	Increase the draft. Check on the type of fuel. Clean the boiler of ***scale***. Blowdown the boiler.
Radiator produces insufficient heat.	Clean the boiler of scale. Change to a larger boiler. Blowdown the boiler. Increase the draft, and check on the type of fuel.
Radiators do not heat.	Insufficient water in the system. Bleed the air from the system. Open the radiator valves, and check the operation of the circulation.
Distribution piping does not transfer hot water to the radiators.	Insufficient water in the system. Bleed the air from the high points in the distribution piping. Check the operation of the circulation pump. Check for corrosion stoppage in the distribution piping.

Operator maintenance on the electrically driven feed pump consists mostly of cleaning the pump and motor. However, the pump motor is lubricated according to the manufacturer's specifications. Remember that not using enough lubricant can result in the bearings running dry or seizing on the motor shaft. But, too much lubricant causes the motor to become dirty and can result in the motor windings becoming saturated with oil and burning out.

When a water leak develops around the pump shaft, tighten the packing-gland nuts or repack the stuffing box as necessary. The strainer, installed between the pump and the condensate receiver, should be kept clean to avoid any restriction of the flow of water to the pump.

The maintenance of feed-water heaters and economizers normally includes removing solid matter that accumulates in the unit, stopping steam and water leaks, and repairing inoperative traps, floats, valves, pumps, and other such associated equipment.

Test your Knowledge (Select the Correct Response)

2. What type of heating medium is used to produce heat in a unit heater?

   A. Cold water
   B. Air
   C. Hot water
   D. Steam

7.0.0 HIGH-TEMPERATURE HOT-WATER SYSTEMS

High-temperature hot-water (HTHW) systems operate at high pressure to maintain water temperature that exceeds the normal boiling temperature of 212°F (at atmospheric pressure) used in other types of heating systems.

HTHW systems consist of standard and heavy-duty equipment, including boilers (sometimes referred to as generators), expansion drums, system circulator pumps, distribution piping, and heat-consuming equipment.

HTHW systems have the hot water pumped from the generator throughout the distribution system. The circulator pumps are large enough to deliver the water at sufficient pressure to overcome any drop in the distribution system and the heat-consuming equipment. The major advantages of the HTHW heating system are makeup requirements, minimum maintenance, high thermal efficiency, and safe, easy operation and control.

The HTHW system is a closed system, so the only water waste is the normal leakage at the pump and valve packing glands. Consequently, little water is consumed during system operation. This means only a small amount of makeup water is used, practically eliminating boiler blowdowns. The closed re-circulating system operates at high thermal efficiency. All of the heat not used by heat-consuming devices in the system or lost through pipe radiation is returned to the boiler plant. Because few boiler blowdowns are required, the heat loss from blowdowns is kept to a minimum.

7.1.0 Types of HTHW Systems

The high-temperature range for most military and federal heating plants is 350°F to 450°F, which corresponds to saturated pressures of 135 psi to 425 psi. However, some types of plants operate at higher pressures and therefore have higher water temperatures. The installation of HTHW plants that operate at temperatures above 400°F must be approved by the Naval Facilities Engineering Command. Costs usually determine the maximum water temperature used because the types of HTHW systems using the higher pressures require more expensive piping, valves, fittings, and heat exchangers.

The degree of complexity of HTHW systems varies according to the size, type, and heat load requirement of the installation. Since methods used to maintain pressure and to assure uniform flow rates depend upon the amount of heat load, they affect the complexity of the heating system. There are two methods of circulating the HTHW through the system—the one-pump system and the two-pump system.

The one-pump system uses only one pump to circulate the hot water throughout the system, which includes the generator. The two-pump system uses one pump to circulate the water through the distribution system, and a second pump to circulate the water through the generator for positive circulation. *Figure 11-71* shows some typical pumps that are used for circulation in the HTHW system. Note that the pumps are of the centrifugal type. Each pump shown is used to circulate the water to different areas in the distribution systems.

Figure 11-71 — HTHW circulation pumps.

There are two common ways of heating the water in the HTHW system—one way is to use hot-water boilers or generators and the other way is to use the cascade or direct contact heater. The water in the HTHW generator is heated as low-temperature hot water is heated. In the cascade heater, however, the water is forced through spray nozzles and comes into direct contact with the steam. The steam condenses into the circulating water. A typical spray nozzle head is shown in *Figure 11-72*.

Figure 11-72 — Cascade heater spray nozzle head.

The spray nozzles are installed in a combination cascade heater expansion drum. A typical cascade heater expansion drum installation is shown in *Figure 11-73*. In the paragraphs that follow, some ways of pressurizing the HTHW system are discussed.

Figure 11-73 — Combination cascade heater expansion drum installation.

7.2.0 Pressurizing the HTHW System

Since water volume varies with changes in temperature, the extra water must be taken care of when the water is heated. It is desirable to operate with the water above the boiling temperature of 212°F; therefore, the pressure in the system must be maintained equal to or greater than the corresponding saturation (steam or vaporization) temperature. An expansion tank is required because the water, which is not compressible to a smaller volume, expands when it is heated. Also, the pressurization prevents the formation of saturated steam or vaporization when the water temperature is raised. There are two basic designs used for pressurizing HTHW systems—first, the saturated steam cushion, and second, the mechanical gas cushion. Although both designs have a variety of modifications, their characteristics are still typical of the basic pressurized system design.

7.2.1 Saturated Steam Cushion

Pressurizing the heating system with steam in the expansion tank is a natural method. Firing the HTHW generator to maintain the system pressure corresponding to the required saturation (steam or vaporization) temperature pressurizes the system. Excess heat is generated to offset the radiant heat loss from the expansion tank. All of the HTHW in the steam-pressurized system flows through the expansion tank and thereby maintains the saturation (steam or vaporization) temperature there.

The steam in the space in the expansion tank provides the pressure or cushion for the system. The pressure maintained is that of the saturated steam. The water in the lower portion of the tank will be approximately saturation (steam or vaporization) temperature corresponding to this pressure. The water to be used in the HTHW heating system is drawn from the lower part of the expansion tank, mixed with the system return water, and circulated throughout the system. The mixing is necessary to prevent cavitation (steam flashing) at the pump suction.

Here are some conditions that are typical of the saturated-steam cushion design. The expansion tank, either integral or separate, is a part of the HTHW system. The entire amount of hot water flowing in the heating system passes through the expansion tank and exposes the tank to maximum system heat and any form of contamination which in turn subjects the expansion tank to thermal stresses and corrosion. There are explosion hazards typical of a steam boiler in the system, and good water-level control is important in maintaining proper operating conditions. Load variations, causing supply pressure changes, create flashing of saturated liquid in the system and produce water hammer.

7.2.2 Mechanical Gas Cushion

The expansion tank contains the mechanical-gas cushion and is connected to the HTHW system return line just ahead of the circulating pump suction connection. The tank contains an inert gas (usually nitrogen) and is the source of pressure in this method. When the system has been pressurized by the nitrogen, pressure in excess of saturation must be maintained, that is, the water temperature throughout the system must always be less than its saturation temperature. In the nitrogen-pressurized system, the expansion tank is installed in the system as a standpipe arrangement so the water does not flow through it. The water in the lower part of this tank is stagnant, except for the changes caused by expansion and contraction brought on by load fluctuations. If you assume the water is virtually incompressible, the tank provides the space available for these changes in the water volume of the system.

Here are some characteristics that are typical of this design. The expansion tank is independent of the generator and remains cool. Corrosion is practically eliminated because the heating system is flooded, with the exception of the nitrogen space in the expansion (cushion) tank. When properly designed, the system is sealed with its fixed charge of water and nitrogen. However, this design does not contain a steam drum or any steam spaces that permit the accumulation of steam. The generator tubes are the weakest link in this entire system. An explosion caused by the dissociation of hydrogen and oxygen cannot occur. The formation of steam cools the otherwise red-hot metal surfaces. Hot-water conditions do not allow the flashing of steam.

7.2.3 Operation

To ensure normal operation, fill the system with treated water taken from the water softener. To prevent oxygen corrosion, add the chemicals for treating the water to furnish 20 to 40 parts of sodium sulfite per million parts (ppm) of water. You thereby maintain a pH value of 9.3 to 9.9. While the water is circulating in the generator and in the system, you should fire the boiler at about 25 percent of its rated capacity to bring the system up to normal operating temperature. You should allow the expansion drum vent in steam-pressurized systems to blow for about 1 hour to rid the system of all oxygen and other non-condensable gases.

The start-up and firing of HTHW boilers or generators are done in much the same manner as for domestic hot water and steam boilers, depending upon the type of fuel-burning equipment used. The specific start-up and operating procedures vary with different installations. Therefore, this information is furnished by your local supervisor and the manufacturer of the equipment.

Coal, oil, and gas are the types of fuels normally used to fire the boilers of HTHW systems. The specific type of fuel used depends upon the type of firing equipment installed in the plant. Each type of fuel requires designated inspections be made and certain precautions be taken to eliminate fire and safety hazards.

When you are transferring fuel oil from one tank to another, be sure both tanks are grounded. Checks must then be made to ensure excessive oil pressures are not generated in the tanks by the expansion of the fuel. Although natural gas is not normally stored on a base ashore, liquid petroleum (LP) gas is often stored near the heating plant. You should check the areas where this gas is stored often to ensure there is no leakage. Liquid petroleum gas is heavier than air, settles in low areas, and creates explosive hazards. When checking for gas leaks, use a standard soap solution.

Because of the large heat storage capacity of HTHW systems, the load demand change for the boiler is slow and smooth. This characteristic provides for improved and safer operation than that provided by the saturated-steam cushion.

7.3.0 Piping System Installation

All piping in an HTHW system should be welded. No screwed joints should be permitted, and flanges should be allowed only where necessary, such as at expansion joints, pumps, and generator connections. Only schedule 40 black steel piping or better is used for HTHW systems. Upon completion, the entire heating system is subjected to a test of 450 psi that lasts for not less than 24 hours.

The possibilities of line failure are remote when the construction recommended above is used. The system piping material is subjected to a minimum factory test of 700 psi. The generator tubes are subjected to an ASME test of 900 psi. All valves and accessories are rated at working pressures of 540 to 1,075 psi at 400°F. The weakest link in the piping network lies within the generator tubing. The worst likely failure is the loss of tubes, and therefore the generator. The safety of the piping system is maintained over the life of the installation because of the absence of corrosion in the hot-water heating systems due to boiler water treatment.

Summary

As a UT, you will be involved with the installation, operation, and maintenance of various types of heating systems. You must understand the basic theory and principles of heating, such as measurement styles and heat transfer concepts. You must have the understanding of the purpose, use, and control of the various combustible fuels used.

You will also be involved in the maintenance and repair of warm air heating systems, low temperature hot water systems, and High-temperature hot-water (HTHW) systems with all the associated distribution components. As a UT you will be responsible for the generation and distribution of hot water to your unit.

Review Questions (Select the Correct Response)

1. What is the range of the Fahrenheit thermometer between the freezing point and the boiling point?

   A. 180°
   B. 190°
   C. 200°
   D. 210°

2. The sum of sensible heat plus latent heat is the definition of what term?

   A. Specific heat
   B. Total heat
   C. Cumulative heat
   D. Super heat

3. What principle is the transfer of heat by means of mediums such as water, air, and steam?

   A. Conduction
   B. Radiation
   C. Convection
   D. Immersion

4. What principle is the transfer of heat through space?

   A. Immersion
   B. Conduction
   C. Convection
   D. Radiation

5. What fuels are most commonly used with heating equipment?

   A. Gas and petroleum
   B. Coal and gas
   C. Wood and petroleum
   D. Steam and gas

6. What is the major element present in natural gas?

   A. Ethane
   B. Methane
   C. Nitrogen
   D. Carbon dioxide

7. Butane and propane are part of what group of liquefied gases?

   A. Natural
   B. Manufactured
   C. Liquefied petroleum
   D. Chemically altered

8. How many types of unit heaters are currently utilized in the Seabee community?

   A. 1
   B. 2
   C. 3
   D. 4

9. Unit heaters rated for less than 50,000 BTUs per hour are designated to operate on what systems?

   A. Low pressure steam
   B. Low temperature hot water
   C. High temperature steam
   D. Fuel oil burning

10. One kilowatt is equal to how many BTUs per hour?

   A. 3355
   B. 3415
   C. 3560
   D. 3745

11. Why is the vented gas heater more satisfactory than the unvented type?

   A. Less expensive installation
   B. Less preventive maintenance required
   C. Less danger of carbon monoxide poisoning
   D. Less accumulation of back soot

12. The burning of 1,000 cubic feet of natural gas will produce approximately how many gallons of water?

   A. 6
   B. 8
   C. 10
   D. 12

13. What grade of fuel oil is required in oil-fired space heaters?

   A. Light
   B. Medium
   C. Heavy
   D. Super heavy

14. A perforated sleeve burner with its circular fuel vaporizing grooves burns what color flame?

A. Cherry red
B. Blue
C. Orange
D. Red

15. What controls the flow of oil in the pot type and perforated sleeve burners?

A. Primary control unit
B. Fuel allocation diffuser
C. Float-operated metering valve
D. Restrictor orifices

16. A chimney top is required to be how many feet above the highest point of a building?

A. 2
B. 3
C. 5
D. 6

17. What type of piping or tubing is used in oil supply systems to the burners?

A. Copper
B. Brass
C. Cast iron
D. Steel

18. Warm-air systems are identified as what types?

A. Forced-air and high temperature
B. Gravity and forced-air
C. Oil fed and gas fed
D. Vented and unvented

19. What part does the plenum join up with in a furnace?

A. Draft diverter
B. Exhaust piping
C. Main trunk duct
D. Intake valve manifold

20. What is the result of improperly placed supply diffusers?

A. Hot floors
B. Excessive condensation
C. Improper air intake
D. Air stratification

21. **(True or False)** In an individual duct system, each duct is connected directly to the furnace plenum.

A. True
B. False

22. What is a register temperature range of a forced warm-air system?

A. 110° to 140°
B. 150° to 180°
C. 180° to 210°
D. 220° to 240°

23. What is the most commonly used airflow design associated with a gas- fired furnace?

A. Horizontal
B. Vertical
C. Upflow highboy
D. Lowboy

24. Duct furnaces are mounted in a duct system where air circulation is provided by what?

A. Furnace blower
B. Internal fan
C. Atmosphere
D. External fan

25. Along with the return-air compartment and warm-air compartment, what other compartment comprises the gas-fired furnace?

A. Combustion air and fuel
B. Supply-air
C. Hot-air
D. Combustion and return

26. What type of blower is installed in a gas-fired furnace?

A. Rotary
B. Centrifugal
C. Jet
D. Displacement

27. Which piece of equipment is NOT part of the gas burner control?

A. Gas pressure regulator
B. Humidifier
C. Manual gas cock
D. Heat exchanger

28. What piece of equipment maintains the desired pressure in the burner as long as the gas main pressure is above the desired pressure?

A. Diaphragm valve
B. Thermocouple control relay
C. Solenoid gas valve
D. Gas pressure regulator

29. What position does the solenoid gas valve revert to upon a current failure?

A. Open
B. Shut
C. As is
D. Bypass

30. How does the design of a recycling solenoid gas valve differ from a standard solenoid gas valve?

A. Standard solenoid valves only ports a set fuel amount.
B. Allows the valve to switch to manual operation during a power failure.
C. Recycling solenoid gas valve maintains system pressure.
D. Allows for quieter operation.

31. What device is used to produce the electrical current used to operate gas valves?

A. Thermoresistors
B. Pilot light
C. Thermopiles
D. Diaphragm valve

32. What device shuts off the gas supply when the temperature inside the heating unit becomes excessive?

A. Recycling solenoid gas valve
B. Heat exchanger
C. Thermocouple control relay
D. Limit control

33. What device is used to reduce updrafts that are detrimental to pilot or burner operation?

A. Diverter
B. Limit control
C. Thermopiles
D. Diaphragm valves

34. What is the voltage produced by the step-up transformer used in a gas fired furnace?

A. 5,000
B. 10,000
C. 15,000
D. 20,000

35. What piece of equipment runs the fuel unit of a gas-fired furnace?

A. Ignition electrodes
B. Horizontal rotary unit
C. Blower motor shaft
D. High pressure gun relay

36. Which grade of fuel oil is used in a gas-fired furnace?

A. Low
B. Medium
C. High
D. Super high

37. What device closes the ignition circuits when the thermostat calls for more heat?

A. Primary control
B. Bimetallic strip
C. Limit control
D. Temperature-responsive relay

38. **(True or False)** The limit control is a device that responds to changes in steam pressure in a steam-heating system.

A. True
B. False

39. What type of element is used in a vapor-tension device?

A. High pressure steam
B. Water temperature
C. Highly volatile liquid
D. Low discharge current

40. Other than the snap-action electrical switch, which other electrical switch is often utilized?

A. Current seeking
B. Float
C. Transducer
D. Mercury

41. What is the nerve center of the heating-control system?

A. Thermostat
B. Primary control
C. Gas regulator valve
D. Step-up transformer

42. How far up on the wall should a thermostat be placed, in feet?

A. 3 1/2
B. 4 1/2
C. 5 1/2
D. 6 1/2

43. **(True or False)** Gas-fired and oil-fired forced-air units, which have the blower below the heating element or combustion chamber, should be set on masonry at least 4 inches thick.

A. True
B. False

44. What is the clearance requirement, in feet, of a furnace from wood or other combustible material?

A. 12
B. 14
C. 16
D. 18

45. One inch of free-air area is required for how many BTUs per hour of furnace input rating?

A. 1000
B. 2000
C. 3000
D. 4000

46. What type of material and diameter piping or tubing are required from the oil tank or valve to the burner?

A. Copper, 1/4 inch
B. Copper, 1/2 inch
C. Cast iron, 1/4 inch
D. Cast iron, 1/2 inch

47. What size is recommended for all vent lines used in furnace installations?

A. 1 inch
B. 1 1/4 inch
C. 1 1/2 inch
D. 1 3/4 inch

48. Why are kerosene, diesel oils, and commercial oils of Grades Nos. 1 and 2 suitable for furnace usage?

A. They are easy to transport via aircraft.
B. They are easier to store than higher grades.
C. Their procurement costs are low.
D. They vaporize at relatively low temperatures.

49. **(True or False)** Burners using air as the atomizing medium are designed for three air pressure ranges.

A. True
B. False

50. At what speed, in rpm, does a cylindrical cup use in a horizontal rotary-cup burner rotate?

A. 3300
B. 3450
C. 3575
D. 3700

51. What is used to remove the air from a burner prior to starting?

A. Regulator
B. Ventilator
C. Petcock
D. Bypass

52. Which is NOT a cause for a flame that is raw and stingy in a oil burner?

A. Partly clogged nozzle
B. Air in the pump
C. Too large an opening in air adjustment
D. Improper draft

53. After the burner flame and draft are properly adjusted, a flue-gas analysis should show a CO_2 content of approximately what percent?

A. 10
B. 11
C. 12
D. 13

54. If the furnace is large enough and the burner has been set for correct oil flow and minimum amount of air, stack temperature should not exceed how many degrees?

A. 550
B. 600
C. 650
D. 675

55. The stack thermometer is used to determine the temperature of gases in what piece of equipment?

A. Combustion chamber
B. Furnace outlet
C. Smoke pipe
D. Draft regulator

56. What is a possible problem in an oil pump, if you have no oil flow at the nozzle?

A. Blown seal
B. Air leak in intake line
C. Loose plugs or fittings
D. Bad coupling alignment

57. What is the disadvantage of using cast iron hot-water heating boilers?

A. Sections cracking
B. Low heat retention
C. Delayed start-up time
D. Scarcity of repair parts

58. How many inches above a finished floor should a low-temperature hot water boiler be?

A. 1
B. 2
C. 3
D. 4

59. Where is the pressure-relief valve located on a boiler used in a low- temperature hot water system?

A. Bottom of boiler
B. Right side of vent valve
C. Top of boiler
D. Left side of vent valve

60. What is another name for the airflow switch used in a low-temperature hot water system?

A. Control valve
B. Extender
C. Draft
D. Sail

61. **(True or False)** A one-pipe, open-tank gravity distribution system consists of a single pipe that carries hot water to all of the radiators and then returns it back to the boiler.

A. True
B. False

62. The amount of temperature drop between the beginning and the end of the line depends on the length of the main and what other factor?

A. Ambient air pressure
B. Heating load
C. Boiler start-up temperature
D. Temperature stabilization

63. The relief valve located in a closed pneumatic compression system is set to lift at what water pressure level, in psi?

A. 15
B. 20
C. 25
D. 30

64. In the heating of larger installations where more than one building is involved, what type of circulation method is used?

A. Free flow
B. Closed
C. Open
D. Forced

65. Mains and branches are pitched so air in the system is discharged through which device?

A. Radiator
B. Surge tank
C. Pressure regulator
D. Diverter

66. How many radiator types are you concerned with as a UT?

A. 1
B. 2
C. 3
D. 4

67. **(True or False)** Circulating pumps used in low-temperature hot water distribution systems ensure the positive flow of water regardless of the height of the system or the rise in water temperature.

A. True
B. False

68. Where is the reducing valve installed on the boiler?

A. At the outlet port
B. Inside the combustion chamber
C. Below the pressure regulating valve
D. At the same level as top of boiler

69. Which is a reason why radiators do not heat?

A. Not enough air in the system
B. Insufficient water in the system
C. Clogged fin-tubes
D. Closed radiator valve

70. What is the high temperature range for most military and federal heating plants?

A. 250°F to 350°F
B. 350°F to 450°F
C. 450°F to 550°F
D. 550°F to 650°F

71. Whose permission is needed to install an HTHW plant that operates above 400°F?

A. Base Commanding Officer
B. Crew Supervisor
C. Naval Facilities Engineering Command
D. Officer in Charge

72. What type of pump is used in an HTHW system?

A. Rotary
B. Jet
C. Submersible
D. Centrifugal

73. Why is an expansion tank required in an HTHW system?

A. To allow for water expansion when heated.
B. To receive excess water run-off from boiler.
C. To allow for excessive condensation to drain.
D. To comply with NACENGCOM directives.

74. What is the optimal pH range for an HTHW system?

A. 7.25 to 9.25
B. 9.3 to 9.9
C. 10.1 to 11.2
D. 12.3 to 15.6

75. Upon completion of an installation of an HTHW system, the entire system is held under what pressure, in psi, for not less than 24 hours?

A. 300
B. 350
C. 400
D. 450

76. Generator tubes utilized in HTHW systems are subjected to an ASME test pressure of what value, in psi?

A. 600
B. 700
C. 800
D. 900

Trade Terms Introduced in This Chapter

British Thermal Unit (BTU)	The amount of heat required to raise the temperature of 1 lb. of water 1°F.
Saturated	Soaked, impregnated, or imbued thoroughly; charged thoroughly or completely.
Baffles	Artificial obstructions for checking or deflecting the flow of gases.
Braziers	A metal receptacle for holding live coals or other fuel, as for heating a room.
Flue	Any duct or passage for air or gas.
Coke	The solid carbonaceous material derived from destructive distillation of low-ash, low-sulfur bituminous coal. Cokes from coal are grey, hard, and porous.
Orifice	An opening or aperture, as of a tube or pipe; a mouth-like opening or hole; mouth; vent.
Bellows	A device for producing a strong current of air, consisting of a chamber that can be expanded to draw in air through a valve and contracted to expel it through a tube.
Scale	A coating or incrustation, as on the inside of a boiler, formed by the precipitation of salts from the water.
Diffusers	A pierced plate or similar device for distributing compressed air.
Refractory	Resistant to heat or has a high melting point.
Dope	An anaerobic chemical sealant that is used to make a pipe thread joint leak proof and pressure tight.
Slag	The vitreous mass left as a residue by the smelting of metallic ore.
Petcock	A small valve or faucet, as for draining off excess or waste material.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Basic Machines, NAVEDTRA 12199, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

OSHA Regulations (Standards – 29 CFR)

Naval Construction Force Manual, *NAVFAC P-315*, Naval Facilities Engineering Command, Washington, D.C., 1985.

Facilities Planning Guide, NAVFAC P-437, Volumes 1 and 2, Naval Facilities Engineering Command, Alexandria, VA, 1982.

Fluid Power, NAVEDTRA 12964, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

National Standard Plumbing Code-Illustrated, National Association of Plumbing- Heating-Cooling Contractors, Washington, DC, 2006.

Safety and Health Requirements Manual, EM-385-1-1, Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 1992.

MIL-STD-17-1, Mechanical Symbols

International Plumbing Code 2009, International Code Council

International Mechanical Code 2009, International Code Council

R. Dodge Woodson, *Plumber's Quick-Reference Manual Tables, Charts, and Calculations,* 1st edition, McGraw-Hill, NY, 1996.

Water Testing Kit, Chemical Agent: M272, Technical Operations Manual, TM 3- 6665-319-10, Department of the Army, Washington, DC, 1983

Boiler Care Handbook, Cleaver-Brooks Division of Aqua-Chem. Inc., Milwaukee, WI, 1985.

COMFIRSTNCDINST 3500.1, Operational Risk Management (ORM).

COMFIRSTNCDINST 5100.2, Naval Construction Force Occupational Safety and Health Program.

UFC 3-430-07, Inspection and Certification of Boilers and Unfired Pressure Vessels.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 12

Refrigeration

Topics

1.0.0	Heat and Refrigeration Principles
2.0.0	Mechanical Refrigeration Systems
3.0.0	Refrigerants
4.0.0	Refrigerant Safety
5.0.0	Refrigerant Equipment
6.0.0	Installation of Refrigeration Equipment
7.0.0	Maintenance, Service, and Repair of Refrigeration Equipment
8.0.0	Maintenance of Compressors
9.0.0	Maintenance of Motors
10.0.0	Logs

To hear audio, click on the box.

Overview

During a deployment, the preservation of food and other necessities that require refrigeration is of the utmost importance. The spoiling of large amounts of galley food or hospital blood reserves due to a malfunctioning refrigerator or freezer can cause serious morale and health problems. Therefore, one of your primary responsibilities as an Utilitiesman is to maintain a unit's refrigeration equipment to ensure proper operation.

This chapter will provide you with the necessary information to understand the principles and theory of refrigeration, the components of mechanical refrigeration systems, and the types of refrigerants and associated equipment. Also covered in this chapter are the methods used for installing, maintaining, and repairing refrigeration equipment, including domestic refrigerators and freezers.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the principles of heating and refrigeration.
2. Describe the components of mechanical refrigeration systems.
3. Identify the different types of refrigerants.
4. State the safety precautions associated with refrigerants.
5. Describe the different types of refrigerant equipment.

6. Describe the installation procedures for refrigerant equipment.
7. Describe the maintenance, service, and repair procedures associated with refrigerant equipment.
8. Describe the maintenance procedures associated with compressors.
9. Describe the maintenance procedures associated with motors.
10. Describe the purpose and use of logs.

Prerequisites

None

This course map shows all of the chapters in Utilitiesman Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Utilities Equipment and Maintenance		
Air Conditioning		
Refrigeration		
Heating Systems		U
Steam Distribution Systems		T
Boilers		
Sewage Disposal, Field Sanitation, and Water Treatment		B
Prime Movers, Pumps, and Compressors		A
Plumbing Fixtures		S
Piping System Layout and Plumbing Accessories		I
Structural Openings and Pipe Material		C
Fundamentals of Water Distribution		
Basic Math, Electrical, and Plumbing Operations		
Plans, Specifications, and Color Coding		

Features of this Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 HEAT and REFRIGERATION PRINCIPLES

Refrigeration is the process of removing heat from an area or a substance. It is usually done by an artificial means of lowering the temperature, such as by the use of ice or mechanical refrigeration, which is a mechanical system or apparatus, designed and constructed to transfer heat from one substance to another.

Since refrigeration deals entirely with the removal or transfer of heat, it is important that you have a clear understanding of the nature and effects of heat.

1.1.0 Nature of Heat

Heat is a form of energy contained to some extent in every substance on earth. All known elements are made up of very small particles known as atoms, which form molecules when joined together. These molecules are particular to the form they represent. For example, carbon and hydrogen in certain combinations form sugar and in others form alcohol.

Molecules are in a constant state of motion. Heat is a form of molecular energy that results from the motion of these molecules. The temperature of the molecules dictates to a degree the molecular activity within a substance. For this reason, substances exist in three different states or forms—solid, liquid, and gas.

Water, for example, may exist in any one of these states. As ice, it is a solid; as water, it is a liquid; as steam, it is a gas (vapor).

When you add heat to a substance, the rate of molecular motion increases causing the substance to change from a solid to a liquid, and then to a gas (vapor). For example, in a cube of ice, molecular motion is slow, but as heat is added, molecular activity increases, changing the solid "ice" to a liquid "water" (*Figure 12-1*).

Further application of heat forces the molecules to greater separation and speeds up their motion so that the water changes to steam. The steam formed no longer has a definite volume, such as a solid or liquid has, but expands and fills whatever space is provided for it.

Heat cannot be destroyed or lost. However, it can be transferred from one body or substance to another or to another form of energy. Since heat is not in itself a substance, it can best be considered in relation to its effect on substances or bodies. When a body or substance is stated to be cold, the heat that it contains is less concentrated or less intense than the heat in some warmer body or substance used for comparison.

Figure 12-1 — The three states of matter.

1.2.0 Unit of Heat

In the theory of heat, the speed of the molecules indicates the temperature or intensity of heat, while the number of molecules of a substance indicates the quantity of heat.

The intensity and quantity of heat may be explained in the following simple way. The water in a quart jar and in a 10-gallon container may have the same intensity or temperature, but the quantity of heat required to raise these amounts of water to a higher uniform temperature (from their present uniform temperature) will differ greatly. The 10 gallons of water will absorb a greater amount of heat than the quart jar of water.

The amount of heat added to, or subtracted from, a body can best be measured by the rise or fall in temperature of a known weight of a substance. The standard unit of heat measure is the amount of heat necessary to raise the temperature of 1 pound of water 1°F at sea level when the water temperature is between 32°F and 212°F. Conversely, it is also the amount of heat that must be extracted to lower by 1°F the temperature of a pound of water between the same temperature limits. This unit of heat is called a ***British thermal unit (Btu)***. The Btu's equivalent in the metric system is the calorie, which is the amount of heat required to raise one gram of water 1° Celsius.

Suppose that the temperature of 2 pounds of water was raised from 35°F to 165°F. To find the number of Btu required to increase the temperature, subtract 35 from 165. This equals a 130° temperature rise for 1 pound of water.

For example:

165

- 35

130 130x 2=260

Since 2 pounds of water were heated, multiply 130 by 2, which equals 260 Btu required to raise 2 pounds of water from 35°F to 165°F.

1.3.0 Measurement of Heat

The usual means of measuring temperature is a thermometer. It measures the degree or intensity of heat and usually consists of a glass tube with a bulb at the lower portion of the tube that contains mercury, colored alcohol, or a volatile liquid. The nature of these liquids causes them to rise or fall uniformly in the hollow tube with each degree in temperature change. Thermometers are used to calibrate the controls of refrigeration. The two most common thermometer scales are the Fahrenheit and the Celsius.

On the Fahrenheit scale, there is a difference of 180° between freezing (32°) and the boiling point (212°) of water. On the Celsius scale, you have only 100° difference between the same points (0° freezing and 100° boiling point).

Of course, a Celsius reading can be converted to a Fahrenheit reading, or vice versa. This can be done using the following formula:

$$F = (C \times 1.8) + 32$$

To change Fahrenheit to a Celsius reading, use the following formula:

$$C = (F-32) \div 1.8$$

1.4.0 Transfer of Heat

Heat flows from a substance of higher temperature to bodies of lower temperature in the same manner that water flows down a hill, and like water, it can be raised again to a higher level so that it may repeat its cycle.

When two substances of different temperatures are brought in contact with each other, the heat will immediately flow from the warmer substance to the colder substance. The greater the difference in temperature between the two substances, the faster the heat flow. As the temperature of the substances tends to equalize, the flow of heat slows and stops completely when the temperatures are equalized. This characteristic is used in refrigeration. The heat of the air, of the lining of the refrigerator, and of the food to be preserved is transferred to a colder substance, called the refrigerant.

Three methods by which heat may be transferred from a warmer substance to a colder substance are conduction, convection, and radiation. These principles are explained in Utilitiesman Basic Chapter 11.

1.5.0 Specific Heat

Specific heat is the ratio between the quantity of heat required to change the temperature of 1 pound of any substance 1°F, as compared to the quantity of heat required to change 1 pound of water 1°F. Specific heat is equal to the number of Btu required to raise the temperature of 1 pound of a substance 1°F. For example, the specific heat of milk is .92, which means that 92 Btu will be needed to raise 100 pounds of milk 1°F. The specific heat of water is 1, by adoption as a standard, and specific heat of another substance (solid, liquid, or gas) is determined experimentally by comparing it to water. Specific heat also expresses the heat-holding capacity of a substance compared to that of water.

A key rule to remember is that .5 Btu of heat is required to raise 1 pound of ice 1°F when the temperature is below 32°F; and .5 Btu of heat is required to raise 1 pound of steam 1°F above the temperature of 212°F.

1.6.0 Sensible Heat

Heat that is added to, or subtracted from, a substance that changes its temperature but not its physical state is called sensible heat. It is the heat that can be indicated on a thermometer. This is the heat human senses also can react to, at least within certain ranges. For example, if you put your finger into a cup of water, your senses readily tell you whether it is cold, cool, tepid, hot, or very hot. Sensible heat is applied to a solid, a liquid, or a gas/vapor as indicated on a thermometer. The term sensible heat does not apply to the process of conversion from one physical state to another.

1.7.0 Latent Heat

Latent heat, or hidden heat, is the term used for the heat absorbed or given off by a substance while it is changing its physical state. When this occurs, the heat given off or absorbed does NOT cause a temperature change in the substance. In other words, sensible heat is the term for heat that affects the temperature of things; latent heat is the term for heat that affects the physical state of things.

To understand the concept of latent heat, you must realize that many substances may exist as solids, as liquids, or as gases, depending primarily upon the temperatures and pressure to which they are subjected. To change a solid to a liquid or a liquid to a gas, you would add heat; to change a gas to a liquid or a liquid to a solid, you would remove heat. Suppose you take an uncovered pan of cold water and put it over a burner. The sensible heat of the water increases and so does the temperature. As you continue adding heat to the water in the pan, the temperature of the water continues to rise until it reaches 212°F. What is happening? The water is now absorbing its latent heat and is changing from a liquid to a vapor. The heat required to change a liquid to a gas without any change in temperature is known as the Latent heat of vaporization.

Suppose you take another pan of cold water, and put it in a place where the temperature is below 32°F. The water gradually loses heat to its surroundings, and the temperature of the water drops to 32°F until all the water has changed to ice. While the water is changing to ice, however, it is still losing heat to its surroundings. The heat that must be removed from a substance to change it from a liquid to a solid without change in temperature, is called the Latent heat of fusion. Note the amount of heat required to cause a change of state (or the amount of heat given off when a substance changes its state) varies according to the pressure under which the process takes place.

Figure 12-2 shows the relationship between sensible heat and latent heat for one substance – water at atmospheric pressure. To raise the temperature of 1 pound of ice from 0°F to 32°F, you must add 16 Btu. To change the pound of ice at 32°F to a pound of water at 32°F, you add 144 Btu (latent heat of fusion). There is no change in temperature while the ice is melting. After the ice is melted, however, the temperature of the water is raised when more heat is applied. When 180 Btu are added, the water boils. To change a pound of water at 212°F to a pound of steam at 212°F, you must add 970 Btu (latent heat of vaporization). After the water is converted to steam at 212°F, adding more heat causes a rise in the temperature of the steam. When you add 44 Btu to the steam at 212°F, the steam is superheated to 300°F.

Figure 12-2 — Relationship between temperature and the amount of heat required per pound (for water at atmospheric pressure).

1.8.0 Total Heat

The sum of sensible heat and latent heat is called “total heat.” Since measurements of the total heat in a certain weight of a substance cannot be started at absolute zero, a temperature is adopted at which it is assumed that there is no heat; and tables of data are constructed on that basis for practical use. Data tables giving the heat content of the most commonly used refrigerants start at 40°F below zero as the assumed point of no heat; tables for water and steam start at 32°F above zero. Tables of data usually contain a notation showing the starting point for heat content measurement.

1.9.1 Day-Ton of Refrigeration

A day-ton of refrigeration (sometimes incorrectly called a ton of refrigeration) is the amount of refrigeration produced by melting 1 ton of ice at a temperature of 32°F in 24 hours. A day-ton is often used to express the amount of cooling produced by a refrigerator or air conditioner. For example, a 1-ton air conditioner can remove as much heat in 24 hours as 1 ton of 32°F ice that melts and becomes water at 32°F.

It is a rate of removing heat, rather than a quantity of heat. A rate can be converted to Btu per day, hour, or minute. To find the rate, proceed as follows:

- Per day: Multiply 2,000 (number of pounds of ice in 1 ton) by 144 (latent heat of fusion per pound) = 288,000 Btu per day
- Per hour: 288,000 (Btu per day) ÷ 24 (hours in a day) = 12,000

So, a "1-ton" air-conditioner would have a rating of 12,000 Btu per hour.

1.10.0 Pressure

Pressure is defined as a force per unit area. It is usually measured in pounds per square inch (psi). Pressure may be in one direction, several directions, or in all directions (*Figure 12-3*). Pascal’s law is utilized when discussing hydraulic or fluid pressures. Pascal’s law states that pressure applied to a confined liquid is transmitted undiminished in all directions and acts with equal force on all equal areas, at right angles to those areas. According to Pascal’s law, any force applied to a confined fluid is transmitted in all directions throughout the fluid regardless of the shape of the container.

Figure 12-3 — Exertion of pressures.

The ice (solid) exerts pressure downward. The water (fluid) exerts pressure on all wetted surfaces of the container. Gases exert pressure on all inside surfaces of their containers.

Pressure is usually measured on gauges that have one of two different scales. One scale is read as so many pounds per square inch gauge (psig) and indicates the pressure above atmospheric pressure surrounding the gauge. The other type of scale is read as so many pounds per square inch absolute (psia) and indicates the pressure above absolute zero pressure (a perfect vacuum).

1.10.1 Atmospheric Pressure

Atmospheric pressure is the pressure of the weight of air above a point on, above, or under the earth. At sea level, atmospheric pressure is 14.7 psia (*Figure 12-4*). As one ascends, the atmospheric pressure decreases about 1.0 psi for every 2,343 feet. Below sea level in excavations and depressions, atmospheric pressure increases. Pressures underwater differ from those under air only because the weight of the water must be added to the pressure of the air.

Figure 12-4 — Atmospheric pressure.

1.10.2 Scale Relationships

A relationship exists between the readings of a gauge calibrated in psig and calibrated in psia. As shown in *Table 12-1*, when the psig gauge reads 0, the psia gauge reads the atmospheric pressure (14.7 psia at sea level). In other words, the psia reading equals the psig reading plus the atmospheric pressure (7.7 psia at 16,400 feet) or, a psig reading equals the psia reading minus the atmospheric pressure.

Table 12-1 — Pressure Relationship.

ABSOLUTE SCALE (PSIA)	GAUGE SCALE (PSIG)	INCHES OF MERCURY	INCHES OF WATER
44.7	30	NOT USED	NOT USED
24.7	10	NOT USED	NOT USED
14.7	0	0	0
0	NOT USED	- 30	- 408

For pressure less than the atmospheric pressure (partial vacuums), a measuring device with a scale reading in inches of mercury (Hg) or in inches of water (H_2O) is used. A perfect vacuum is equal to -30 inches of mercury or -408 inches of water (*Table 12-1*). In refrigeration work, pressures above atmospheric are measured in pounds per square inch, and pressures below atmospheric are measured in inches of mercury.

1.10.3 Effects of Pressure on Gases

The exertion of pressure on a substance with a constant temperature decreases its volume in proportion to the increase of pressure. For example, suppose that a given amount of gas is placed in a cylinder that is sealed on one end and has a movable piston on the other end. When 60 psi of absolute pressure is exerted on the piston as the volume of the gas is compressed to 3 cubic feet (*Figure 12-5, View A*). When 90 psi of absolute pressure is exerted on the piston, the volume of the gas is compressed to 1.5 cubic feet (*Figure 12-5, View B*). Finally, when 180 psi of absolute pressure is exerted on the piston, the volume of the gas is compressed to 1 cubic foot (*Figure 12-5, View C*). Thus, if a given amount of gas is confined in a container and subject to changes of pressure, its volume changes, so the product of volume multiplied by absolute pressure is always the same.

Figure 12-5 — Pressure-volume relationship.

Pressure has a relationship to the boiling point of a substance. There is a definite temperature at which a liquid boils for every definite pressure exerted upon it.

For instance, water boils at 212°F at atmospheric pressure (14.7 psia) (*Figure 12-6, View A*). The same water boils at 228°F if the pressure is raised 5.3 psig (20 psia),

(*Figure 12-6, View B*). On the other hand, the same water boils at 32°F in a partial vacuum of 29.74 inches of mercury (Hg) (*Figure 12-7*).

This effect of reduced pressure on the boiling temperature of refrigerants makes the operation of a refrigeration system possible. The pressure-temperature relationship chart in *Table 12-2* gives the pressures for several different refrigerants.

Figure 12-6 — A. Water boils at atmospheric pressure; B. Water boils at 20 psia absolute pressure.

Figure 12-7 — Water boils in a vacuum.

Table 12-2 — Pressure-Temperature Relationship Chart.

Temp °F	113	141b	123	11	114	124	134	12	500	22	502	125
-40.0	29.5	29.0	28.8	28.4	26.1	22.8*	14.7	11.0	7.6	0.6	4.1	4.9
-35.0	29.4	28.8	28.6	28.1	25.4		12.3	8.4	4.6	2.6	6.5	
-30.0	29.3	28.6	28.3	27.8	24.7	20.2*	9.7	5.5	1.2	4.9	9.2	10.6
-25.0	29.2	28.3	28.1	27.4	23.8		6.8	2.3	1.2	7.5	12.1	
-20.0	29.0	28.1	27.7	27.0	22.9	16.9*	3.6	0.6	3.2	10.2	15.3	17.4
-15.0	28.8	27.7	27.3	26.6	21.8		0.0	2.5	5.4	13.2	18.8	
-10.0	28.7	27.3	26.9	26.0	20.6	12.7*	2.0	4.5	7.8	16.5	22.6	25.6
-5.0	28.4	26.9	26.4	25.4	19.3		4.1	6.7	10.4	20.1	26.7	
0.0	28.2	26.4	25.8	24.7	17.8	7.6*	6.5	9.2	13.3	24.0	31.1	35.1
5.0	27.9	25.8	25.2	23.0	16.2		9.1	11.8	16.4	28.3	35.9	
10.0	27.5	25.2	24.5	23.1	14.4	1.4*	12.0	14.7	19.7	32.8	41.0	46.3
15.0	27.2	24.5	23.7	22.1	12.4		15.1	17.7	23.3	37.8	46.5	
20.0	26.7	23.7	22.8	21.1	10.2	3.0	18.4	21.1	27.2	43.1	52.5	59.2
25.0	26.3	22.8	21.8	19.9	7.8		22.1	24.6	31.4	48.8	58.8	
30.0	25.7	21.8	20.7	18.6	5.1	7.5	26.1	28.5	36.0	54.9	65.6	74.1
35.0	25.1	20.7	19.5	17.1	2.2		30.4	32.6	40.8	61.5	72.8	
40.0	24.4	19.5	18.1	15.6	0.4	12.7	35.0	37.0	46.0	68.5	80.5	91.2
45.0	23.7	18.1	16.6	13.8	2.1		40.0	41.7	51.6	76.1	88.7	
50.0	22.9	16.7	15.0	12.0	3.9	18.8	45.4	46.7	57.5	84.1	97.4	110.6
55.0	21.9	13.1	13.1	9.9	5.9		51.2	52.1	63.8	92.6	106.6	
60.0	20.9	13.4	11.2	7.7	8.0	25.9	57.4	57.8	70.6	101.6	116.4	132.8
65.0	19.8	11.5	9.0	5.2	10.3		64.0	63.8	77.7	111.3	127.6	
70.0	18.6	9.4	6.6	2.6	12.7	34.1	71.1	70.2	85.3	121.4	137.6	157.8
75.0	17.3	7.2	4.1	0.1	15.3		78.6	77.0	93.4	132.2	149.1	
80.0	15.8	4.8	1.3	1.6	18.2	43.5	86.7	84.2	101.9	143.7	161.2	186.0
85.0	14.2	2.3	0.9	3.3	21.2		95.2	91.7	110.9	155.7	174.0	
90.0	12.5	0.2	2.5	5.0	24.4	54.1	104.3	99.7	120.5	168.4	187.4	217.5
95.0	10.6	1.7	4.2	6.9	27.8		113.9	108.2	130.5	181.8	201.4	
100.0	8.6	3.2	6.1	8.9	31.4	66.2	124.1	117.0	141.1	196.0	216.2	252.7
105.0	6.4	4.8	8.1	11.1	35.3		134.9	126.4	152.2	210.8	231.7	
110.0	4.0	6.6	10.2	13.4	39.4	79.7	146.3	136.2	163.9	226.4	247.9	291.6
115.0	1.4	8.4	12.6	15.9	43.8		158.4	146.5	176.3	242.8	264.9	
120.0	0.7	10.4	15.0	18.5	48.4	94.9	171.1	157.3	189.2	260.0	282.7	334.3

Note: Vapor pressures in psig, except (*) which are inches of mercury (Hg).

An increase in the temperature of a refrigerant, results in an increase in pressure, and a decrease in temperature causes a decrease in pressure. By the same token, a decrease in pressure results in a corresponding decrease in temperature.

This means that as the pressure of a refrigerant is increased, so is the temperature at which the refrigerant boils. Thus, by regulating the pressure of the refrigerant, the temperature at which evaporation takes place and at which the latent heat of evaporation is used can be controlled.

1.11.0 Vaporization

Vaporization is the process of changing a liquid to vapor, either by evaporation or boiling. When a glass is filled with water and exposed to the rays of the sun for a day or two, you should note that the water level drops gradually (*Figure 12-8*). The loss of water is due to evaporation. In this case, evaporation takes place only at the surface of the liquid, and is gradual, but the evaporation of the water can be speeded up if additional heat is applied to it. In this case, the boiling of the water takes place throughout the interior of the liquid. Thus the absorption of heat by a liquid causes it to boil and evaporate.

Figure 12-8 — Normal surface evaporation.

Vaporization can also be increased by reducing the pressure on the liquid (*Figure 12-9*). Pressure reduction lowers the temperature at which liquid boils and hastens its evaporation. When a liquid evaporates, it absorbs heat from warmer surrounding objects and cools them. Refrigeration by evaporation is based on this method. The liquid is allowed to expand under reduced pressure, vaporizing and extracting heat from the container (freezing compartment), as it changes from a liquid to a gas. After the gas is expanded (and heated), it is compressed, cooled, and condensed into a liquid again.

Figure 12-9 — Evaporation by pressure reduction.

1.12.0 Condensation

Condensation is the process of changing a vapor into a liquid. For example, in *Figure 12-10*, a warm atmosphere gives up heat to a cold glass of water, causing moisture to condense out of the air and form on the outside surface of the glass. Thus the removal of heat from a vapor causes the vapor to condense.

An increase in pressure on a confined vapor also causes the vapor to change to a liquid. This fact is shown in *Figure 12-11*. When the compressor increases the pressure on the vapor, the condensing vapor changes to a liquid and gives up heat to the cooler surrounding objects and atmosphere.

These conditions exist when the vaporized refrigerant is compressed by the compressor of a refrigeration system and forced into the condenser. The condenser removes the superheat, latent heat of vaporization, and in some cases, sensible heat from the refrigerant.

Figure 12-10 — Condensation of moisture on a glass of cold water.

Figure 12-11 — Pressure causes a vapor to condense.

Test Your Knowledge (Select the Correct Response)

1. What term is used for the heat absorbed or given off by a substance while it is changing its physical state?

   A. Sensible
   B. Specific
   C. Latent
   D. Total

2.0.0 MECHANICAL REFRIGERATION SYSTEMS

Mechanical refrigeration systems are an arrangement of components in a system that puts the theory of gases into practice to provide artificial cooling. To do this, you must provide the following: (1) a metered supply of relatively cool liquid under pressure; (2) a device in the space to be cooled that operates at reduced pressure so that when the cool, pressurized liquid enters, it will expand, evaporate, and take heat from the space to be cooled; (3) a means of repressurizing (compressing) the vapor; and (4) a means of condensing it back into a liquid, removing its superheat, latent heat of vaporization, and some of its sensible heat.

Every mechanical refrigeration system operates at two different pressure levels. The dividing line is shown in *Figure 12-12*. The line passes through the discharge valves of the compressor on one end and through the orifice of the metering device or expansion valve on the other.

Figure 12-12 — Refrigeration cycle.

The high-pressure side of the refrigeration system consists of all the components that operate at or above condensing pressure. These components are the discharge side of the compressor, the condenser, the receiver, and all interconnected tubing up to the metering device or expansion valve.

The low-pressure side of a refrigeration system consists of all the components that operate at or below evaporating pressure. These components comprise the low-pressure side of the expansion valve, the evaporator, and all the interconnecting tubing up to and including the low side of the compressor.

Refrigeration mechanics call the pressure on the high side discharge pressure, head pressure, or high-side pressure. On the low side, the pressure is called suction pressure or low-side pressure.

The refrigeration cycle of a mechanical refrigeration system may be explained by using *Figure 12-12*. The pumping action of the compressor (1) draws vapor from the evaporator (2). This action reduces the pressure in the evaporator, causing the liquid particles to evaporate. As the liquid particles evaporate, the evaporator is cooled. Both the liquid and vapor refrigerant tend to extract heat from the warmer objects in the insulated refrigerator cabinet. The ability of the liquid to absorb heat as it vaporizes is very high in comparison to that of the vapor. As the liquid refrigerant is vaporized, the low-pressure vapor is drawn into the suction line by the suction action of the compressor (1). The evaporation of the liquid refrigerant would soon remove the entire refrigerant from the evaporator if it were not replaced. The replacement of the liquid refrigerant is usually controlled by a metering device or expansion valve (3). This device acts as a restrictor to the flow of the liquid refrigerant in the liquid line. Its function is to change the high-pressure, subcooled liquid refrigerant to low-pressure, low-temperature liquid particles, which will continue the cycle by absorbing heat.

The refrigerant low-pressure vapor drawn from the evaporator by the compressor through the suction line in turn is compressed by the compressor to a high-pressure vapor, which is forced into the condenser (4). In the condenser, the high-pressure vapor condenses to a liquid under high pressure and gives up heat to the condenser. The heat is removed from the condenser by the cooling medium of air or water. The condensed liquid refrigerant is then forced into the liquid receiver (5) and through the liquid line to the expansion valve by pressure created by the compressor, making a complete cycle.

Although the receiver is indicated as part of the refrigeration system in *Figure 12-12*, it is not a vital component. However, the omission of the receiver requires exactly the proper amount of refrigerant in the system. The refrigerant charge in systems without receivers is to be considered critical, as any variations in quantity affect the operating efficiency of the unit.

The refrigeration cycle of any refrigeration system must be clearly understood by a mechanic before repairing the system. Knowing how a refrigerant works makes it easier to detect faults in a refrigeration system.

2.1.1 Components

The refrigeration system consists of four basic components:

- Compressor
- Liquid receiver
- Evaporator
- Control devices

These components are essential for any system to operate on the principles previously discussed. Information on these components is described in the following sections.

2.1.1 Compressors

The purpose of the compressor is to withdraw the heat-laden refrigerant vapor from the evaporator and compress the gas to a pressure that will liquefy in the condenser. The designs of compressors vary, depending upon the application and type of refrigerant. There are three types of compressors classified according to the principle of operation—reciprocating, rotary, and centrifugal.

Many refrigerator compressors have components besides those normally found on compressors, such as unloaders, oil pumps, mufflers, and so on. These devices are too complicated to explain here. Before repairing any compressor, check the manufacturer's manual for an explanation of their operation, adjustment, and repair.

2.1.1.1 External-Drive Compressor

An external drive or open-type compressor is bolted together. Its crankshaft extends through the crankcase and is driven by a flywheel (pulley) and belt, or it can be driven directly by an electric motor. A leak-proof seal must be maintained where the crankshaft extends out of the crankcase of an open-type compressor. The seal must be designed to hold the pressure developed inside of the compressor. It must prevent refrigerant and oil from leaking out and prevent air and moisture from entering the compressor. Two types of seals are used—the stationary bellows seal and the rotating bellows seal.

An internal stationary crankshaft seal consists of a corrugated thin brass tube (seal bellows) fastened to a bronze ring (seal guide) at one end and to the flange plate at the other (*Figure 12-13*). The flange plate is bolted to the crankcase with a gasket between the two units. A spring presses the seal guide mounted on the other end of the bellows against a seal ring positioned against the shoulder of the crankshaft. As the pressure builds up in the crankcase, the bellows tend to lengthen, causing additional force to press the seal guide against the seal ring. Oil from the crankcase lubricates the surfaces of the seal guide and seal ring. This forms a gastight seal whether the compressor is operating or idle.

Figure 12-13 — Internal stationary bellows crankshaft seal.

An external stationary bellows crankshaft seal is shown in *Figure 12-14*. This seal is the same as the internal seal, except it is positioned on the outside of the crankcase.

An external rotating bellows crankcase seal is shown in *Figure 12-15*. This seal turns with the crankshaft. This seal also consists of a corrugated thin brass tube (seal bellows) with a seal ring fastened to one end and a seal flange fastened to the other. A seal spring is enclosed within the bellows. The complete bellows assembly slips on the end of the crankshaft and is held in place by a nut. The seal ring that is the inner portion of the bellows is positioned against a non-rotating seal fastened directly to the crankcase.

During operation, the complete bellows assembly rotates with the shaft, causing the seal ring to rotate against the stationary seal. The pressure of the seal spring holds the seal ring against the seal. The expansion of the bellows caused by the pressure from the crankcase also exerts pressure on the seal ring. Because of this design, double pressure is exerted against the seal ring to provide a gastight seal.

2.1.1.2 Hermetic Compressor

In the hermetically sealed compressor, the electric motor and compressor are both in the same airtight (hermetic) housing and share the same shaft. *Figure 12-16* shows a hermetically sealed unit. Note that after assembly, the two halves of the case are welded together to form an airtight cover.

Figure 12-14 — External stationary bellow crankshaft seal.

Figure 12-15 — External rotating bellows crankshaft seal.

Figure 12-17 shows an accessible type of hermetically sealed unit. The compressor in this case is a double-piston reciprocating type. Other compressors may be of the centrifugal or rotary types.

Cooling and lubrication are provided by the circulating oil and the movement of the refrigerant vapor throughout the case. The advantages of the hermetically sealed unit (elimination of pulleys, belts and other coupling methods, elimination of a source of refrigerant leaks) are offset somewhat by the inaccessibility for repair and generally lower capacity.

Figure 12-16 — Hermetic compressor.

2.1.2 Condensers

The condenser removes and dissipates heat from the compressed vapor to the surrounding air or water to condense the refrigerant vapor to a liquid. The liquid refrigerant then falls by gravity to a receiver (usually located below the condenser), where it is stored and available for future use in the system.

The three basic types of condensers are as follows:

- Air-cooled
- Water-cooled
- Evaporative

The first two are the most common, but the evaporative types are used where low-quality water and its disposal make the use of circulating water-cooled types impractical.

Figure 12-17 — A cutaway view of a hermetic compressor and motor.

2.1.2.1 Air-Cooled Condensers

The construction of air-cooled condensers makes use of several layers of small tubing formed into flat cells. The external surface of this tubing is provided with fins to ease the transfer of heat from the condensing refrigerant inside the tubes to the air circulated through the condenser core around the external surface of the tubes (*Figure 12-18*). Condensation takes place as the refrigerant flows through the tubing, and the liquid refrigerant is discharged from the lower ends of the tubing coils to a liquid receiver on the condensing unit assembly.

Figure 12-18 — Air-cooled condenser mounted on a compressor unit.

2.1.2.2 Water-Cooled Condensers

Water-cooled condensers are of the multi-pass shell and tube type, with circulating water flowing through the tubes. The refrigerant vapor is admitted to the shell and condensed on the outer surfaces of the tubes (*Figure 12-19*).

The condenser is constructed with a tube sheet brazed to each end of a shell. Copper-nickel tubes are inserted through drilled openings in the tube sheet and are expanded or rolled into the tube sheet to make a gastight seal. Headers, or water boxes, are bolted to the tube sheet to complete the waterside of the condenser. Zinc-wasting bars are installed in the water boxes to minimize electrolytic corrosion of the condenser parts.

A purge connection with a valve is at the topside of the condenser shell to allow manual release of any accumulated air in the refrigerant circuit.

The capacity of the water-cooled condenser is affected by the temperature of the water, quantity of water circulated, and temperature of the refrigerant gas. The capacity of the condenser varies whenever the temperature difference between the refrigerant gas and the water is changed. An increased temperature difference or greater flow of water increases the capacity of the condenser. The use of colder water can cause the temperature difference to increase.

Figure 12-19 — Water-cooled condenser.

2.1.2.3 Evaporative Condensers

An evaporative condenser operates on the principle that heat can be removed from condensing coils by spraying them with water or letting water drip onto them and then forcing air through the coils by a fan.

This evaporation of the water cools the coils and condenses the refrigerant within.

2.1.3 Liquid Receiver

A liquid receiver, as shown in *Figure 12-12,* serves to accumulate the reserve liquid refrigerant, to provide storage for off-peak operation, and to permit pumping down of the system. The receiver also serves as a seal against the entrance of gaseous refrigerant into the liquid line.

When stop valves are provided at each side of the receiver for confinement of the liquid refrigerant, a pressure relief valve is generally installed between the valves in the receiver and condenser equalizing line to protect the receiver against any excessive hydraulic pressure being built up.

2.1.4 Evaporators

The evaporator is a bank or coil of tubing placed inside the refrigeration space. The refrigerant is at a low-pressure and low-temperature liquid as it enters the evaporator.

As the refrigerant circulates through the evaporator tubes, it absorbs its heat of vaporization from the surrounding space and substances. The absorption of this heat causes the refrigerant to boil. As the temperature of the surrounding space (and contents) is lowered, the liquid refrigerant gradually changes to a vapor. The refrigerant vapor then passes into the suction line by the action of the compressor.

Most evaporators are made of steel, copper, brass, stainless steel, aluminum, or almost any other kind of rolled metal that resists the corrosion of refrigerants and the chemical action of the foods.

The two main types of evaporators are dry or flooded. The inside of a dry evaporator refrigerant is fed to the coils only as fast as necessary to maintain the temperature wanted. The coil is always filled with a mixture of liquid and vapor refrigerant. At the inlet side of the coil, there is mostly liquid; the refrigerant flows through the coil (as required); it is vaporized until, at the end, there is nothing but vapor. In a flooded evaporator, the evaporator is always filled with liquid refrigerant. A float maintains liquid refrigerant at a constant level. As fast as the liquid refrigerant evaporates, the float admits more liquid, and, as a result, the entire inside of the evaporator is flooded with liquid refrigerant up to a certain level determined by the float.

The two basic types of evaporators are further classified by their method of evaporation, either direct expanding or indirect expanding. In the direct-expanding evaporator, heat is transferred directly from the refrigerating space through the tubes and absorbed by the refrigerant. In the indirect-expanding evaporator, the refrigerant in the evaporator is used to cool some secondary medium, other than air. This secondary medium or refrigerant maintains the desired temperature of the space. Usually brine, a solution of calcium chloride is used as the secondary refrigerant.

Natural convection or forced-air circulation is used to circulate air within a refrigerated space. Air around the evaporator must be moved to the stored food so that heat can be extracted, and the warmer air from the food returned to the evaporator. Natural convection can be used by installing the evaporator in the uppermost portion of the space to be refrigerated so heavier cooled air will fall to the lower food storage and the lighter food-warmed air will rise to the evaporator. Forced-air circulation speeds up this process and is usually used in large refrigerated spaces to ensure all areas are cooled.

2.1.5 Control Devices

As a UT you should have an understanding of the control devices which are a necessity in a refrigeration system to maintain correct operating conditions.

2.1.5.1 Metering Devices

Metering devices, such as expansion valves and float valves, control the flow of liquid refrigerant between the high side and the low side of the system. These devices are at the end of the line between the condenser and the evaporator. There are five different types: an automatic expansion valve (also known as a constant-pressure expansion valve), a thermostatic expansion valve, low-side and high-side float valves, and a capillary tube.

2.1.5.2 Automatic Expansion Valve

An automatic expansion valve maintains a constant pressure in the evaporator (*Figure 12-20*). Normally this valve is used only with direct expansion, dry type of evaporators. During operation, the valve feeds the required amount of liquid refrigerant to the evaporator to maintain a constant pressure in the coils. This type of valve is generally used in a system where constant loads are expected. When a large variable load occurs, the valve will not feed enough refrigerant to the evaporator under high load and will over-feed the evaporator at low load. Compressor damage can result when slugs of liquid enter the compressor.

Figure 12-20 — Automatic expansion valve.

2.1.5.3 Thermostatic Expansion Valve

Before discussing the thermostatic expansion valve, let us explain the term superheat. A vapor gas is superheated when its temperature is higher than the boiling point corresponding to its pressure. When the boiling point begins, both the liquid and the vapor are at the same temperature. But in an evaporator, as the gas vapor moves along the coils toward the suction line, the gas may absorb additional heat and its temperature rises. The difference in degrees between the saturation temperature and the increased temperature of the gas is called superheat.

A thermostatic expansion valve keeps a constant superheat in the refrigerant vapor leaving the coil (*Figure 12-21*). The valve controls the liquid refrigerant so the evaporator coils maintain the correct amount of refrigerant at all times.

Figure 12-21 — Thermostatic expansion valve.

The valve has a power element that is activated by a remote bulb located at the end of the evaporator coils. The bulb senses the superheat at the suction line and adjusts the flow of refrigerant into the evaporator.

As the superheat increases at the suction line, the temperature and the pressure in the remote bulb also increase. This increased pressure, applied to the top of the diaphragm, forces it down along with the pin, which opens the valve, admitting replacement refrigerant from the receiver to flow into the evaporator. This replacement has three effects. First, it provides additional liquid refrigerant to absorb heat from the evaporator. Second, it applies higher pressure to the bottom of the diaphragm, forcing it upward, tending to close the valve. And third, it reduces the degree of superheat by forcing more refrigerant through the suction line.

2.1.5.4 Low-Side Float Expansion Valve

The low-side float expansion valve controls the liquid refrigerant flow where a flooded evaporator is used (*Figure 12-22*). It consists of a ball float in either a chamber or the evaporator on the low-pressure side of the system. The float actuates a needle valve through a lever mechanism. As the float lowers, refrigerant enters through the open valve; when it rises, the valve closes.

2.1.5.5 High-Side Float Expansion Valve

In a high-side float expansion valve the valve float is in a liquid receiver or in an auxiliary container on the high-pressure side of the system (*Figure 12-23*). Refrigerant from the condenser flows into the valve and immediately opens it, allowing refrigerant to expand and pass into the evaporator. Refrigerant charge is critical. An overcharge of the system floods back and damages the compressor. An undercharge results in a capacity drop.

Figure 12-22 — Low-side float expansion valve.

Figure 12-23 — Low-side float expansion valve.

2.1.5.6 Capillary Tube

The capillary tube consists of a long tube of small diameter. It acts as a constant throttle on the refrigerant. The length and diameter of the tube are important; any restrictions cause trouble in the system. It feeds refrigerant to the evaporator as fast as it is produced by the condenser. When the quantity of refrigerant in the system is correct or the charge is balanced, the flow of refrigerant from the condenser to the evaporator stops when the compressor unit stops. When the condensing unit is running, the operating characteristics of the capillary tube-equipped evaporator are the same as if it were equipped with a high-side float. The capillary tube is best suited for household boxes, such as freezers and window air conditioners, where the refrigeration load is reasonably constant and small horsepower motors are used.

2.1.6 Accessory Devices

The four basic or major components of a refrigeration system just described are enough for a refrigeration unit to function. However, you should know that additional devices, such as the receiver already described, make for a smoother and more controlled cycle. Before proceeding, you need to take a close look at *Figure 12-24*, which shows one type of refrigeration system with additional devices installed.

2.1.6.1 Relief Valve

A refrigeration system is a sealed system in which pressures vary. Excessive pressures can cause a component of the system to explode. The National Refrigeration Code makes the installation of a relief valve mandatory. A spring-loaded relief valve is most often used and it is installed in the compressor discharge line between the compressor discharge connection and the discharge line stop valve to protect the high-pressure side of the system. No valves can be installed between the compressor and the relief valve. The discharge from the relief valve is led to the compressor suction line.

2.1.6.2 Discharge Pressure Gauge and Thermometer

A discharge pressure gauge and thermometer are installed in the compressor discharge line (liquid line) to show the pressure and temperature of the compressed refrigerant gas. The temperature indicated on the gauge is always higher than that corresponding to the pressure when the compressor is operating.

Figure 12-24 — Basic refrigeration system.

2.1.6.3 Compressor Motor Controls

The starting and stopping of the compressor motor are usually controlled by either a pressure-actuated or temperature-actuated motor control. The operation of the pressure motor control depends on the relationship between pressure and temperature. A pressure motor control is shown in *Figure 12-25*.

The device consists of a low-pressure bellows, or in some cases, a low-pressure diaphragm, connected by a small diameter tube to the compressor crankcase or to the suction line. The pressure in the suction line or compressor crankcase is transmitted through the tube and actuates the bellows or diaphragm. The

Figure 12-25 — Pressure-actuated motor control.

bellows move according to their pressure, and its movement causes an electric switch to start (cut in) or stop (cut out) the compressor motor.

Adjustments can be made to the start and stop pressures under the manufacturer's instruction. Usually the cutout pressure is adjusted to correspond to a temperature a few degrees below the desired evaporator coil temperature, and the cut-in pressure is adjusted to correspond to the temperature of the coil.

The term pressure-actuated motor control is similar to the pressure device. The main difference is that a temperature-sensing bulb and a capillary tube replace the pressure tube. The temperature motor control cuts in or cuts out the compressor according to the temperature in the cooled space.

The refrigeration system may also be equipped with a high-pressure safety cutout switch that shuts off the power to the compressor motor when the high-side pressure exceeds a preset limit.

2.1.6.4 Solenoid Stop Valves

Solenoid stop valves or magnetic stop valves control gas or liquid flow. They are most commonly used to control liquid refrigerant to the expansion valve but are used throughout the system. The compressor motor and solenoid stop valve are electrically in parallel; that is, the electrical power is applied or removed from both at the same time. The liquid line is open for passage of refrigerant only when the compressor is in operation and the solenoid is energized. *Figure 12-26* shows a typical solenoid stop valve.

Figure 12-26 — Solenoid stop valve.

Improper operation of these valves can be caused by a burned-out solenoid coil or foreign material lodged between the stem and the seat of the valve, allowing fluid to leak. Carefully check the valve before replacing or discarding. The valve must be installed so that the coil and plunger are in a true vertical position. When the valve is cocked, the plunger will not reseat properly, causing refrigerant leakage.

2.1.6.5 Thermostat Switch

Occasionally, a thermostat in the refrigerated space operates a solenoid stop valve, and the compressor motor is controlled independently by a low-pressure switch. The solenoid control switch, or thermostat, makes and breaks the electrical circuit, thereby controlling the liquid refrigerant to the expansion valve.

The control bulb is charged with a refrigerant so that temperature changes of the bulb itself produce like changes in pressure within the control bulb. These pressure changes are transmitted through the tubing to the switch power element to operate the switch. The switch opens the contacts releasing the solenoid valve, stopping the flow of refrigerant to the cooling coil when the temperature of the refrigerated space has reached the desired point. The compressor continues to operate until it has evacuated the evaporator. The resulting low pressure in the evaporator then activates the low-pressure switch, which stops the compressor. As the temperature rises, the increase in bulb pressure closes the switch contacts, and the refrigerant is supplied to the expansion valve.

2.1.6.6 Liquid Line

The refrigerant accumulated in the bottom of the receiver shell is conveyed to the cooling coils through the main refrigerant liquid line. A stop valve and thermometer are usually installed in this line next to the receiver. Where the sight-flow indicator, dehydrator, or filter-drier is close to the receiver, the built-in shutoff valves may be used instead of a separate shutoff valve.

2.1.6.7 Liquid Line Filter-Drier or Dehydrator

A liquid line filter-drier prevents or removes moisture, dirt, and other foreign materials from the liquid line that would harm the system components and reduce efficiency (*Figure 12-27*). This tank-like accessory offers some resistance to flow. For this reason, some manufacturers install it in a bypass line. A filter-drier consists of a tubular shell with strainers on the inlet and outlet connections to prevent escape of drying material into the system. Some filter-driers are equipped with a sight-glass indicator, shown in *Figure 12-27*. A dehydrator is similar to a filter-drier, except that it mainly removes moisture.

Figure 12-27 — Liquid line filter-drier with sight glass indicator.

2.1.6.8 Sight-Flow Indicator

The sight-flow indicator, also known as a sight glass, is a special fitting that has a glass (with gasket), single or double port, and seal caps for protection when not in use (*Figure 12-28*). The double-port unit permits the use of a flashlight background. The refrigerant may be viewed passing through the pipe to determine the presence and amount of vapor bubbles in the liquid that would indicate low refrigerant or unfavorable operating conditions. Some filter-driers are equipped with built-in sight-flow indicators and commonly have a color comparison on them to indicate either wet or dry, shown in *Figure 12-28*.

2.1.6.9 Suction Line

Suction pressure regulators are sometimes placed between the outlet of the evaporator and the compressor to prevent the evaporator pressure from being drawn down below a predetermined level despite load fluctuations. These regulators are usually installed in systems that require a higher than normal evaporator temperature.

2.1.6.10 Pressure Control Switches

Pressure control switches, often called low-pressure cutouts, are essentially a single-pole, single-throw electrical switch and are mainly used to control starting and stopping of the compressor (*Figure 12-29*). The suction pressure acts on the bellows of the power element of the switch and produces movement of a lever mechanism operating electrical contacts. A rise in pressure closes the switch contacts completing the motor controller circuit, which automatically starts the compressor. As the operation of the compressor gradually decreases the suction pressure, the movement of the switch linkage reverses until the contacts are separated at a predetermined low-suction pressure, thus breaking the motor controller circuit and stopping the compressor.

Figure 12-28 — Sight-flow indicators with different types of connections.

Figure 12-29 — Pressure type cut-in, cutout control switch.

2.1.6.11 Suction Line Filter-Drier

Some systems include a low-side filter-drier at the compressor end of the suction line (*Figure 12-30*).

The filter-drier used in the suction line should offer little resistance to flow of the vaporized refrigerant, as the pressure difference between the pressure in the evaporator and the inlet of the compressor should be small.

These filter-driers function to remove dirt, scale, and moisture from the refrigerant before it enters the compressor.

Figure 12-30 — Suction line filter-drier.

2.1.6.12 Gauges and Thermometers

Between the suction line stop valve and the compressor, a pressure gauge and thermometer may be provided to show the suction conditions at which the compressor is operating. The thermometer shows a higher temperature than the temperature corresponding to the suction pressure indicated on the gauge, because the refrigerant vapor is superheated during its passage from the evaporator to the compressor.

2.1.6.12 Accumulators and Oil Separators

Liquid refrigerant must never be allowed to enter the compressor. Liquids are non-compressible; in other words, their volume remains the same when compressed. An accumulator is a small tank safety device designed to prevent liquid refrigerant from flowing into the suction line and into the compressor (*Figure 12-31*). A typical accumulator has an outlet at the top. Any liquid refrigerant that flows into the accumulator is evaporated, and then the vapor will flow into the suction line to the compressor.

Oil from the compressor must not move into the rest of the refrigeration system. Oil in the lines and evaporator reduces the efficiency of the system. An oil separator is located between the compressor discharge and the inlet of the condenser (*Figure 12-32*). The oil separator consists of a tank or cylinder with a series of baffles and screens which collect the oil. This oil settles to the bottom of the separator. A float arrangement operates a needle valve, which opens a return line to the compressor crankcase.

Figure 12-31 — Accumulator location.

Figure 12-32 — Cutaway view of an oil separator.

Test your Knowledge (Select the Correct Response)

2. Which expansion valve controls the liquid refrigerant flow where a flooded evaporator is used?

   A. Thermostatic
   B. Low-side
   C. High-side
   D. Automatic

3. Which accessory device consists of a low-pressure bellows or a low-pressure diaphragm connected by a small diagram tube to the compressor?

A. Compressor-motor control
B. Relief valve
C. Solenoid stop valve
D. Suction line

3.0.0 REFRIGERANTS

A refrigerant is a compound used in a heat cycle that reversibly undergoes a phase change from a gas to a liquid. Traditionally, fluorocarbons (FC), especially chlorofluorocarbons (CFC) were used as refrigerants. Other refrigerants are air, water ammonia, sulfur dioxide, carbon dioxide, and non-halogenated hydrocarbons such as methane.

The ideal refrigerant has good thermodynamic properties, is unreactive chemically, and is safe. The desired thermodynamic properties are a boiling point somewhat below the target temperature, a high heat of vaporization, and moderate density in liquid form, a relatively high density in gaseous form, and high critical temperature.

Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application by choice of operating pressure.

3.1.0 R-12 Dichlorodifluoromethane ($CC1_2F_2$)

For decades R-12, which is a ***chlorofluorocarbon***, was a primary refrigerant for refrigerators and air-conditioning systems. In 1996, however, the production of R-12 in the United States was banned due to a 1992 international environmental agreement to phase out all ozone-depleting CFCs.

Even though production of R-12 is no longer legal in the U.S., it is important for you, as a UT, to know that R-12 is still used in some older refrigeration systems. That means when it is time to change the refrigerant in an existing system, you will have to replace or retrofit the parts of the system to accommodate the new refrigerant.

3.2.0 R-22 Monochlorodifluoromethane ($CHClF_2$)

The R-22 refrigerant is a ***hydrochlorofluorocarbon*** (HCFC). It is a synthetic refrigerant developed for refrigeration systems that need a low-evaporating temperature. This explains its extensive use in household refrigerators and window air conditioners. R-22 is nontoxic, noncorrosive, nonflammable, and has a boiling point of -41°F at atmospheric pressure. R-22 can be used with reciprocating or centrifugal compressors. Water mixes readily with R-22, so larger amounts of desiccant are needed in the filter-driers to dry the refrigerant.

3.3.0 R-502 Refrigerant ($CHClF_2/CClF_2CF_3$)

R-502 is an ***azeotropic*** mixture of 48.8 percent R-22 and 51.2 percent R-115. Azeotropic refrigerants are liquid mixtures of refrigerants that exhibit a constant maximum and minimum boiling point. These mixtures act as a single refrigerant. R-502 is noncorrosive, nonflammable, practically nontoxic, and has a boiling point of -50°F at atmospheric pressure. This refrigerant can be used only with reciprocating compressors. It is most often used in refrigeration applications for commercial frozen food equipment, such as walk-in refrigerators, display cases, and processing plants.

3.4.0 R-134a Tetrafluoroethane (CH_2FCF_3)

R-134a refrigerant is a ***hydrofluorocabon*** (HFC). It is very similar to R-12, but has no harmful influence on the ozone layer. R-134a has become a replacement for R-12 because it is noncorrosive, nonflammable, and nontoxic, and has a boiling point of -15°F at atmospheric pressure. Used for medium-temperature applications, such as air conditioning and commercial refrigeration, this refrigerant is now used in automobile air-conditioners.

3.5.0 R-717 Ammonia (NH_3)

R-717 ammonia is commonly used in industrial systems. It has a boiling point of -28°F at atmospheric pressure. This property makes it possible to have refrigeration at temperatures considerably below zero without using pressure below atmospheric in the evaporator. Normally it is a colorless gas, is slightly flammable, and, with proper portions of air it can form an explosive mixture, but accidents are rare.

3.6.0 R-125 Pentafluoroethane ($CHCF_5$)

The R-125 refrigerant is a blend component used in low- and medium-temperature applications. It has a boiling point of -55.3°F at atmospheric pressure. R-125 is nontoxic, nonflammable, and noncorrosive. R-125 is one replacement refrigerant for R-502.

3.7.0 R-410A Refrigerant

R-410A is a near-azeotropic mixture of R-32 and R-125 and is used as a refrigerant in air conditioning applications. Unlike many ***haloalkane*** refrigerants it does not contribute to ozone depletion, and is recognized by the EPA as an acceptable substitute for R-22. However, it has a high global warming potential of 1725 (1725 times the effect of carbon dioxide), similar to that of R-22.

3.8.0 Ozone Protection and the Clean Air Act

In 1987 the Montreal Protocol, an international environmental agreement, established requirements that began the worldwide phase-out of ozone-depleting CFCs. These requirements were later modified, leading to the phase-out in 1996 of CFC production in all developed nations, including the U.S.

In 1992 the Montreal Protocol was amended to establish a schedule for the phase-out of HCFCs. HCFCs are less damaging to the ozone layer than CFC, but still contain ozone-destroying chlorine. The Montreal Protocol, as amended, is carried out in the U.S. through the Title IV of the Clean Air Act, which is implemented by the Environmental Protection Agency (EPA).

After 2010, manufacturers will no longer be able to produce, and companies will no longer be able to import the HCFC R-22 for use in new air-conditioning systems. However, they will be able to produce and import R-22 for use in servicing existing equipment until 2020. The international agreement also calls for the elimination of all HCFCs by 2030.

Test your Knowledge (Select the Correct Response)

4. Which refrigerant has become a replacement for R-12 because it is noncorrosive, nonflammable, practically nontoxic, and has a boiling point of -50°F at atmospheric pressure?

   A. R-502
   B. R-134a
   C. R-125
   D. R-22

5. In what year was the Montreal Protocol amended to establish a schedule for the phase-out of HCFCs?

   A. 1987
   B. 1992
   C. 1990
   D. 1996

4.0.0 REFRIGERANT SAFETY

As a UT you are required to adhere to all safety standards. Safety is always paramount and this is especially true when working with refrigerants. It is important to remember that following the required safety standards is not only for your safety, but also for the safety of your fellow technicians.

4.1.1 Personal Protection

Since R-22, R134a, R-125, and R-410A are nontoxic, you will not have to wear a gas mask; however, you must protect your eyes by wearing splash-proof goggles to guard against liquid refrigerant freezing the moisture of your eyes. When liquid R-22, R-134a, R-125, or R-410A, contacts the eyes, make sure the injured person gets to medical as soon as possible. Avoid rubbing or irritating the eyes. Give the following first aid immediately:

- Drop sterile mineral oil into the eyes and irrigate them.
- Wash the eyes during the irrigation with a weak boric acid solution or a sterile salt solution that does not exceed 2 percent salt.

Should the refrigerant contact the skin, flush the affected area repeatedly with water. Strip refrigerant-saturated clothing from the body, wash the skin with water, and take the patient immediately to the dispensary. Should a person have a hard time breathing in a space which lacks oxygen due to a high concentration of refrigerant, provide assistance to the individual by administering artificial respiration.

4.2.1 Handling and Storage of Refrigerant Cylinders

The procedures for handling and storing refrigerant cylinders are similar to those of any other type of compressed gas cylinders. When handling and storing cylinders, keep the following rules in mind:

- Open valves slowly; never use any tools except those approved by the manufacturer.

- Keep the cylinder cap on the cylinder unless the cylinder is in use.
- When refrigerant is discharged from a cylinder, immediately weigh the cylinder.
- Record the weight of the refrigerant remaining in the cylinder.
- Ensure only regulators and pressure gauges designed for the particular refrigerant in the cylinder are used.
- Do NOT use different refrigerants in the same regulator or gauges.
- Never drop the cylinders or permit them to strike each other violently.
- Never use a lifting magnet or a sling. A crane may be used when a safe cradle is provided to hold the cylinders.
- Never use cylinders for any other purpose than to carry refrigerants.
- Never tamper with safety devices in the cylinder valves.
- Never force connections that do not fit. Ensure the cylinder valve outlet threads are the same as what is being connected to it.
- Never attempt to alter or repair cylinders or valves.
- Cylinders stored in the open must be protected from extremes of weather and direct sunlight. A cylinder should never be exposed to temperature above 120°F.
- Store full and empty cylinders apart to avoid confusion.
- Never store cylinders near elevators or gangways.
- Never store cylinders near highly flammable substances.
- Never expose cylinders to continuous dampness, salt water, or spray.

Test your Knowledge (Select the Correct Response)

6. How often should you weigh a refrigerant cylinder?

   A. Twice daily
   B. Every time refrigerant is discharged
   C. Only after the first discharge of refrigerant
   D. Once per day

7. **(True or False)** Goggles are not required when working with refrigerants.

   A. True
   B. False

5.1.1 REFRIGERANT EQUIPMENT

The equipment used for refrigeration can be classified as either self-contained or remote units. Self-contained equipment houses both the insulated storage compartments (refrigerated), in which the evaporator is located, and a non-insulated compartment (non-refrigerated), in which the condensing unit is located, in the same cabinet. This type of equipment can be designed with a hermetically sealed, semi-sealed, or an open condensing unit. These units are completely assembled and charged at the factory and come ready for use with little or no installation work.

Self-contained refrigerating units include the following types of equipment:

- Domestic refrigerators and freezers
- Water coolers
- Reach-in and walk-in refrigerators
- Small cold-storage plants
- Ice plants

Remote refrigerating equipment has the condensing unit installed in a remote location from the main unit. These types of units are used where the heat liberated from the condenser cannot enter the space where the unit is installed or space is limited for installation.

5.1.0 Reach-In Refrigerators

Reach-in refrigerators have a storage capacity of 15 cubic feet or greater. They are used at Navy installations to store perishable foods in galleys and messes. Navy hospitals and medical clinics also use them to store biologicals, serums, and other medical supplies that require temperatures between 30°F and 45°F. The most frequently used are standard-size units with storage capacities between 15 and 85 cubic feet. *Figure 12-33* shows a typical reach-in refrigerator with a remote (detached) condensing unit.

Figure 12-33 — Reach-in refrigerator with a remote condensing unit.

The exterior finishes for reach-in refrigerators are usually of stainless steel, aluminum, or vinyl, while the interior finishes are usually metal or plastic. The refrigerator cabinet is insulated with board or batten type polystyrene or urethane. Reach-in refrigerators are normally self-contained, with an air-cooled condenser. Water-cooled condensers are sometimes used in larger refrigerators with remote condensers.

A typical self-contained unit is shown in *Figure 12-34*. The evaporator is mounted in the center of the upper portion of the food compartment. In operation, warm air is drawn by the fan into the upper part of the unit cooler, where it passes over the evaporator coils, is cooled, and then is discharged at the bottom of the cooler. The air then passes up through the interior and around the contents of the refrigerator.

The cycle is completed when the air again enters the evaporator. The low-pressure control is set to operate the evaporator on a self-defrosting cycle, and temperature is thus controlled. Another type of control system uses both temperature and low-pressure control or defrost on each cycle. The evaporator fan is wired for continuous operation within the cabinet.

Figure 12-34 — Self-contained reach-in refrigerator.

Evaporators in reach-in refrigerators are generally the unit cooler type with dry coils (*Figure 12-35*). In smaller capacity refrigerators, ice-making coils, similar to those used in domestic refrigerators, are often used as well as straight gravity coils.

Figure 12-35 — Unit and dome coolers used in reach-in refrigerators.

5.2.0 Walk-In Refrigerators

Walk-in refrigerators are normally larger than reach-in types and are either built-in or pre-fabricated sectional walk-in units. They are made in two types—one for bulk storage of fresh meats, dairy products, vegetables, and fruits requiring a temperature from 35°F to 38°F and the other for the storage of frozen food at temperatures of 10°F or below. The 35°F to 38°F refrigerators are built and shipped in sections and assembled at the location where they are installed. They can be taken apart, moved, and reassembled in another area if needed. Standard-size coolers can be from 24 square feet up to 120 square feet in floor area. A walk-in refrigerator with reach-in doors is shown in *Figure 12-36*.

Normally, the exteriors and interiors of walk-in refrigerators are galvanized steel or aluminum. Vinyl, porcelain, and stainless steel are also used. Most walk-in refrigerators use rigid polyurethane board, batten, or foamed insulation between

Figure 12-36 — Walk-in refrigerator with reach-in doors.

the inner and outer walls. Insulation 3 to 4 inches in thickness is generally used for storage temperatures between 35°F to 40°F. For low-temperature applications, 5 inches or more of insulation is used. These refrigerators are equipped with meat racks and hooks to store meat carcasses. Walk-in refrigerators also have a lighting system inside the refrigerator compartment. Most systems have the compressor and condenser outside the main structure and use either a wall-mounted forced-air or gravity-type evaporator that is separated from the main part of the cabinet interior by a vertical baffle.

The operation of walk-in and reach-in refrigerators is similar. The evaporator must have sufficient capacity (Btu per hour) to handle the heat load from infiltration and product load.

5.3.0 Domestic Refrigerators

Domestic refrigerators are used in most facilities on a Navy installation. Most domestic refrigerators are of two types—either a single door fresh food refrigerator or a two-door refrigerator-freezer combination, with the freezer compartment on the top portion of the cabinet, or a vertically split cabinet (side-by-side), with the freezer compartment on the left side of the cabinet. They are completely self-contained units and are easy to install. Most refrigerators use R-22 refrigerant, which maintains temperatures of 0°F in the freezer compartment and about 35°F to 45°F in the refrigerator compartment.

As a UT, you must be able to perform maintenance and repair duties of domestic refrigerators, water coolers, and ice machines at Navy activities. This section provides information that will aid you when performing troubleshooting duties. However, you need to remember that the information provided is intended as a general guide, and should be used along with the manufacturer's detailed instructions. For troubleshooting guidance, see *Table 12-3*.

Table 12-3 — Troubleshooting Checklist for Domestic Refrigerators and Freezers.

Trouble	Possible Causes	What to look for and what to do
1. Unit fails to start	Wiring	Loose connections, broken wires, ground leads, open contacts, blown fuses, poor plug contacts, poorly soldered connections. Correct defects found.
	Low voltage	Rated voltage should be ± 10 percent. Overloaded circuits; read the voltage across the compressor-motor terminals; if it reads 100 volts or under, the circuit is overloaded. Check the voltage at the fuse panel; if this voltage is low, the power supply voltage needs correction. Provide a separate circuit for the unit.
	Compressor motor	Remove leads from the compressor motor. Apply 115 volts to the motor running winding terminals on the terminal plate from a separate two-conductor cable. Then, touch a jumper wire across both the starting and the running winding terminals. If the motor starts and runs, the trouble is isolated in the control or in the compressor motor thermostat. If the motor does not start, replace it.
	Motor thermostat	Connect a jumper to shunt the thermostat from the line-side terminal of the thermostat across to the common terminal of the compressor motor. If the compressor starts, the thermostat is open and should be replaced. Do not attempt to correct calibration of the thermostat. Replace the thermostat.
2. Unit runs normally but temperature is too high	Temperature selector control set too high	Reset the dial to its normal position.
	Temperature control out of adjustment	Readjust the control in accordance with the manufacturer's instructions.
	Poor air circulation in the cabinet	Paper on shelves; too much food in storage; other obstructions to proper air circulation. Maintain sufficient space in the cabinet for proper air circulation.
	Damper control faulty	On models with this type of control it is best to replace the control or to follow the manufacturer's instructions.
3. Unit runs normally but temperature is too low	Temperature selector control out of adjustment	Reset the control to a higher position.
	Temperature control out of adjustment	Readjust the control in accordance with the manufacturer's instructions.
4. Unit runs too long and temperature is too low	Temperature bulb improperly located or defective	Replace or relocate the bulb in accordance with the manufacturer's instructions. Be sure the bulb is securely attached to the evaporator. Replace defective bulbs.
	Compressor	Refer to item 7.

Table 12-3 — Troubleshooting Checklist for Domestic Refrigerators and Freezers (cont.).

Trouble	Possible Causes	What to look for and what to do
5. Unit does not run and temperature is too high	No power at outlet	Check the fuses If any are burned-out replace them.
	Poor plug contact	Spread the plug contacts.
	Temperature control inoperative	Examine the control main contacts; clean them with a magneto file or with fine sandpaper; replace them if they are badly burned or pitted. Do not use emery cloth. Check and replace the relay assembly, if necessary. If the temperature control main contacts are found open, try warming the temperature control bulb by hand. If this does not close the control contacts, the control bellows has lost its charge, and the control should be replaced.
	Pressures in system not equalized	Wait for a period of about 5 minutes before trying to restart the unit. See item 3.
	Open circuit in wiring	Make voltmeter or test-lamp checks to determine whether any part of the electrical wiring system is open, or any controls are inoperative. Correct defective connections, and replace worn or damaged controls.
	Compressor thermostat open	See item 1.
	Open motor windings	See item 1.
6. Unit runs for short periods; temperature too high	Defroster heater	On a unit equipped with a defrosting heater, check the defrosting cycle in accordance with the manufacturer's instructions. Ascertain whether the defrosting heater is turned off by making sure that no current flows through it during the refrigerating cycle.
	Unit operates on thermostat	See item 9.
7. Unit runs continuously; temperature too high	Moisture, obstruction, or restriction in liquid line	Before checking for moisture, be certain that the symptoms observed are not caused by improper operation of the defrosting heater, if so equipped. These heaters are wired into the cabinet wiring so that the control contacts short out the heaters when the contacts are closed. Thus the heaters are on only if the machine is off, when the control contacts open, and the evaporator is on the defrost cycle. Check the control contacts to see that the defrosting heaters are off when the machine is running. At high ambient temperature the unit will cycle on its thermostat. The evaporator will warm up over its entire surface if the liquid circulation is completely obstructed. If partly obstructed, part of the frost on the evaporator will melt. Under these conditions, the unit will probably operate noisily, and the motor will tend to draw a heavy current. If the liquid line is obstructed by ice, it will melt after the unit has warmed up. The unit will then refrigerate normally. If this obstruction occurs frequently and spare units are available, replace the unit.

Table 12-3 — Troubleshooting Checklist for Domestic Refrigerators and Freezers (cont.).

Trouble	Possible Causes	What to look for and what to do
7. Unit runs continuously; temperature too high (cont.)	Broken valves	Exceedingly high current to the motor. No cooling in the evaporator and no heating in the condenser. Excessive compressor noise. Replace the hermetic compressor or replace the valves in an open-type compressor.
	Clogged tubing	Check the tubing for damage, sharp bends, kinks, pinches, etc. Straighten the tubing, if possible, or replace the unit.
	Refrigerant leaks or is under-charged	The unit may tend to run normally but more frequently. The evaporator becomes only partly covered with frost. The frost will tend to build up nearest to the capillary tube while the section nearest to the suction line will be free from frost. As leakage continues, the frostline will move back across the evaporator. When the refrigerant is entirely gone, no refrigeration will occur. Units with large evaporators will not frost up unless the evaporator is mounted inside of the box. Test for leaks with a halide leak detector. Recharge the unit, if necessary.
	Cabinet light	Check the operation of the light switch. See that the light goes out as the door is closed.
	Air circulation	See that sufficient space is allowed for air circulation. Relocate or reposition the unit, if possible.
	Evaporator needs defrosting	Advise the user on defrosting instructions.
	Gasket seals	Give them a thorough cleaning. If worn they should be replaced.
	Ambient temperature	Relocated the unit tin a location where the ambient temperature ranges from 55 degrees to 95 degrees.
	Defroster heater	On units so equipped, check the defroster heater circuit. See item 6.
	Compressor suction valve sticks open or is obstructed by corrosion or dirt	Ascertain whether the condenser gets warm, and check the current drawn by the motor. If the condenser does not get warm and the current drawn is low, disassemble the compressor (open type) and check the action of the suction valve.
	Compressor discharge valve sticks open or is obstructed	Connect the test gauge assembly and run the unit until the low-side pressure is normal. With an ear in close proximity to the compressor, listen for a hissing sound of escaping gas past the discharge valve. The low-side pressure gauge will rise, and the high side will drop equally until both are the same. Clean out obstructions.

Table 12-3 — Troubleshooting Checklist for Domestic Refrigerators and Freezers (cont.).

Trouble	Possible Causes	What to look for and what to do
8. Unit runs too long; temperature too high	Condenser	Check for any obstruction in the path of air circulation around the condenser. Clean any dust accumulation.
	Fan	On units so equipped, check to see that the fan blades are free to turn and that the fan motor operates.
	Door seal	Clean seals around the door. Check closure of the door with a strip of paper between the gasket and the cabinet at all points around the door. The gasket should grip the paper tightly at all points.
	Refrigerant	Check for leakage and undercharge of the refrigerant. See item 7.
	Usage	Warn the user against too frequent opening of the door, storage of hot foods, heavy freezing loads, and other improper usage.
9. Unit operates on thermostat; temperature too high	Voltage	Check voltage $\pm$ 10 percent of rating.
	Defrosting heater	See that the defrosting heater is turned off.
	Starting relay	Determine that the starting relay does not stick closed. Follow the manufacturer's instructions on methods of checking.
	Condenser	Check the air circulation around the condenser; also check the operation of the fan.
	Pressure not equalized	Wait 5 minutes after stopping, then restart; turn to the coldest position, then to the normal position.
	Restrictions in liquid line	See item 7.
	Thermostat	Thermostat may be out of calibration. Replace the thermostat.
10. Noisy operation	Fan blades	If the blades are bent, realign them, and remove any obstructions. If the blades are so badly bent or warped that they cannot be realigned, they should be replaced.
	Fan motor	Check the motor mounting and tighten the connection.
	Tube rattling	Adjust the tubes so that they do not rub together.
	Food shelves	Adjust them to fit tightly.
	Compressor	Malfunctioning valves; loose bolted connections; improper alignment of open-type compressor. Replace the hermetic compressor tighten the connections; realign the open-type compressor.

Table 12-3 — Troubleshooting Checklist for Domestic Refrigerators and Freezers (cont.).

Trouble	Possible Causes	What to look for and what to do
10. Noisy operation (cont.)	Floor or walls	Check to see that the floor is rigid, and whether the walls vibrate. Locate and correct any such sources of noise. Make corrections by bolting or nailing loose portions to structural members.
	Belt	Check the condition of the motor belt. Replace it when it becomes worn or frayed.
11. Unit uses too much electricity	Door	Check the door seal. See item 7.
	Usage	Instruct the user on proper usage of the motor. See item 8. Check the overload.
	Ambient temperature too high	See item 7. The unit will operate more frequently and over longer periods of time in a high-temperature atmosphere. Correct, if possible, by changing the location of the unit.
	Defrost control	Check the defrost circuit according to the manufacturer's instructions.
	Temperature control	Selector control dial set too low. Advise the user. Operate it as near to the "Normal" setting as possible.
12. Stained ice trays	Poor cleaning procedures	Use soap and warm water to wash trays. Rinse them thoroughly. Do not use metal sponges, steel wool, or course cleaning powders.

5.3.1 Single Door Fresh Food Refrigerator

A single door fresh food refrigerator consists of an evaporator placed either across the top or in one of the upper corners of the cabinet (*Figure 12-37*). The condenser is on the back of the cabinet or in the bottom of the cabinet below the hermetic compressor. During operation, the cold air from the evaporator flows by natural circulation through the refrigerated space. The shelves inside the cabinet are constructed so air can circulate freely past the ends and sides, eliminating the need for a fan.

This type of refrigerator has a manual defrost, which requires the refrigerator to be turned off periodically (usually overnight), to allow the frost buildup on the evaporator to melt. Both the outside and inside finish is usually baked-on enamel. Porcelain enamel is found on steel cabinet liners. The interior of the unit contains the shelves, lights, thermostats, and temperature controls.

Figure 12-37 — Single-door fresh food refrigerator.

5.3.2 Two-Door Refrigerator-Freezer Combination

The two-door refrigerator-freezer combination is the most popular type of refrigerator (*Figure 12-38*). It is similar to the fresh food refrigerators in construction and the location of components except it sometimes has an evaporator for both the freezer compartment and the refrigerator compartment. Also, if it is a frost-free unit, the evaporators are on the outside of the cabinet. Because of the two separate compartments (refrigerator-freezer) and the larger capacity, these types of refrigerators use forced air (fans) to circulate the air through the inside of both compartments. In addition to the automatic icemaker in the freezer compartment, it has an option for a cold water dispenser, a cube or crushed ice dispenser, and a liquid dispenser built into the door The two-door refrigerator also has one of the following three types of evaporator defrost systems: manual defrost, automatic defrost, or frost-free.

Figure 12-38 — Two-door refrigerator-freezer combination.

There are two types of automatic defrosting: the hot gas system or the electric heater system. The hot gas system has solenoid valves, and uses the heated vapor from the compressor discharge line and the condenser to defrost the evaporator. The other system uses electric heaters to melt the ice on the evaporator surface.

A frost-free refrigerator-freezer has the evaporator located outside the refrigerated compartment (*Figure 12-39*). On the running part of the cycle, air is drawn over the evaporator and is forced into the freezer and refrigerator compartments by a fan. On the off part of the cycle, the evaporators automatically defrost.

Refrigerator-freezer cabinets are made of pressed steel with a vinyl or plastic lining on the interior wall surfaces and a lacquer exterior finish. Most domestic refrigerators have urethane foam or fiber glass insulation in the cabinet walls. The side-by-side refrigerator-freezer arrangement has a number of features not found in other refrigerators.

Figure 12-39 — Frost-free refrigerator airflow diagram.

5.4.0 Water Coolers and Ice Machines

Water coolers provide drinking water at a temperature under 50°F. Two types of water coolers are instantaneous and storage. The instantaneous type only cools water when it is being drawn; the storage type maintains a reservoir of cooled water. One instantaneous method places coils in a flooded evaporator through which the water flows. A second instantaneous method uses double coils with water flowing through the inner coil and refrigerant flowing in the space between the inner coil and the outer coil. A third instantaneous method is to coil the tubing in a water storage tank, allowing refrigerant to flow through it (*Figure 12-40*).

Figure 12-40 — Storage type of water cooler.

The two basic designs for water coolers are wall mounted or floor mounted. Both types are the same in construction and operation; the only difference is in the method of installation. Water cooler cabinets have a sheet metal housing attached to a steel framework. The condenser and hermetic compressor are located in the housing base, and the evaporator is located in the cabinet depending on its type of evaporator, but normally under the drain basin. Most water coolers use a heat exchanger or precooler, which precools the fresh water line to the evaporator, reducing cooling requirements for the evaporator. A thermostat, which is manually set and adjusted, is located in the cooler housing close to the evaporator.

Automatic ice machines are often used in galleys, barracks, gymnasiums, and other public areas. Ice machines are self-contained, automatic machines, ranging from a small unit producing 50 pounds of ice per day (*Figure 12-41*) to a commercial unit producing 2,400 pounds of ice per day (*Figure 12-42*). The primary difference in the design of these machines is the evaporator. They automatically control water feed to the evaporator, freeze the water in an ice cube mold, heat the mold and empty the ice into a storage bin, and shut down when the storage bin is full. Floats and solenoids control water flow, and switches operate the storing action when ice is made.

Figure 12-41 — Small automatic ice machine.

Depending on the type of unit, electrical heating elements, hot water, hot gas defrosting, or mechanical devices remove the ice from the freezing surfaces. *Figure 12-43* and *Figure 12-44* show the freezing and defrost cycle of a typical ice cube machine.

Figure 12-42 — Commercial automatic ice machine.

Figure 12-43 — Freeze cycle of an ice cube machine.

Figure 12-44 — Defrost cycle of an ice cube machine.

Test your Knowledge (Select the Correct Response)

8. What type of refrigerator has a manual defrost that requires the unit to be turned off to melt the frost buildup on the evaporator?

   A. Two-door refrigerator-freezer
   B. Reach-in
   C. Single-door fresh food
   D. Walk-in

9. **(True or False)** The two basic designs for water coolers, wall mounted and floor mounted, are very different when it comes to construction and operation.

   A. True
   B. False

6.0.0 INSTALLATION of REFRIGERATION EQUIPMENT

As a UT, you can be tasked to install refrigeration systems. Therefore, it is important for you to understand the basic requirements for installing the various types of refrigeration equipment.

When installing a refrigeration or air-conditioning plant, you must not allow dirt, scale, sand, or moisture to enter any part of the refrigerant system. Since air contains moisture, its entrance into the circuit should be controlled as much as possible during installation. Most maintenance problems come from careless erection and installation. All openings to the refrigerant circuit—piping, controls, compressor, condensers, and so on—must be adequately sealed when you are working on them.

Most refrigerants are powerful solvents that readily dissolve foreign matter and moisture that may have entered the system during installation. This material is soon carried to the operating valves and the compressor. It becomes a distinct menace to bearings, pistons, cylinder walls, valves, and the lubricating oil. Scoring of moving parts frequently occurs when the equipment is first operated, starting with minor scratches that increase until the operation of the compressor is seriously affected.

Under existing specifications, copper tubing and copper piping needed for installation should be cleaned, deoxidized, and sealed. If you are not sure about the cleanliness of the tubing or piping you are going to use, blow out each length of pipe with a strong blast of dry air. Next, use a copper wire with a cloth swab attached to it to pull back and forth in the tube unit it is clean and shiny. Then seal the ends of the tubes to keep them clean until they are connected to the rest of the system.

6.1.0 Effects of Moisture

As little as 15 to 20 parts of moisture per million parts of refrigerant can cause severe corrosion in a system. When the refrigerant comes in contact with water, hydrochloric acid is formed causing corrosion. Corrosion products are formed when a chemical reaction takes place between the acid and the iron and copper in the system.

Combining a strong acid with high discharge and compressor temperature can cause decomposition of the system’s lubricating oil, and produce a sludge containing breakdown products. A serous casualty can occur when either the corrosion or the oil breakdown products plug the valves, strainers, and dryers.

NOTE

The formation of ice from a minute quantity of moisture in expansion valves and capillary tubes can occur when operating below 32°F.

6.2.1 Location of Equipment

You should always leave adequate space around major portions of equipment for servicing purposes; otherwise, the equipment must be moved after installation to have access to serviceable parts (*Figures 12-45* and *12-46*). Enough overhead clearance is required for compressors when removing the head, discharge valve plate, and pistons. There should also be enough side clearance if it becomes necessary to remove the flywheel and crankshaft. Water-cooled condensers require a free area equal to the length of the condenser at one end to provide room for cleaning tubes, installing new tubes, or removing the condenser tube assembly. Space is needed for servicing valves and accessory equipment. In most instances, service openings and inspection panels on unit equipment require at least 18 inches of clearance when removing the panels. Place air-cooled condensing units in a location that permits unrestricted flow of air for condensing, whether the condenser is part of the unit or separate. Overloading of the motor and loss of capacity can occur when there is inadequate ventilation around air-cooled condensers.

Figure 12-45 — Low-temperature screw or helix compressor system. (1) Compressor; (2) Oil separator and reservoir; (3) Oil cooler; (4) Oil filters; (5) Hot gas discharge line.

Figure 12-46 — Twelve-cylinder semi-hermetic reciprocating direct drive compressor system. (1) Compressor; (2) Control panel; (3) Oil return from reservoir; (4) Section line; (5) Hot gas discharge line.

6.3.0 Refrigerant Piping

If you are assigned to install refrigerant lines, your must follow certain general precautions. When the receiver is above the cooling coil, the liquid line should be turned up before going down to the evaporator. This inverted loop prevents siphoning of the liquid from the receiver over into the cooling coil through an open or leaking expansion valve during compressor shutdown periods. If siphoning starts, the liquid refrigerant flashes into a gas at the top of the loop, breaking the continuity of the liquid volume and stopping the siphoning action. Where the cooling coils and compressors are on the same level, both the suction and liquid lines should be run to the overhead and then down to the condensing unit, pitching the suction line toward the compressor to ease oil return. On close-coupled installations, running both lines up to the overhead helps to eliminate vibration strains as well as provide the necessary trap at the cooling coil.

Make sure you use care when preparing pipes and fittings. This is particularly important when cutting copper tubing or pipe to prevent the small filings or cuttings from entering the pipe. You should completely remove the small particles of copper to prevent them from passing through the suction strainer. Cut the tube square, and remove all burrs and dents to prevent internal restrictions and to permit proper fit with the companion fittings. If you are going to do the cutting with a hacksaw, use a fine-toothed blade, preferably 32 teeth per inch. Whenever possible, you should avoid using a hacksaw. When making silver-solder joints, brighten up the ends of the tubing or pipe with a wire brush or crocus cloth to make a good bond. When you are doing this cleaning, you should not use sandpaper, emery cloth, or steel wool because this type material can cause problems if it enters the system.

Acid should never be used for soldering, nor should flux be used if its residue forms an acid. If you do use flux, use it sparingly so no residue will enter inside the system and eventually be washed back to the compressor crankcase. If tubing and fittings are improperly fitted because of distortion, too much flux, solder, and brazing material may enter the system.

The temperature required to solder or braze pipe joints causes oxidation within the tubing. Once the system is in operation, the refrigerant flow eventually removes the oxidation. When the oxide breaks up into a fine powder, it contaminates the lubricant in the compressor and plugs strainers and driers. To eliminate the oxide breakup, you need to provide a neutral atmosphere within the tube being soldered or brazed. Use gas-bled nitrogen through the tubing during soldering or brazing, and for a sufficient time after the bond is made, which lowers the heat of the copper below the temperature of oxidation.

All joints should be silver-soldered and kept to a minimum to reduce leaks. Make sure you use special copper tube fittings which are designed for refrigeration service. These types of fittings are manufactured with close tolerances to assure tight capillary joints during the brazing process.

Figure 12-47 — Swivel-head flaring tool.

SAE flare joints are generally not desired, but when necessary, you should take care when making the joint. The flare must be of uniform thickness and present a smooth, accurate surface, free from tool marks, splits, or scratches. The tubing must be cut square, provided with a full flare, and any burrs and saw filings removed. The flare seat of the fitting connector must be free from dents or scratches. The flare can best be made with a special swivel head flaring tool, which remains stationary and does not tear or scar the face of the flare in the tubing (*Figure 12-47*).

When you are making up the flare or securing it to the fitting, do not use oil on the face of the flare. If oil is placed on the face, it will eventually be dissolved by the system's refrigerant, resulting in a leak through the displacement of the oil. Always use two wrenches when you are tightening the flare joint. Use one wrench to turn the nut while the other holds the connecting piece to avoid strain on the connection, which can cause a leak.

Where pipe or tubing has to be bent, bends should be made with special tools designed for this type of work (*Figure 12-48*). Do not use rosin, sand, or any other filler inside the tubing to make a bend. Threaded joints should be coated with a special refrigerant pipe dope. In an emergency, use a thread compound for making up a joint; remember if you using refrigerants that are hydrocarbons, they will dissolve any compound containing oil. Also, you should not use a compound containing an acid or one whose residual substance forms an acid. The use of a thick paste made of fresh lethargy and glycerin makes a satisfactory joint compound; however, the joint should be thoroughly cleaned with a solvent to eliminate oil or grease. Thread compounds should be applied to the male part of the thread after it has entered the female coupling one and one-half to two threads to prevent any excess compound from entering the system.

Figure 12-48 — Pipe or tube bending tool.

When securing, anchoring, or hanging the suction and liquid lines, be sure and allow enough flexibility between the compressor and the first set of hangers or points where the lines are secured to permit some degree of freedom. This flexibility relieves strain in the joints of these lines at the compressor due to compressor vibration.

6.4.0 Multiple Compressors

Parallel operation of two or more reciprocating compressors should be avoided unless there are strong and valid reasons for not using a single compressor. If you have a situation where you have to use two compressors, it is essential that you take extreme care when sizing and arranging the piping system.

An acceptable arrangement of two compressors and two condensers is shown in *Figure 12-49*. An equalizer line connects the crankcase at the oil level of each machine. Therefore, the oil in both machines will be at a common level. If machines of different sizes are used, the height of the bases beneath the machines must be adjusted so the normal oil level of both machines is at the same elevation; otherwise, the oil accumulates in the lower machine.

This arrangement is called a single-pipe crankcase equalizer. It can be used only on those machines with a single equalizer tapping entering the crankcase in such a position that the bottom of the tapping just touches the normal oil level.

Figure 12-49 — Parallel compressors with separate condensers.

Another method of piping to maintain proper oil level in two or more compressors uses two equalizer lines between the crankcase—one above the normal oil level and one below. The double equalizer system must be used on compressors having two equalizer tappings. Make sure you never use a single equalizer line on machines having two equalizer tappings.

The lower oil equalizer line must not rise above the oil level in the crankcase and should be as level as possible. This is important since the oil builds up in one crankcase if the line rises. The upper equalizer line is a gas line intended to prevent any difference in crankcase pressure that would influence the gravity flow of oil in the lower equalizer line or the level of oil in the crankcase. This upper line must not dip, and care should be taken to eliminate pockets in which oil could accumulate to block the flow of gas. Valves in the crankcase equalizer lines are installed with the stems horizontal, so no false oil levels are created by oil rising over the valve seat and minimizing flow resistance.

When making up the equalizer line, you should not skimp on the piping. Also, oversize piping is preferred to undersize piping. A good rule to follow is to use oil equalizer lines equal to the full size of the tapping in the compressor.

The discharge lines from the compressors are also equalized before they enter the condensers. This, in effect, causes the individual condensers to function as a single unit. This is the most critical point in the piping system. It is here that pressure drop is extremely important—a pressure drop of 0.5 psi being equal to a 1.0 foot head of liquid. Excessive pressure drop in the equalizer line may rob one condenser of all liquid by forcing it into the other condenser. One of the results may be the pumping of large quantities of hot refrigerant vapor into the liquid lines from the condenser of the operating compressor. This could reduce the capacity of the system materially. For this reason, the equalizer line should be just as short and level as possible. A long equalizer line introduces an unequal pressure in condensers if one of the compressors is not operating. The refrigerant then accumulates in the condenser of the non-operating compressor. The equalizer line should also be generously sized and should be equal to or larger than the discharge line of the largest compressor being used.

If the condensers are more than 10 feet above the compressor, U-traps or oil separators should be installed in the horizontal discharge line where it comes from each compressor.

The traps or separators prevent the oil from draining back to the compressor head on shutdown. Should a single compressor or multiple compressors with capacity modulation be used in an instance of this kind, another solution may be dictated. When a compressor unloads, less refrigerant gas is pumped through the system. The velocity of flow in the refrigerant lines drops off as the flow decreases. It is necessary to maintain gas velocities above some minimum value to keep the entrained oil moving with the refrigerant. The problem becomes particularly acute in refrigerant gas lines when the flow is upward. It does not matter whether the line is on the suction or discharge side of the compressor; the velocity must not be allowed to drop too low under low refrigerant flow conditions. Knowing the minimum velocity, 1,000 feet per minute (fpm) for oil entrainment up a vertical riser and the minimum compressor capacity, the designer of the piping can overcome this problem using a double riser.

The smaller line in the double riser is designed for minimum velocity, at the minimum step, of compressor capacity. The larger line is sized to assure that the velocity in the two lines at full load is approximately the same as in the horizontal flow lines. A trap of minimum dimensions is formed at the bottom of the double-riser assembly, which collects oil at minimum load. Trapped oil then seals off the larger line so the entire flow is through the smaller line.

If an oil separator is used at the bottom of a discharge gas riser, the need for a double riser is eliminated. The oil separator will do as its name implies—separate the major part of the oil from the gas flowing to it and return the oil to the compressor crankcase. Since no oil separator is 100 percent effective, the use of an oil separator in the discharge line does not eliminate the need for double risers in the suction lines of the same system if there are vertical risers in the suction lines. When multiple compressors with individual condensers are used, the liquid lines from the condenser should join the common liquid line at a level well below the bottoms of the condensers. The low liquid line prevents gas from an "empty" condenser from entering the line because of the seal formed by the liquid from other condensers.

NOTE

A common water-regulating valve should control the condenser water supply for a multiple system using individual condensers so each condenser receives a proportional amount of the condenser water.

Frequently, when multiple compressors are installed, only one condenser is provided. Such installations are satisfactory only as long as all of the compressors are operating at the same suction pressure. However, several compressors may occasionally be installed which operate at different suction pressures—the pressures corresponding, of course, to the various temperatures needed for the different cooling loads. When this is the case, a separate condenser must be installed for each compressor or group of compressors operating at the same suction pressure. Each compressor or group of compressors operating at one suction pressure must have a complete piping system with an evaporator and condenser separate from the remaining compressors operating at other suction pressures. Separate systems are required because the crankcase of compressors operating at different suction pressures cannot be interconnected. There is no way of equalizing the oil return to such compressors.

The suction connection to a multiple compressor system should be made through a suction manifold, as shown in *Figure 12-49*. The suction manifold should be as short as possible and should be taken off in such a manner that any oil accumulating in the header returns equally to each machine. Evaporative condensers can be constructed with two or more condensers built into one spray housing. This is accomplished quite simply by providing a separate condensing coil for each compressor, or a group of compressors operating at the same suction pressure. All of the condensing coils are built into one spray housing; this provides two or more separate condensers in one condenser housing.

Test your Knowledge (Select the Correct Response)

10. What type of acid is formed when refrigerant is mixed with water?

    A. Hydrofluoric
    B. Sulfuric
    C. Hydrochloric
    D. Carbonic

11. U-traps or oil separators should be installed on multiple compressor systems when the condensers are how many feet above the compressor?

    A. 10
    B. 12
    C. 13
    D. 15

7.0.0 MAINTENANCE, SERVICE, and REPAIR of REFRIGERATION EQUIPMENT

As a UT, you must be able to maintain, service, and repair refrigeration equipment. When information here varies from that in the latest federal or military specifications, the specifications apply. You will find *Table 12-4* helpful in troubleshooting refrigeration system problems. It is not intended to be all encompassing. Manufacturers also provide instruction manuals to aid you in maintaining and servicing their equipment.

Table 12-4 — Troubleshooting checklist for refrigeration systems

TROUBLE	POSSIBLE CAUSE	CORRECTIVE MEASURE
High condensing pressure	Air or non-condensable gas in system.	Purge air from condenser.
	Inlet water warm.	Increase quantity of condensing water.
	Insufficient water flowing through condenser.	Increase quantity of water.
	Condenser tubes clogged or scaled.	Clean condenser water tubes.

Table 12-4 — Troubleshooting checklist for refrigeration systems (cont.)

TROUBLE	POSSIBLE CAUSE	CORRECTIVE MEASURE
	Too much liquid in receiver, condenser tubes submerged in liquid refrigerant.	Draw off liquid into service cylinder.
	Insufficient cooling of air-cooled condenser.	Check fan operation, cleanliness of condenser, and for adequate source of air flow.
Low condensing pressure.	Too much water flowing through condenser.	Reduce quantity of water.
	Water too cold.	Reduce quantity of water.
	Liquid refrigerant flooding back from evaporator.	Change expansion valve adjustment, examine fastening of thermal bulb.
	Leaky discharge valve.	Remove head, examine valves. Replace any found defective.
High auction pressure.	Overfeeding of expansion valve. Leaky suction valve.	Regulate expansion valve, check bulb attachment. Remove head, examine valve and replace if worn.
Low suction pressure.	Restricted liquid line and expansion valve or suction screens.	Pump down, remove, examine and clean screens.
	Insufficient refrigerant in system.	Check for refrigerant storage.
	Condenser tubes clogged or scaled.	Clean condenser water tubes.
	Too much oil circulating in system.	Check for too much oil in circulation. Remove oil.
	Improper adjustment of expansion valves.	Adjust valve to give more flow.
	Expansion valve power element dead or weak.	Replace expansion valve power element.
	Low refrigerant charge.	Locate and repair leaks. Charge refrigerant.
Compressor short cycles on low-pressure control.	Thermal expansion valve not feeding properly. 1. Dirty strainers 2. Moisture frozen in orifice or orifice plugged with dirt. 3. Power element dead or weak.	Adjust, repair, or replace thermal expansion valve. 1. Clean strainers. 2. Remove moisture or dirt (Use system dehydrator). 3. Replace power element.
	Water flow through evaporators restricted or stopped. Evaporator coils plugged, dirty, or clogged with frost.	Remove restriction. Check water flow. Clean coils or tubes.

Table 12-4 — Troubleshooting checklist for refrigeration systems (cont.)

TROUBLE	POSSIBLE CAUSE	CORRECTIVE MEASURE
Compressor short cycles on low-pressure control (cont.).	Defective low-pressure control switch.	Repair or replace low-pressure control switch.
Compressor runs continuously.	Shortage of refrigerant.	Repair leak and recharge system.
	Leaking discharge valves.	Replace discharge valves.
Compressor short cycles on high-pressure control switch.	Insufficient water flowing through condenser, clogged condenser.	Determine if water has been turned off. Check for scaled or fouled condenser.
	Defective high-pressure control switch.	Repair or replace high-pressure control switch.
Compressor will not run.	Seized compressor.	Repair or replace compressor.
	Cut-in point of low-pressure control switch too high. High-pressure control switch does not cut in. 1. Defective switch. 2. Electric power cut-off. 3. Service or disconnect switch open. 4. Fuses blown. 5. Overload relays tripped. 6. Low voltage. 7. Electrical motor in trouble. 8. Trouble in starting switch or control circuit. 9. Compressor motor stopped by oil-pressure differential switch.	Set L.P. control switch to cut in at correct pressure. Check discharge pressure and reset H.P. control switch. 1. Repair or replace switch. 2. Check power supply. 3. Close switches. 4. Test fuses and renew if necessary. 5. Reset relays and find cause of overload. 6. Check voltage (should be within 10 percent of nameplate rating). 7. Repair or replace motor. 8. Close switch manually to test power supply. If OK check control circuit including temperature and pressure controls. 9. Check oil levels in crankcase. Check oil pressure.
Sudden loss of oil from crankcase.	Liquid refrigerant slugging back to compressor crankcase.	Adjust or replace expansion valve.
Capacity reduction system fails.	Hand-operating stem of capacity control valve not turned to automatic position.	Set hand-operating stem to automatic position.

Table 12-4 — Troubleshooting checklist for refrigeration systems (cont.)

TROUBLE	POSSIBLE CAUSE	CORRECTIVE MEASURE
Compressor continues to operate at full or partial load.	Pressure-regulating valve not opening.	Adjust or repair pressure-regulating valve.
Capacity reduction system fails to load cylinders.	Broken or leaking oil tube between pump and power element.	Repair leak.
Compressor continues to operate unloaded.	Pressure-regulating valve not closing.	Adjust or repair pressure-regulating valve.

7.1.0 Servicing Equipment

Repair and service work on a refrigeration system consists mainly of containing refrigerant and measuring pressures accurately. One piece of equipment is the refrigerant gauge manifold set (*Figure 12-50*). It consists of a 0-500 psig gauge for measuring pressure at the compressor high side, a compound gauge (0-250 psig and 0 to -30 inches of mercury) to measure the low or suction side, and valves to control admission of the refrigerant to the refrigeration system. It also has the connections and lines required to connect the test set to the system.

Depending on test and service requirements, the gauge set can be connected to the low side, the high side, a source of vacuum, or a refrigerant cylinder. A swiveling hanger allows the test set to be hung easily.

Figure 12-50 — Refrigerant gauge manifold set.

Another important piece of equipment is the portable vacuum pump. The type listed in the Seabee Table of Allowance is a sealed unit consisting of a single-piston vacuum pump driven by an electric motor. A vacuum pump is the same as a compressor, except the valves are arranged so the suction valve is opened only when the suction, developed by the downward stroke of the piston, is greater than the vacuum already in the line. This vacuum pump can develop a vacuum close to -30 inches of mercury, which can be read on the gauge mounted on the unit (*Figure 12-51*). The pump reduces the pressure in a refrigeration system to below atmospheric pressure.

The Navy uses hermetic refrigeration systems produced by various manufacturers, which can vary the connectors and tubing size being used. The Table of Allowance provides for a refrigeration service kit that contains several adapters, wrenches, and other materials to help connect different makes of systems to the refrigerant manifold gauge set and the vacuum pump lines. A table affixed to the lid of the storage container identifies the adapter you should use for a particular refrigeration unit.

Figure 12-51 — Portable vacuum pump.

7.2.0 Transferring Refrigerants

Refrigerants are shipped in compressed gas cylinders as a liquid under pressure. Liquids are usually removed from the shipping containers and transferred to a service cylinder (*Figure 12-52*). Before attempting transfer of refrigerants, you should precool the service cylinder until its pressure is lower than that of the storage cylinder. Precool the cylinder by placing it in ice water or a refrigerated tank. You must also weigh the service cylinder, including cap, and compare it with the ***tare weight*** stamped or tagged on the cylinder. The amount of refrigerant that may be placed in a cylinder is 85 percent of the tare weight (the weight of a full cylinder and its cap minus the weight of the empty cylinder and its cap).

To transfer refrigerants, you connect a flexible charging line on a 1/4-inch copper tube several feet long with a circular loop about 8 to 10 inches in diameter. Be sure to install a 1/4-inch refrigerant shutoff valve (*Figure 12-52*) in the charging line to the service cylinder. This valve should be inserted so no more than 3 inches of tubing is between the last fitting and the valve itself. This arrangement prevents the loss of refrigerant when the service drum is finally disconnected.

The entire line must be cleared of air by leaving the flare nut on the service cylinder loose and cracking the storage cylinder valve. This arrangement allows refrigerant to flow through the tubing, clearing it.

After clearing the line, tighten the flare nut and then open the valve on the service cylinder, the valve on the storage cylinder, and the 1/4-inch valve in the refrigerant line. When the weight of the service cylinder shows a sufficient amount of refrigerant is in the serviced cylinder, close all valves tightly, and disconnect the charging line at the service cylinder.

Figure 12-52 — Method of transferring refrigerants to service cylinders.

CAUTION

To warm refrigerant containers or cylinders for more rapid discharge, use care to prevent a temperature above 120°F because the fusible plugs in the cylinder and valve have a melting point of about 157°F.

7.3.0 Evacuating and Charging a System

One of your duties will be charging a system with refrigerant. If a system develops a leak, you must first repair the leak and then charge the system. Also, if a system component becomes faulty and has to be replaced, some refrigerant will be lost which requires you to recharge the system.

7.3.1 Evacuation

Before a system can be charged, all moisture and air must be eliminated from the components by drawing a vacuum on the system. To draw a vacuum on the system, proceed as follows:

1. Connect the portable vacuum pump to the vacuum fitting on the refrigerant manifold gauge set (*Figure 12-50*).
2. Connect the LO line (suction) to the suction service valve of the compressor, using appropriate connectors if required.
3. Turn the suction service valve to mid-position so vacuum draws from the compressor crankcase and suction line back through the evaporator, expansion

valve, condenser service valve, and liquid line. When the receiver service valve, condenser service valve, and discharge service valve are open, the pump draws back through the receiver and condenser to the compressor.

4. Attach one end of the 1/4-inch copper tube to the vacuum pump discharge outlet (*Figure 12-53*). Allow the vacuum pump to draw a vacuum of at least 25 inches. Submerge the other end of the copper tubing under 2 or 3 inches of clean compressor oil contained in a bottle.
5. Continue to operate the vacuum pump until there are no more bubbles of air and vapor in the oil, which indicates that a deep vacuum has been obtained.
6. Maintain the deep vacuum operation for at least 5 minutes, and then stop the vacuum pump. When vacuum pump discharge valves leak, it can cause oil to be sucked up into the copper discharge tube. It is important to keep the vacuum pump off for at least 15 minutes which allows air to enter the system through any leaks. Next, start the vacuum pump. Remember, a leaky system causes bubbling of the oil in the bottle.
7. Examine and tighten any suspected joints in the line, including the line to the vacuum pump. Repeat the test.

Figure 12-53 — Connections for drawing a vacuum.

7.3.2 Charging

In most small refrigerating systems, low-side charging is generally recommended for adding refrigerant after repairs have been made, and the system has been cleaned and tested for leaks (*Figure 12-54*).

Figure 12-54 — Connections for low-side charging.

The steps for low-side charging a refrigeration system are as follows:

1. Connect a line from a refrigerant cylinder to the bottom center connection on the refrigerant gauge manifold set. Be certain the refrigerant cylinder is in a vertical position, so only refrigerant in the form of gas, not liquid, can enter the system. Leave the connection loose and crack the valve on the cylinder. This fills the line with gas and clears the air from the line. After clearing, tighten the connection.
2. Connect a line from the LOW (LO) valve (suction) on the gauge manifold to the suction service valve of the compressor.
3. Start the compressor.
4. Open the valve on the cylinder and the LOW (LO) valve (suction) on the gauge manifold set.
5. Open the suction service valve on the compressor to permit the gas to enter the compressor where it will be compressed and fed to the high side. Add the refrigerant slowly and check the liquid level indicator regularly until the system is fully charged. It is easy to check the receiver refrigerant level in some makes of condensing units because the receiver has minimum and maximum liquid level

indicator valves which show the height of the liquid level when opened. If a liquid line sight glass is used, the proper charge may be determined when there is no bubbling of refrigerant as it passes by the glass. The sight glass will appear empty.

Remember, liquid is not compressible, so be certain the refrigerant cylinder is in the vertical position at all times; otherwise, the liquid refrigerant will enter the compressor and damage the piston or other parts of the compressor.

7.4.0 Refrigerant Leaks

The best time for you to test the system joints and connections is when there is enough pressure to increase the rate at which the refrigerant seeps from the leaking joint. There is usually enough pressure in the high-pressure side of the system that is, in the condenser, receiver, and liquid line, including dehydrators, strainers, line valves, and solenoid valves. This is not necessarily true of the low-pressure side of the system, especially if it is a low-pressure installation for frozen foods and ice cream, where pressures may run only slightly above zero on the gauge. When there is little pressure, increase the pressure in the low-pressure side of the system by bypassing the discharging pressure from the condenser to the low-pressure side through the service gauge manifold. Regardless of the test method used, small leaks cannot be found unless the pressure inside the system is at least 40 to 50 psi.

7.4.1 Halide Leak Detector

The use of a halide leak detector is the most positive method of detecting leaks in a refrigerant system using halogen refrigerants (R-12, R-22, R-11, R-502, etc.) (*Figure 12-55*). Such a detector consists essentially of a torch burner, a copper reactor plate, and a rubber exploring hose.

Detectors use acetylene gas, alcohol, or propane as a fuel. A pump supplies the pressure for a detector that uses alcohol. If a pump-pressure type of alcohol-burning detector is used, be sure that the air pumped into the fuel tank is pure

An atmosphere suspected of containing a halogen vapor is drawn through the rubber exploring hose into the torch burner of the detector. Here the air passes over the copper reactor plate, which is heated to ***incandescence***. If there is a minute trace of a halogen refrigerant present, the color of the torch flame changes from blue (neutral) to green as the halogen refrigerant contacts the reactor plate. The shade of green depends upon the amount of halogen refrigerant; a pale green color shows a small concentration and a darker green color, a heavier concentration. Too much of a halogen refrigerant causes the flame to burn with a vivid purple color. Extreme concentrations of a halogen refrigerant may extinguish the flame by crowding out the oxygen available from the air.

Normally, a halide leak detector is used for R-12 and R-22 systems. In testing for leaks always start at the highest point of the system and work towards the lowest point because halogen refrigerants are heavier than air.

Figure 12-55 — Halide leak detector.

When using a leak detector, you will obtain the best results by following the precautions listed below:

1. Be sure the reactor plate is placed properly.
2. Adjust the flame so it does not extend beyond the end of the burner. (A small flame is more sensitive than a large flame. If it is hard to light the torch when it is adjusted to produce a small flame, block the end of the exploring hose until the fuel ignites; then gradually open the hose.)
3. Clean out the rubber exploring hose if the flame continues to have a white or yellow color. (A white or yellow flame is an indication that the exploring tube is partially blocked with dirt.)
4. Check to see that air is being drawn into the exploring tube; this check can be made from time to time by holding the end of the hose to your ear.
5. Hold the end of the exploring hose close to the joint being tested to prevent dilution of the sample by stray air currents.
6. Move the end of the exploring hose slowly and completely around each joint being tested. (Leak testing cannot be safely hurried. There is a definite time lag between the moment when air enters the exploring hose and the moment it reaches the reactor plate; permit enough time for the sample to reach the reactor plate.)

If a greenish flame is noted, repeat the test in the same area until the source of the refrigerant is located.

When testing for refrigerant leaks, you should always follow a definite procedure so none of the joints are missed. Even the smallest leaks are important. However slight a leak may seem, it eventually empties the system of its charge and causes faulty operation. In the long run, the extra time you spent in testing each joint will be justified. A refrigerant system should never be recharged until all leaks are found and repaired.

7.4.2 Electronic Leak Detector

The most sensitive leak detector of all is the electronic type (*Figure 12-56*). The principle of operation is based on the dielectric difference of gases. In operation, the gun is turned on and adjusted in a normal atmosphere. The leak-detecting probe is then passed around the surfaces suspected of leaking. If there is a leak, no matter how tiny, the halogenated refrigerant is drawn into the probe. The leak gun then gives out a piercing sound, or a light flashes, or both, because the new gas changes the resistance in the circuit.

When using an electronic leak detector, minimize drafts by shutting off fans or other devices that cause air movement. Always position the sniffer below the suspected leak. Refrigerant drifts downward because it is heavier than air. Always remove the plastic tip and clean it before each use. Avoid clogging the tip with dirt and/or lint. After cleaning the tip move it slowly around the suspected leak.

Figure 12-56 — Electronic leak detector.

7.4.3 Soap and Water Test

Leakage of refrigerant with a pressure higher than atmospheric pressure may be tested using soap and water. Make a soap and water solution by mixing a lot of soap with water to a thick consistency. Let it stand until the bubbles have disappeared, and then apply it to the suspected leaking joint with a soft brush. Wait for bubbles to appear under the clear, thick soap solution.

When you are looking for extremely small leaks, use a strong light to examine any places that are suspect. If necessary, use a mirror to view the rear side of joints or other connections suspected of leaking.

7.5.0 Recovery, Recycling, and Reclaiming Refrigerant

Laws governing the release of chlorofluorocarbon refrigerants (CFCs) into the atmosphere have resulted in the development of procedures to recover, recycle, and reuse these refrigerants. Many companies have developed equipment necessary to prevent the release of CFCs into the atmosphere. Refrigerant recovery management equipment can be divided into three categories—recovery, recycle, and reclaiming equipment.

7.5.1 Recovery

Removing refrigerant from a system in any condition and storing it in an external container is called "recovery." When repair of a system is needed, removal of system refrigerant is necessary. To accomplish this task, you are required to use the special recovery equipment, which ensures complete removal of system refrigerant. This is sometimes referred to as pumping-down the system.

Recovery is similar to evacuating a system with the vacuum pump and is accomplished by either the vapor recovery or liquid recovery method. In the vapor recovery method a hose is connected to the low-side access point (compressor suction valve) through a filter-drier to the transfer unit, compressor suction valve (*Figure 12-57*). A hose is then connected from the transfer unit, compressor discharge valve to an external storage cylinder. When the transfer unit is turned on, it withdraws vapor refrigerant from the system into the transfer unit compressor, which in turn condenses the refrigerant vapor to a liquid and discharges it into the external storage cylinder.

Figure 12-57 — Vapor recovery method.

In the liquid recovery method a hose is connected to the low-side access point to the transfer unit compressor discharge valve (*Figure 12-58*). Another hose is then connected from the transfer unit compressor suction valve through a filter-drier to a two-valve external storage cylinder. A third hose is connected from the high-side access point (liquid valve at the receiver) to the two-valve external storage cylinder. When the transfer unit is turned on, the transfer unit compressor pumps refrigerant vapor from the external storage cylinder into the refrigeration system, which pressurizes it. The difference in pressure between the system and the external storage cylinder forces the liquid refrigerant from the system into the external cylinder. Once the liquid refrigerant is removed from the system, the remaining vapor refrigerant is removed using the vapor recovery method as previously described.

Most recovery units automatically shut off when the refrigerant has been completely recovered, but check the manufacturer's operational manual for specific instructions. You should make sure that the external storage cylinder is not overfilled. Eighty percent capacity is normal. If the recovery unit is equipped with a sight-glass indicator, you should note any changes that may occur.

Figure 12-58 — Liquid recovery method.

7.5.2 Recycling

The process of cleaning refrigerant for reuse by oil separation and single or multiple passes through filter-driers which reduce moisture, acidity, and matter is called “recycling.” In the past, refrigerant was typically vented into the atmosphere. Modern technology has developed equipment to enable reuse of old, damaged, or previously used refrigerant.

Refrigerant removed from a system cannot be simply reused—it must be clean. Recycling performed in the field by most recycling machines uses oil separation and filtration to reduce contaminants. Normally recycling is accomplished during the recovery of the vapor or liquid refrigerant by using equipment that does both recovery and recycling of refrigerant.

Recycling machines use either the single-pass or multiple-pass method of recycling. The single-pass method processes refrigerant through a filter-drier and/or uses distillation (*Figure 12-59*). It makes only one pass through the recycling process to a storage cylinder. The multiple-pass method re-circulates refrigerant through the filter-drier (*Figure 12-60*). After a period of time has elapsed or a number of cycles have occurred, the refrigerant is transferred to a storage cylinder.

Figure 12-59 — Single-pass method of recycling.

Figure 12-60 — Multiple-pass method of recycling.

7.5.3 Reclaiming

The reprocessing of a refrigerant to original production specifications after verification by chemical analysis is called "reclaiming." Equipment used for this process must meet SAE standards and remove 100 percent of the moisture and oil particles.

Most reclaiming equipment uses the same process cycle for reclaiming refrigerant. The refrigerant enters the unit as a vapor or liquid and is boiled violently at a high temperature at extreme high pressure (distillation). The refrigerant then enters a large, unique separator chamber where the velocity is radically reduced, which allows the high-temperature vapor to rise.

During this phase all the contaminants, such as copper chips, carbon, oil, and acid, drop to the bottom of the separator to be removed during the "oil out" operation. The distilled vapor then leaves the separator and enters an air-cooled condenser where it is converted to a liquid. The liquid refrigerant then passes through a filter-drier and into a storage chamber where the refrigerant is cooled to a temperature of 38°F to 40°F by an evaporator assembly.

7.6.0 Component Removal and Replacement

As a UT you are responsible for maintaining refrigerant systems at an optimum operating condition. To meet this requirement you may be assigned to remove or replace system components. Therefore, it is important that you understand the following procedures for removing and replacing system components.

7.6.1 oving Expansion or Float Valves

To help ensure good results in removing expansion or float valves, you should pump the system down to a suction pressure of just over zero. You should do this at least three times before removing the expansion valve. Plug the opened end of the liquid line and evaporator coil to prevent air from entering the system. Repair or replace the expansion valve and connect it to the liquid valve. Crack the receiver service valve to clear air from the liquid line and the expansion valve. Connect the expansion valve to the evaporator coil inlet and tighten the connection. Pump a vacuum into the low side of the system to remove any air.

7.6.2 Replacing an Evaporator

To replace an evaporator, pump down the system and disconnect the liquid and suction lines. Then remove the expansion valve and the evaporator. Make the necessary repairs or install a new evaporator as required. Replace the expansion valve and connect the liquid and suction lines. Remove moisture and air by evacuating the system. When the evaporator is back in place, pump a deep vacuum as in starting a new installation for the first time. Check for leaks and correct them if they occur. If leaks do occur, be certain to repair them; then pump the system into a deep vacuum. Repeat the process until no more leaks are found.

7.6.3 Removing the Compressor

Using the gauge manifold and a vacuum pump, pump down the system. Most of the refrigerant will be trapped in the condenser and the receiver. To remove the compressor from service, proceed as follows:

1. Once the pump down is complete, the suction valve should already be closed and the suction gauge should read a vacuum. Mid-seat the discharge service

valve. Open both manifold valves to allow high-pressure vapor to build up the compressor crankcase pressure to 0 psi.

2. Front-seat (close) the discharge service valve. Then crack the suction service valve until the compound gauge reads 0 to 1 psi to equalize the pressures and then front-seat the valve.
3. Joints should be cleaned with a grease solvent and dried before opening. Unbolt the suction service and discharge service valves from the compressor. DO NOT remove the suction or discharge lines from the compressor service valves.
4. Immediately plug all openings through which refrigerant flows using dry rubber, "cork" stoppers, or tape.
5. Disconnect the bolts that hold the compressor to the base and remove the drive belt or disconnect the drive coupling. You can now remove the compressor.

7.6.4 Removing Hermetic Compressors

Systems using hermetic compressors are not easily repaired, as most of the maintenance performed on them consists of removal and replacement. To remove or replace a hermetic compressor, proceed as follows:

1. Disconnect the electrical circuit including the overload switch.
2. Install a gauge manifold. Use a piercing valve (Schrader) if needed
3. Remove the refrigerant using an EPA-approved recovery/recycling unit.
4. Disconnect the suction and discharge lines. Using a pinching tool, pinch the tubing on both the suction and discharge lines, and cut both lines between the compressor and the pinched area.
5. Disconnect the bolts holding the compressor to the base and remove the compressor.

If necessary, do not forget to pump down the system and equalize the suction and head pressure to the atmosphere. Wear goggles to prevent refrigerant from getting in your eyes. After replacement, the procedures given for removing air and moisture and recharging the system can be followed; however, the procedures may have to be modified because of the lack of some valves and connections. Follow the specific procedures contained in the manufacturer's manual.

Test your Knowledge (Select the Correct Response)

12. When transferring refrigerant, the amount of refrigerant that may be placed in a cylinder is what percentage of the tare-weight?

    A. 50
    B. 65
    C. 70
    D. 85

13. What is the best leak detector to use when trying to detect a halogen refrigerant leak?

A. Hydraulic
B. Scanning
C. Halide
D. Electronic

8.0.0 MAINTENANCE of COMPRESSORS

In order for you to perform the required maintenance on compressors, it is important that you know the locations of the inspection points for open-type refrigeration compressors. It is also important for you to know the repair procedures for common problems associated with those types of compressors.

8.1.0 Open Types of Compressors

A vertical single-acting reciprocating compressor is shown in *Figure 12-61*. Some of the duties you may perform in maintaining this and other open-type compressors are discussed below.

8.1.1 Shaft Bellow Seal

Refrigerant leakage often occurs at the shaft bellows seal with consequent loss of charge. Install a test gauge in the line leading from the drum to the compressor. Attach a refrigerant drum to the suction end of the shutoff valve outlet port. Apply the proper amount of pressure, as recommended in the manufacturer's instructions.

Test for leaks with a halide leak detector around the compressor shaft, seal gasket, and seal nut. Slowly turn the shaft by hand. When a leak is located at the seal nut, replace the seal plate, gasket, and seal assembly; when the leak is at the gasket, replace the gasket only. Retest the seal after reassembly. (This procedure is typical for most shaft seals on reciprocating open-type compressors.)

8.1.2 Valve Obstructions

Obstructions such as dirt or corrosion may be formed under seats of suction or discharge valves. To locate the source of these problems, proceed as follows:

When the suction valve side is obstructed, the unit tends to run for long periods of time or continuously. Connect the gauge manifold and start the unit. This pressure gauge (HI) will not indicate an increase in pressure. The low-side gauge (LO) will fluctuate and will not indicate any decrease in pressure. Clean out any obstructions and recheck again by using the test gauge assembly.

If you want to determine if there is a discharge valve leak, connect the gauge manifold and start the unit. Run it until the low-side (LO) pressure gauge indicates normal pressure for the unit. Stop the unit. Place an ear near the compressor housing and listen for a hissing sound. Also, watch the gauges. When leaking caused by an obstruction is present, the low-side pressure rises, and the high side decreases until the pressures are equalized. A quick equalization of pressures indicates a bad leak that should be repaired immediately or the compressor replaced.

Figure 12-61 — Vertical single-acting reciprocating compressor.

8.1.3 Compressor Lubrication

The oil level in the compressor crankcase should be checked by following the procedure in the manufacturer's manual. This procedure normally includes the following steps:

1. Attach the gauge manifold to the suction and discharge service valves.
2. Pump the system down.
3. Close the suction and discharge valves, isolating the compressor.
4. Remove the oil filter plug and measure the oil level as per the manufacturer’s manual.

8.1.4 Compressor Knocks

If you hear a knocking in the compressor, you may have to disassemble the compressor to determine whether the cause is a loose connecting rod, piston pin, or crankshaft. Sometimes a loose piston can be detected without doing a complete disassembly of the compressor. In cases requiring disassembly, you should take the following steps:

1. Remove the cylinder head and valve plate to expose the top of the piston.
2. Start the motor and press down on the top of the piston with your finger. If you feel any looseness with each stroke of the piston, replace the loose part.
3. Check the oil level because oil levels that are too high can cause knocks. Always make sure that a low oil level is actually the result of a lack of oil, rather than a low charge.

8.1.5 Stuck or Tight Compressor

A stuck or tight compressor often occurs as a result of poor reassembly after a breakdown repair. In such cases, determine where the binding occurs and reassemble the unit with correct tolerances; avoid uneven tightening of screws or seal covers.

8.2.1 Inspection of Compressors

From time to time you will have to perform an inspection on a refrigeration unit. During the inspection you should have the unit operating, then check for knocks, thumps, rattles, and other noises. Make sure you clean any of the external parts that have excessive grease, dirt, or lint on them. Before beginning any cleaning, you should always ensure the power is off.

It is essential that you do a careful check of the entire system using the required instruments and tools to determine if there is any loss of refrigerant.

Remember, NO LEAK IS TOO SMALL TO BE FIXED. Each leak must be stopped immediately.

Some specific conditions to look for during the inspection of a refrigeration system are as follows:

- Check for inadequate lubrication of bearings and other moving parts.
- Rusty or corroded parts discovered during the inspection should be cleaned and painted.
- Hissing sounds at the expansion valve, low readings on the discharge pressure gauge, and bubbles in the receiver sight glass all indicate a weak refrigerant charge.
- Loose connections and worn or pitted switch contacts result in inoperative equipment or reduced reliability.
- Thermostats with burned contacts may produce abnormal temperatures in the cooled compartment.
- Fans with bent blades, loose or worn belts are hard to rotate by hand and can cause problems. During inspections, fan troubles are easy to locate and correct.

- Air filters clogged with dirt should be cleaned or replaced during the inspection.
- Hermetically sealed units should be inspected for signs of leaks and high temperatures and for too much noise or vibration.

Test your Knowledge (Select the Correct Response)

14. What unit valve is considered to be obstructed when the unit runs continuously?

    A. Detector
    B. Suction
    C. Shutoff
    D. Discharge

15. What can cause the unit's compressor to become stuck or tight?

    A. Loose piston pin
    B. Excessive grease
    C. Poor reassembly
    D. Clogged air filter

9.0.0 MAINTENANCE of MOTORS

As a UT, you need to have an understanding of the basic maintenance and the troubleshooting methods used for electrical motors.

Mechanical and electrical are the types of problems you may encounter with electrical motors used to drive the compressors of mechanical refrigeration systems.

9.1.0 Mechanical Problems

The electrical motors of some compressors are belt-driven, which means you will have to adjust the belt tension and pulley alignment for proper operation. The belt tension should be adjusted so 1-pound of force on the center of the belt, either up or down, does not depress it more than one-half inch. To adjust the alignment, loosen the setscrew on the motor pulley after tension adjustment is made. Be sure the pulley turns freely on the shaft; add a little oil if necessary. Turn the flywheel forward and backward several times. When it is correctly aligned, the pulley does not move inward or outward on the motor shaft. Tighten the setscrew holding the pulley to the shaft before starting the motor.

Compressors may also be driven directly by a mechanical coupling between the motor and compressor shafts. Be sure the two shafts are positioned so they form a straight line with each other. The coupling on direct drive units should be realigned after repair or replacement. Clamp a dial indicator to the motor half coupling with its pointer against the outer edge of the compressor half coupling. Rotate the motor shaft, and observe any fluctuations of the indicator. Move the motor or compressor until the indicator is stationary when revolving the shaft one full turn. Secure the hold-down bolts and then recheck.

9.1.1 Moisture in the System

When liquid refrigerant that contains moisture vaporizes, the moisture separates from the vapor. Because the vaporization of the refrigerant causes a cooling effect, the water that has separated can freeze. Most of the expansion and vaporization of the refrigerant

occurs in the evaporator. However, a small amount of the liquid refrigerant vaporizes in the expansion valve, and the valve is cooled below the freezing point of water.
As a result, ice can form in the expansion valve and interfere with its operation. If the needle in the valve freezes in a slightly off-seat position, the valve cannot permit the passage of enough refrigerant. If the needle freezes in a position far from the seat, the valve feeds too much refrigerant. In either case, you must observe all precautions to assure the system stays moisture-free.

A dehydrator is filled with a chemical known as a desiccant, which absorbs moisture from the refrigerant passing through the dehydrator (*Figure 12-62*). Dehydrators are installed in the liquid line to absorb moisture in the system after the original installation. An arrow on the dehydrator indicates the direction of flow. Desiccants are granular and are composed of silica gel, activated alumina, or calcium sulfate. Do not use calcium chloride or chemicals that form a nonfreezing solution. These solutions may react with moisture to form undesirable substances, such as gums, sledges, or waxes. Follow the manufacturer's instructions as to limitations of dehydrators, as well as operation, recharging, replacing, and servicing.

Figure 12-62 — Refrigeration dehydrator

9.1.2 Loose Copper Tubing

In sealed units, loose copper tubing is usually detected by the sound of rattling or metallic vibration. Bending the tubing carefully to the position of least vibration usually eliminates the defect. Do not touch it against other tubing or parts at a point of free movement, and do not change the tubing pitch or the tubing diameter by careless bending.

In open units, lengths of tubing must be well supported by conduit straps or other devices attached to walls, ceilings, or fixtures. Use friction tape pads to protect the copper tubing from the metal of the strap. When two tubes are together in a parallel position, wrapping and binding them together with tape can prevent vibration. When two lines are placed in contact for heat exchange, they should be soldered to prevent rattling and to permit better heat transfer.

9.1.3 Doors and Hardware

If you have to replace door hinges because they lack lubrication or have other problems, replace them with same type of hinges, when possible. If you find any loose hinge pins you should securely braid them. When thrust bearing are provided, they are held in place by a pin.

The latch or catch is usually adjusted for proper gasket compression. Shims or spacers may be added or removed for adjustment. Latch mechanisms should be lubricated and adjusted for easy operation. Latch rollers must not bind when operated. Be sure to provide sufficient clearance between the body of the latch and catch, so no contact is made. The only contact is made between the catch and the latch bolt or roller. These instructions also apply to safety door latches when they are provided for opening the door from the inside, although it is locked from the outside.

A lack of complete gasket contact between the door overlap and the doorframe is usually caused by a warped door. This condition can be corrected if you install a long tapered wooden shim or splicer under the door seal. If this does not tighten the door to the frame, remove the door and realign or rebuild it.

If you find any door gaskets that are missing, worn, warped, or loose, you should repair or replace them. When the gasket is clamped or held in place by the doorframe or the door panel, use the same type of gasket to replace it. In either case, the gasket should be installed so when the door is closed a complete and uniformly tight seal results. When condensation causes the doors to freeze shut, you should apply a light coat of glycerin on the gaskets.

9.1.4 Defrosting

Setting the low-pressure control switch to a predetermined level will usually defrost cooling units in the 35°F to 45°F refrigerators or cold storage rooms. Manual defrosting is required if this setting causes an overload, resulting in heavy frosting of the coil. Cooling units with temperatures of 35°F and lower are defrosted manually. The most common method for manual defrosting is to spray water over the cooling coil. Warm air, electric heating, or hot gas refrigerant can also be used for defrosting. In any case, the fans must not be in operation during the defrosting.

Plate-type evaporator banks in below-freezing refrigerators should be defrosted when the ice becomes one-half inch thick. They should also be defrosted when the buildup of ice affects the temperature of the fixtures or the suction pressure. Before removing frost from the plates, place a tarpaulin on the floor or over the contents of the refrigerator to catch the frost under the bank.

9.2.0 Electrical Defects

The control systems for modern refrigeration systems are composed of many components that use or pass electrical power. These components include compressor drive motors, pressure switches, thermostats, and solenoid stop valves. Although you are not responsible for troubleshooting these electrical components, you must be able to use the multi-meter for locating opens, shorts, and grounds, and measuring voltage and current. Navy Electricity and Electronics Training Series (NEETS), NAVEDTRA 14175, *Introduction to Circuit Protection, Control, and Measurement* will help you in learning to use electrical meters and testing equipment.

9.2.1 Opens

Figure 12-63, View A, shows a simple refrigeration control system. You have learned the basics of electricity and how to use meters. Using this figure, you will put that knowledge to work. Remember, if you are having problems, call your supervisor or arrange for a Construction Electrician to help you.

Figure 12-63 — Simple refrigeration control system.

An "open" is defined as the condition of a component that prevents it from passing current. It may be a broken wire, a burned or pitted relay contact, a blown fuse, a broken relay coil, or a burned-out coil winding. An open can be located in one of two ways.

A voltmeter should be used for the components in series, such as the main disconnect switch, fuses, the wire from Point C to Point D (*Figure 12-63*), the relay contacts, and the wire from Point E to Point F. Set up the voltmeter to measure the source voltage (120 volts ac, in this case). If the suspected component is open, the source will be measured across it. To check part of the main disconnect switch, close the switch and measure from Point A to Point B. If the meter reading is 0 volts, that part of the switch is good; if the voltage equals the source voltage, the switch is open.

To check the fuse F2, measure across it, Point B to Point C as shown in *Figure 12-63, view B*. Measuring across Points C and D or E and F will check the connecting wires for opens. One set of relay contacts can be checked by taking meter readings at Points D and E. These are just a few examples, but the rule of series components can always be applied. Remember, the three sets of contacts of relay K1 will not close unless voltage is present across the relay coil; the coil cannot be open or shorted. When testing an electrical circuit, follow the safe practices you have been taught and use procedures outlined in equipment manuals.

Opens in components that are in parallel cannot easily be found with a voltmeter because, as you know, parallel components have voltage across them at all times when the circuit is energized. In *Figure 12-63*, the branch with the motor relay K1 and the dual refrigerant pressure control are considered a parallel circuit because when the main disconnect switch is closed and the fuses are good, there is voltage between Points C and H, regardless of whether the relay coil and pressure switch are open.
To check for opens in these components, use an ohmmeter set at a low range. Disconnect all power by opening (and locking out, if possible) the main disconnect switch. This action removes all power and ensures both personal and equipment safety. To check the motor relay K1 to see if its coil is open, put the ohmmeter leads on Points C and G. A reading near infinity (extremely high resistance) indicates an open. The contacts of the dual refrigerant pressure control can be tested by putting the ohmmeter leads from Point G to Point H. Again, a reading near infinity indicates open contacts. You may need to consult the manufacturer's manual for the physical location of Points G and H. Notice the contacts of the control are normally closed when neither the head pressure nor the suction pressure is above its set limits.

9.2.2 Shorts

Shorts are just the opposite of opens. Instead of preventing the flow of current, they allow too much current to flow, often blowing fuses. The ohmmeter on its lowest range is used to locate shorts by measuring the resistance across suspected components. If the coil of the motor relay K1 is suspected of being shorted, put the leads on Points C and G as shown in *Figure 12-63, View C*. A lower than normal reading (usually almost zero) indicates a short. You may have to determine the normal reading by consulting the manufacturer’s manual or by measuring the resistance of the coil of a known good relay. If fuses F2 and F3 blow and you suspect a short between the middle and bottom lines (*Figure 12-63*), put the ohmmeter leads between Points C and H. Again, a low reading indicates a short. Remember, in all operations using an ohmmeter, it is imperative that all power be removed from the circuit for equipment and personal safety. Do not fail to do this!

9.2.3 Grounds

A ground is an accidental connection between a part of an electrical circuit and ground, due perhaps, to physical contact through wearing of insulation or movement. To locate a ground, follow the same procedure you used to locate a short. The earth itself, a cold-water pipe, or the frame of a machine, are all examples of ground points.

To see whether a component is shorted to ground, put one ohmmeter lead on the ground and the other on the point suspected to be grounded and follow the rules for locating a short.

Be sure to turn off all power to the unit. It may even be wise to check for the presence of voltage first. Use a voltmeter set to the range suitable for measuring source voltage. If power does not exist, then use the ohmmeter.

The limited amount of instruction presented here is not enough to qualify you as an electrician, but it should enable you to find such troubles as blown fuses, poor electrical connections, and the like. If the trouble appears more complicated than this, call your supervisor or ask for assistance from a Construction Electrician.

9.2.4 Testing the Motor

As a UT, you should be able to make voltage measurements in a refrigeration system to ensure the proper voltage is applied to the drive motor, as shown on the motor's rating plate. If the proper voltage is applied (within 10 percent) to the terminals of the motor and it does not run, you must decide what to do. If it is an open system (not hermetically sealed), it is the Construction Electrician's job to repair the motor. If it is a hermetically sealed unit, you must try to make the motor operational again by completing further tests using special test equipment.

If the unit doesn't run, it may be because the motor rotor or compressor crankshaft is stuck (remember, in a hermetically sealed unit, they are one and the same). If you apply electrical power to try and move the motor in the correct direction first and then reverse the power, you may be able to rock it free and not have to replace the unit. This is one of the purposes of the hermetic unit analyzer (*Figure 12-64*). Use the following steps to rock the rotor of a hermetically sealed unit:

1. Determine from the manufacturer's manual whether the motor is a split-phase or a capacitor-start type.
2. Remove any external wiring from the motor terminals.
3. Place the analyzer plugs in the jacks of the same color. If a split-phase motor is used, put the red plug in jack No. 3; if the capacitor-start motor is used, put the red plug in jack No. 4; and select a capacity value close to the old one with the toggle switches.
4. Connect the test clips as follows:
   - White to common
   - Black to the running winding
   - Red to the starting winding

Figure 12-64 — Hermetic unit analyzer.

5. Hold the push-to-start button down and at the same time move the handle of the rocker switch from normal to reverse. The frequency of rocking should not exceed five times within a 15-second period. If the motor starts, be certain that the rocker switch is in the normal position before releasing the push-to-start button.
6. More tests can be made with the hermetic unit analyzer, such as testing for continuity of windings and for grounded windings. Procedures for these tests are provided in the manual that comes with the analyzer. Generally, if the rocking procedure does not result in a free and running motor, the unit must be replaced.

9.3.1 Troubleshooting Refrigeration Equipment

Troubleshooting of any type of refrigeration unit depends on your ability to compare normal operation with that obtained from the unit being operated. Obviously for you to detect these abnormal operations, you must first know what normal operation is. Climate affects running time. A refrigeration unit generally operates more efficiently in a dry climate. In an ambient temperature of 75°F, the running period usually approximates 2 to 4 minutes, and the off period, 12 to 20 minutes.

It is beyond the scope of this text to cover all of the troubles you may encounter in working with refrigeration equipment. If you apply yourself, you can acquire a lot of additional information through on-the-job training and experience and studying the manufacturer's instruction manuals.

First and foremost, safety must be stressed and safe operating practices followed before and while doing any troubleshooting or service work. All local and national codes must be observed, as well as DoD rules concerning safety. Some of the more important safety steps that are often overlooked are as follows:

- Protective equipment, such as eye protection, gloves, hard hats, and so forth must be available and worn.
- Fire extinguishers must be readily available, in good working order, and adequate for the situation.
- Safety tags with such notations as "Danger," "Hands Off," "Do Not Operate," and "Do Not Throw Switch" should be attached to valves and switches, and at other strategic locations when servicing or making repairs.
- Install machinery guards properly before operating machinery.

The above is only a short list and not intended to be all-inclusive. You will also find *Table 12-3* (discussed earlier in this chapter), and *Table 12-5* (shown below) useful guides for locating and correcting different troubles in refrigeration equipment.

Table 12-5 — Troubleshooting Industrial Refrigeration

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Compressor will not start	No power to motor.	Check power to and from fuses; replace fuses if necessary. Check starter contacts, connections, overloads, and timer (if part winding start). Reset or repair as necessary. Check power at motor terminals. Repair wiring, if damaged.

Table 12-5 — Troubleshooting Industrial Refrigeration (cont.)

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Compressor will not start (cont.)	Control circuit is open.	Safety switches are holding circuit open. Check high pressure, oil failure, and low-pressure switches. Also check oil filter pressure differential switch is supplied. Thermostat is satisfied Check control circuit fuses if blown; replace. Check wiring for open circuit.
Motor "hums" but does not start	Low voltage to motor.	Check incoming power for correct voltage. Call power company or inspect/repair power wiring. Check at motor terminals. Repair or replace as necessary.
	Motor shorted.	Check at motor terminals. Repair or replace as necessary.
	Single-phase failure in the three-phase power supply.	Check power wiring circuit for component or fuse failure.
	Compressor is seized due to damage or liquid.	Remove belts or coupling. Manually turn crankshaft to check compressor.
	Compressor is not unloaded.	Check unloader system.
Compressor starts but motor cycles off on overloads	Compressor has liquid or oil in cylinders.	Check compressor crankcase temperature. Throttle suction stop valve on compressor to clear cylinders and act to prevent recurrence of liquid accumulation.
	Suction pressure is too high.	Unload compressor when starting. Use internal unloaders if present. Install external bypass unloader.
	Motor control.	Motor control located in hot ambient. Low voltage. Motor overloads may be defective or weak. Check motor control relay. Adjust circuit breaker setting to full load amps.
	Bearings are "tight."	Check motor and compressor bearings for temperature. Lubricate motor bearings.
	Motor is running on single-phase power.	Check power lines, fuses, starter, motor, etc., to determine where open circuit has occurred.

Table 12-5 — Troubleshooting Industrial Refrigeration (cont.)

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Compressor starts but short cycles automatically	Low refrigerant charge.	Check refrigerant level and add if necessary
	Driers plugged or saturated with moisture.	Replace cores.
	Refrigerant feed control is defective.	Repair or replace.
	No load.	To prevent short cycling, if objectionable, install pump-down circuit, anti-recycle timer or false load system.
	Unit is too large for load.	Reduce compressor speed. Install false load system.
	Suction strainer blocked or restricted.	Check and clean or replace as necessary.
Motor is noisy or erratic	Motor bearing failure or winding failure.	Check and repair as needed.
	If electric starter, check calibration on control elements.	Adjust as necessary.
Compressor runs continuously but does not keep up with the load	Load is too high.	Speed up compressor or add compressor capacity. Reduce load.
	Refrigerant metering device is underfeeding causing compressor to run at too low a suction pressure.	Check and repair liquid feed problems. Check discharge pressure and increase if low.
	Faulty control circuit, may be low pressure control or capacity controls.	Check and repair.
	Compressor may have broken valve plates.	Check compressor for condition of parts. This condition can usually be detected by checking compressor discharge temperature.
	Thermostat control is defective and keeps unit running.	Check temperatures of product or space and compare with thermostat control. Replace or readjust thermostat.
	Defrost system on evaporator not working properly.	Check and repair as needed.
	Suction bags in strainers are dirty and restrict gas flow.	Clean or remove.
	Hot gas bypass or false load valve stuck.	Check and repair or replace.

Table 12-5 — Troubleshooting Industrial Refrigeration (cont.)

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Compressor loses excessive amount of oil	High suction superheat causes oil to vaporize.	Insulate suction lines Adjust expansion valves to proper superheat. Install liquid injection (suction line desuperheating).
	Too low of an operating level in chiller will keep oil in vessel.	Raise liquid level in flooded evaporator (R-12 systems only)
	Oil not returning from compressor.	Make sure all valves are open. Check float mechanism and clean orifice. Check and clean return line.
	Oil separator is too small.	Check selection.
	Broken valves cause excessive heat in compressor and vaporization of oil.	Repair compressor.
	"Slugging" of compressor with liquid refrigerant that causes excessive foam in the crankcase.	"Dry up" suction gas to compressor by repairing evaporator. Refrigerant feed controls are overfeeding. Check suction trap level controls. Install a refrigerant liquid transfer system to return liquid to high side.
Noisy compressor operation	Loose flywheel or coupling.	Tighten.
	Coupling not properly aligned.	Check and align if required.
	Loose belts.	Align and tighten per specs. Check sheave grooves.
	Poor foundation or mounting.	Tighten mounting belts, grout base, or install heavier foundation.
	Check compressor with stethoscope if noise is internal.	Open, inspect, and repair as necessary.
	Check for liquid or oil slugging.	Eliminate liquid from suction mains. Check crankcase oil level.
Low evaporator capacity	Inadequate refrigerant feed to evaporators.	Clean strainers and driers. Check expansion valve superheat setting. Check for excessive pressure drop due to change in elevation, too small of lines (suction and liquid lines). A heat exchanger may correct this. Check expansion valve size.

Table 12-5 — Troubleshooting Industrial Refrigeration (cont.)

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Low evaporator capacity (cont.)	Expansion valve bulb in a trap.	Change piping or bulb location to correct.
	Oil in evaporator.	Warm the evaporator, drain oil, and install an oil trap to collect oil.
	Evaporator surface fouled.	Clean.
	Air or product velocity is too low.	Increase to rated velocity. Coil not properly defrosting. Check the defrost time. Check method of defrost.
	Brine flow through evaporator may be restricted.	Chiller may be fouled or plugged. Check re-circulating pumps. Check process piping for restriction.
Discharge pressure too high	Air in condenser.	Purge non-condensibles.
	Condenser tubes fouled.	Clean.
	Water flow inadequate.	Check water supply and pump. Clean control valve. Check water temperature.
	Airflow is restricted.	Check and clean: Coils, Eliminators, and Dampers.
	Liquid refrigerant backed up in condenser.	Find source of restriction and clear. If system is overcharged, remove refrigerant as required. Check to make sure equalizer (vent) line is properly installed and sized.
	Spray nozzles on condensers plugged.	Clean
Discharge pressure too low	Ambient air is too cold.	Install a fan cycling control system.
	Water quantity not being regulated properly through condenser.	Install or repair water regulating valve.
	Refrigerant level low.	Check for liquid seal, add refrigerant if necessary.
	Evaporative condenser fan and water switches are improperly set.	Reset condenser controls.
Suction pressure too low	Light load condition.	Shut off some compressors. Unload compressors. Slow down RPM of compressor. Check process flow.

Table 12-5 — Troubleshooting Industrial Refrigeration (cont.)

PROBLEM	POSSIBLE CAUSE	REMEDY OR COMMENT
Suction pressure too low (cont.)	Short of refrigeration.	Add refrigerant if necessary.
	Evaporators not getting enough refrigerant.	Discharge pressure too low. Increase to maintain adequate refrigerant flow. Check liquid feed lines for adequate refrigerant supply. Check liquid line driers.
	Refrigerant metering controls are too small.	Check superheat or liquid level and correct as indicated.
Suction pressure too high	Low compressor capacity.	Check compressors for possible internal damage. Check system load. Add more compressor capacity.

Test your Knowledge (Select the Correct Response)

16. **(True or False)**. The coupling on the shaft of direct drive motors should be realigned after any repair or replacement.

    A. True
    B. False

17. Manually defrosting is normally required on refrigeration units that operate at what temperature?

    A. 50°F
    B. 45°F
    C. 40°F
    D. 35°F

10.1.1 LOGS

As a UT, you need to have an understanding of the importance and use of maintaining, operating, and inspecting logs for refrigeration equipment.

When you are maintaining, standing watch, operating, or inspecting refrigerating equipment, you may be responsible for keeping equipment operation, inspection, or maintenance logs. Try to keep the logs neat and clean. You must ensure that any information recorded in them is accurate and legible.

Operation and maintenance logs can help you spot trouble in the equipment. They also aid in ensuring proper periodic maintenance and inspection are performed on the equipment. Logs may provide a means of self-protection when trouble occurs and the cause can be placed on an individual.

Good judgment must always be used in analysis of service troubles; and whenever possible, specific corrections should be followed. When equipment is not operating properly, one method for determining when and what corrective measures are necessary is to compare current and past readings. Specifically, compare the pressures and temperatures of various parts of the system with corresponding readings taken in the past when the equipment was operating properly. Keep in mind that the readings must be taken under similar heat load and circulating water temperature conditions.

A typical operating log may contain the following types of entries:

- Date and time of readings
- Ambient temperature
- Suction pressure and temperature readings
- Discharge pressure and temperature readings
- Condenser pressure and temperature
- Evaporator pressure and temperature
- Oil level in the compressor
- Operating hours

These types of readings give you a complete picture of the current and past operating conditions of the equipment. They can also assist you in keeping the equipment at its maximum efficiency.

Maintenance logs contain entries of when, what, and who performed routine periodic maintenance on the equipment. Such logs help ensure that the equipment is well maintained, and there is full use of the equipment's life expectancy. These logs also assist in determining estimates for future budget requirements for maintaining the equipment. Maintenance log entries may include the following:

- Date of maintenance
- Type of maintenance
- What was done
- Who did the work
- Cost of the work
- Materials used

It is important to compare equipment operating log readings before and after the maintenance was completed. This comparison helps ensure that the maintenance was accomplished properly, with no ill effects on the equipment.

Summary

Refrigeration systems are of the utmost importance for preserving medicine, blood, and most important, keeping food from spoiling. In this chapter you were introduced to the stages of heat theory and the principles involved in heat transfer. It also described how to recognize refrigeration system components along with their application. Finally, this chapter described how to recognize the characteristics and procedures required to service and troubleshoot refrigeration system equipment.

Review Questions (Select the Correct Response)

1. What formula is used to change a Fahrenheit heat reading to a Celsius reading?

   A. C = (F -32) ÷ 1.8
   B. C = (F +10) x 1.3
   C. C = (F -25) ÷ 1.4
   D. C = (F +16) x 1.7

2. What type of heat changes the temperature of a substance, but not its physical state?

   A. Specific
   B. Sensible
   C. Total
   D. Latent

3. What is the process called, that changes a vapor into a liquid?

   A. Evaporation
   B. Absorption
   C. Compression
   D. Condensation

4. **(True or False)** The components of a refrigeration system consist of a compressor, liquid receiver, evaporator, and control devices.

   A. True
   B. False

5. What type of refrigeration system compressor is bolted together, has a crankshaft that extends through the crankcase, and is driven by a flywheel and belt?

   A. Internal drive
   B. Hermetic
   C. External drive
   D. Offset

6. Which expansion valve is used to maintain a constant pressure in direct drive and dry type evaporators?

   A. Low-side
   B. Automatic
   C. High-side
   D. Thermostatic

7. Which refrigerant is an azeotropic that can only be used with reciprocating compressors?

   A. R-143a
   B. R-22
   C. R-125
   D. R-502

8. Which refrigerant has a boiling point of -55.3°F at atmospheric pressure, and is used to replace R-502 refrigerant?

   A. R-410A
   B. R-125
   C. R-717
   D. R-143a

9. **(True or False)** When storing refrigerants in a cylinder, it is acceptable to use the same regulator for different types of refrigerants.

   A. True
   B. False

10. **(True or False)** Refrigerant cylinders should never be exposed to continuous dampness or salt water.

   A. True
   B. False

11. Which type of refrigerator has a storage capacity of 15 cubic feet or greater, and is used at Navy installations to store perishable foods in galleys and messes?

   A. Two-door refrigerator-freezer
   B. Reach-in
   C. Single-door fresh food
   D. Walk-in

12. Which type of refrigerator is the most popular and is frost free?

   A. Single-door fresh food
   B. Walk-in
   C. Reach-in
   D. Two-door refrigerator-freezer

13. **(True or False)** A common practice is the parallel operation of two or more reciprocating compressors for refrigeration system.

   A. True
   B. False

14. **(True or False)** Using two equalizer lines between the crankcase, on above the normal oil level and one below, is a method of piping that maintains proper oil level in two or more compressors.

    A. True
    B. False

15. What size refrigerant shutoff valve, in inches, should be used when transferring refrigerant from the storage cylinder to the service cylinder?

    A. 1
    B. 1/8
    C. 1/4
    D. 2

16. What is the most sensitive type of leak detector?

    A. Electronic
    B. Halide
    C. Atmospheric
    D. Probing

17. **(True or False)** The first step to follow when disassembling a compressor because of knocking is to expose the top of the piston by removing the cylinder head and valve plate.

    A. True
    B. False

18. **(True or False)** Fan troubles are very hard to locate and correct during compressor inspections.

    A. True
    B. False

19. What type of chemical is used in a unit dehydrator to absorb moisture from the refrigerant as it passes through the dehydrator?

    A. Diethyl
    B. Ethane
    C. Desiccant
    D. Freon

20. Which action should be taken to any loose hinge pins that are found on a unit's door hinge?

    A. Adjustment
    B. Braiding
    C. Replacement
    D. Lubricating

21. **(True or False)** Operation and maintenance logs should not be used for spotting troubles in refrigeration equipment.

A. True
B. False

22. **(True or False)** Maintenance logs can be used to figure future maintenance cost requirements.

A. True
B. False

Trade Terms Introduced in this Chapter

British Thermal Unit (BTU)	The amount of heat required to raise the temperature of 1 lb. of water 1°F.
Chlorofluorocarbon (CFC)	An organic compound that contains carbon, chlorine, and fluorine, produced as a volatile derivative of methane and ethane.
Hydrochlorofluorocarbon (HCFC)	A group of man-made compounds containing hydrogen, chlorine, fluorine and carbon, used for refrigeration, aerosol propellants, foam manufacture and air conditioning.
Azeotropic	A mixture of two or more liquids (chemicals) in such a ratio that its composition cannot be changed by simple distillation.
Hydrofluorocarbon (HFC)	A synthetic refrigerant developed for refrigeration systems that need a low-evaporating temperature. It is also a fluorocarbon emitted as a by-product of industrial manufacturing.
Haloalkane	An organic chemical compound consisting of an alkane in which one or more hydrogen atoms have been substituted by a halogen element. Used as solvents and in organic synthesis.
Tare Weight	Also called un-laden weight is the weight of an empty vehicle or container. By subtracting it from the gross weight (laden weight), the weight of the goods carried (the net weight) may be determined.
Incandescence	An emission by a hot body of radiation that makes it visible.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Introduction to Circuit Protection, Control, and Measurement, NAVEDTRA 14175, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1998

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 13

Air Conditioning

Topics

1.0.0 Principles of Air Conditioning

2.0.0 Air-Conditioning Systems

3.0.0 Major System Components and Controls

4.0.0 Automotive Air Conditioning

5.0.0 Ductwork

To hear audio, click on the box.

Overview

Air conditioning is used throughout the world to counter the negative effects caused by heat and humidity. Without air conditioning people tire easily and feel lethargic, resulting in low morale and productivity. As a Utilitiesman, one of your duties will be to install, operate, maintain, and repair air-conditioning systems to provide the required comfort in working spaces.

In order to provide this comfortable environment, you need to have an understanding of the principles and theory of air conditioning, be able to recognize system components and controls, and understand how they work within the system.

This chapter will provide you with the information required to meet those requirements. Also, covered in this chapter are the basic types of ductwork systems that deliver the conditioned air necessary to cool a specified area.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the principles of air conditioning.
2. Describe the components of air conditioning systems.
3. Describe the major components and controls associated with air conditioning.
4. Describe the purpose, components, and certification of automotive air conditioning.
5. Describe the different classifications of ductwork.

Prerequisites

None

This course map shows all of the chapters in Utilitiesman Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Utilities Equipment and Maintenance	↑	
Air Conditioning		
Refrigeration		
Heating Systems		U
Steam Distribution Systems		T
Boilers		
Sewage Disposal, Field Sanitation, and Water Treatment		B
Prime Movers, Pumps, and Compressors		A
Plumbing Fixtures		S
Piping System Layout and Plumbing Accessories		I
Structural Openings and Pipe Material		C
Fundamentals of Water Distribution		
Basic Math, Electrical, and Plumbing Operations		
Plans, Specifications, and Color Coding		

Features of this Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PRINCIPLES of AIR CONDITIONING

Air conditioning is the process of conditioning the air in a space to maintain a predetermined temperature-humidity relationship to meet comfort or technical requirements. This warming and cooling of the air is usually referred to as winter and summer air conditioning.

1.1.0 Temperature

Temperature, humidity, and air motion are interrelated in their effects on health and comfort. The term given to the net effects of these factors is ***effective temperature****.* This effective temperature cannot be measured with a single instrument; therefore, a ***psychrometric*** chart aids in calculating the effective temperature when given sufficient known conditions relating to air temperatures and velocity.

Research has shown that most persons are comfortable in air where the effective temperature lies within a narrow range. The range of effective temperatures that most people feel comfortable in is called the COMFORT ZONE. Since winter and summer weather conditions are markedly different, the summer zone varies from the winter zone. The specific effective temperature within the zone at which most people feel comfortable is called the COMFORT LINE (*Figure 13-1*).

Figure 13-1 — Comfort zones and lines.

1.2.0 Humidity

When air is at a high temperature and saturated with moisture, it makes people feel uncomfortable. However, people usually feel quite comfortable at the same temperature with fairly dry air. As dry air passes over the surface of the skin, it evaporates the moisture sooner than damp air, producing a greater cooling effect. However, if the air is too dry it causes discomfort. When air is too dry, it causes the surface of the skin to become dry and irritated.

Humidity is the amount of water vapor in a given volume of air. *Relative humidity* is the amount of water vapor in a given amount of air in comparison to the amount of water vapor the air would hold at a temperature if it were saturated. Relative humidity may be remembered as a fraction or percentage of water vapor in the air; that is, *DOES HOLD* divided by *CAN HOLD.*

Relative humidity is determined by using a sling psychrometer. It consists of a wet-bulb thermometer and a dry-bulb thermometer, as shown in *Figure 13-2*. The wet-bulb thermometer is an ordinary thermometer similar to the dry-bulb thermometer, except that the bulb is enclosed in a wick that is wet with distilled water. The wet bulb is cooled as the moisture evaporates from it while it is being spun through the air. This action causes the wet-bulb thermometer to register a lower temperature than the dry-bulb thermometer. For certain conditions, tables and charts have been designed that use these two temperatures to arrive at a relative humidity.

A comfort zone chart is shown in *Figure 13-3*. The comfort zone is the range of effective temperatures that feel comfortable to the majority of adults. In looking over the chart, note that the comfort zone represents a considerable area. The charts show the wet- and dry-bulb temperature combinations that are also comfortable to the majority of adults. The summer comfort zone extends from 66°F effective temperature to 75°F effective temperature for 98 percent of all personnel. The winter comfort zone extends from 63°F effective temperature to 71°F effective temperature for 97 percent of all personnel.

1.2.1 Dew-Point Temperature

The dew point depends on the amount of water vapor in the air. If the air at a certain temperature is not saturated (maximum water vapor at that temperature) and the air temperature falls, a point is finally reached saturating the air for the new and lower temperature, and moisture condensation begins. This is the dew-point temperature of the air for the quantity of water vapor present.

Figure 13-2 — Standard sling psychrometer.

Figure 13-3 — Comfort zone chart.

1.2.2 Relationship of Wet-Bulb, Dry-Bulb, and Dew-Point Temperatures

A definite relationship exists between the wet-bulb, dry-bulb, and dew-point temperatures. These relationships are as follows:

- When the air is not saturated but contains some moisture, the dew-point temperature is lower than the dry-bulb temperature, and the wet-bulb temperature is in between.
- As the amount of moisture in the air increases, the amount of evaporation (and therefore, cooling) decreases. The difference between the temperatures becomes less.
- When the air becomes saturated, all three temperatures are the same and the relative humidity is 100 percent.

To humidify air is to increase its water vapor content. To dehumidify air is to decrease its water vapor content. The device used to add moisture to the air is a *humidifier*, and the device used to remove the moisture from the air is a *dehumidifier*. The control device, sensitive to various degrees of humidity, is called a *humidistat*.

Methods for humidifying air in air-conditioning units usually consist of an arrangement that causes air to pick up moisture. One arrangement consists of a heated water surface over which conditioned air passes and picks up a certain amount of water vapor by evaporation, depending upon the degree of humidifying required. A second arrangement to humidify air is to spray or wash the air as it passes through the air-conditioning unit.

During the heat of the day, the air usually absorbs moisture. As the air cools at night, it may reach the dew point and give up moisture, which is deposited on objects. This principle is used in dehumidifying air by mechanical means.

Dehumidifying equipment for air conditioning usually consists of cooling coils within the air conditioner. As warm, humid air passes over the cooling coils (*Figure 13-4*), its temperature drops below the dew point and some of its moisture condenses into water on the surface of the coils. The condensing moisture gives up latent heat that creates a part of the cooling load that must be overcome by the air-conditioning unit. For this reason, the relative humidity of the air entering the air conditioner has a definite bearing on the total cooling load. The amount of water vapor that can be removed from the air depends upon the air over the coils and the temperature of the coils.

Figure 13-4 — Air conditioning cooling coils.

1.3.0 Purity of Air

The air should be free from all foreign materials, such as ordinary dust, rust, animal and vegetable matter, and pollen. It should also be free of carbon (soot) from poor combustion, fumes, smoke, and gases. These types of pollution alone are harmful to the human body but they also carry bacteria and harmful germs, which can cause additional dangers. During air conditioning, the outside air brought into a space or the re-circulating air within a space should be filtered.

Air in an air conditioner may be purified or cleaned by filters, air washing, or electricity.

The types of filters that can be used consist of permanent or throwaway. They are usually made of fibrous material that collects the particles of dust and other foreign matter from the air as it passes through the filter. In some cases, the fibers are dry, while in others they have a viscous (sticky) coating. Filters usually have a large dust-holding capacity. When permanent filters become dust-laden they can be cleaned. Throwaway filters are only one-time filters and are discarded when they become dust-laden.

Water sprays can be used to recondition the air by washing and cleaning it. These sprays may also serve to humidify or dehumidify the air to some extent.

In some large air-conditioning systems, air is cleaned by electricity. In this type of system, electrical precipitators remove the dust particles from the air. The air is first passed between plates where the dust particles are charged with electricity. Then the air is passed through a second set of oppositely charged plates that attract and remove the dust particles (*Figure 13-5*). This method is by far the best method of air cleaning, but the most expensive.

Figure 13-5 — Electrostatic filter diagram.

1.4.0 Circulation of Air

The velocity of the air is the primary factor that determines what temperature and humidity are required to produce comfort. (The chart in *Figure 13-3* is based on an air movement of 15 to 25 feet per minute.) We know from experience that a high velocity of air produces a cooling effect on human beings. However, air velocity does not produce a cooling effect on a surface that does not have exposed moisture. A fan does not cool the air, but merely increases its velocity. The increased velocity of air passing over the skin surfaces evaporates moisture at a greater rate thereby cooling the individual. For this reason, circulation of air has a decided influence on comfort conditions. Air can be circulated by gravity or mechanical means.

When air is circulated by gravity, the heavier cold tends to settle to the floor, forcing the warm and lighter air to the ceiling. When the air at the ceiling is cooled by some sort of refrigeration, it will settle to the floor and cause the warm air to rise. The circulation of the air by this method will eventually stop when the temperature of the air at the ceiling is the same as the temperature on the floor. Axial or radial fans can also be used to circulate the air. When axial or radial fans are mounted in an enclosure, they are often called blowers.

Test your Knowledge (Select the Correct Response)

1. What is the term used for the range of effective temperatures that most people feel comfortable in?

   A. Best temperature
   B. Comfort zone
   C. Area of comfort
   D. Health range

2. **(True or False)** Using electricity to clean the air of large air-conditioning systems is the best method and the cheapest.

   A. True
   B. False

2.1.1 AIR CONDITIONING SYSTEMS

As a UT, it is necessary that you be able to recognize the basic types of air-conditioning systems and understand the operation, maintenance, and repair methods and procedures.

A complete air-conditioning system includes a means of refrigeration, one or more heat transfer units, air filters, a means of air distribution, an arrangement for piping the refrigerant and heating medium, and controls to regulate the proper capacity of these components. In addition, the application and design requirements that an air-conditioning system must meet make it necessary to arrange some of these components to condition the air in a certain sequence.

For example, an installation that requires reheating of the conditioned air must be arranged with the reheating coil on the downstream side of the dehumidifying coil; otherwise, it is impossible to reheat the cooled and dehumidified air.

There has been a tendency by many designers to classify an air-conditioning system by referring to one of its components. For example, the air-conditioning system that includes a dual duct arrangement to distribute the conditioned air; is referred to as a dual duct system. This classification makes no reference to the type of refrigeration, the piping arrangement, or the type of controls.

For the purpose of classification, the following definitions are used:

- An air-conditioning unit is understood to consist of a heat transfer surface for heating and cooling, a fan for air circulation, and a means of cleaning the air, motor, drive, and casing.

- A self-contained air-conditioning unit is understood to be an air-conditioning unit that is complete with compressor, condenser, evaporator, controls, and casing.

- An air-handling unit consists of a fan, heat transfer surface, and casing.
- A remote air-handling unit or a remote air-conditioning unit is a unit located outside the conditioned space that it serves.

2.1.0 Self-Contained Air-Conditioning Units

Air-conditioning units that are self-contained may be divided into two types: window-mounted and floor-mounted units. Window-mounted air-conditioning units usually range from 4,000 to 36,000 Btu per hour in capacity (*Figure 13-6*). The use of windows to install these units is not a necessity. They may be installed in transoms or directly in the outside walls (commonly called a "through-the-wall" installation). A package type of room air conditioner, showing airflow patterns for cooling, ventilating, and exhausting services, is shown in *Figure 13-7*.

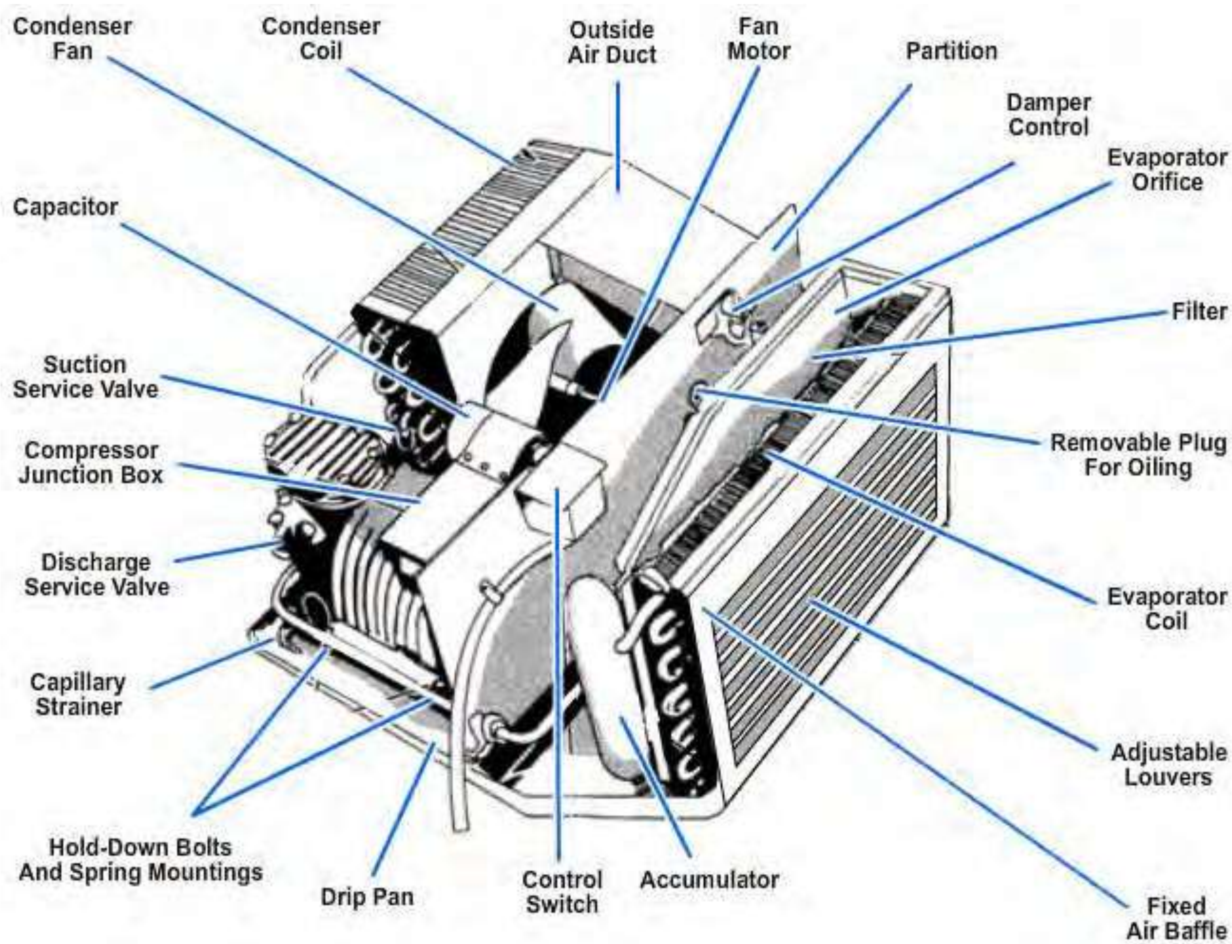


Figure 13-6 — Window air conditioner.

In construction and operating principles, the window unit is a small and simplified version of much larger systems. As shown in *Figures 13-8* and *13-9*, the basic refrigeration components are present in the window unit. The outside air cools the condenser coils. The room air is circulated by a fan that blows across the evaporator coils. Moisture, condensed from the humid air by these coils, is collected in a pan at the bottom of the unit; it is usually drained to the back of the unit and discharged.

Figure 13-7 — Airflow patterns of a package type air conditioner.

Figure 13-8 — Refrigerant cycle of a package air conditioner.

Figure 13-9 — Air-handling components of a package room air conditioner.

Most window units are equipped with thermostats that maintain a fixed dry-bulb temperature and moisture content in an area within reasonable limits. These units are installed so there is a slight tilt of the unit towards the outside, toward the condenser, to assist in drainage of the condensate. It is a good idea to mount the unit on the eastside of the building to take advantage of the afternoon shade. These units require very little mechanical attention before they are put into operation. Window units are normally operated by the user, who should be properly instructed on their use.

Floor-mounted air-conditioning units range in size from 24,000 to 360,000 Btu per hour and are also referred to as PACKAGE units, as the entire system is located in the conditioned space. Like window units, these larger units contain a complete system of refrigeration components. A self-contained unit with panels removed is shown in *Figure 13-10*. These units normally use either a water-cooled or air-cooled condenser.

Self-contained units should be checked regularly to ensure they operate properly. Filters should be renewed or cleaned weekly or more often if necessary. Always stop the blower when changing filters to keep loose dust from circulating through the system. When the filters are permanent, they should be returned to the shop for cleaning. At least once a year, the unit should be serviced.

Figure 13-10 — Floor-mounted air-conditioning unit.

If the unit has been designed with a spray humidifier, spray nozzle, water strainers, and cooling coils, each device should be cleaned each month to remove water solids and scale. Cooling coil casings, drain pans, fan scrolls, and fan wheels should be wire brushed and repainted when necessary. Oiling and greasing of the blower and motor bearings should be performed as required.

2.2.0 Heat Pumps

A heat pump removes heat from one place and puts it into another. A domestic refrigerator is considered to be a heat pump because it removes heat from inside a box and releases it on the outside. The only difference between a refrigerator and a residential or commercial heat pump is that the latter can reverse its system. The heat pump is one of the most modern means of heating and cooling. Using no fuel, the electric heat pump automatically heats or cools, as determined by outside temperature.

The air type of unit works on the principle of removing heat from the atmosphere. No matter how cold the weather, some heat can always be extracted and pumped indoors to provide warmth. To cool during the hot months, this cycle is merely reversed with the unit removing heat from the area to be cooled and exhausting it to the outside air. The heat pump is designed to control the moisture in the air and to remove dust and pollen. Cool air, provided during hot weather, enters the area with uncomfortable moisture removed. In winter, when a natural atmosphere is desirable, air is not dried out when pumped indoors.

The heat pump is simple in operation (*Figure 13-11*). In summer, the evaporator is cooling and the condenser outside is giving off heat the evaporator picked up. During the winter the condenser outside is picking up heat from the outside air because its temperature is lower than that of the outside air (until it reaches the balance point). This heat is then sent to the evaporator by the compressor and is given off into the conditioned space.

A reversing valve is the key to this operation. The compressor always pumps in one direction, so the reversing valve changes the hot-gas direction from the condenser to the evaporator, as indicated by the setting on the thermostat. The setting of the thermostat assures the operator of a constant temperature through an automatic change from heating to cooling anytime outside conditions warrant.

2.2.1 Heating Cycle

The initial heating demand of the thermostat starts the compressor. The reversing valve is de-energized during the heating mode. The compressor pumps the hot refrigerant gas through the indoor coil, where heat is released into the indoor air stream. This supply of warmed air is distributed through the conditioned space.

Figure 13-11 — Basic heat pump operation.

As the refrigerant releases its heat, it changes into a liquid, which is then transported to the outdoor coil. The outdoor coil absorbs heat from the air blown across the coil by the outdoor fan. The refrigerant changes from a liquid into a vapor, as it passes through the outdoor coil. The vapor returns to the compressor where it increases temperature and pressure. The hot refrigerant is then pumped back to the indoor coil to start another cycle. A graphic presentation of the nine steps of the cycle is shown in *Figure 13-12*.

Figure 13-12 — Heating cycle.

2.2.2 ooling Cycle

Once the thermostat is put in the cooling mode, the reversing valve is energized. A cooling demand starts the compressor. The compressor pumps hot high-pressure gas to the outdoor coil where heat is released by the outdoor fan. The refrigerant changes into a liquid, which is transported to the indoor blower. The refrigerant absorbs heat from the indoor air of the supply air, which is distributed throughout the controlled space. This temperature change removes moisture from the air and forms condensate, which must be piped away. The compressor suction pressure draws the cool vapor back into the compressor where the temperature and pressure are greatly increased. This completes the cooling refrigerant cycle. *Figure 13-13* shows a graphic presentation of the nine steps of the cycle.

2.2.3 Defrost Cycle

Heat pumps operating at temperatures below 45°F accumulate frost or ice on the outdoor coil. The relative humidity and ambient temperature affect the degree of accumulation. This ice buildup restricts the airflow through the outdoor coil, which consequently affects the system operating pressures. The defrost control detects this restriction and switches the unit into a defrost mode to melt the ice.

The reversing valve is energized and the machine temporarily goes into the cooling cycle, where hot refrigerant flows to the outdoor coil. The outdoor fan stops at the same time, thus allowing the discharge temperature to increase rapidly to shorten the length of the defrost cycle. If there is supplemental heat, a defrost relay activates it to offset the cooling released by the indoor coil.

Figure 13-13 — Cooling cycle.

2.2.4 Supplemental Heat

As the outside temperature drops, the heat pump runs for longer periods until it eventually operates continually to satisfy the thermostat. The system "balance point" is when the heat pump capacity exactly matches the heating loss. The balance point varies between homes, depending on actual heat loss and the heat pump capacity. However, the balance point usually ranges between 15°F and 40°F. Either electric heat or fossil fuels provide the auxiliary heat.

Conventional heat pump applications use electric heaters downstream from the indoor coil. This design prevents damaging head pressures when the heat pump and auxiliary heat run simultaneously. The indoor coil can only be installed downstream from the auxiliary heat if a Fuelmaster® control system is used. This control package uses a two-stage heat thermostat with the first stage controlling heat pump operation and the second stage controlling furnace operation.

2.3.0 Chilled-Water Systems

Water chillers (*Figures 13-14* and *13-15*) are used for air conditioning large tonnage capacities and for central refrigeration plants serving a number of zones, each with its individual air-cooling and air-circulating units. An example is a large hospital with wings off a corridor. Air conditioning may be necessary in operating rooms, treatment suites, and possibly some recovery wards. Chilled water-producing and water-circulating equipment is in a mechanical equipment room. Long mains with many joints between condensing equipment and conditioning units increase the chance of leaks. Expensive refrigerant has to be replaced. It may be better to provide water-cooling equipment close to the condensing units and to circulate chilled water to remote air-cooling coils. Chilled water is circulated to various room-located coils by a pump, and the temperature of the air leaving each coil may be controlled by a thermostat that controls a water valve or stops and starts each cooling coil fan motor.

Figure 13-14 — Rotary screw compressor unit.

Figure 13-15 — Two-stage semi-hermetic centrifugal unit.

2.3.1 Types of Coolers

For chilled-water air conditioning, the two most commonly used water coolers (evaporators) are the flooded shell-and-tube (*Figure 13-16*) and dry-expansion (*Figure 13-17*). The disadvantage to using the flooded shell-and-tube cooler is that it needs more refrigeration than other systems of equal size. Furthermore, when the load falls off, water in tubes may freeze, causing the tubes to split.

2.3.2 ontrols

Flooded coolers should be controlled with a low-pressure float control-afloat valve placed so the float is about the same level as the predetermined refrigerant level. The float, as a pilot, moves a valve in the liquid line to control the flow of refrigerant to the evaporator. Automatic or thermostatic expansion valves control the dry-expansion coolers. The refrigerant is inside the tubes; therefore, freezing of water on the tubes is less likely to cause damage.

2.3.3 Condensers

The primary purpose of the condenser is to liquefy the refrigerant vapor. The heat added to the refrigerant in the evaporator and compressor must be transferred to some other medium from the condenser. This medium is the air or water used to cool the condenser.

2.3.4 Water-Cooled Condensers

Condensing water must be noncorrosive, clean, inexpensive, below a certain maximum temperature, and available in sufficient quantity. The use of corrosive or dirty water results in high maintenance costs for condensers and piping. Dirty water can generally be economically filtered if it is noncorrosive. Corrosive water, if it is clean, can sometimes be economically treated to neutralize its corrosive properties. An inexpensive source of water that must be filtered and chemically treated will probably not be economical to use without some means of conservation, such as an evaporative condenser or a cooling tower.

Water circulated in evaporative condensers and cooling towers must always be treated to reduce the formation of scale, algae, and chalky deposits. However, overtreatment of water can waste costly chemicals and result in just as much maintenance as under-treatment.

2.3.4.1 Shell-and-Coil Condensers

A shell-and-coil water-cooled condenser (*Figure 13-16*) is simply a continuous copper coil mounted inside a steel shell. Water flows through the coil, and the refrigerant vapor from the compressor is discharged inside the shell to condense on the outside of the cold tubes. In many designs, the shell also serves as a liquid receiver.

The shell-and-coil condenser has a low manufacturing cost, but is difficult to service in the field. If a leak develops in the coil, the head from the shell must be removed and the entire coil pulled from the shell to find and repair the leak. A continuous coil is a nuisance to clean, whereas straight tubes are easy to clean with mechanical tube cleaners. In summary, it may be difficult to maintain a high rate of heat transfer with a shell-and-coil condenser, with some types of cooling water.

Figure 13-16 — Shell-and-coil condenser.

2.3.4.2 Shell-and-Tube Condensers

The shell-and-tube water-cooled condenser shown in *Figure 13-17* permits a large amount of condensing surface to be installed in a comparatively small space. The condenser consists of a large number of 3/4- or 5/8-inch tubes installed inside a steel shell. The water flows inside the tubes while the vapor flows outside around the nest of tubes. The vapor condenses on the outside surface of the tubes and drips to the bottom of the condenser, which may be used as a receiver for the storage of liquid refrigerant. Shell-and-tube condensers are used for practically all water-cooled refrigeration systems.

To obtain a high rate of heat transfer through the surface of a condenser, it is necessary for the water to pass through the tubes at a fairly high velocity. For this reason, the tubes in shell-and-tube condensers are separated into several groups with the same water traveling in series through each of these various groups. A condenser having four groups of tubes is known as a four-pass condenser because the water flows back and forth along its length four times. Four-pass condensers are common although any reasonable number of passes may be used. The fewer the number of water passes in a condenser, the greater the number of tubes in each pass.

The friction of water flowing through a condenser with a few passes is lower than in one having a large number of passes. This means a lower power cost in pumping the water through a condenser with a smaller number of passes.

Figure 13-17 — Shell-and-tube condenser.

2.3.4.3 Tube-Within-A-Tube Condensers

The use of tube-within-a-tube for condensing purposes is popular because it is easy to make. Water passing through the inner tube along with the exterior air condenses the refrigerant in the outer tube (*Figure 13-18*). This "double cooling" improves efficiency of the condenser. Water enters the condenser at the point where the refrigerant leaves the condenser. It leaves the condenser at the point where the hot vapor from the compressor enters the condenser. This arrangement is called counter-flow design.

Figure 13-18 — Tube-within-a-tube condenser.

The rectangular type of tube-within-a-tube condenser uses a straight hard copper pipe with manifolds on the ends. The water pipes can be clean mechanically after the manifolds have been removed

2.4.1 Cleaning Water-Cooled Condensers

As a UT, you may be assigned to some activities where water-cooled condensers are used in the air-conditioning system. One of your jobs will probably include cleaning the condensers.

Water contains many impurities that can vary, depending on the location. Especially harmful to components are lime and iron. These two impurities form a hard scale on the walls of water tubes that reduces the efficiency of the condenser. Condensers can be cleaned mechanically or chemically.

Scale on tube walls of condensers with removable heads is removed by attaching a round steel brush to a rod and by working it in and out of the tubes. After the tubes have been cleaned with a brush, flush them by running water through them. Some scale deposits are harder to remove than others, and a steel brush may not do the job. Several types of tube cleaners for removing hard scale can usually be purchased from local sources. Be sure that the type selected does not injure water tubes.

When the condenser tubes are not accessible for mechanical cleaning, the simplest method for removing scale and dirt is to use inhibited acid to clean the coils or tubes. This is called chemical action.

WARNING

Prevent chemical solution from splashing in eyes and on skin or clothing.

Equipment and connections for circulating inhibited acid through the condenser using gravity flow, as shown in *Figure 13-19*, are as follows:

1. A rubber or plastic bucket for mixing solution. Do not use galvanized materials because prolonged contact with acid deteriorates such surfaces.
2. A crock or wooden bucket for catching the drainage residue.
3. One-inch steel pipe that is long enough to make the connections shown.
4. Fittings for 1-inch steel pipe. The vent pipe shown should be installed at the highest connection of the condenser.

Equipment and connections for circulating inhibited acid through the condenser using forced circulation, as shown in *Figure 13-20*, are as follows:

1. A pump suitable for this application. A centrifugal pump and a 1/2-horsepower motor are recommended (30 gallons per minute at 35-foot head capacity).
2. A non-galvanized metal tank, stone or porcelain crock, or wooden barrel with a capacity of about 50 gallons with ordinary bronze or copper screening to keep large pieces of scale or dirt from getting into the pump intakes.
3. A one-inch pipe that is long enough to make the piping connections shown.
4. Fittings for 1-inch steel globe valves. The vent pipe, as shown, should be installed at the higher connection of the condenser.

Remember, when you are cleaning with acid make sure to follow the usual precautions observed when handling acids. It stains hands and clothing and attacks concrete and if an inhibitor is not present, it reacts with steel. Therefore, use every precaution to prevent spilling or splashing. When splashing might occur, cover the surfaces with burlap or boards. Gas produced during cleaning that escapes through the vent pipe is not harmful but prevents any liquid or spray from being carried through with the gas. The basic formula should be maintained as closely as possible, but a variation of 5 percent is permissible. The inhibited acid solution is made up of the following:

- Water
- Commercial hydrochloric (muriatic) acid with specific gravity of 1.19. Eleven quarts of acid should be used for each 10 gallons of water.
- Three and two-fifths ounces of inhibitor powder for each 10 gallons of water used

Place the required amount of water in a non-galvanized metal tank or wooden barrel, and add the necessary amount of inhibitor powder while stirring the water. Continue stirring the water until the powder is completely dissolved; then add the required quantity of acid.

Figure 13-17 — Gravity method.

Figure 13-18 — Forced Circulation Method.

WARNING

NEVER add water to acid; this mistake may cause an explosion.

When gravity flow is used to charge the system with an acid solution, introduce the inhibited acid as shown in *Figure 13-19*. Do not add the solution faster than the vent can exhaust the gases generated during cleaning. When the condenser has been filled, allow the solution to remain overnight.

When ***forced circulation*** is used (*Figure 13-20*), the valve in the vent pipe should be fully opened while the solution is introduced into the condenser but must be closed when the condenser is completely charged and the solution is circulated by the pump. When a centrifugal pump is used, the valve in the supply line may be fully closed while the pump is running.

The solution should be allowed to stand or be circulated in the system overnight for cleaning out average scale deposits. The cleaning time also depends on the size of the condenser to be cleaned. For extremely heavy deposits, forced circulation is recommended, and the time should be increased to 24 hours. The solution acts more rapidly if it is warm, but the cleaning action is just as thorough with a cold solution if adequate time is allowed.

After the solution has been allowed to stand or has been circulated for the required time through the condenser, it should be drained and the condenser thoroughly flushed with water. To clean condensers with removable heads by using inhibited acid, use the above procedure without removing the heads.

However, exercise extra precaution when flushing out the condenser with clear water after the acid has been circulated through the condenser to ensure removal of the acid from all water passages.

2.5.0 Maintenance

A well-planned maintenance program avoids unnecessary downtime, prolongs the life of the unit, and reduces the possibility of costly equipment failure. It is recommended that a maintenance log be maintained for recording the maintenance activities. This action provides a valuable guide and aids in obtaining extended length of service from the unit.

This section describes specific maintenance procedures, which must be performed as a part of the maintenance program of the unit. Use and follow the manufacturer's manual for the unit undergoing maintenance. When specific directions or requirements are furnished, follow them. Before performing any of these operations, ensure that the power to the unit is disconnected, unless otherwise instructed.

WARNING

When maintenance checks and procedures must be completed with the electrical power on, care must be taken to avoid contact with energized components or moving parts. Failure to exercise caution when working with electrically powered equipment may result in serious injury or death.

2.5.1 Coil Cleaning

Refrigerant coils (*Figure 13-21*) must be cleaned at least once a year or more frequently if the unit is located in a dirty environment. This action helps maintain unit operating efficiency and reliability. The relationship between regular coil maintenance and efficient/reliable unit operation is as follows:

- Clean condenser coils minimize compressor head pressure and amperage draw, which promote system efficiency.
- Clean evaporator coils minimize water carry over and help eliminate frosting and/or compressor flood-back problems.
- Clean coils minimize required fan brake horsepower and maximize efficiency by keeping coil static pressure loss at a minimum.
- Clean coils keep the motor temperature and system pressure within safe operating limits for good reliability.

The following equipment is required to clean condenser coils: a soft brush and either a garden pump-up sprayer or a high-pressure sprayer. In addition, a high-quality detergent must be used. Follow the manufacturer's recommendations for mixing to make sure the detergent is alkaline with a pH value less than 8.5.

Specific steps required for cleaning the condenser coils are as follows:

1. Disconnect the power to the unit.

WARNING

Open the unit disconnect switch. Failure to disconnect the unit from the electrical power source may result in severe electrical shock and possible injury or death.

2. Remove enough panels from the unit to gain access to the coil.
3. Protect all electrical devices, such as motors and controllers, from dust and spray.
4. Straighten coil fins with a fin rake, if necessary.
5. Use a soft brush to remove loose dirt and debris from both sides of the coil.
6. Mix the detergent with water according to the manufacturer's instructions. The detergent and water solution may be heated to a maximum of 150°F to improve its cleaning ability.

WARNING

Do not heat the detergent and water solution to temperatures in excess of 150°F. High-temperature liquids sprayed on the coil exterior raise the pressure within the coil and may cause it to burst. Should this occur, the result could be both injury to personnel and equipment damage.

7. Place the detergent and water solution in the sprayer. If a high-pressure sprayer is used, be sure to follow these guidelines:
    - Minimum nozzle spray angle is 15 degrees.
    - Spray the solution perpendicular (at a 90-degree angle) to the coil face.
    - Keep the sprayer nozzle at least 6 inches from the coil.
    - Sprayer pressure must not exceed 600 psi.

CAUTION

Do **NOT** spray motors or other electrical components. Moisture from the spray can cause component failure.

8. Spray the side of the coil where the air leaves first then spray the other side (where the air enters). Allow the detergent and water solution to stand on the coil for 5 minutes.
9. Rinse both sides of the coil with cool water.
10. Inspect the coil and if it still appears dirty, repeat Steps 8 and 9.
11. Remove the protective covers installed in Step 3.
12. Replace all unit panels and parts, and restore electrical power to the unit.

2.5.2 Fan Motors

The inspection of fan motors should be conducted periodically to check for excessive vibration or temperature. Operating conditions vary the frequency of inspection and lubrication. Motor lubrication instructions are found on the motor tag or nameplate. If not available, contact the motor manufacturer for instructions.

To re-lubricate the motor, complete the following steps:

WARNING

Ensure that the power source is disconnected prior to lubricating the motor. Failure to do so may result in injury or death from electrical shock or moving parts.

1. Turn the motor off. Make sure it cannot accidentally restart.
2. Remove the relief plug and clean out any hardened grease.
3. Add fresh grease through the fitting with a low-pressure grease gun.
4. Run the motor for a few minutes to expel any excess grease through the relief vent.
5. Stop the motor and replace the relief plug

2.5.3 Fan Bearing Lubrication

Fan bearings with grease fittings or grease line extensions should be lubricated with lithium-base grease that is free of chemical impurities. Improper lubrication can result in early bearing failure. To lubricate the fan bearings, complete the following steps:

1. Lubricate the bearings while the unit is not running then disconnect the main power switch
2. Connect a manual grease gun to the grease line or fitting.
3. Add grease, preferably when the bearing is warm, while turning the fan wheel manually until a light bead of grease appears at the bearing grease seal.

2.5.4 Filters

To clean permanent filters, wash under a stream of hot water to remove dirt and lint. Follow with a wash of mild alkali solution to remove old filter oil. Rinse thoroughly and let dry. Recoat both sides of the filter with filter oil and let dry. Replace the filter element in the unit.

CAUTION

Always install filters with directional arrows pointing toward the fans.

2.6.0 Periodic Maintenance

All indicated maintenance procedures should be performed as scheduled. This prolongs the life of the unit and reduces the possibility of costly equipment failure and downtime. A checklist should be prepared listing the required service operations and the times they should to be performed.

2.6.1 Weekly Maintenance Checklist

1. Check the compressor oil level. If low, allow the compressor to operate continually at full load for 3 to 4 hours. Check the oil level at 30-minute intervals. If the level remains low, add oil.
2. Observe the oil pressure. The oil pressure gauge reading should be approximately 20 to 35 psi above the suction pressure gauge reading.
3. Stop the compressor and check the shaft seal for excessive oil leakage. If found, check the seal with a refrigerant leak detector (open compressor only).
4. Check the condition of the air filters and air-handling equipment. Clean or replace filters, as necessary.
5. Check the general operating conditions, system pressures, refrigerant sight glass, and so forth.

2.6.2 Monthly Maintenance Checklist

(Repeat items 1 through 5 from the weekly checklist)

6. Lubricate the fan and motor bearings, as necessary. Obtain and follow the manufacturer's lubricant specifications and bearing care instructions.
7. Check the fan belt tension and alignment.
8. Tighten all fan sheaves and pulleys. If found to be loose, check alignment before tightening.
9. Check the condition of the condensing equipment. Observe the condition of the condenser coil in the air-cooled condenser. Clean, as necessary. Check the cooling tower water in the water-cooled condenser. If algae or scaling is evident, water treatment is needed. Clean the sump strainer screen of the cooling tower.

2.6.3 Annual Maintenance Checklist

(Repeat the items 1 through 9 from the monthly checklist)

10. Drain all circuits of the water-condensing system. Inspect the condenser piping and clean any scale or sludge from the tubes of the condenser.
11. If a cooling tower or evaporative condenser is used, flush the pumps and sump tank. Remove any rust or corrosion from the metal surfaces and repaint.
12. Inspect all motor and fan shaft bearings for signs of wear. Check the shafts for proper end-play adjustment.

13. Replace worn or frayed fan belts.
14. Clean all water strainers.
15. Check the condition of the ductwork.
16. Check the condition of the electrical contacts of all contactors, starters, and controls. Remove the condensing unit control box cover and inspect the panel wiring. All electrical connections should be secure. Inspect the compressor and condenser fan motor contactors. If the contacts appear severely burned or pitted, replace the contactor. Do not clean the contacts. Inspect the condenser fan capacitors for visible damage.

2.7.0 Seasonal Shutdown-Startup

2.7.1 Shutdown

In preparation for seasonal shutdown, it is advisable to pump down the system and valve off the bulk of the refrigerant charge in the condenser. This action minimizes the quantity of refrigerant that might be lost due to any minor leak on the low-pressure side of the system, and, in the case of the open compressor, refrigerant that might leak through the shaft seal.

For hermetic compressor pump down, complete the following steps:

1. Close the liquid line shutoff valve at the condenser and start the system. The compressor will stop when the suction pressure drops to the low-pressure control cutout setting.
2. Open the compressor electrical disconnect switch to prevent the compressor from restarting, and then front-seat the compressor discharge and suction valves.

For open compressor pump down, complete the following steps:

1. If the system is not equipped with gauges, install a pressure gauge in the back-seat port of the compressor suction valve. Crack the valve off the backseat.
2. Close the liquid line shutoff valve at the condenser.
3. Manually open the liquid line solenoid valve(s). If the valves do not have manual opening devices, lower the setting of the system temperature controller so the valves are held open during the pump down.
4. Install a jumper wire across the terminals of the low-pressure switch. Since the system suction pressure is to be pumped down below the cutout setting of the low-pressure switch, the jumper is necessary to keep the compressor running.
5. Start the compressor. Watching the suction pressure gauge, stop the compressor by opening its electrical disconnect switch when the gauge reading reaches 2 psig.
6. Front-seat the compressor discharge valve.

CAUTION

Do not allow the compressor to pump the suction pressure into a vacuum. A slight positive pressure is necessary to prevent air and moisture from being drawn into the system through minor leaks and through the now unmoving shaft seal.

7. Remove the jumper wire from the low-pressure control.

8. Remove the gauge from the port of the suction valve; replace the port plug and front-seat the valve.

The following steps are required for all systems:

1. Use a refrigerant leak detector to check the condenser and liquid receiver for refrigerant leaks.
2. Valve off the supply and return water connections of the water-cooled condenser. Allow the condenser to remain full of water during the off season. A drained condenser shell is more likely to rust and corrode than one full of water. If the condenser will be subjected to freezing temperatures, drain the water and refill it with an antifreeze solution.
3. Drain the cooling tower or evaporative condenser, if used; flush the sump and paint any rusted or corroded areas.
4. Open the system master disconnect switch and padlock it in the OPEN position.

2.7.1 Startup

The following steps are completed for seasonal start-up:

1. Perform all annual maintenance on the air-handling system and other related equipment.
2. If they are used, fill the water sumps of the cooling tower or evaporative condenser.
3. Open the shutoff valves of the water-cooled condenser.
4. Make certain the liquid line solenoid valve(s) is on automatic control.
5. Open the liquid line shutoff valve.
6. Back-seat the compressor suction and discharge valves.
7. Close the system master electrical disconnect switch.
8. Start the system.
9. After the system has operated for 15 to 20 minutes, check the compressor oil level sight glass, oil pressure, and the liquid line sight glass. If satisfactory, readjust the system temperature controller to the proper temperature setting.

2.8.0 Safety Warnings

Most units used for comfort air conditioning operate using refrigerants that are not toxic except when decomposed by a flame. If liquefied refrigerant contacts an individual's eyes, get that person to a doctor immediately.

Should the skin come in contact with the liquefied refrigerant, the skin is to be treated as though it had been frostbitten or frozen. Refer to NAVEDTRA 13119, *Standard First Aid for Treatment of Frostbite.*

Do not adjust, clean, lubricate, or service any parts of equipment that are in motion. Ensure that moving parts, such as pulleys, belts, or flywheels, are fully enclosed with proper guards attached.

Before making repairs, open all electric switches controlling the equipment. Tag and lock the switches to prevent short circuits or accidental starting of equipment. When moisture and brine are on the floor, fatal grounding through the body is possible when exposed electrical connections can be reached or touched by personnel. De-energize electrical lines before repairing them, and ground all electrical tools.

Test your Knowledge (Select the Correct Response)

3. Which of the following is another name for a floor-mounted air-conditioning unit?

   A. Path-mounted unit
   B. Package unit
   C. Self-contained unit
   D. Hallway unit

4. What type of system is used for air conditioning large tonnage capacities?

   A. Heat pump
   B. Oversized chiller
   C. Strong cycle
   D. Chilled-water

5. **(True or False)** The lubrication of fan bearings should be done when the unit is running.

   A. True
   B. False

3.0.0 MAJOR SYSTEM COMPONENTS and CONTROLS

As a UT, you need to be able to recognize and have an understanding of the different types of air-conditioning cooling towers, compressors, and control elements. Also, it is necessary that you have an understanding of the basic maintenance requirements for cooling towers.

3.1.1 Cooling Towers

Cooling towers (*Figures 13-21 and 13-22*) are classified according to the method of moving air through the tower. These air moving methods include the following:

- Natural draft
- Induced draft
- Forced draft

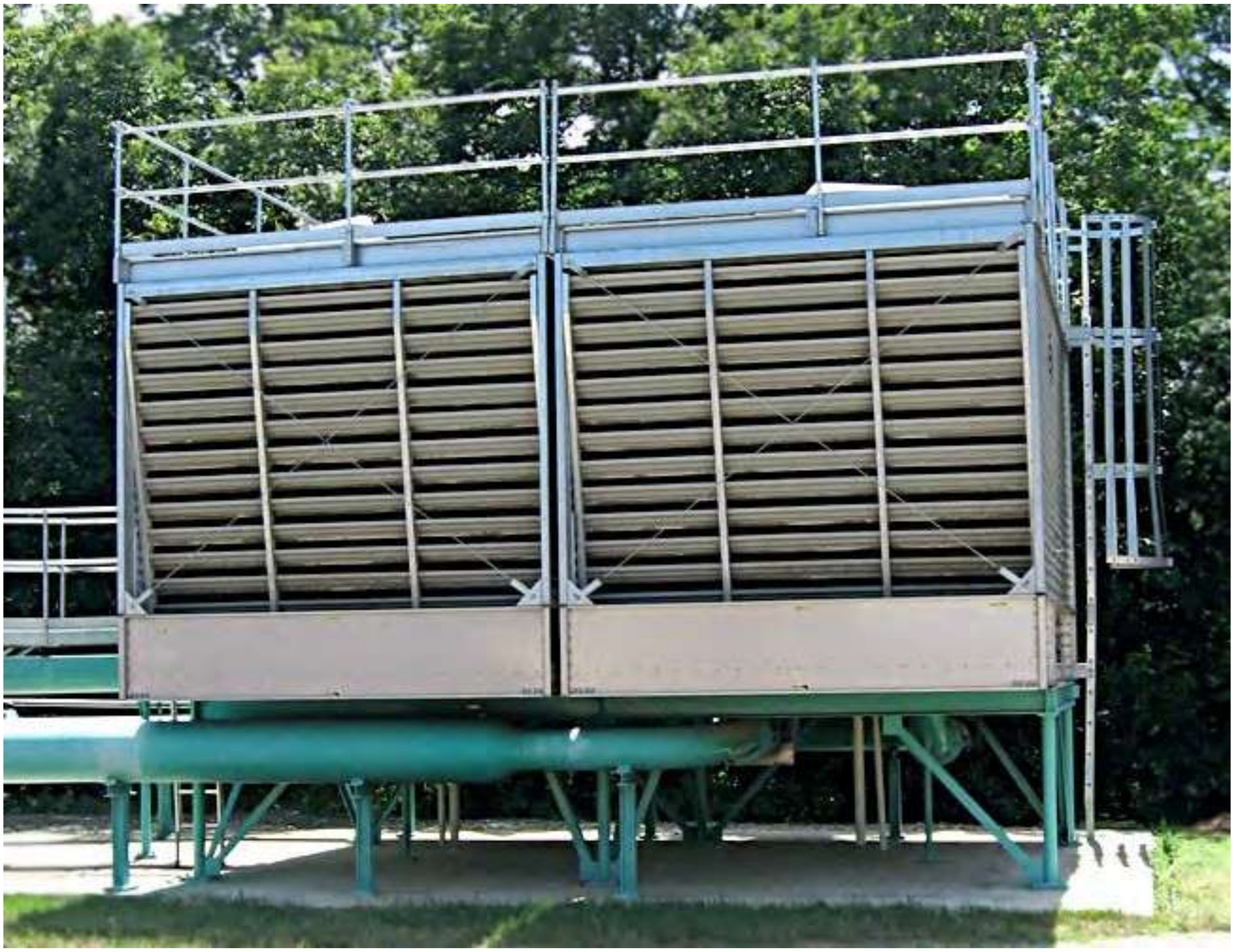


Figure 13-21 — Package tower with a remote, variable speed pump.

Figure 13-22 — Paralleled package towers.

3.1.1 Natural Draft

The natural draft cooling tower is designed to cool water by means of air moving through the tower at the low velocities prevalent in open spaces during the summer. Natural draft towers are constructed of cypress or redwood and have numerous wooden decks of splash bars installed at regular intervals from the bottom to the top. Warm water from the condenser is flooded or sprayed over the distributing deck and flows by gravity to the water-collecting basin.

A completely open space is required for the natural draft tower since its performance depends on existing air currents. Ordinarily, a roof is an excellent location. Louvers must be placed on all sides of a natural draft tower to reduce drift loss.

Important design considerations are the wind velocity and the height of the tower. A wind velocity of 3-miles per hour is generally used for a design of natural draft cooling towers. The natural draft cooling tower was once the standard design for cooling condenser water in refrigeration systems up to about 75 tons. It is now rarely selected unless low initial cost and minimum power requirements are primary considerations. The drift loss and space requirements are much greater than for other cooling tower designs.

3.1.2 Inducted Draft

An induced draft cooling tower is provided with a top-mounted fan that induces atmospheric air to flow up through the tower, as warm water falls downward. An induced draft tower may have only spray nozzles for water backup, or it may be filled with various slat and deck arrangements. There are several types of inducted draft cooling towers.

In a counter-flow induced draft tower (*Figure 13-23*), a top-mounted fan forces air into the bottom of the tower, which flows vertically upward as the water cascades down through the tower. The counter-flow tower is particularly well adapted to a restricted space as the discharge air is directed vertically upward, and if equipped with an inlet on each side, requires only minimum clearance for air intake area. The primary breakup of water may be either by pressure spray or by gravity from pressure-filled flumes.

Figure 13-23 — Counter-flow induced draft tower.

A parallel-flow induced draft tower (*Figure 13-24*) operates the same way as a counter-flow tower, except the top-mounted fan pulls the air in through the top of the tower and pushes it out the bottom.

The airflow goes in the same direction as the water. Comparing counter-flow and parallel-flow induced draft towers of equal capacity, the parallel-flow tower is somewhat wider, but the height is much less. Cooling towers must be braced against the wind. From a structural standpoint, therefore, it is much easier to design a parallel-flow than a counter-flow tower, as the low silhouette of the parallel-flow type offers

Figure 13-24 — Parallel-flow induced draft tower.

much less resistance to the force of the winds.

Mechanical equipment for counter-flow and parallel-flow towers is mounted on top of the tower and is readily accessible for inspection and maintenance. The water-distributing systems are completely open on top of the tower and can be inspected during operation. This makes it possible to adjust the float valves and clean stopped-up nozzles while the towers are operating.

The cross-flow induced draft tower (*Figure 13-25*) is a modified version of the parallel-flow induced draft tower. The fan in a cross-flow cooling tower draws air through a single, horizontal opening at one end and discharges the air at the opposite end. The cooling tower is a packaged tower that is inexpensive to manufacture and is extremely popular for small installations. As a packaged cooling tower with piping and wiring in place, it is simple to install and may be placed wherever there is a clearance of 2 feet for the intake end and a space of 10 feet or more in front of the fan. The discharge end must not face the prevailing wind and should not be directed into a traffic area because drift loss may be objectionable.

Figure 13-25 — Cross-flow induced draft tower.

In some situations, the cooling tower may need to be located indoors. For indoor installations, a counter-flow or cross-flow design is generally selected. Two connections to the outside are usually required—one for drawing outdoor air into the tower and the other for discharging it back outside. A centrifugal blower is often necessary for this application to overcome the static pressure of the ductwork. There are many options available for the point of air entrance and air discharge. This flexibility is often important in designing an indoor installation. Primary water breakup is by pressure spray and fill of various types.

The induced draft cooling tower for indoor installation is a completely assembled packaged unit. However, it is designed to allow partial disassembly, which permits it to pass through limited entrances. Indoor installations of cooling towers are becoming more popular. External space restrictions, architectural compatibility, and convenience for observation and maintenance all combine to favor an indoor location. The installation cost is somewhat higher than an outdoor location. Packaged towers are available in capacities to serve the cooling requirements of refrigeration plants in the 5- to 75-ton range.

3.1.3 Forced Draft

A forced draft cooling tower (*Figure 13-26*) uses a fan to force air into the tower. In the usual installation, the fan shaft is in a horizontal plane. The air is forced horizontally through the fill and upward to be discharged out of the top of the tower. Underflow cooling towers are an improved design of the forced draft tower that retains all the advantages of the efficient parallel-flow design. Air is forced into the center of the tower at the bottom. The air is then turned horizontally (both right and left) through fill chambers and is discharged vertically at both ends.

Figure 13-26 — Forced draft cooling tower.

By forcing the air to flow upward and outward through the fill and leave at the ends, operating noise is baffled and a desirable reduction of sound level is achieved. All sides of the underflow tower are smoothly encased with no louver openings. This blends with modern architecture and eliminates the necessity of masonry walls or other screening devices often necessary to conceal cooling towers of other types.

3.1.4 Cooling Tower Materials

For many years, redwood has been the standard construction material for cooling towers. Other materials, such as cypress, and treated fir and pine, have also been used. Casings are constructed of laminated, waterproof plywood. In areas having a highly corrosive atmosphere, the use of casings and other noncorrosive materials at critical points is essential. During cooling tower construction, nails, bolts, and copper or aluminum nuts are usually standard practice.

Cooling towers of metal coated with plastic or bituminous materials that have air intake louvers and fill made of redwood have met with only limited success. The limited success is primarily because of the high maintenance cost as compared to wood towers.

Some cooling towers are constructed of metal coated with plastic or bituminous materials, and have air intake louvers and fill made of redwood. Due to their high maintenance costs, metal cooling towers have had only limited success.

Packaged towers with metal sides and wood fill are reasonably common. For limited periods of time, some manufacturers used sheet aluminum for siding. Plastic slats have been used for fill material but have not proved satisfactory in all cases.

Fire ordinances of a large city may require that no cooling towers can be constructed of wood. A cooling tower constructed of steel or some other fireproof casing and without fill will comply with the most restrictive ordinances.

3.1.5 Maintenance of cooling towers

It has been found that cooling towers have been linked to the spread of Legionnaire's disease. Several precautionary measures are recommended to help eliminate this problem. These measures include placing cooling towers downwind and using chloride compounds as disinfectants during scheduled monthly maintenance.

An important part of cooling tower operation is water treatment. During the cooling tower water evaporation process, some solids are left behind. Recirculation of the water in the condenser cooling tower circuit, and in the accompanying evaporation, causes the concentration of solids to increase. This concentration must be controlled or scale and corrosion will result.

One method of control is to drain the system from time to time and then refill it with fresh water. However, this method is not recommended because after refilling the system, the dissolved solids again build up to a dangerous concentration.

A more common practice is to waste a certain amount of water continually from the system to the sewer. The water wasted is called blow-down. Blow-down is sometimes accomplished by wasting sump water through an overflow. A better practice is to bleed the required quantity of blow-down from the warm water that leaves the condenser on its way to the cooling tower. If serious corrosion and scaling difficulties are to be avoided, a mineral salt buildup (calcium bicarbonate concentration) of 10 grains per gallon is considered the maximum allowable concentration for untreated water in the sump.

For each ton of refrigeration, cooling towers will evaporate about 2 gallons of water every hour. A gallon of water weighs 8.3 pounds, and about 1,000 Btu is needed to evaporate 1 pound of water. Thus, to evaporate a gallon of water, 8.3 x 1,000 or 8,300 Btu is required.

In many instances, the makeup water contains dissolved salts in excess of 10 grains per gallon. It is obvious, then, that even 100 percent blow-down will not maintain a sump concentration of 10 grains. If the blow-down alone cannot maintain satisfactory control, then chemicals should be used.

Cooling tower makeup water is the sum of drift loss, evaporation, and blow-down. The drift loss for mechanical draft towers ranges from 0.1 percent of the total water being cooled and as much as 0.3 percent for better designed towers. In estimating makeup water for a cooling tower, the higher value of 0.3 percent for drift loss is suggested. If the drift loss is actually less than this value, the excess makeup water supplied is merely wasted down the overflow. This increases the amount of blow-down, which is favorable because it lowers the concentration of scale-forming compounds in the tower sump.

Redwood is a highly durable material but it is not immune to deterioration. The type of deterioration varies depending on the nature of the environmental conditions to which the wood is exposed. The principal types of deterioration are leaching, ***delignification***, and microbiological attack.

The rate of heat transfer in the condenser will be materially reduced if the algae and slime present in the water are not chemically controlled. Condenser tubing, cooling tower piping, and metal surfaces in the water-circulating system must be protected from scale and corrosion.

Using too much of a chemical or using the wrong chemical is known as overtreatment. It can materially reduce the performance or the life of a cooling tower condenser circuit.

3.2.1 Compressors

A compressor is the machine used to withdraw the heat-laden refrigerant vapor from the evaporator, compress it from the evaporator pressure to the condensing pressure, and push it to the condenser. A compressor is merely a simple pump that compresses the refrigerant gas. Compressors may be divided into the following three types:

- Reciprocating
- Rotary
- Centrifugal

The function of compressing a refrigerant is the same in all three general types, but the mechanical means are considerably different. Rotary compressors are used in small sizes only, and their use is limited almost exclusively to domestic refrigerators and small water coolers. Centrifugal compressors are used in large refrigerating and air-conditioning systems (*Figure 13-27*).

3.2.1 Reciprocating Compressors

Reciprocating compressors are usually powered by electric motors, although gasoline, diesel, and turbine drivers are sometimes used. In terms of capacity, reciprocating compressors are made in fractional horsepower for small, self-contained air conditioners and refrigeration equipment, increasing in size to about 250 tons or more capacity in larger installations. The types of reciprocating compressors consist of furnished in open, semi-sealed, and sealed (hermetic).

3.2.1.1 Open

The shaft of an open type of compressor is driven by an external motor. The shaft is equipped with a seal that prevents refrigerant and oil from leaking or moisture and air from entering the compressor as the shaft passes through the crankcase housing. Pistons are actuated by crankshafts or eccentric drive mechanisms mounted on the shaft. Discharge valves are usually mounted in a plate over the pistons. Suction valves are usually mounted either in the pistons, if suction vapors enter the cylinder through the side of the cylinder or through the crankcase, or in the valve plate over the pistons, if suction vapors enter the cylinder through the head and valve plate.

Figure 13-27 — High-speed (36,000 rpm) single-stage centrifugal chiller.

Figure 13-28 shows a cross section of a typical open type of eccentric shaft compressor with suction valves in the valve plate of the head. Most belt-driven, open type of compressors under 3 horsepower use a splash feed lubrication, but in larger size compressors, forced feed systems having positive displacement oil pumps are more common. The oil pump is usually driven from the rear end of the main shaft. Oil from the crankcase is forced under pressure through a hole in the main shaft to the seal, main bearing, and rod bearing, and through a hole in the rod up to the piston pins. Hermetically sealed compressor units used in window air conditioners are quite common in commercial sizes (under 5 horsepower) and are even made by some manufacturers in large tonnage sizes.

Figure 13-28 — Cross section of an open type of reciprocating compressor.

3.2.1.2 Semi-sealed

Large tonnage units are always semi-sealed type compressors, but these compressors can also be made in smaller sizes. The primary difference between a fully sealed and a semi-sealed motor compressor is that in semi-sealed types, the valve plates, and in some units the oil pump, can be removed for repair or replacement. This type of construction is helpful in larger sizes that are so bulky they would cause considerable trouble and expense in shipping, removing, and replacing the unit as a whole. *Figure 13-29* shows a small semi-sealed compressor.

Figure 13-29 — Small semi-sealed compressor.

Sealed or semi-sealed units eliminate the belt drive and crankshaft seal, both of which are among the chief causes of service calls. Sealed and semi-sealed compressors are made either vertical or horizontal. Although vertical type compressors (*Figure 13-30*) can be splash oiled, they usually have positive displacement oil pumps that use 10 to 30 psi of pressure to force oil to the main bearings, rod, or eccentric and pins.

Although oil pumps for forced feed lubrication are also used on horizontal hermetic compressors, oil circulation at low oil pressure may be provided by slingers, screw type of devices, and the like. Splash and other types of oil feed must not be considered inferior forced feed. With good design, they lubricate well.

Figure 13-30 — Vertical semi-sealed compressor.

It is most important to maintain the proper oil level, use a correct grade of oil, and keep the system clean and free of dirt and moisture. This is true for all compression refrigeration systems, especially those equipped with hermetically sealed units whose motor windings may be attacked by acids or other corrosive substances introduced into the system or formed by the chemical reaction of moisture, air, or other foreign substances.

3.2.1.3 Hermetic

The term *sealed* or *hermetic* unit merely means that the motor rotor and compressor crankshaft of the refrigeration system are made in one piece, and the entire motor and compressor assembly are put into a gastight housing that is welded shut (*Figure 13-31*). This method of assembly eliminates the need for certain parts found in the open unit.

These parts are as follows:

- Motor pulley
- Belt
- Compressor flywheel
- Compressor seal

The elimination of the preceding parts in the sealed unit similarly does away with the following service operations: replacing motor pulleys, replacing flywheels, replacing belts, aligning belts, and repairing or replacing seals. When it is realized there are major and minor operations that maintenance personnel must perform and the sealed unit dispenses with only five of these, it can be readily seen that servicing is still necessary.

Figure 13-31 — Reciprocating hermetic compressor.

3.2.2 Rotary

Rotary compressors are generally associated with refrigerators, water coolers, and similar small capacity equipment. However, they are available in larger sizes. A typical application of a large compressor is found in compound compressor systems where high capacity must be provided with a minimum of floor space.

In a rotary compressor (*Figure 13-32*), an eccentric rotor revolves within a housing in which the suction and discharge passages are separated by means of a sealing blade. When the rotating eccentric first passes this blade, the suction area is at a minimum. Further rotation enlarges the space and draws in the charge of refrigerant. As the eccentric again passes the blade, the gas charge is shut off at the inlet, compressed, and discharged from the compressor. There are variations of this basic design, some of which provide the rotor with blades to trap and compress the vapor.

Figure 13-32 — Cutaway view of a rotary compressor.

3.2.3 Centrifugal Compressors

Centrifugal compressors are used in large refrigeration and air-conditioning systems, handling large volumes of refrigerants at low-pressure differentials. Their operating principles are based on the use of centrifugal force as a means of compressing and discharging the vaporized refrigerant. *Figure 13-33* is a cutaway view of one type of centrifugal compressor. In this application, one or two compression stages are used, and the condenser and evaporator are integral parts of the unit. The impeller wheel is the heart of this type of compressor.

Figure 13-33 — Cutaway view of one type of centrifugal compressor.

3.2.4 Scroll Compressors

A scroll compressor has two different offset spiral disks to compress the refrigerant vapor. The upper scroll is stationary, while the lower scroll is the driven scroll. Intake of refrigerant is at the outer edge of the driven scroll, and the discharge of the refrigerant is at the center of the stationary scroll. The driven scroll is rotated around the stationary or "fixed" scroll in an orbiting motion. During this movement, the refrigerant vapor is trapped between the two scrolls. As the driven scroll rotates, it compresses the refrigerant vapor through the discharge port. Scroll compressors have few moving parts and have a very smooth and quiet operation.

3.3.0 Controls

The controls used in air conditioning and refrigeration are generally the same—thermostats, humidistats, pressure and flow controllers, and motor overload protectors shown in *Figure 13-34* are discussed in detail below.

Figure 13-34 — Packaged air-cooled chiller controls.

3.3.1 Thermostats

The thermostat (*Figure 13-34, View 6*) is an adjustable temperature-sensitive device, which through the opening and closing of its contacts controls the operation of the cooling unit. The temperature-sensitive element may be a bimetallic strip or a confined vaporized liquid.

The thermostats used with air conditioners are similar to those used with heating equipment, except their action is reversed. The operating circuit is closed when the room temperature rises to the thermostat control point and remains closed until the cooling unit decreases the temperature enough. Also, cooling thermostats are not equipped with heat-anticipating coils.

Wall type of thermostats most common for heating and air conditioning in the home and on some commercial units use a bimetallic strip and a set of contacts, as shown in *Figure 13-35*. This type of thermostat operates on the principle that when two dissimilar metals, such as brass and steel, are bonded together, one tends to expand faster than the other does when heat is applied. This causes the strip to bend and close the controls.

As a UT, you may be required to make an adjustment that sets the temperature difference between the cut-in and cutout temperatures. For example, if the system is set to cut in at 76°F and cut out at 84°F, then the differential is 8°F. This condition prevents the unit from cycling continually as it would if there were no differential.

3.3.2 Humidistats

A room "humidistat" may be defined as a humidity-sensitive device controlling the equipment that maintains a predetermined humidity of the space where it is installed. The contact of the humidistat is opened and closed by the expansion or contraction of natural blonde human hairs, which are one of the major elements of this control. It has been found that this type of human hair is most sensitive to the moisture content of the air surrounding them.

Figure 13-35 — Bimetallic thermostat.

3.3.3 Pressure-Flow Controllers

Pressure-flow controllers (*Figure 13-34, View 4*) are discussed in Chapter 12. The purpose of air conditioning controllers is to act as safety switches by securing the system, regardless of the position of the operating switches, when head pressure is too high or suction pressure is too low.

3.3.4 Refrigerant-Flow Controllers

The refrigerant-flow controllers used with air conditioners are also similar to the ones discussed in Chapter 12. These controllers are either of the capillary type or externally equalized expansion valve type and are usually of larger tonnage than those used for refrigerators.

3.3.5 Motor Overload Protectors

When the compressor is powered by an electric motor, either belt driven or as an integral part of the compressor assembly, the motor is usually protected by a heat-actuated overload device. This is in addition to the line power fuses (*Figure 13-34, View 1*). The heat to actuate the overload device is supplied by the electrical energy to the motor, as well as the heat generated by the motor itself. If there is too much heat from either source of heat or a combination of the two, it causes the overload device to open, removing the motor from the line.

Figure 13-36 shows a thermal-element type of overload cutout relay. It is housed in the magnetic starter box (*Figure 13-34, View 2*). When current overload occurs, the relay contacts open allowing the holding coil to release the starting mechanism, causing the motor to stop.

An oil failure cutout switch (*Figure 13-34, View 5*) is provided on many systems to protect the compressor against oil failure. The switch is connected to register pressure differential between the oil pump and the suction line.

Figure 13-36 — Thermal overload relay.

Figure 13-37 shows a typical oil failure cutout switch. The switch contains two bellows, which work against each other, and springs for adjusting. Tubing from the oil pump is connected to the bottom bellows of the switch. Tubing from the suction line is connected to the upper bellows. When a predetermined pressure differential is not maintained, a pair of contacts in the switch is opened and breaks the circuit to the compressor motor. A heating element with a built-in delay is in the switch to provide for starting the compressor when oil pressure is low.

Figure 13-37 — Oil failure cutout switch.

The water-regulating valve used with a water-cooled condenser responds to a predetermined condensing pressure. A connection from the discharge side of the compressor to the valve transmits condensing pressure directly to a bellows inside the valve. High pressure opens the valve, allowing a greater flow of water; low pressure throttles the flow. Use of such a valve provides for a more economical use of water for condensing. *Figure 13-38* shows a typical water-regulating valve. When condenser water is supplied by a cooling tower, water-regulating valves are not customarily used because the cooling tower fan and circulating pump are wired into the compressor motor control circuit.

Figure 13-38 — Water-regulating valve.

3.3.6 Step Controller

The step controller contains a shaft with a series of cams mounted on it. When the shaft cams start rotating, electrical switches begin to operate. Adjustment of the cams establishes the temperature at which each switch is to close and open (differential). The switches can also be adjusted to operate in almost any sequence. *Figure 13-39, View A*) shows the internal components and how you could rearrange the wires to change the sequence. The pressure sensor (Figure 13-39, View B) is connected to the step controller.

Figure 13-39 — Step controller and pressure-sensor configuration.

3.4.0 Troubleshooting

A troubleshooting chart (Table 13-1) is generally applicable to all types of air conditioners. Most manufacturers include more detailed and specific information in publications pertaining to their units. If you unpack the unit and find that it did not include a manual, write the manufacturer to have one sent as soon as possible.

Table 13-1 — Troubleshooting Chart for Air Conditioners.

Type of Unit	Complaint	Cause	Possible Remedy
With open-type compressor	Electric motor will not start	Power failure	Check circuit for power source
		Compressor stuck	Locate cause and repair
		Belt too tight	Adjust belt tension
		Manual reset in starter open	Determine cause of overload and repair. Reset overload cutout
		Thermostat setting too high	Lower thermostat setting
		Low voltage	Check with voltmeter, then call power company
		Burned-out motor	Repair or replace
		Frozen compressor caused by locked or damaged mechanism	Remove and repair compressor
	Unit cycles on and off	Intermittent power interruption	Tighten connections or replace defective power supply parts
		High-pressure cutout defective	Replace high-pressure cutout
		High-pressure cutout set too low. Overload opens after having been reset	Raise cutout pressure. Check voltage and current drawn
		Leaky liquid-line solenoid valve	Repair or replace
		Dirty or iced evaporator	Clean or defrost evaporator. Check filters and fan drive
		Overcharge or refrigerant non-condensable gas	Remove excess refrigerant or purge non-condensable gas
		Lack of refrigerant	Repair refrigerant leak and recharge

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
With open-type compressor (cont.)		Restricted liquid-line	Clean strainer
		Faulty motor	Repair or replace faulty motor
	Coil frosts	Filters dirty	Clean filters
		Not enough air over coil	Clean or remove restriction from supply or return ducts or grilles
		Defective expansion valve	Replace valve
	Unit runs but will not cool	Unit not fully charged	Recharge slightly, then check for leaks in the refrigerant circuit, then full charge
		Leaky suction valve	Remove compressor cylinder head and clean or replace valve plate
		Expansion valve not set correctly	Adjust expansion valve
		Strainer clogged	Remove, clean, and replace valve
		Air in refrigerant circuit. Moisture in expansion-valve orifice	Purge unit of air. Clean orifice and install silica gel dryer
		Flash gas in liquid line	Add refrigerant
	No air blows from supply grille	Ice or dirt on evaporator	Clean coil or defrost
		Blower belt broken or loose	Adjust belt tension, or replace belt
		Blower bearing frozen	Repair or replace bearing and lubricate as directed
	Discharge pressure too high	Improper operation of condenser	Correct airflow. Clean coil surface
		Air in system	Purge
		Overcharge of refrigerant	Remove excess or purge
	Discharge pressure too low	Lack of refrigerant	Repair leak and charge
		Broken or leaky compressor discharge valves	Remove head, examine valves and replace those found to be operating improperly

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
With open-type compressor (cont.)	Suction pressure too high	Overfeeding of expansion valve	Regulate superheat setting expansion valve and check to see that remove bulb is properly attached to suction line
		Expansion valve stuck in open position	Repair or replace valve
		Broken suction valves in compressor	Remove head, examine valves and replaced those found to be inoperative
	Suction pressure too low	Lack of refrigerant	Repair leak and charge
		Clogged liquid line strainer	Clean strainer
		Expansion-valve power assembly has lost charge	Replace expansion-valve power assembly
		Obstructed expansion-valve	Clean valve and replace if necessary
		Contact on control thermostat stuck on closed position	Repair thermostat or replace if necessary
With hermetic motor-compressor combination	Compressor runs continuously; good refrigeration effect	Air over condenser restricted	Remove restriction or provide for more air circulation over the condenser
	Compressor runs continuously; unit is too cold	Thermostatic switch contacts badly burned	Replace thermostatic switch
		Thermostatic switch bulb has become loose	Secure bulb in place
		Thermostatic switch improperly adjusted	Readjust thermostatic switch
	Compressor runs continuously; little refrigeration effect	Extremely dirty compressor	Clean compressor
		No air circulating over condenser	Provide air circulation
		Ambient temperature too high	Provide ventilation or move to a cooler location
		Load too great	Analyze load

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
With hermetic motor-compressor combination (cont.)	Compressor runs continuously; no refrigeration	A restriction that prevents the refrigerant from entering the evaporator. A restriction is usually indicated by a slight refrigeration effect at the point of restriction	Locate the possible points of restriction, and try jarring it with a plastic hammer, or heating to a temperature of about 110 degrees F. If the restriction does not open, replace the unit.
		Compressor not pumping. A cool discharge line and a hot compressor housing, indicates this. The wattage is generally low.	Replace the unit
		Short of refrigerant	See manufacturer's instructions
	Compressor short cycles, poor refrigeration effect	Loose electrical connections	Locate loose connections and make them secure
		Defective thermostatic switch	Replace thermostatic switch
		Defective motor starter	Replace defective motor starter or relay
		Air restriction at evaporator	Remove air restriction
	Compressor short cycles, no refrigeration	Dirty condenser	Clean the condenser
		Ambient temperature too high	Provide ventilation or move to a cooler location
		Defective wiring	Repair or replace defective wiring
		Thermostatic switch operating erratically	Replace thermostatic switch
		Relay erratic	Replace relay
	Compressor runs too frequently	Poor air circulation around the condenser or ambient temperature too high	Increase the air circulation around the condenser. In some localities the temperature is extremely high, and nothing can be done to correct the problem

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
With hermetic motor-compressor combination (cont.)		Load too great. Worn compressor. Generally accompanied by rattles and knocks	Analyze end use. Replace unit or bring it to the shop for repairs
	Compressor does not run	Motor is not operating	If the trouble is outside the sealed unit, it should be corrected; for example, wires should be repaired or replaced and thermostatic switches or relays should be replaced. If the trouble is inside the sealed unit, the sealed unit should be replaced.
	Compressor will not run (Assume that the thermostatic switch and relay and the electric wiring and current supply are in good condition and operating normally)	If the cabinet has been moved, some oil may be on top of the piston	Wait an hour or so, and then attempt to start the motor by turning the current on and off many times. On some compressors, it may be necessary to wait 6 or 8 hours
		Compressor may be stuck, or some parts may be broken	Replace the unit
		Connections may be broken on the inside of the unit, or the motor winding may be open	Replace the unit. Sometimes after sealed units have been standing idle for a long time, the piston may be stuck in the cylinder wall. It is sometimes possible to start the compressor by turning on the current and bumping the outer housing with a rubber mallet.
	Compressor is unusually hot	Condenser is dirty, or there is a lack of air circulation	Clean the condenser, increase the air circulation
		Unusually heavy service or load	If possible, decrease load. Perhaps another unit is required

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
With hermetic motor-compressor combination (cont.)		Low voltage	Feed wires too small could cause this. If the wires feeding the refrigerating unit become warm, it is an indication that they are too small and should be replaced with larger wires
		A shortage of oil	Add oil if possible; if this is not possible, the unit must be replaced. A shortage of refrigerant will cause a shortage of oil in the crankcase of the compressor
	No refrigeration after starting up after a long shutdown or on delivery	Generally, during a long shutdown, an amount of liquid refrigerant will get into the crankcase of the compressor. When this happens, the compressor operation will cause no noticeable refrigeration effect until the entire liquid refrigerant has evaporated from the crankcase.	Allow the compressor to operate until its internal heat driver the liquid refrigerant from the crankcase. Under some conditions, this may take as long as 24 hours. This time can be shortened by turning an electric heater on the compressor and raising the compressor temperature, not exceeding 110 degrees F.
	Compressor is noisy	Mountings have become worn or deteriorated. The walls against which the unit is placed may be of an extremely hand surface and may resound and amplify the slight noise from the compressor into the room.	Replace the rubber mountings. Place a piece of sound-absorbing material on the wall against which the unit is placed or move the unit to a new location.
		Shortage of oil and/or refrigerant	Add oil and refrigerant if possible. If it is impossible, the unit must be replaced.
		The sealed unit mechanism has become worn	Replace the unit
	After each defrosting there is a long on cycle before refrigeration is again normal	Slight shortage of refrigerant	Add refrigerant if possible, if not, replace the unit.

Table 13-1 — Troubleshooting Chart for Air Conditioners (cont.).

Type of Unit	Complaint	Cause	Possible Remedy
		Condenser is dirty	Clean the condenser
		Thermostatic switch bulb is loose	Secure the bulb in place
With hermetic motor-compressor combination (cont.)		There is a restriction between the receiver or condenser and/or the evaporator	Attempt to remove the restriction by jarring with a plastic hammer or by heating the possible points of restriction to about 110 degrees F. If this does not correct the trouble, the unit must be replaced or brought to the shop for repairs.

Test your Knowledge (Select the Correct Response)

6. What type of cooling tower requires a completely open space because its performance depends on existing air currents?

   A. Induced draft
   B. Natural draft
   C. Forced draft
   D. Single draft

7. Which of the following reciprocating compressors is driven by an external motor?

   A. Open
   B. Hermetic
   C. Rotary
   D. Semi-sealed

4.0.0 AUTOMOTIVE AIR CONDITIONING

As part of the responsibilities as a UT, it is important that you have an understanding of the basic principles of operation, maintenance, and repair of automotive air conditioning

Vehicle air conditioning is the cooling (refrigeration) of air within a passenger compartment. Refrigeration is accomplished by using heat transfer, latent heat of vaporization, and the effects of pressure on boiling or condensation. Heat transfer and latent heat were covered in Chapter 12.

4.1.1 Effect of Pressure on Boiling or Condensation

The saturation temperature (the temperature where boiling or condensation occurs) of a liquid or vapor increases or decreases according to the pressure exerted on it.

In the fixed orifice tube refrigerant system, liquid refrigerant is stored in the condenser under high pressure (*Figure 13-40*). When the liquid refrigerant is released into the evaporator by the fixed orifice tube, the resulting decrease in pressure and partial boiling lowers its temperature to its new boiling point.

As the refrigerant flows through the evaporator, passenger compartment air passes over the outside surface of the evaporator coils. As it boils, the refrigerant absorbs heat from the air and cools the passenger compartment. The heat from the passenger compartment is absorbed by the boiling refrigerant and hidden in the vapor. The refrigeration cycle is now under way. The following functions must be done to complete the refrigeration cycle:

1. Disposing of the heat in the vapor
2. Converting the vapor back to liquid for reuse
3. Returning of the liquid to the starting point in the refrigeration cycle

Figure 13-40 — Air-conditioning refrigeration system-fixed orifice.

The compressor and condenser (*Figure 13-40*) perform these functions. The compressor pumps the refrigerant vapor (containing the hidden heat) out of the evaporator and suction accumulator drier, then forces it under high pressure into the condenser which is located in the outside air stream at the front of the vehicle. The increased pressure in the condenser raises the refrigerant condensation or saturation temperature to a point higher than that of the outside air. As the heat transfers from the hot vapor to the cooler air, the refrigerant condenses back to a liquid. The liquid under high pressure now returns through the liquid line to the fixed orifice tube for reuse.

It may seem difficult to understand how heat can be transferred from a comparatively cooler vehicle passenger compartment to the hot outside air. The answer lies in the difference between the refrigerant pressure that exists in the evaporator and the pressure that exists in the condenser. In the evaporator, the compressor suction reduces the pressure and the boiling point below the temperature of the passenger compartment, thus, heat transfers from the passenger compartment to the boiling refrigerant. In the condenser, the compressor raises the condensation point above the temperature of the outside air, thus, the heat transfers from the condensing refrigerant to the outside air. The fixed orifice tube and the compressor simply create pressure conditions that permit the laws of nature to function.

4.2.1 Automotive Compressors

For automotive applications, there are three basic types of air-conditioning compressors in general use. These types of compressors include the following:

- Two-cylinder reciprocating
- Swash plate
- Scotch yoke

Each of these uses a reciprocating (back-and-forth motion) piston arrangement. Most automotive compressors are semi-hermetic.

Two-cylinder compressors (*Figure 13-41*) usually contain two pistons in a parallel V-type configuration. The pistons are attached to a connecting rod, which is driven by the crankshaft. The crankshaft is connected to the compressor clutch assembly, which is driven by an engine belt. Reed valves generally are used to control the intake and exhaust of the refrigerant gas during the pumping operation. These compressors are usually constructed of die cast aluminum.

In the swash plate or "wobble plate" compressor (*Figure 13-42*), the piston motion is parallel to the crankshaft. The pistons are connected to an angled swash plate using ball joints. Swash plate compressors consist of the following three types

- five-cylinder
- six-cylinder
- five-cylinder variable

Figure 13-41 — Two-cylinder reciprocating compressor.

The five- and six-cylinder swash compressor has three cylinders at each end of its inner assembly. A swash plate of diagonal design is mounted on the compressor shaft. It actuates the pistons, forcing them to move back and forth in the cylinders as the shaft is rotated. Reed valves control suction and discharge; crossover passages feed refrigerant to both high- and low-service fittings at the rear end of the compressor. A gear-type oil pump in the rear head provides compressor lubrication.

The five-cylinder variable swash plate compressor is different from the other swash plate compressors. It uses a plate connected to a hinge pin that permits the swash plate to change its angle. The angle of the swash plate is controlled by a bellows valve that senses suction pressure. During high load conditions the swash plate angle is large, and during low load conditions, the swash plate angle is smaller. The displacement of the compressor is high at a large angle and low at a small angle.

A scotch-yoke compressor changes rotary motion into reciprocating motion. The basic mechanism of the scotch yoke contains four pistons mounted 90 degrees from each other. Opposed pistons are pressed into a yoke that rides on a slide block located on the shaft eccentric *(Figure 13-43)*. Rotation of the shaft provides a reciprocating motion with no connecting rods. Refrigerant flows into the crankcase through the rear and is drained through the reeds attached to the piston tops during the suction stroke. Refrigerant is then discharged through the valve plate out the connector block at the rear. These compressors are shorter in length and larger in diameter than other compressors.

Figure 13-42 — Five-cylinder swash plate compressor.

Figure 13-43 — Four-cylinder scotch-yoke mechanism.

4.2.1 Compressor Service Valves

Some air-conditioning systems have compressor service valves built into them. They serve as a point of attachment for test gauges or servicing hoses. Service valves have the following three position controls:

- Front seated
- Back seated
- Midposition

The position of this double-faced valve (*Figure 13-44*) is controlled by rotating the valve stem with a service valve wrench. Clockwise rotation seats the front face of the valve and shuts off all refrigerant flow in the system. This position isolates the compressor from the rest of the system.

Counterclockwise rotation unseats the valve and opens the system to refrigerant flow (midposition). Systematic checks are performed with a manifold gauge set with the service valve in midposition.

Further counterclockwise rotation of the valve stem seats the rear face of the valve. This position opens the system to the flow of refrigerant but shuts off refrigerant to the test connector. The service valves are used for observing of operating pressures; isolating the compressor for repair or replacement; and discharging, evacuating, and charging the system.

Figure 13-44 — Service valve positions.

Compressors used in automotive air-conditioning systems generally are equipped with an electromagnetic clutch that energizes and de-energizes to engage and disengage the compressor. The rotating coil and stationary coil are the two types of clutches that are used most often.

The rotating coil clutch has a magnetic coil mounted in the pulley that rotates with the pulley. It operates electrically through connections to a stationary brush assembly and rotating slip rings. The clutch permits the compressor to engage or disengage as required for adequate air conditioning. The stationary coil clutch has the magnetic coil mounted on the end of the compressor. Electrical connections are made directly to the coil leads.

The belt-driven pulley is always in rotation while the engine is running. The compressor is in rotation and operation only when the clutch engages it to the pulley.

Air-conditioning and refrigeration systems use various control devices, including those for the refrigerant, the capillary tube usually found on window units, the automatic expansion valves also found on window units and small package units, the thermal expansion valve, and various types of suction pressure-regulating valves and devices. A suction pressure-regulating valve is used on automotive air conditioning because the varying rpm of the compressor unit must maintain a constant pressure in the evaporator.

4.2.2 Suction Pressure-Regulating Valves

Suction pressure-regulating valves may be installed in the suction line at the outlet of the evaporator when a minimum temperature must be maintained. Suction pressure-regulating valves decrease the temperature difference, which would otherwise exist between the compartment temperature and the surface of the cooling coils. The amount of heat that can be transferred into the evaporating refrigerant is directly proportional to the temperature difference. *Figure 13-45* shows an exploded view of a typical suction pressure-regulating valve, sometimes called a suction throttling valve in automotive air conditioners.

Figure 13-45 — Suction pressure-regulating valve.

The following three types of suction pressure-regulating valves are in use:

- Suction throttling valve (STV)
- Evaporator pressure regulators (EPR)
- Pilot-operated absolute valve (POA)

These valves were developed by General Motors, and are adjustable in most cases.

The POA valve uses a sealed pressure element that maintains a constant pressure independent of the altitude of the vehicle. The following two basic types of metering devices are built into a single container:

- Valves-In-Receiver (VIR)
- Evaporator Equalized Valves-In-Receiver (EEVIR)

These units combine the POA valve, receiver-drier, thermostatic expansion valve, and sight glass into a single unit.

The VIR assembly is mounted next to the evaporator, which eliminates the need for an external equalizer line between the thermostatic expansion valve and the outlet of the POA valve. The equalizer function is carried out by a drilled-hole (equalizer port) between the two-valve cavities in the VIR housing.

The thermostatic expansion valve is also eliminated. The diaphragm of the VIR expansion valve is exposed to the refrigerant vapor entering the VIR unit from the outlet of the evaporator. The sight glass is in the valve housing at the inlet end of the thermostatic valve cavity where it gives a liquid indication of the refrigerant level.

The VIR thermostatic expansion valve controls the flow of refrigerant to the evaporator by sensing the temperature and pressure of the refrigerant gas as it passes through the VIR unit on its way to the compressor. The POA valve controls the flow of refrigerant from the evaporator to maintain a constant evaporator pressure of 30 psi. The VIR and the POA valves are capsule type of valves. When found to be defective, you must replace the complete valve capsule.

The drier desiccant is in a bag in the receiver shell. It is replaceable by removing the shell and removing the old bag and installing a new bag of desiccant. Service procedures for the VIR system differ in some respects from the service procedures performed on conventional automotive air-conditioning systems.

4.3.1 Service Precautions

When tasked to service air-conditioning equipment observe the following precautions:

- Never open or loosen a connection before discharging the system.
- Immediately after disconnecting a component from the system, seal the open fittings with a cap or plug.
- Before disconnecting a component from the system, clean the outside of the fittings thoroughly.
- Do not remove the sealing caps from a replacement component until you are ready to install it.
- Do not open an oil container until it is ready to use, and install the cap immediately after using. Refrigerant oil absorbs moisture from the atmosphere if it is uncapped. Store the oil only in a clean, moisture-free container.
- Before connecting to an open fitting, always install a new seal ring. Coat the fitting and seal with the refrigerant oil before connecting.
- When installing a refrigerant line, avoid sharp bends. Position the line away from the exhaust or any sharp edges that may chafe the line.
- Tighten the fittings only to specified torque. The copper and aluminum fittings that are used in refrigerant systems will not tolerate over-tightening.
- When disconnecting a fitting, use a wrench on both halves of the fitting to prevent twisting of refrigerant lines or tubes.
- Do not open a refrigerant system or uncap a replacement component unless it is as close as possible to room temperature. This prevents condensation from forming inside a component that is cooler than the surrounding air.
- Keep the service tools and work area clean. Contamination of a refrigerant system through careless work habits must be avoided.

4.4.1 Diagnosis, Testing, and Servicing

Diagnosis is more than just following a series of interrelated steps to find the solution to a specific condition. It is a way of looking at systems that are not functioning the way they should and finding out why. Also, diagnosis includes knowing how the system should work and whether it is working correctly. All good diagnosticians use the same basic procedures. There are basic rules for diagnosis. Follow these rules when going through the system the first time to find the cause of the condition.

1. Know the system; know how the parts go together. Also, know how the system operates and its limits, and what happens when something goes wrong. Sometimes this means comparing a system that is working properly with the one you are servicing.
2. Know the history of the system. How old or new is the system? What kind of treatment has it had? Has it been serviced in the past in such a manner that might relate to the present condition? What is the service history? A clue in any of these areas might save a lot of diagnosis time.
3. Know the probability of certain conditions developing. It is true that most conditions are caused by simple things, rather than by complex ones, and they occur in a fairly predictable pattern. Electrical problem conditions, for instance, usually occur at connections rather than in components. An engine "no-start" is more likely to be caused by a loose wire or some component out of adjustment than a sheared-off camshaft. Know the difference between impossible and improbable. Many good technicians have spent hours diagnosing a system because they thought certain failures were "impossible," only to find out the failures eventually were just "improbable" and actually had happened. Remember, new parts are just that—new. It does not mean they are good functioning parts.
4. Do not cure the symptom and leave the cause. Recharging a refrigerant system may correct the condition of insufficient cooling, but it does not correct the original problem unless a cause is found. A properly working system does not lose refrigerant over time.
5. Be sure to find the cause. Do not be fooled into thinking the cause of the problem has been found. Perform the proper tests then double-check the results. The system should have been checked for refrigerant leaks. If no leaks were found, perform a leak test with the system under extremely high pressure. If the system performed properly when new, it had to have a leak to be low in charge.
6. No matter what form charts may take, they are simply a way of expressing the relationship between the basic logic and a physical system of components. It is a way of determining the cause of a condition in the shortest possible amount of time. Diagnosis charts combine many areas of diagnosis into one visual display that allows you to determine the following:
    - The probability of certain things occurring in a system
    - The speed of checking certain components or functions before others
    - The simplicity of performing certain tests before others
    - The elimination of checking huge sections of a system by performing simple tests

- The certainties of narrowing down the search to a small area before performing in-depth testing

The fastest way to find a condition is to work with the tools that are available, which means working with proven diagnosis charts and the proper special tools for the system being worked on.

Servicing procedures for automotive air-conditioning units are similar to those used to service conventional air-conditioning systems. Discharging, evacuating, charging procedures, connections, and positions of valves on the gauge manifold set are shown in *Figure 13-46*.

Servicing procedures for the VIR system are also similar to those used when servicing conventional air-conditioning systems. However, the hookup of the manifold gauge set is to the VIR unit. The high-pressure fitting is located in the VIR inlet line. The low-pressure fitting is located in the VIR unit.

4.5.0 System Visual Inspection

When conducting a careful visual inspection of a unit's refrigerant system, it is often possible to find out what could be causing a problem. This could include broken belts, obstructed condenser air passages, a loose clutch, loose or broken mounting brackets, disconnected or broken wires, and refrigerant leaks.

A refrigerant leak usually appears as an oily residue at the leakage point in the system. The oily residue will appear greasy because it has picked up dust or dirt particles from the surrounding air. Through time, this builds up and appears to be heavy, dirt-impregnated grease.

Another type of leak may appear at the internal Schrader type of air-conditioning charging valve core in the service gauge port valve fittings. If tightening the valve core does not stop the leak, it should be replaced with a new air-conditioning charging valve core.

A refrigerant leak can also be caused if a service gauge port valve cap is missing. When the valve cap is missing, dirt enters the area of the air-conditioning charging valve core. After the service hose is attached, the valve depressor in the end of the service hose forces the dirt into the valve seat area, and it destroys the sealing surface of the air-conditioning charging valve core. If you find a service gauge port valve cap is missing, you should clean the protected area of the charging valve core and install a new service gauge port valve cap.

CAUTION

The service gauge port valve cap must be installed finger tight. If tightened with pliers, the sealing surface of the service gauge port valve may be damaged.

Figure 13-46 — Procedures for observing operating pressures, charging, purging, and evacuating a unit.

4.6.1 Cleaning a Badly Contaminated Refrigerant System

A refrigerant system can become badly contaminated for a number of reasons.

- The compressor may have failed due to damage or wear.
- The compressor may have been run for some time with a severe leak or an opening in the system.
- The system may have been damaged by a collision and left open for some time.
- The system may not have been cleaned properly after a previous failure.
- The system may have been operated for a time with water or moisture in it.

A badly contaminated system contains water, carbon, and other decomposition products. When such a condition exists, the system must be flushed with a special flushing agent, using equipment designed especially for this purpose.

4.6.1 Flushing Agents

A refrigerant to be suitable as a flushing agent must remain in the liquid state during the flushing operation to wash the inside surfaces of the system components. Refrigerant vapor will not remove contaminant particles. They must be flushed with a liquid. Some refrigerants are better suited for this purpose than others.

For years, R-11 and R-113 refrigerants were used as the primary flushing agents however, both were phased out in the year 2000. At this time there are other refrigerants that are being used in their place. R-123 refrigerant has replaced R-11, and R-113 has been replaced by R-141b refrigerant.

CAUTION

Use extreme care and adhere to all safety precautions related to the use of refrigerants when flushing a system.

4.6.2 System Cleaning and Flushing

When it is necessary to flush a refrigerant system, the suction accumulator/drier must be removed and replaced, as it is impossible to clean. Remove the fixed orifice tube. If a new tube is available, replace the contaminated one; otherwise, wash it carefully in flushing refrigerant or mineral spirits and blow it dry. If it does not show signs of damage or deterioration, it may be reused. Install new O rings.

Any moisture in the evaporator will be removed during leak testing and system evacuation following the cleaning job. Perform the following steps of the cleaning procedure carefully:

1. Check the hose connections at the flushing cylinder outlet and flushing nozzle to ensure they are secure.
2. Ensure the flushing cylinder is filled with approximately 1 pint of R-141b and that the valve assembly on top of the cylinder is tightened securely.
3. Connect a can of R-134a to the Schrader valve at the top of the charging cylinder. A refrigerant hose and a special, safety type of refrigerant dispensing valve are required for connecting the small can to the cylinder. Ensure all connections are secure.
4. Connect a gauge manifold and a discharge system. Disconnect the gauge manifold.

5. Remove and discard the suction accumulator/drier. Install a new accumulator/drier and connect it to the evaporator. Do not connect it to the suction line from the compressor. Ensure a protective cap is in place on the suction line connection.
6. Replace the fixed orifice tube. Install a protective cap on the evaporator inlet tube as soon as the new orifice tube is in place. The liquid line will be connected later.
7. Remove the compressor from the vehicle for cleaning and servicing or replacement, whichever is required. If the compressor is cleaned and serviced, add the specified amount of refrigerant oil before installing it on the mounting brackets in the vehicle. Install the shipping caps on the compressor connections. Install a new compressor on the mounting brackets in the vehicle.
8. Back flush the condenser and the liquid line as follows:
    a. Remove two O rings from the condenser inlet tube spring lock coupling.
    b. Remove the discharge hose from the condenser and clamp a piece of (1/2-inch ID) heater hose to the condenser inlet line. Ensure the hose is long enough to insert the free end into a suitable waste container to catch the flushing refrigerant.
    c. Move the flushing equipment into position and open the valve on the can of R-134a (fully counterclockwise).
    d. Back flush the condenser and the liquid line by introducing flushing refrigerant into the supported end of the liquid line with the flushing nozzle. Hold the nozzle firmly against the open end of the liquid line.
    e. After the liquid line and condenser have been flushed, lay the charging cylinder on its side so the R-134a will not force more of the flushing refrigerant into the liquid line. Press the nozzle firmly to the liquid line and admit the R-134a to force all the flushing refrigerant from the liquid line and condenser.
    f. Remove the 1/2-inch hose and clamp from the condenser inlet connection.
    g. Stand the flushing cylinder upright and flush the compressor discharge hose. Secure it so the flushing refrigerant goes into the waste container.
    h. Close the dispensing valve of the R-134a can (fully clockwise). If there is any flushing refrigerant in the cylinder, it may be left there until the next flushing job. Put the flushing kit and R-134a can in a suitable storage location.
    i. Install the new lubricated O rings on the spring lock coupling male fittings on both the condenser inlet and the liquid lines. Assemble the couplings.
9. Connect all refrigerant lines. All connections should be cleaned and new O rings should be used. Lubricate new O rings with clean refrigerant oil.
10. Connect a charging station or manifold gauge set and charge the system with 1 pound of R-134a. (Do not evacuate the system until after it has been leak tested.)
11. Leak-test all connections and components with a flame type of leak detector or an electronic leak detector. If no leaks are found, go to Step 12. If leaks are found, service as necessary; check the system and then go to Step 12.
12. Evacuate and charge the system with a specified amount of R-134a. Operate the system to ensure it is cooling properly.

4.7.0 Safety Precautions

The use of safety when handling or using refrigerants can never be stressed enough. As discussed in Chapter 12, routinely think of safety for yourself and co-workers.

Extreme care must be taken to prevent any liquid refrigerant from coming in contact with the skin and especially the eyes. A bottle of sterile mineral oil and a quantity of weak boric acid solution must always be kept nearby when servicing the air-conditioning system. Should any liquid refrigerant get into your eyes, immediately use a few drops of mineral oil to wash them out; then wash the eyes clean with the weak boric acid solution. Seek a doctor's aid immediately even though irritation may have ceased. *Always wear safety goggles when servicing any part of the refrigerant system*.

To avoid a dangerous explosion, never weld, solder, steam clean, bake body finishes, or use any excessive amount of heat on or in the immediate area of any part of the refrigerant system or refrigerant supply tank while they are closed to the atmosphere, whether filled with refrigerant or not.

The liquid refrigerant evaporates so rapidly that the resulting refrigerant gas displaces the air surrounding the area where the refrigerant is released. To prevent possible suffocation in enclosed areas, always discharge the refrigerant into recycling/reclaiming equipment. *Always maintain good ventilation surrounding the work area*.

Even though R-12 refrigerant was banned in 1996, some systems you may be working on may still contain R-12. Therefore, it is important that you adhere to the following information.

Under normal conditions, R-12 gas is non-poisonous. However, the discharge of R-12 near an open flame can produce a very poisonous gas. This gas, which also attacks all bright metal surfaces, is generated when you use the flame type of leak detector. *Avoid inhaling the fumes from the leak detector*. Chances are you will have to replace the R-12 with R-134a and modify system components accordingly. After exchanging R-12, it is important that it is properly disposed of according to federal, state, and local ordinances.

When admitting R-134a gas into the cooling unit, always keep the tank in an upright position. The tank cannot be on its side or upside down because liquid R-134a will enter the system and may damage the compressor.

The following EPA website provides a list of current replacement refrigerants http://www.epa.gov/Ozone/snap/refrigerants/lists/

4.8.0 Truck and Bus Air Conditioning

Many truck-tractors, long distance hauling trucks, and earthmoving equipment have cabs that are air-conditioned. Most of this air-conditioning equipment is the "hang on" type and is installed after the cab has been made.

Some truck air-conditioning units have two evaporators—one for the cab and one for the relief driver's quarters in back of the driver. Some systems use a remote condenser, mounted on the roof of the cab. This type of installation removes the condenser from in front of the radiator so the radiator can operate at full efficiency. This is especially important during long pulls in low gear.

The system is similar to the automobile air conditioner and is installed and serviced in the same general way.

The air conditioning of buses has progressed rapidly. Because of the large size of the unit, most bus air-conditioning systems use a separate gasoline engine with an automatic starting device to drive the compressor. The system is standard in construction except for the condensing unit. It is made as compact as possible and is installed in the bus, so it can be easily reached for servicing.

To aid in servicing the system, condensing units are often mounted on rails with flexible suction and liquid lines, which allow sliding of the condensing unit out of the bus.

Air-cooled condensers are used. Thermostatic expansion valve refrigerant controls are standard. Finned blower evaporators are also used.

The duct system usually runs between a false ceiling and the roof of the bus. The ducts, usually one on each side of the bus, have grilles at the passenger seats. The passengers may control the grille by opening and closing.

4.9.1 Certification

In accordance with the Clean Air Act (CAA), the Environmental Protection Agency (EPA) has established that all technicians who maintain or repair air-conditioning or refrigeration equipment must be certified. Technicians who operate recycling, reclaiming, and recovery equipment must also be certified. Certification is administered by organizations with certification programs that are approved by the EPA.

As a UT, it is important that you understand if you are not certified, you cannot service any Heating Ventilation Air Conditioning and Refrigeration (HVA/R) units that require you to use or remove refrigerants. Certification requirements are divided into the following two areas:

- Automotive air-conditioning
- HVA/R

4.9.1 Automotive Air-Conditioning Certification

In today's world, people spend more and more time in their vehicles, causing the air conditioning to be used continuously during the hotter months of the year. This higher usage requires that automotive air-conditioning be serviced or repaired more than other types of air-conditioning systems.

To become a certified technician, you must meet the following EPA requirements:

- Be aware that venting refrigerant is illegal.
- Understand why all the regulations are being created. Understand what is happening to the environment.
- Have a working knowledge of SAE standards J-1989, J-1990, and J-1991.
- Perform service in a safe manner without injuring personnel or damaging equipment. Areas that must be understood include venting, handling, transporting, and disposing of refrigerant.

A certification card is issued to the applicant after being tested and meeting the EPA requirements.

4.9.2 ting, Ventilating, Air Conditioning, and Refrigeration Certification

The certification requirements for standard types of air-conditioning systems are the same as those for automotive air-conditioning certification.

Unlike the automotive certification program, standard air-conditioning certification is divided into levels corresponding to the type of service the technician performs. There are four types of certification:

- Type I – Servicing small appliances
- Type II – Servicing high or very high-pressure appliances
- Type III – Servicing or disposing of low-pressure appliances
- Type IV (Universal) – Servicing all types of equipment

Individuals will be required to take a proctored, closed-book test. These tests are offered by organizations approved by the EPA for the specific type of certification required by the technician. Technicians can only work on air-conditioning systems that they have been certified to service.

Test your Knowledge (Select the Correct Response)

8. What type of swash plate compressor uses a plate connected to a hinge pin that permits the swash plate to change its angle?

   A. Six-cylinder
   B. Scotch-yoke
   C. Two-cylinder
   D. Five-cylinder variable

9. What type of suction pressure-regulating valve uses a sealed pressure element to maintain a constant pressure independent of the altitude of the vehicle?

   A. Isolated system pressure (ISP) valve
   B. Pilot operated absolute (POA) valve
   C. Suction throttling valve (STV)
   D. Evaporator pressure regulators (EPR)

10. Which of the following refrigerants has replaced R-113 as a primary flushing agent used for cleaning a system?

   A. R-141b
   B. R-502
   C. R-22
   D. R-123

5.0.0 DUCTWORK

As a UT, it is important that you understand the basic types of ductwork systems, and the components of those systems used for distributing conditioned air.

Distributed air must be clean, provide the proper amount of ventilation, and absorb enough heat to cool the conditioned spaces. To deliver air to the conditioned space, air carriers are required, which are called ducts. Ducts work on the principle of air pressure difference. If a pressure difference exists, air will flow from an area of high pressure to an area of low pressure. The larger this difference, the faster the air will flow to the low-pressure area.

5.1.1 Classification of Ducts

The three common classifications of ducts are:

- Conditioned air ducts
- Recirculating air ducts
- Fresh-air ducts

Conditioned air ducts carry conditioned air from the system and distribute it to the conditioned area. Recirculating air ducts take air from the conditioned space and distribute it back into the system. Fresh air ducts bring fresh air into the system from outside the conditioned space.

Ducts commonly used for carrying air are round, square, or rectangular in shape. The most efficient duct is a round duct, based on the volume of air handled per perimeter distance. In other words, less material is needed for the same capacity as a square or rectangular duct because circular ducts cause less turbulence and allow more flow.

Square or rectangular duct fits better to building construction. It fits above ceilings and into walls and is much easier to install between joists and studs.

5.2.1 Types of Duct Systems

There are several types of supply duct systems (*Figure 13-47*) that deliver air to room(s) and then return the air from the room(s) to the cooling (evaporator) system. These supply systems can be grouped into the following four types:

1. Individual round pipe system
2. Extended plenum system
3. Reducing trunk system
4. Combination (of two or more systems)

Return air systems are normally of three types—single return, multiple return (*Figure 13-47*), or a combination of the two systems.

5.3.0 Construction

Ducts may be made of metal, wood, ceramic, and plastic. Most commonly used is sheet steel coated with zinc (galvanized steel). Sheet metal brakes and forming machines are used in fabricating ducts. Elbows and other connections, such as branches, are designed using geometric principles. Some types of duct connections used in constructing duct systems are shown in *Figure 13-48*.

When sheet metal ducts heat and cool, they expand and contract. To absorb this movement, fabric joints are often used. Fabric joints should also be used where the duct connects to the air conditioner. Many ducts are insulated to lower noise and reduce heat transfer. The insulation can be on the inside or the outside of the duct. Adhesives or metal clips are commonly used to fasten the insulation to the duct. As we are only briefly discussing construction here, you can find construction and fabrication methods in the Steelworker Basic, Chapter 13*, Layout and Fabrication of Sheet-metal and Fiber-class Duct*. It details design and fabrication of steel ductwork.

Figure 13-47 — Supply duct systems.

Figure 13-48 — Typical duct connections.

5.4.0 Components

To enable a duct system to circulate air at the proper velocity and volume to the proper conditioned areas, you can use different components within the duct system, such as diffusers, grilles, and dampers

5.4.1 Diffusers, Grilles and Registers

Room openings to ducts have several devices that control the airflow and keep large objects out of the duct. These devices consist of the following:

- Diffusers
- Grilles
- Registers

Diffusers deliver fan-shaped airflow into a room. In certain types of diffusers duct air will mix with some room air.

Grilles control the distance, height, and spread of air-throw, as well as amount of air. Grilles cause some resistance to airflow. Grille cross-section pieces block about 30 percent of the air. Because of this reason and to reduce noise, cross sections are usually enlarged at the grille. Grilles have many different designs, such as fixed vanes which force air in one direction, or adjustable, which forces air in different directions.

Registers are used to deliver a concentrated air stream into a room, and many have one-way or two-way adjustable air stream deflectors.

5.4.2 Dampers

One way of getting even air distribution is through the use of duct dampers. Dampers balance airflow or can shut off or open certain ducts for zone control. Some are located in the grille, and some are in the duct itself. The following three types of dampers, shown in *Figure 13-49*, are used in air-conditioning ductwork:

- Butterfly
- Multiple blade
- Split damper

Always draw a line on temperature control when installing a damper.

5.4.3 Fire Dampers

Automatic fire dampers should be installed in all vertical ducts. Ducts, especially vertical ducts, will carry fumes and flames from fires. Fire dampers must be inspected and tested at least once a year to be sure they are in proper working order. The following two types of fire dampers are fail-safe units:

- Spring-loaded to close
- Weight-loaded to close

Fire dampers are usually held open by a fusible link. Heat will melt the link and the damper will be closed by gravity, weights, or springs (*Figure 13-50*).

Figure 13-49 — Three types of duct dampers.

5.4.4 Fans

Air movement is usually produced by some type of forced airflow. Fans are normally located in the inlet of the air conditioner. Air is moved by creating either a positive pressure or negative pressure in the ductwork. The two most popular types of fans are the axial flow (propeller) or radial flow (squirrel cage) (*Figure 13-51*).

The axial-flow fan is usually direct-driven by mounting the fan blades on the motor shaft. The radial-flow fan is normally belt-driven but can also be direct-driven.

Figure 13-50 — Fire damper in OPEN position.

Figure 13-51 — Principal types of fans.

5.5.1 Balancing the System

Balancing a system basically means sizing the ducts and adjusting the dampers to ensure each room receives the correct amount of air. To balance a system, follow these steps:

1. Inspect the complete system. Locate all ducts, openings, and dampers.
2. Open all dampers in the ducts and at the grilles.
3. Check the velocities at each outlet.
4. Measure the "free" grille area.
5. Calculate the volume at each outlet. Velocity x Area = Volume
6. Area in square inches divided by 144 multiplied by feet per minute equals cubic feet/minute.
7. Total the cubic feet/minute.
8. Determine the floor areas of each room. Add to determine total area.
9. Determine the cubic feet per minute (cfm) for each room. The area of the room divided by the total floor area, multiplied by the total cfm, equals cfm for the room.
10. Adjust duct dampers and grille dampers to obtain these values.
11. Recheck all outlet grilles.

In some cases, it may be necessary to overcome excess duct resistance by installing an air duct booster. These are fans used to increase airflow when a duct is too small, too long, or has too many elbows.

Test your Knowledge (Select the Correct Response)

11. What classification of air ducts takes air from the conditioned space and then distributes it back into the air conditioner system?

    A. Fresh-air
    B. Recirculating air
    C. Full-capacity air
    D. Conditioned air

12. Which of the following duct components is used to deliver a concentrated air stream into a room?

    A. Grille
    B. Diffuser
    C. Damper
    D. Register

13. **(True or False)** A radial flow fan can be belt-driven or direct-drive.

    A. True
    B. False

Summary

Air conditioning is the simultaneous control of temperature, humidity, air movement, and the quality of air in a conditioned space or building. This chapter introduced the principles of air conditioning and the operation of basic air-conditioning systems. It also described how to recognize the characteristics and procedures required to install, operate, and maintain air-conditioning systems. Finally, this chapter described how to recognize air-conditioning system components and controls along with their application, and the types of duct systems that can be used.

Review Questions (Select the Correct Response)

1. What is the term given to the net effects of temperature, humidity, and air motion?

    A. Comfort zone
    B. Effective temperature
    C. Relative humidity
    D. Dew point

2. **(True or False)** Electricity can be used to purify the air in some large air-conditioning systems.

    A. True
    B. False

3. Window-mounted air-conditioning units usually range from 4,000 to _ Btu per hour in capacity.

    A. 16,000
    B. 28,000
    C. 32,000
    D. 36,000

4. Floor-mounted air-conditioning units that range in size from 24,000 to 360,000 Btu per hour are also referred to as what type of unit?

    A. Complete
    B. Controlled
    C. Major
    D. Package

5. **(True or False)** Flooded shell-and-tube coolers use less refrigeration than other systems of equal size.

    A. True
    B. False

6. What type of condenser is used for practically all water-cooled refrigeration systems?

    A. Shell-and-tube
    B. Tube-within-a-tube
    C. Shell-and-coil
    D. Coil-and-tube

7. Cooling towers have been linked to the spread of what disease?

   A. Pneumonia
   B. Emphysema
   C. Legionnaire's
   D. Cystic fibrosis

8. How much Btu is required to evaporate 3 gallons of water?

   A. 16,400
   B. 18,700
   C. 21,800
   D. 24,900

9. What type of compressor is used in large air-conditioning systems that handle large volumes of refrigerants at low-pressure differentials?

   A. Centrifugal
   B. Rotary
   C. Hermetic
   D. Scroll

10. What air-conditioning control is an adjustable temperature-sensitive device that has contacts that open and close to control the operation of the air conditioner?

    A. Step controller
    B. Motor overload protector
    C. Thermostat
    D. Humidistat

11. What type of automotive air-conditioning compressor changes rotary motion into reciprocating motion, and contains four pistons mounted 90 degrees from each other?

    A. Scotch-yoke
    B. Swash plate
    C. Two-cylinder reciprocating
    D. Five-cylinder variable

12. What is the first step to be followed when performing diagnosis of an air-conditioning system?

    A. Know the probability of certain conditions developing
    B. Know how to cure the symptoms
    C. Know the history of the system
    D. Know the system and how the parts work together

13. According to the EPA, what refrigerant can now be used to replace R-12 refrigerant in air-conditioning systems?

    A. R-141b
    B. R-134a
    C. R-123
    D. R-113

14. **(True or False)** When servicing HVA/R units, certification is not required for using or removing refrigerants.

    A. True
    B. False

15. What type of standard air-conditioning certification must a technician have to service or dispose of low-pressure appliances?

    A. Type I
    B. Type II
    C. Type III
    D. Type IV

16. **(True or False)** Conditioned air ducts bring outside air into the air-conditioning system, then distributes it to the conditioned area.

    A. True
    B. False

17. What air-conditioning duct is the most efficient?

    A. Rectangular
    B. Round
    C. Triangular
    D. Square

18. Which of the following duct components controls the distance, height, and spread of air-throw, as well as the amount of air, but can also cause some resistance to airflow?

    A. Diffuser
    B. Register
    C. Grille
    D. Damper

19. **(True or False)** Automatic fire dampers that are installed in vertical ducts must be inspected at least once a year to ensure they are working properly.

    A. True
    B. False

20. What type of air conditioner fan is also known as a squirrel cage fan?

A. Axial flow
B. Straight stream
C. Uneven draw
D. Radial flow

21. What is the fourth step that a technician should follow when balancing the system?

A. Measure the “free” grille area.
B. Check the velocities at each outlet.
C. Open all dampers in the ducts and at the grilles.
D. Determine the cubic feet per minute for each room.

Trade Terms Introduced in This Chapter

Delignification	The process of removing the natural glue from the wood, either by chemical or physical methods.
Psychrometric	A chart that presents physical and thermal properties of moist air in a graphical form.
Effective Temperature	A comfort index that takes into account the temperature of air, its moisture content, and movement.
Forced-circulation	The use of a pump or other fluid-movement device in conjunction with liquid-processing equipment to move the liquid through pipes and process vessels; contrasted to gravity or thermal circulation.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

NAVEDTRA 14250A, Steelworker Basic, Chapter 13, *Layout and Fabrication of Sheet-metal and Fiber-class Duct*

Environmental Protection Agency (EPA) website: http://epa.gov/Ozone/snap/refrigerants/lists/

NAVEDTRA 13119, *Standard First Aid for Treatment of Frostbite*

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 14

Utilities Equipment and Maintenance

Topics

1.0.0 Installation of Industrial Food Grinders

2.0.0 Maintenance of Industrial Food Grinders

3.0.0 Galley Equipment

4.0.0 Emergency Showers and Eyewash Stations

5.0.0 Fire Hydrants

6.0.0 Inspection of Fire Hydrants

7.0.0 Backflow Prevention

8.0.0 Installation of Backflow Prevention Devices

9.0.0 Equipment Maintenance

To hear audio, click on the box.

Overview

As an Utilitiesman, or UT, you need to have an understanding of the various types of utilities equipment and of the installation and maintenance procedures involved with these types of equipment. This chapter will discuss galley equipment installation, troubleshooting, and maintenance. Emergency showers, eyewash stations, and fire hydrants.

This chapter will also cover the testing procedures associated with backflow prevention and maintenance procedures for miscellaneous equipment. The information covered here is by no means comprehensive, so always refer to the manufacturers' operating and maintenance manuals for detailed instructions and specifications.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the installation procedures for industrial food grinders.
2. Describe the maintenance procedures for industrial food grinders.
3. Describe the maintenance procedures for galley equipment.
4. Describe the different types of galley equipment.
5. Describe the inspection procedures associated with galley equipment.
6. Describe the installation procedures for emergency showers and eyewash stations.

7. Describe the different types and components of fire hydrants.
8. Describe the inspection procedures associated with fire hydrants.
9. Describe the maintenance procedures for backflow prevention.
10. Describe the installation procedures for backflow prevention devices.
11. Describe the different maintenance procedures for miscellaneous equipment.

Prerequisites

None.

This course map shows all of the chapters in Utilitiesman Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Utilities Equipment and Maintenance	↑	
Air Conditioning		
Refrigeration		
Heating Systems		U
Steam Distribution Systems		T
Boilers		
Sewage Disposal, Field Sanitation, and Water Treatment		B
Prime Movers, Pumps, and Compressors		A
Plumbing Fixtures		S
Piping System Layout and Plumbing Accessories		I
Structural Openings and Pipe Material		C
Fundamentals of Water Distribution		
Basic Math, Electrical, and Plumbing Operations		
Plans, Specifications, and Color Coding		

Features of This Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 COMPONENTS AND FUNCTIONS

The garbage disposal is mounted to the underside of a sink and is designed to store waste food in a hopper chamber (just beneath the sink drain and the upper part of the disposal). When turned on, the motor spins the flywheel and attached impellers (*Figure 14-1*). The attached impellers work to throw the waste food against the shredder ring and together they grind and pulverize the garbage (*Figure 14-2*). Water from the kitchen faucet flushes the pulverized waste material out the waste line discharge and down the sewer system, or in some cases, into the septic system.

Figure 14-1 — Components of an industrial food grinder.

Figure 14-2 — Impeller.

1.1.1 Installation of Industrial Food Grinders

As a UT, you will be called on to install pretty much anything to do with pipes, to include an industrial food grinder or under-sink garbage disposal unit (*Figure 14-3*). The units with which you will work may vary greatly in size but will generally be installed the same manner. The following guidelines are by no means all inclusive, so always use the manufacturer's installation instructions. Before installing the disposer, first read and understand the entire safety and installation instructions.

Figure 14-3 — Industrial food grinder.

First, determine if you are replacing an existing unit or if it is a first-time installation.

CAUTION

Turn off electrical supply and secure water supply.

If you are replacing an existing disposer:

1. Disconnect the drain trap from the waste discharge tube. Disconnect the dishwasher or direct water connection if connected to the disposer.
2. Support the disposer, insert the end of Allen wrench into the right side of the mounting lug, and turn. The disposer will fall free.
3. Flip the disposer over and remove the electrical cover plate. Save the cable connector, if applicable.
4. Disconnect the disposer wires from the electrical supply.
5. Remove the old disposer.

If the mounting hardware is the same as the original disposal's, then just reverse the order of disassembly. If the mount is different, then follow these steps:

1. Loosen the screws on the mounting assembly.
2. Using a screwdriver, remove the snap ring or D-ring.
3. Remove the flange from sink.
4. Remove old plumber's putty from the sink with a putty knife.
5. Ensure all surfaces are clean.

The following steps are for the installation of the new disposal unit:

1. In the sink basin, evenly apply a ½-inch thick rope of plumber's putty around the flange seat on the sink.
2. Press the new disposal's flange into the sink flange seat firmly. Remove any excess putty.
3. Under the sink, slide the fiber gasket, backup ring, and mounting ring onto the flange. Hold in place while inserting the snap ring.

4. In the sink, place a weight, such as the disposer, on the sink flange to hold it in place. Use a towel to prevent scratching the sink.
5. Under the sink, pull the snap ring open and press firmly until it snaps into place.
6. Tighten screws evenly and firmly against the backup flange. Use the correct length screws based on the thickness of the sink.

If the disposal unit is directly connected to either a dishwasher or a water source, follow these steps:

1. Turn the disposer on it’s side and insert screwdriver into the dishwasher inlet.
2. Knock out the drain plug and remove the plug from inside the disposer. You will see the knock out plug in the throat of the disposal.
3. Turn the disposer over and remove the electrical cover plate.
4. Pull out wires.
5. Insert the cable connector and run the electrical cable through the access hole on the bottom of the disposer. Tighten the cable connector.
6. Connect the corresponding wires with wire nuts. Ground the wire to the green grounding screw. The unit must be grounded for safe and proper installation.
7. Push the wires into the disposer and replace the electrical cover plate.
8. Rotate the disposer around. Place the rubber gasket on the end of the discharge tube and slide on the metal flange from the reverse end. Place the assembled discharge tube in the tailpipe mount opening and secure with screw provided.
9. Hang the disposer by aligning three mounting tabs with slide-up ramps on mounting ring.
10. Turn the mounting ring until all three mounting tabs lock over the ridges on the slide-up ramps.
11. You may need to trim the tube for a proper fit. Reconnect plumbing (and dishwasher or direct water connection, if used). Make sure the tailpipe mount is straight.
12. Insert stopper into the sink opening. Fill the sink with water, then test for leaks.

Once again, not all aspects of installation were covered here. Always use the manufacturer’s installation manual.

1.2.0 Industrial Sink

Scullery sinks are large sheet metal sinks used for washing large pots and pans and for general scouring purposes (*Figure 14-4*). The large amount of grease that usually passes through a scullery sink makes a 2-inch waste pipe necessary. The bracket should be screwed into the mounting board in a position where the sink, when mounted, is at a convenient height for use. As a rule of thumb, the distance between the top of the drain board and finished floor should not be less than 36 inches.

Figure 14-4 — Industrial sink.

After screwing the bracket into place, lower the sink into position on the bracket so the lugs, which are cast into the back of the sink, fit down into the corresponding notches in the bracket. Screw the strainer and tailpiece into the sink bowl and connect the trap to the rough-in waste. To complete the installation, select a suitable faucet. Install the faucet on the sink and connect the water supply to it. Then install and connect the waste lines to the sink, as shown in *Figure 14-5.*

Figure 14-5 — Installation of waste lines.

2.0.0 MAINTENANCE of INDUSTRIAL FOOD GRINDERS

Maintaining a garbage disposal is very easy: every month, put some ice cubes and some natural salt into the disposal and let it run until the large cubes have been crushed. Wash down the remaining salt with water. Slice a lemon in half and place both halves into the disposal, run until the lemon peel is pulverized, and wash down with water. This technique removes grease and food particles from the impeller and hopper, and the lemon removes odors.

2.1.1 Common Malfunctions

Before you start with any troubleshooting, you must observe one simple rule: Do not put your hand into the hopper of the garbage disposal. It sounds ridiculous, but it is worth noting.

Let us look at some of the more common problems you may encounter and how to fix them.

Problem:

Disposal will not turn on (no noise).
If the disposal will not turn on and it is NOT making a humming sound, then there is an electrical problem. Follow these steps and the manufacturer's instructions.

1. Make sure the disposal is plugged in.

2. If it is plugged in, then press the Reset button found on the bottom of the unit. If it has reset, the button will usually be popped out.
3. If that does not work, check to see if the circuit breaker has tripped and turned off in the electrical service panel.
4. If the breaker has not tripped and the reset button is not popped out, then it is either a faulty switch or a faulty garbage disposal. First locate the switch that powers the disposal unit. It should be located on the wall but may be under the sink. Using a Fluke multimeter, test the switch, if the switch tests bad continue with the following
5. Turn off the circuit breaker at the service panel that powers the disposal.
6. Replace the switch.
7. Turn power back on at the service panel and check the disposal for operation.
8. If the disposal will still not turn on and makes no noise, the garbage disposal is beyond repair and needs to be replaced.

Problem:

Flywheel is stuck/Disposal will not run (makes a humming noise).
If the garbage disposal will not turn on but makes a humming sound when you flip the switch, it will not make the sound for long. That sound indicates that you have a stuck flywheel, and the reset button on the unit itself, the fuse, or circuit breaker in the electrical service panel will trip and turn off very quickly. The flywheel is stuck because something is lodged between it or the impeller(s) and the shredder ring.

1. To start the repair, turn off power to the garbage disposal at the electrical service panel.
2. Reminder: Do not ever put your hand down into the garbage disposal hopper (grinding chamber).
3. Take the offset wrench that came with the disposal unit and insert the wrench into the flywheel turning hole in the bottom of the unit. If you do not have the wrench, you can pick one up from a location that sells garbage disposals and replacement parts.
4. Once the wrench is inserted, turn it clockwise to dislodge the stuck impeller or flywheel. When it dislodges, you will feel the flywheel turn freely.
5. Another approach is to try and use a wooden broom handle or similar wooden object to free the stuck impeller and flywheel from the top of the unit through the drain.
6. Place the broom handle into the hopper and against an impeller. Use leverage to try and free the stuck flywheel. As before, when it dislodges, you will feel the flywheel turn freely.
7. Once freed, turn the power back on at the panel but do not turn on the disposal yet.
8. Go back to the disposal and press the reset button.
9. Run some tap water into the disposal and quickly flip the switch on and off, turning the disposal on for a short burst. Turn on and off again quickly. That should spin the flywheel and the dislodged obstruction should be washed down the drain.

Problem:

Garbage disposal is leaking.

Leaks can occur at a number of places on a garbage disposer. Let us look at the most common:

Leak at the sink flange

1. Turn off power to the disposal at the electrical service panel.
2. At the disposer mount, turn the disposal clockwise to loosen and remove the unit from the mounting flange.
3. Tighten the three mounting bolts.
4. If the bolts are tight, the leak may be caused by failed plumber's putty. Loosen the bolts and push the sink flange slightly above the surface of the sink.
5. Force plumber's putty between the sink flange and the sink, going completely around the flange.
6. Tighten the mounting bolts, drawing the sink flange tight to the sink surface. The putty will ooze out. Wipe away excess putty.
7. Reinstall the disposal and turn power back on at the service panel.
8. Check for leaks.

Leak at the dishwasher connection

1. Tighten the clamp on the dishwasher hose connected to the dishwasher inlet on the disposer.
2. Replace the hose if the hose is leaking.

Leak at the discharge drainpipe

1. Check the bolts holding the discharge pipe to the disposal for tightness.
2. If that does not work, remove the bolts and the pipe and replace the gasket.
3. Reinstall bolts and tighten.

Problem:

Slow draining

Slow draining of a garbage disposal can be caused by a number of problems.

1. Assuming you have given the disposal enough time to run and clear the garbage, you probably have a clogged drain line.

NOTE

Never use chemical drain cleaners with a garbage disposal! You will damage the disposal and because the chemicals probably will not work anyway, you will end up with a sink full of toxic chemicals that you will have to hand bail into a bucket and flush down the toilet.

2. Remove the bolts that hold the discharge pipe to the disposal.
3. Disconnect the drain trap and remove the trap and the discharge drain pipe.
4. Check for clogs or obstructions.

5. If none are found, the clog lies in the line going into the wall or beyond the vertical pipe going into the wall.
6. Clear the obstruction with a sink auger.

2.2.0 Repair Procedures

Repair procedures should only be performed in accordance with the manufacturer's repair manual. Always use the proper personal protective equipment. Follow all safety precautions when working around energized equipment. Water and electricity are a deadly combination.

2.3.0 Replacement of Industrial Sinks

Replacing a sink is easy because all of the plumbing is already there. You may have to adjust the height of the tail piece, depending on the depth of the replacement sink. Ensure you have all parts and tools needed prior to installation. Follow the recommended installation procedures that accompany the sink. As always, use the proper personal protective equipment.

3.0.0 GALLEY EQUIPMENT

Most stateside galleys, as well as many overseas, are now operated and maintained through civilian contracts. But there are still installations maintained by overseas Public Works Departments (PWD), which require military personnel. We will discuss information on the maintenance of common types of galley equipment.

Because of the contracted galley facilities and differences in types of equipment you are expected to maintain, only general information is presented, as you should study the manufacturer's manual that comes with a new piece of equipment before you attempt to install or maintain it.

3.1.0 Steam Kettles

Steam kettles, more commonly called "coppers," are either direct-steam or self-contained type units. Self-contained units generate their own steam though either a gas burner or electrical connections. Direct-steam coppers are supplied with steam from a central boiler located in the galley. Because direct-steam units are more common than self-contained units, we will mainly cover direct-steam coppers. *Figure 14-6* is a direct-steam tilting kettle.

Figure 14-6 — Tilting steam kettle.

Maintenance requirements for coppers are small when compared to other pieces of galley equipment. You should consider this fact when you are developing a preventive maintenance inspection schedule. The maintenance schedule for coppers requires monthly inspections and an annual preventive maintenance inspection. When conducting monthly or annual inspections, talk to galley personnel about the operation of the coppers. These personnel can give you information that will assist you in diagnosing possible operational or maintenance problems. A few factors for inspecting direct-steam coppers are as follows:

Monthly inspection:

1. Check the faucets, valves, and piping for leaks.
2. Check the steam pressure-reducing valve to ensure it is in good condition and functions properly.
3. Lubricate the hinges of the cover with mineral oil.

Annual inspection:

1. Check the copper for leaks, cracks, and dents.
2. Examine the cover, hinges, and latch for warp and alignment.
3. Check the steam and condensate piping, valves, and traps for leaks and obstructions.
4. Remove the safety valves and remove any rust and corrosion using Navy-approved solvents. Then, lubricate and calibrate the valves before replacing them.

Other than visual inspections, each individual piece of galley equipment requires its own type of preventive maintenance. *Table 14-1* provides the recommended schedules for inspection and maintenance of coppers.

Table 14-1— Inspection and Maintenance of Coppers and Other Steam-Related Equipment.

Inspection Point	Symptoms	Time	Possible Trouble/Causes	Possible Corrections
Steam jacket	Not heating	When noted	No steam; valve stuck closed; trap malfunctioning	Check steam supply; free stuck valve.
Steam jacket	Stays hot	When noted	Valve partly open or scored seat	Repair or replace valve.
Steam jacket	Leaks	Monthly	Rapid changes in temperature causing cracks; faulty weld	Raise heat slower; re-weld bust or crack.
Pipe joints	Leaks	Monthly	Joint made incorrectly; not tight	Unscrew; clean and repair joint.
Pipe joints	Corrosion	Monthly	Leaks or condensation	Repair and/or clean.
Control valves	Stuck open or closed	When noted	No steam or too much steam; packing too tight or valve frozen	Loosen packing gland or free frozen valve steam.
Control valves	Leaks at stem	Weekly	Packing not tight enough	Tighten packing.
Condensate strainer	No flow	When noted	Restricted strainer	Clean strainer.
Steam trap	Malfunctioning	Every 6 months	Parts worn or dirty	Disassemble, clean, and repair.
Lagging	Broken or crushed	Quarterly	Water soaked; stepped on	Replace defective sections.
Reducing valve	Incorrect pressure	When noted	Parts worn or dirty	Disassemble, clean, and repair; clean and adjust pressure every 6 months.
Safety valve	Stuck open or lifting under pressure	When noted	Leaks or corrosion	Replace or repair valve.
Covers	Tight operation	When noted	Hinges dirty	Clean and lubricate hinges.
Draw off valve	Leaks	When noted	Scored	Resurface or replace. Do not replace with regular gate valve.

3.2.1 Steam Chests

Steam chests are used to cook food through a steaming process (*Figure 14-7*). The escape of steam from a steam chest harms the food being prepared and also poses a safety hazard to personnel. To ensure steam-tight operation, ensure the door latches, hinges, and gaskets are kept close fitting. A physical preventive maintenance inspection of the steam chests should be made each week.

Figure 14-7 — Steam chest.

The weekly inspection should ensure the following:

1. The compartment drains are free of obstructions.
2. The door hinges, locking devices, and shelf drawbars work well.
3. The pressure setting of the gauge pressure is correct.

When a plunger type of valve is used with the locking device, the plunger must be adjusted so the valve is fully depressed when the door is closed. This action allows a full measure of steam to enter the compartment. When the door is opened, the valve must function to stop the steam supply completely. To ensure a tight fit of the doors, replace hinge pins and bushings when they show too much wear. Some full-floating doors are adjustable by means of hexagon-head bolts extending through the door near each corner. When door gaskets need to be replaced, you have to remove the door from the unit to remove the worn gasket and to clean the channel. Failure to complete these actions can provide a path for steam leakage. Apply gasket cement, and press the new gasket into the channel at the corners, working it in toward the center. You are now ready to hang the door; be sure to place paper along the edge of the door opening to prevent excess cement from adhering to the mating surfaces when the door is closed. Any excess cement can be cleaned off after it has hardened. When the door has hexagon-head bolts, adjust them so the closed door touches the steamer evenly without binding at the corners. Unless you have a good fit, the gasket will cut by the corners of the door and steam will escape. For inspection and preventive maintenance of the steam service and condensate system, include those items that apply in *Table 14-1.*

3.3.1 Steam Tables

Steam tables are used to keep food hot during serving by use of steam and hot water (*Figure 14-8*). Careful inspections of steam tables should be done monthly and yearly.

The monthly inspection should include the following:

1. Check the water compartment, steam coil, valves, and piping for leaks and corrosion.
2. Check the steam pressure on the gauge, keeping in mind that the pressure should not exceed maximum pressure shown on the nameplate.
3. Check and calibrate the temperature control, if needed.

The annual inspection should include the following:

1. De-scale the water compartment, examine the top and frame for scale, and check the level of the steam tabletop.

Figure 14-8 — Steam table.

2. Remove the rust and corrosion within the water compartment, as necessary, with solvent, and paint the bare spots with heat-resistant aluminum paint.
3. Check the thermostat with a mercury thermometer. The thermostat must be accurate to within either plus or minus 5°F.

NOTE

Use *Table 14-1* to check other items that apply to this equipment.

3.4.0 Dishwashers

From time to time, you may be called upon to adjust dishwashing machines that have become defective. Some of the most common difficulties, the usual reasons for their occurrence, and possible remedies for them are listed in *Table 14-2*.

Table 14-2 — Dishwasher Troubleshooting.

TROUBLE	PROBABLE CAUSE	POSSIBLE REMEDY
Dish racks slide off chain conveyor	Change of tension of either chain	Reset idler sprockets to proper tension on each chain.
Water pressure too low	Spray nozzles or slot plugged; strainer baskets plugged; slipped belts on pumps	Dismantle spray assembly. Wash out all piping and clean parts. Disassemble and clean strainer. If belts are frayed or torn, replace them. Adjust tension by resetting idler pulley or by moving motor on sliding base.
Water splashing on floor or into wrong compartment	Leaks around doors; torn curtains or curtains not in proper position	Realign door. Repair or replace gasket. Repair or realign curtain. Readjust spray to keep it within limits of tank.
Rinse water temperature is less than 180°F	Insufficient heat from booster heater	Remove scale from steam coil. Correct leaking fittings. Adjust gas burners. Calibrate or replace thermostat.
Spot or film on eating utensils after final rinse	Wash water saturated with grease; dirty tank; weak sprays in wrong direction; improper detergent mixture	Stop operation and clean all equipment. Adjust speed of conveyor. Examine spray equipment. Clean nozzles, spray pipes, scrap trays, and strainers. Check piping for leaks. Check to see if valves are operating properly. Examine pump. Clean impellor, if necessary.

Now and then, de-scaling deposits from within the machine, the piping, and the pumps will be required. You can fill the tank halfway with hot water, add an approved cleaning solution, fill the tanks to overflowing, and then operate the machine for 30 minutes at high temperature with trays, spray arms, and curtains in place. Next, drain the tanks and fill them with hot water and run the machine for 5 minutes. This rinsing action should be repeated several times to make sure all of the cleaning solution is removed from the unit.

Dishwashing machines and accessories should be lubricated according to the manufacturer’s instructions. This is especially true in the selection grades and viscosities of the oil used, the levels at which the oil is to be maintained, and the places to be oiled. All damaged or missing lubrication fittings should be replaced. The grease cups on the drive end, connecting rod, and the rinse lever should be turned once each quarter and be refilled when empty. Also, the revolving wash arms and valve stems should have a few drops of light oil applied to them about once each quarter.

3.5.1 Ranges

Observing a schedule of monthly and annual inspections ensures the safe and efficient operation of a range, including the oven, broiler, griddle, and so on (*Figure 14-9*). Some of the major items that should be covered as part of the monthly inspection are as follows:

- Check the pipe for leaks.
- Clean and lubricate the motors.
- Check the burner flame. Remember, the burner should give off a blue flame when the air-oil mixture is correct. A flue-gas analysis should be performed to find the proper fuel-air mixture.
- Check the equipment for alignment and fit of doors, for sliding action of racks, and for levelness.

Figure 14-9 — Industrial range.

The annual inspection of oil- and gas-fired equipment should include the following:

- Check on all the parts for damage, corrosion, and lack of paint. Remove the rust with solvents, and paint the bare spots with heat-resistant aluminum paint. **(NOTE:** If bare spots total more than 20 percent of the entire surface, paint the equipment.)
- Check the thermostat. If the accuracy of the thermostat cannot be adjusted to within 5°F accuracy, replace it with a new thermostat.
- Clean soot deposits and jet openings, and repair or replace leaking piping.
- Clean and tighten the nuts and bolts.

Refer to *Table 14-3* for further troubleshooting help.

Table 14-3 — Troubleshooting Chart for Ovens, Ranges, and Boilers.

Trouble	Check	Cause
OIL-FIRED OVENS		
MOTOR: Will not start Runs, but fails to light oven	Fuse Thermostat Solenoid valve Fuel tank Ignition Transformer Fuel nozzle	Blown Set below baking chamber temperature; reset Activated or foreign particles in valve Empty Carbon on electrodes damaged or bad; replace. Clogged; clean.
COMBUSTION FLAME: Disorganized and smoky	Damper Flue pipes	Closed Heavy soot deposits
UNEVEN COOKING:	Secondary air damper door	Too far open or too near shut;adjust.
IGNITION: Difficult	Oil supply	Too low; open valve
BURNER: Starts, functions properly, but fails after short intervals	Burner openings Suction line Strainers Oil tank vent Controls	Shut off by solenoid valve Dirty; clean. Air leak; repair. Clogged; clean. Obstructed; clean. Out of order or improperly adjusted
Puffs when started; runs, but flame pulsates	Ignition Draft Chimney	Poor or delayed. Clean nozzle. Insufficient A downdraft
COMBUSTION CHAMBER: Smoke in chamber or in chimney	Air Nozzle	Insufficient Clogged or defective; replace
Carbon forms in chamber	Oil burning rate. Nozzle (oil spray on walls)	Excessive; reduce. Dirty or incorrect model Clean/Replace
FIRE: On one side	Nozzle	Dirty or damaged; clean/replace.
OIL CONSUMPTION: High	Air Heat-absorbing surfaces Oil storage tank	Too little; increase. Dirty; clean ducts. Leaks; repair.
SOLENOID VALVE: Fails to function	Valve itself Thermostat Connections Emergency bypass valve	Dirty or defective; replace. Damaged; replace. Defective; replace.

Trouble	Check	Cause
OIL-FIRED OVENS		
PILOT FLAME: Inoperative or too low	Fuel passage Solenoid valve	Clogged clean. Adjust setscrew to increase fuel to pilot flame.
OVEN: Overheats Underheats	Thermostat Solenoid valve Fuel line Fuel shutoff valve Vaporizing parts	Damaged; replace. Stuck plunger; dirty; clean. Clogged; clean/replace. Not fully open Full of carbon; clean.
OVEN OR RANGE: Fails to ignite Does not heat fast enough Cooks unevenly No gas	Pilot flame Main gas or shutoff valve Air shutter Gas input Cooling damper Flue Doors Bypass Flame Main service valve Solenoid valve	Insufficient or none Closed (adjacent to unit) Completely closed Too low or out of adjustment Open Too much draft.(pulls heat through flue) Do not close tightly; clean. Adjust. Closed Clogged, dirty or defective; Clean/replace.
OVEN OR RANGE: Constant "burning" Temperature rises, when not in use Fumes in room Flare back on turndown	Draft Thermostat Low flame setting Chimney Fans in room Bypass flame	Too much; remove draft. Faulty; replace. Too high (Cut low flame to a minimum.) Faulty, backdraft, or improper gas adjustment Running with doors and windows closed Too low; adjust.

3.6.0 Field Range

As a Utilitiesman, you need to know how to maintain, repair, and troubleshoot the field range. Unfortunately, this manual CANNOT cover all you need to know about the field range; therefore, you should refer to other sources of pertinent information.

The portable field range used by the NCF has a self-contained burner unit that is portable. The burner unit can be used with a range unit or by itself. *Figure 14-10* shows the M-59 range unit and M-2 burner unit. When the M-59 range outfit is used for cooking or baking, the M-2 burner should be placed in the bottom position. When the cabinet is used for frying, the burner should be placed in the top position.

Figure 14-10 — M-59 field range and M-2 burner unit.

Keeping the field range in a constant state of readiness is important to everyone in the field. This is accomplished by performing preventive maintenance checks and services quarterly or after every 250 hours of operation, whichever occurs first. *Table 14-4* provides a listing of possible malfunctions that may occur in the field range outfit. This listing will help you in diagnosing and correcting unsatisfactory operation or failure of the field range outfit.

Table 14-4 — Troubleshooting for Field Ranges.

Trouble	Check	Cause
FIELD RANGES		
FUEL SYSTEM: Fails to maintain pressure	Fuel filter Air valve Fuel tank Safety valve	Leaks; replace gasket. Defective; replace. Defective; replace. Does not reseat; replace.
PREHEATER: Fails to ignite	Fuel feed tube assembly Preheater generator	Damaged or missing; replace. Defective; replace.
BURNER: Fails to ignite	Preheater generator Generator Feed tube assembly	Defective; replace. Defective; replace. Missing, clogged, or dented; clean/replace.
Flame too low –	Generator	Defective
BURNER FLAME: Yellow	Generator flame valve	Defective; repack/replace.
GENERATOR OR PREHEATER VALVE: Fuel leaks	Generator flame valve Generator	Defective; repack/replace. Defective; replace.
AIR PRESSURE GAUGE: Pressure rises above safe limit	Valves Fuel tank Gauge	Defective; repack or replace. Too full; only 8 quarts Defective; replace.

3.7.1 Bakery Ovens

Routine maintenance of bakery ovens (*Figure 14-11*) requires weekly, monthly, and annual inspections.

The weekly inspections should include the following:

1. Adjust the heating units for proper fuel-air mixtures and constant operating temperature.
2. Check the pilot flame of the gas-fired ovens and adjust it, if necessary, so the burner gas ignites without wasting fuel and the flame is not blown out by the flue draft. Adjust the fuel-air mixture to produce a blue flame.
3. Check the operation of the purging fan and the flame failure devices.
4. Clean the soot and dirt from the pilot and gas burner.

Figure 14-11 — Reel oven.

5. Check the oil supply for leaks and stoppages and clean the strainer basket of oil-fired ovens.
6. Examine the operation of the electric-ignition and flame-failure devices and repair them, if necessary.
7. Adjust the oil burner for proper spread of fuel across the combustion chamber and for proper fuel-air mixture to maintain a blue flame.
8. Examine the operation of dampers; clean and adjust them, if required.
9. Check the settings of automatic temperature and humidity controls; reset the settings of the thermostat and humidistat, if necessary.

The monthly inspections should include the following:

1. Inspect the conveyor and drive, and adjust loose chains, belt tension, and any other component that may be misaligned.
2. Adjust the chains of the V-belt tension by moving the idler sprocket or sliding motor base.
3. Check the lubrication of gearboxes, bearings, and moving parts.
4. Examine the oven top and walls for cracks and breaks; make the repairs, if necessary, to ensure tightness.

The annual inspections should include the following:

1. Drain, flush, and renew the lubricant in the gearboxes. Check the sprockets, gears, and bearings, and renew the lubricant according to the manufacturer's instructions.
2. Conduct electrical checks of the insulation resistance of motor windings, controls, and wiring. Clean all contacts of the controls.

3.8.1 Interceptors and Grease Traps

Removal of grease from greasy wastes is necessary if the sewage system is to function properly. One way grease is collected is by ceramic or cast-iron grease interceptors installed inside mess halls. Another way of collecting grease is to use concrete or brick grease traps outside buildings (*Figure 14-12*). Mess personnel usually clean the inside interceptors, but you may have to clean the outside traps. When inside grease interceptors are maintained properly, they should collect most of the grease from the waste. They may need cleaning once each day.

Remember that outside grease traps are intended to serve kitchen plumbing fixtures and equipment only, so they should never be connected to soil and waste lines from toilet rooms. To help ensure proper functioning, clean grease traps at least once a week. Since accumulated odor-forming solids cause septic action within a short time, remove all solids each time the traps are cleaned.

The steps of the procedure for cleaning outside grease traps include the following:

1. Skim grease from the surface of the trap using an ordinary perforated sewer scoop, and place it in suitable containers for disposal.
2. Remove as much odor-forming material as possible with the same scoop. Treat this refuse as disposable.
3. Pump out the liquid from the traps every 3 months, and remove all sediment from the sidewalls and the bottom if necessary

Figure 14-12 — Grease trap.

4.0.0 EMERGENCY SHOWERS and EYEWASH STATIONS

Emergency showers also known as drench or deluge showers, are designed to flush the user's head and body. They should NOT be used to flush the user's eyes because the high rate or pressure of water flow could damage the eyes in some instances. Eyewash stations are designed to flush the eye and face area only. There are combination units available that contain both features: a shower and an eyewash station.

The need for emergency showers or eyewash stations is based on the properties of the chemicals that workers use and the tasks that they do in the workplace. A job hazard analysis can provide an evaluation of the potential hazards of the job and the work areas. The selection of an emergency shower, eyewash station, or both should match the hazard.

4.1.0 Types of Units

Emergency showers and eyewash stations are available either plumbed or portable (*Figure 14-13*). The plumbed versions come configured as showers only, eye/face wash only, or as combination units with both showers and eye/face washes. Portable models should be able to deliver the same volumes of water as well as meet the dimensions for plumbed models, as specified in the standard. We will only be discussing the plumbed version.

Figure 14-13 — Plumbed and mobile emergency shower/eyewash stations.

4.2.1 Components and Functions

Table 14-5 has a listing of common components of an emergency shower along with some recommended signs that should be posted on and near the shower station.

Table 14-5 — Components of an Emergency Shower.
Click on each component to see a larger view.

1. Eye/Face Wash Head Assembly
2. Eyewash Valve
3. High-Visibility Stripe
4. In-Line Strainer
5. Mounting
6. Receptor
7. Pull Rod
8. Shower Valve
9. Shower Head
10. Test This Week Tag is a green, waterproof test card with space for date and initials of inspector. It is sed to record weekly testing of emergency equipment.
11. Vertical universal combination emergency shower and eyewash sign. Size: 8" x 10-3/4".

4.3.1 Installation Procedures

The following are generic installation procedures. Refer to the unit's installation drawings for clarification. Check parts list to insure all required parts are included. Use the recommended pipe joint sealant on all connections.

1. Prepare the emergency shower foundation by using the floor flange assembly as a template. Locate the holes for the anchor bolts. They should extend 1 inch above the floor level.
2. Once the concrete foundation is ready (dry), assemble the floor flange assembly to the anchor bolts, and then securely fasten. Seal and tighten floor flange and tee, making certain the waste tee is facing the proper location and the foot control holes are facing side to side.
3. Assemble nipple to the floor flange assembly and tighten with a pipe wrench.
4. Assemble the eyewash loop assembly to the nipple from Step 3. Connect the pipe wrench to the galvanized nipple between the two tees to avoid damage.
5. Assemble the shower head assembly in the following order:
    a. Attach pipe onto the loop assembly.
    b. Attach pipe onto the tee that attaches to the water supply pipe.
    c. Attach tee onto the pipe.
    d. Attach showerhead valve assembly onto tee.
    e. Assemble the street elbow onto nipple.
    f. Attach pipe onto valve.
6. Assemble showerhead onto street elbow.
7. Assemble the sign onto the unit. Use the strap, screws, washers, and nuts provided to mount the sign onto the upright. The sign should be positioned for maximum visibility.
8. Insert the plug into the optional supply line tee that is not used before connecting the supply waterline to the emergency shower.

NOTE

Flush the line thoroughly.

4.4.0 Common Malfunctions

Table 14-6 is a general compilation of possible malfunctions and repair recommendations. Please refer to the manufacturer's operating and repair manual for more specific details.

Table 14-6 — Common Malfunctions and Repair Checklist.

TROUBLESHOOTING	
PROBLEM	**REPAIR CHECKLIST**
No flow.	Check the main shut-off valve.
Water leaks between joints or fittings.	Tighten loose connections. If leak persists, the application of hot water will sometimes reseat improperly applied joint compound. After 30 minutes, retest. A persistent leak will necessitate reassembly and additional sealant.
Shower and eyewash water flow is insufficient.	Verify minimum 30 psi (2 ATM) flowing supply line pressure.
Water does not drain properly.	Check your drain system for debris. Check the main waste line of your building to see if it does handle the capacity required for the entire drainage system.
Water flow on eyewash is insufficient, but shower is sufficient.	Verify minimum 30 psi (2 ATM) flowing supply line pressure.
	Probable clogging of flow control due to inadequate line flushing; unscrew eye/face wash head and remove the four screws to disassemble head. Clean flow control and reassemble head.
	Remove cap located on L–strainer using a 3/8" allen wrench to access and clean filter screen.
Eyewash or face wash streams do not meet at desired eye level or are not balanced.	Possible blocked flow control; see above solution. (Possible non-leveled eyewash assembly)
Water flow is insufficient at the showerhead, but eyewash is sufficient.	Probable clogging of flow control inside shower head; unscrew shower head off elbow and clean rubber flow control.

4.5.0 Repair Procedures

Repair procedures for the emergency shower and eyewash station should be followed in the manufacturer's repair manual as well as any applicable plumbing standards. ANSI Z358.1-2009 "Emergency Eyewash and Shower Equipment "must be complied with for all work concerning Emergency Eye/Face Wash and Shower Equipment.

5.0.0 FIRE HYDRANTS

A fire hydrant is an above-ground connection that provides access to a water supply for the purpose of fighting fires. The water supply may be pressurized, as in the case of hydrants connected to water mains buried in the street, or unpressurized, as in the case of hydrants connected to nearby ponds or cisterns. Every hydrant has one or more outlets to which a fire hose may be connected. If the water supply is pressurized, the hydrant will also have one or more valves to regulate the water flow. To provide sufficient water for firefighting, hydrants are sized to provide a minimum flow-rate of about 250 gallons per minute (945 liters per minute), although most hydrants can provide much more.

5.1.0 Types of Hydrants

The two types of pressurized fire hydrants are wet barrel and dry barrel (*Figure 14-14*).

In a wet-barrel design, the hydrant is connected directly to the pressurized water source. The upper section, or barrel, of the hydrant is always filled with water, and each outlet has its own valve with a stem that sticks out the side of the barrel.

In a dry-barrel design, the hydrant is separated from the pressurized water source by a main valve in the lower section of the hydrant below ground. The upper section remains dry until the main valve is opened by means of a long stem that extends up through the top, or bonnet, of the hydrant. There are no valves on the outlets. Dry-barrel hydrants

Figure 14-14 — Wet- and dry-barrel fire hydrants.

are usually used where winter temperatures fall below 32° F (0° C) to prevent the hydrant from freezing.

Unpressurized hydrants are always a dry barrel design. The upper section does not fill with water until the fire pumper applies a vacuum.

5.2.1 Hydrant Components

The following is a list of some of the terms and definitions used with fire hydrants:

- Base. A part that provides a lateral connection to the hydrant lead and directs the flow vertically upward into the lower barrel; also called shoe, bottom, boot, elbow, or bury
- Bonnet. A part that attaches to the top of the nozzle section and encloses the support portions of the operating mechanism; may be integral with the nozzle section; also called cap or cover
- Breakable barrel coupling. A coupling used to fasten the upper barrel to the lower barrel; designed to break if stressed severely, should a vehicle strike the hydrant
- Breakable bolt. Used to fasten the upper barrel to the lower barrel; designed to break if stressed severely, should a vehicle strike the hydrant
- Breakable flange. A part that bolts to a mating flange at a joint between the hydrant upper and lower barrels, which is located immediately above the ground line; designed to break if stressed severely, should a vehicle strike the hydrant; also called breakaway flange or traffic flange
- Direction to open. The direction in which the operating nut is rotated to open the hydrant; open left is counterclockwise when viewed from above and open right is clockwise
- Drain outlet. The opening in the base through which water escapes to the ground when the drain valve is open
- Drain valve. Located at or adjacent to the valve seat ring; opens automatically when the main valve is closed; allows water to drain from the barrel into the ground; closes automatically when the main valve is being opened; closes completely after only one to five turns of the operating nut
- Dry top. A compression-type hydrant in which the operating mechanism at the top of the hydrant is sealed from the barrel so that water does not come into contact with the mechanism during hydrant use
- Frangible stem coupling. A stem coupling designed to break if it is stressed severely, should a vehicle strike the hydrant; also called breakable coupling
- Gate. A part that supports the main valve that is moved, first horizontally and then vertically, to open or close the main valve opening in a slide gate hydrant
- Gland bushing. A part that is used to line a gland
- Hose outlet nozzle. An outlet nozzle that has an opening that is 3 inches or smaller in diameter, and is suitable for attachment of a fire hose
- Lower barrel. A part that extends from the base to the ground line, enclosing the stem; conducts water from the base to the upper portion of the hydrant

- Lower valve plate. A part that is positioned below that main valve and clamps the main valve against the upper valve plate
- Main valve. A part made of rubber or some similar resilient material; is forced against a seat to form a watertight seal when the hydrant is closed; also called valve, valve rubber, valve ball rubber, valve seat, valve gasket, or valve disc
- Main valve opening. The inside diameter of the valve seat ring
- Nozzle section. A part that extends upward from the barrel and contains the outlet nozzles; may be integral with the upper barrel
- Operating nut. An external hydrant part that is turned by a hydrant wrench to rotate the stem nut or stem; may be integral with the stem nut or stem
- Outlet nozzle. Is secured in the nozzle section and has an opening through which water can be discharged; is threaded or otherwise formed to permit attachment of a fire hose connection
- Outlet nozzle cap. A cap that is attached to an outlet nozzle and covers the nozzle opening; furnished with a nut or other means to permit the application of force adequate to firmly attach it to or remove it from the outlet nozzle
- Packing gland. A part that compresses packing rings in a stuffing box
- Packing plate. A part that partitions the interior of the hydrant and contains or supports a stuffing box or other means of sealing one compartment from another; also called seal plate or support ring
- Pumper outlet nozzle. An outlet nozzle with an opening of at least 3.5 inches in diameter, suitable for attachment of a fire hose; also called steamer nozzle or steamer connection
- Seat-ring insert. A part with internal threads that is secured and sealed to the hydrant base, and internal threads that engage with the external threads on the valve seat ring; may also serve as a part of the drain system; also called drain ring, retainer ring, or insert ring
- Stem. A part of the operating mechanism that extends down to the main valve assembly and moves the main valve to close or open the hydrant; is often in two parts, particularly in a traffic model: the upper stem and the lower stem; also called upper rod or lower rod
- Stem coupling. A part that joins the portions of a two-part stem; also called a rod coupling
- Stem nut. A part that is internally threaded and engages with threads on the stem so that when the part is rotated, or when the stem is rotated and the stem nut is stationary, the stem is raised or lowered to move the valve; also called operating nut or operating stem nut, revolving nut
- Stop nut. A part that is permanently threaded or otherwise attached to the stem and limits the vertical travel of the stem; also called stem stop or travel stop nut
- Stuffing box. A cylindrical cavity that surrounds the stem and contains a number of packing rings used to prevent leakage along the stem; may be an individual component or a portion of another component; also called packing box
- Traffic model. A hydrant designed and constructed so that if it is struck by a vehicle, certain easily replaceable components will break and allow the upper

portion (above the ground line) to become detached from the lower portion (below the ground line), which will remain intact and undamaged

- Upper barrel. A part that extends from the lower barrel at the ground line to the nozzle section, enclosing the stem;; may be integral with the nozzle section
- Upper valve plate. A support for the main valve, positioned above the valve; may also serve as the portion of the drain valve that is moved when the stem rotates; may also serve as the means to prevent rotation of the valve, stem, ad associated parts
- Valve seat ring. A part threaded into and sealed to the hydrant base (or associated part adjacent to the base); has main valve that is forced against the valve seat ring to close the hydrant
- Weather shield. A part that forms a skirt above and surrounding the opening in the hydrant top through which the stem, stem nut, or operating nut protrudes; may be integral with the operating nut; also called the weather cap
- Wet top. A compression type hydrant in which the operating mechanism at the top of the hydrant is not sealed from the water when the hydrant is opened

5.3.0 Location of Hydrants

Although you will not determine the location of a fire hydrant, it is good to know what to look for when installing one. You may notice that the hydrant has been incorrectly placed, based on your knowledge of proper hydrant placement. When determining locations to place fire hydrants, consideration should be given to accessibility, obstructions, proximity to structures, driveway entrances, and other circumstances where adjustments to a specific hydrant's location would be warranted.

Criteria for fire hydrants are found in *Fire Protection for Facilities Engineering, Design, and Construction,* MIL-HDBK-1008. Street intersections are the preferred locations for fire hydrants because fire hoses can be laid along any of the radiating streets. Hydrants should be located a minimum of 6 feet and a maximum of 7 feet from the edge of paved roadway surfaces. If they are located more than 7 feet from the edge of a road, then ground stabilizing or paving next to the hydrants may be necessary to accommodate fire-fighting equipment. Hydrants should not be placed closer than 3 feet to any obstruction and never in front of entranceways. In general, hydrants should be at least 50 feet from a building and never closer than 25 feet to a building, except where building walls are blank firewalls.

5.4.0 Installation of Hydrants

There are a number of common errors made with respect to the installation of new fire hydrants. Most have to do with variations between preliminary grading designs and final grading. Others involve specific uses of areas near where hydrants are installed. If these issues are not monitored, hydrants can end up being situated in such a manner that they at best look strange and at worst are difficult or impossible to operate.

Hydrant installation details need to be coordinated among all parties involved at the construction site. If hydrants are being installed in areas to be landscaped or if final grading elevations are not clear, the hydrant design that is specified should easily accommodate placement of riser extensions of various lengths so that the final hydrant installation is compatible with the final grade elevation.

Coordination between the electricians should be made to ensure that utility poles, vaults, and cabinets will not interfere with access to fire hydrants or impede the operation of the hydrants. As a general rule, no equipment or facilities should be within 3 feet (1m) of the hydrant body nor be placed in front of any hydrant outlet, nor be placed between the hydrant and the roadway. Whoever is landscaping near hydrants should be apprised of these conditions as walls, plants, and other landscape materials must be kept outside the hydrant's clearance space.

While it may seem insignificant, outlet orientation can have a pivotal impact on the efficiency of fire crews making hookups to hydrants. In locations where main pressures are sufficient to allow fire companies to lay supply lines directly to engines at the scene, outlet orientation is primarily an issue of convenience and getting lines past parked vehicles. In locations where main pressures are low and engines have to pump directly from fire hydrants, how outlets are oriented can make the difference between a fast and efficient hookup versus a complicated procedure.

Generally, hydrants are either oriented with the pumper outlet perpendicular to the curb that faces the street, or with the pumper outlet set at a 45-degree angle to the street. Whether an agency chooses a perpendicular or 45-degree configuration depends on the type of hydrant chosen, the operations of the fire department, and prevailing conditions, such as on-street parking, that may restrict hydrant access.

5.5.1 Common Malfunctions

The following are common malfunctions associated with fire hydrants. Use the manufacturer’s manuals for recommended troubleshooting procedures.

Problem - Operating nut turns freely but hydrant does not open.

Solution - Inspect the rod coupling for breakage and ensure rod pin is properly installed.

Problem - Ground around hydrant is highly saturated.

Solution - Close the hydrant and remove the nozzle cap. Check with listening device to determine if water is passing by the main valve. If it is determined that the main valve is leaking, try the following:

a. Flush hydrant in fully open position (watch to see if rocks or other foreign objects flush out of barrel).
b. After flushing for several minutes, shut off the hydrant. Watch for several minutes to see if flow stops. Place hand over the open hose nozzle; suction should be felt, indicating the hydrant is no longer leaking and drains are working properly.
c. If flushing does not solve the problem, it indicates that something is trapped or has cut the main valve rubber. Follow seat-removing instructions to replace the valve. Check threads on the bronze seat to be sure that it is not damaged. If threads appear worn or bent, replace bronze seat.
d. If replacing the valve does not stop leakage, the bolting at the hydrant shoe may be loose, or the base gasket is damaged. The hydrant must be excavated to make repair.

Problem - External leakage is noticed around the operating nut.

Solution - This indicates that O-rings are cut or missing. O-rings can be replaced without shutting off water. See repair section of applicable manual for proper replacement.

Problem - Operating nut is extremely hard to turn.

Solution - Remove the pipe plug in the top of the operating nut. Put in a grease fitting and squirt one or two shots of food-grade lubricating grease. If the hydrant remains hard to operate, replace thrust washers in the hydrant head. If this does not solve the problem, remove the hydrant seat and flush thoroughly.

Problem - Water is dripping around nozzles.

Solution - Remove the nozzle cap and replace the cap gasket. Check the nozzle to be sure that it is properly installed. Hydrants installed prior to 1980 used leaded-in nozzles. The nozzle may require re-caulking. If the hydrant has a cast date of 1981 or later, it has an O-ring behind the nozzle. If leakage is coming from behind the nozzle, replace the O-ring.

Problem - Hydrant will not drain properly.

Solution - Check to be sure the water table has not risen too high to allow for drainage. Flush the hydrant to be sure the drains are clear. Open the hydrant slowly several turns while leaving the caps firmly in place. This will ensure that the hydrant drains are clear. Close the hydrant and repeat this procedure. Repeat slowly three or four times. If this does not solve problem, remove the hydrant seat assembly and check the rubber drain facings. If no problems are found, excavate the hydrant to see if concrete or other materials have blocked the drain holes.

5.6.0 Repair Procedures

Make all repairs in accordance with the applicable hydrant’s maintenance and repair manuals. Ensure all safety measures are followed. Water under high pressure can cause damage to equipment and personnel.

6.0.0 INSPECTION of FIRE HYDRANTS

Just like any valve, the fire hydrant needs to be periodically inspected. Visual inspections should be conducted monthly to ensure there have been no changes in the functionality and accessibility of the hydrant. Annual inspections should be conducted to test the flow and leak down rates of the hydrant. As a UT, you will be mainly concerned about the initial hydrostatic tests to ensure all joints are sealed correctly and that the valves are functioning properly.

6.1.0 Purpose of Inspections

Fire hydrants are designed as an integral part of public and private water supply networks. Hydrants are not to be located on mains smaller than 6 inches in diameter, and should be connected to the main by a short run of 6-inch diameter pipe controlled by a gate valve. Hydrants must be tested on a regular basis to ensure that they are capable of delivering water at a pressure and a rate of flow for public health and effective firefighting operations. A water pressure of 20 psi is considered the minimum required for effective firefighting operations and preventing the contamination of public water supplies by backflow.

6.2.1 Visual Inspections

Visual inspections are necessary augment functional tests. Since there are different manufacturers of fire hydrants, we will discuss a generic visual inspection. Prior to heading out into the field, ensure you have a current map of the locations and identification numbers of all the hydrants you will be inspecting. To start:

1. Identify hydrant location and number.
2. Verify hydrant number is on the hydrant. All hydrants with brass stems will have the number stamped on the top of the hydrant nut. All others will have a brass tab located to the right of the steamer connection.
3. Check the hydrant for physical damage and defects.
4. Check for obstructions that affect our ability to operate the hydrant. Maintain a 3-foot clear radius around all hydrants.
5. Check to see that the hydrant outlets are facing the proper direction and there is a minimum 15-inch clearance between the lowest outlet and ground level.
6. Check to see if the hydrant is set too close to the curb, exposing it to vehicular traffic.
7. Check condition of the paint.
8. Operate the valve stem for ease of operation.
9. Check hydrant caps and outlets for rust; remove rust from caps and outlets with a wire brush.

6.3.0 Operational Inspection

At certain times, usually during the installation of a new water main, fire hydrants may be used to conduct a pressure test at pressures above main pressure. Certain steps should be followed to ensure the safety of the persons conducting the pressure test and to protect the system.

WARNING

Hydrostatic testing shall be conducted with water because of the inherent safety hazard potential associated with testing components and systems with compressed air or other compressed gases.

Procedure. Visually inspect the hydrant for any defects. Check the bolts and breakaway flange. Check the nozzle caps and gaskets. Ensure the caps are tightened; a loose cap or damaged nozzle can blow off under pressure. Visible leaks shall be stopped. Defective elements shall be repaired or removed and replaced and the test repeated until the test requirements have been met.

To prevent damage to the system, it is imperative that hydrants are opened and closed slowly. When the test is completed and the pressure is removed from the main, close the hydrant slowly. Once all testing is done, ensure that the hydrant is pumped to prevent freezing.

The American Water Works Association (AWWA) and the National Fire Protection Association (NFPA) have published guidelines for hydrant flow testing. A hydrant flow test is primarily concerned with the measurement of static pressure and pitot pressure at a hydrant located in the field.

Test Hydrants and Flow Hydrants. A flow test usually involves two fire hydrants. The first one is called the test hydrant or residual hydrant. The second one is called the flow hydrant. A test proceeds as follows:

1. The cap covering one of the hydrant outlets is unscrewed and replaced with one equipped with a pressure gage. The valve on the test hydrant is opened, allowing water under pressure into the hydrant. The pressure is referred to as the static pressure. This represents the water pressure in the water main as measured at the elevation of the hydrant outlet.
2. One or more caps on the flow hydrant are opened and the inside diameter of each outlet is measured and recorded. The flow hydrant valve is then fully opened to create a steady flow of water from the outlet. In some cases, the resulting horizontal geyser may be sufficiently disruptive to justify street closures.
3. A pitot gage is used to measure the velocity pressure of the stream issuing from the hydrant. While the pitot pressure is being recorded, a second pressure reading is taken at the test hydrant. This is called the residual pressure. The residual pressure records both the domestic and fire flows occurring in the water main.
4. The final step in the flow test involves shutting down the flow hydrant and taking another static pressure reading as a check on the previous reading. The two readings must be similar. If the second reading is higher, it may be due to a pump automatically starting to meet the demand imposed by the flow test. In that case, the flow test must be repeated after shutting down the pump. There are good reasons to double-check the static pressure. If the second static pressure reading falls very far below the first one recorded, it is possible that a water main broke during the test.

7.0.0 BACKFLOW PREVENTION

Anywhere people congregate and utilize communal water supplies, water using equipment, and drainage systems, the dangers of unprotected cross connections and backflow incidents continue to threaten public health. Public perception has been that widespread waterborne disease outbreaks have been controlled, but localized incidents have not yet been eliminated. Ongoing municipal water pressure breakdowns (most often main breaks) or other systems' failure-related contamination incidents, and subsequent "do not drink" and "boil water" notifications, however, have focused the intense spotlight of public attention on drinking water safety as never before. One recent result is that there is a widening recognition that properly installed, maintained, and tested backflow prevention devices are critical elements of safe drinking water systems in our communities and workplaces.

7.1.0 Definition of Backflow

The definition of backflow is as follows: the flow of water or other liquids, mixtures, or substances into the distributing pipes of a potable supply of water from any other than its intended source.

7.2.0 Types of Backflow

There are two types of backflow: backpressure and back-siphonage. Back-siphonage is the most common form.

Back-siphonage is backflow caused by a negative pressure (vacuum) in a potable water system. The effect is like drinking water through a straw.

Back-siphonage can occur when there is a broken water main, when there is a fire nearby where a fire department is using large quantities of water, or even when a fire hydrant is opened for testing. Any buildings near such a break or unusual fire hydrant usage will experience lower water pressure. This is when back-siphonage can occur.

Backpressure is backflow caused by a downstream pressure that is greater than the supply pressure.

Backpressure can result from a reduction in the supply pressure, an increase in downstream pressure, or a combination of both.

Pumps can create increases in downstream pressure, as can temperature increases in boilers Reductions in supply pressure occur whenever the amount of water being used exceeds the amount of water being supplied, such as during waterline flushing, firefighting, or breaks in water mains.

7.3.0 Definition of Cross Connection

Cross connections are defined as existing or potential connections between potable, or safe to drink, and non-potable water supplies, water-using equipment, or drainage systems.

7.4.0 Types of Cross-Connections

There are two basic types of cross-connections: a direct cross-connection and an indirect cross-connection. The difference between these two types of cross-connections is very simple. A direct cross-connection is subject to backpressure; an indirect cross-connection is not subject to backpressure. An example of a direct cross-connection is the make-up waterline feeding a recirculating system. An over-the-rim inlet used to fill an open receiving vessel is an example of an indirect cross-connection. Backpressure cannot be introduced into the supply line with this type of connection.

7.5.0 Classes of Hazards

The type of backflow preventer used to prevent backflow from occurring at the point of a cross-connection depends on the type of substance that may flow into the potable water supply. A pollutant is considered to be any substance that affects the color or odor of the water, but does not pose a health hazard. This is also considered a non-health hazard. A substance is considered a health hazard if it causes illness or death if ingested. This health hazard is called a contaminant.

Sewage and radioactive materials are considered lethal hazards. This is because of the epidemic possibilities associated with sewage and the tremendous dangers associated with radioactive material.

7.6.0 Backflow Devices Description and Installation

When installing a backflow preventer, many details must be evaluated before you break out the wrenches. There are two basic considerations to evaluate in the installation process: the hydraulic conditions and the mechanical conditions. The hydraulic conditions have to do with the flow of water through the piping system. The mechanical conditions have to do with the pipe, valves, and fittings needed to properly install the backflow preventer into a piping system. The reason we need to make sure the assembly is properly installed is to ensure the assembly continues to protect the drinking water system to which it is connected.

7.6.1.0 General Information

The hydraulic considerations of installing a backflow preventer must evaluate sizing, pressure, and temperature. In most installations, the size of the piping and the backflow preventer has already been determined by an engineer. If there has not been a hydraulic review of an existing or newly designed piping system, be sure the changes to flow and pressure by the installation of a backflow preventer are evaluated before it is installed. Installing a backflow preventer into an existing piping system can change the workings of some piping arrangements, such as irrigation or fire systems.

Some installations will require continuous water supply due their water needs. Applications such as hospitals are considered critical services where water cannot be discontinued even for short periods of time. This type of critical service will require the installation of parallel backflow preventers to guarantee when one backflow preventer is shut off for servicing, the other preventer will allow water to flow to the piping system. When installing parallel installations, be sure the separate and combined flows of the backflow preventers meet the needs of the water user.

Once we get past the problems of hydraulics, we must look to the mechanical concerns of installing a backflow preventer. The first concern to evaluate is the installation orientation. Backflow preventers must be installed in the orientation they were designed and approved for, such as vertical or horizontal. There are backflow preventers that can be installed horizontally, vertically, and other orientations that can make an installation easier. The key point to recognize is that they can only be installed in the orientation that the approval agency has determined. Some manufacturers may state that it is acceptable to install them in other orientations, but we must be sure the list of approved assemblies approves the desired orientation. For some installations, a vertical orientation will be more advantageous than a horizontal orientation. By placing a backflow preventer in an orientation other than what it is approved for may cause it not to work properly. To be sure, confirm with your list of approved assemblies but also consult your local administrative authority.

Air Gap. An air gap is a physical separation of the supply pipe by at least two pipe diameters (never less than 1) vertically above the overflow rim of the receiving vessel (*Figure 14-15*). In this case, line pressure is lost; therefore, a booster pump is needed downstream, unless the flow of the

Figure 14-15 — Air gap.

water by gravity is sufficient for the water use. With an air gap, there is no direct connection between the supply main and the equipment. An air gap may be used to protect against a contaminant or a pollutant, and will protect against both back-siphonage and backpressure. An air gap is the only acceptable means of protecting against lethal hazards.

Atmospheric Vacuum Breaker. The purpose of the atmospheric vacuum breaker is to prevent a siphon from allowing a contaminant or pollutant into the potable water system. This plumbing system safety valve is considered protection from high hazard or toxic substances, and may be used for low-hazard materials as well (*Figure 14-16*).

Figure 14-16 — Atmospheric vacuum breaker.

There are three flow conditions for the atmospheric vacuum breaker. The user obtains water by opening a valve to the potable supply, allowing water to flow through the device. The user will then close the potable water supply and the device will drain. Finally, if a siphon or loss of pressure occurs in the supply piping, the inlet valve will open, allowing atmosphere into the outlet piping to prevent a reversal of flow or back-siphonage to the potable supply.

The AVB is commonly placed downstream from all shut-off valves. Its air inlet valve closes when the water flows in the normal direction. Once the water ceases to flow, the air inlet valve opens, thus interrupting the possible back-siphonage effect. If piping or a hose is attached to this assembly and run to a point of higher elevation, the backpressure will keep the air inlet valve closed because of the pressure created by the elevation of water; therefore, it would not provide the intended protection. This type of assembly must be installed at least six (6) inches above all downstream piping and outlets. Additionally, this assembly may not have shut-off valves or obstructions downstream. A shut-off valve keeps the assembly under pressure and allow the air inlet valve (or float check) to seal against the air inlet port, thus causing the assembly to act as an elbow, not a backflow preventer. The AVB may not be under continuous pressure for this same reason. An AVB must not be used for more than twelve (12) out of any twenty-four (24) hour period. It may be used to protect against either a pollutant or a contaminant, but may only be used to protect against a back-siphonage condition.

Pressure Vacuum Breaker. The principle behind a pressure vacuum breaker (PVB) backflow prevention device is to break the vacuum created during a back-siphonage event, thereby preventing backflow (*Figure 14-17*). A PVB consists of a spring-loaded check valve that closes tightly when the pressure in the assembly drops or when zero flow occurs, plus an air relief valve (located on the discharge side of the check valve) that opens to break a siphon when the pressure in the assembly drops. The assembly also includes two shut-off valves and two test cocks for periodic testing of the assembly. The air relief valve ensures that no non-potable liquid is siphoned back into the potable water system.

PVBs prevent the backflow of contaminated water into a potable drinking main line, but they are not designed for backpressure conditions. PVBs may be used under continuous pressure, but the air inlet valve may become stuck in the closed position after long periods of continuous pressure. A PVB may only be used against back-siphonage and may be used to protect against pollutant or contaminant hazards.

The PVB must be installed at least twelve (12) inches above all downstream piping and outlets. The PVB may be used to protect against a pollutant or contaminant; however, it may only be used to protect against back-siphonage. It is not acceptable protection against backpressure.

American Society of Sanitary Engineering (ASSE) Standard 1020 covers PVB backflow prevention assemblies.

Figure 14-17 — Pressure vacuum breaker.

Double Check Valve. A double check valve is a mechanical device that consists of two single check valves coupled within one body, and two tightly closing gate valves, one located at each end of the unit (*Figure 14-18*). Each check valve consists of a physical plate connected to the top of the pipe by a hinge. The hinge is oriented such that flow in the intended flow direction keeps pressure on the plate and keeps it open, permitting the passage of fluid in the intended flow direction. Thus, under normal conditions, the check valves remain open. In the absence of water flow, the plate is not being held open by flow in the correct direction, and the valves close until the normal water flow resumes. In the event of backflow, the flow is against the direction of the hinge, so the plate remains closed. A double check valve may be used under continuous pressure. It can be effective against either backpressure or back-siphonage, and may be used to protect against pollutant hazards. It should be noted that double check valves are susceptible to interference from materials within the piping system. For example, grit or fibers can catch under the valves, causing them to remain open and potentially allowing leakage back into the system.

A double check valve shall be located as close as practical to the building that you are plumbing and shall be installed above grade no more than 5’ and in a manner that makes the valve accessible for testing and maintenance. Ensure the valve is installed in accordance with all applicable local and federal regulations.

AWWA Standard C510-97 and ASSE standard 1015 cover double check valve backflow prevention assemblies.

Figure 14-18 — Double check valve.

Reduced Pressure Principle Device. The principle behind a reduced pressure principle backflow prevention device (*Figure 14-19*) is to reduce a negative pressure differential between the upstream and downstream ends of a line, thereby preventing backflow. A reduced pressure principle assembly is a mechanical backflow preventer that is essentially two check valves with an automatically operating pressure relief valve placed between the two checks. This system is designed such that this zone between the two checks is always kept at a lower pressure than the supply pressure. Under normal flow conditions, the check valves remain open and the relief valve is closed. In the event of back-siphonage, the relief valve will open to allow the induction of air to break the vacuum. In the event of backpressure, the opened relief valve routes the contaminated water out of the system (drainage can be provided for such spillage). The reduced pressure principle assembly also contains two shut-off valves upstream and downstream of the check valves and a series of test cocks for periodic testing of the valves.

Figure 14-19 — Reduced pressure principle device.

A reduced pressure principle assembly is effective against either backpressure or back-siphonage, and may be used to protect against pollutant or contaminant hazards. Reduced pressure principle assemblies may be used under constant pressure, and are commonly installed on high hazard installations.

A reduced pressure principle device shall be located as close to as practical to the project you are plumbing and shall be installed a minimum of twelve inches above grade and not more than thirty-six inches above grade measured from the bottom of the device and with a minimum of twelve inches side clearance. Ensure the valve is installed in accordance with all applicable local and federal regulations.

AWWA standard C511-97 and ASSE standard 1013 cover reduced pressure principle backflow prevention assemblies.

8.0.0 EQUIPMENT MAINTENANCE

Properly maintained equipment within a water treatment plant ensures smooth and efficient operation of water treatment. It is not possible to provide detailed instructions on the maintenance of each type of equipment in a water treatment plant; therefore, this chapter covers general maintenance requirements and safety procedures on some of the more common types of water treatment equipment. For specific and detailed maintenance instructions, refer to the manufacturer’s manual for the type and make of equipment at your facility. In addition, this chapter provides information regarding different types of water storage facilities and the maintenance procedures applying to them.

8.1.0 Maintenance of Chemical Feeders

There are two main styles of chemical feeders: dry chemical and solution. There are many different types of each style of chemical feeder so we will only discuss generic instructions. Always refer to the manufacturer’s manual for specifics of the unit on which you are working.

8.1.1 Dry Chemical Feeders

The instructions given apply to all types of volumetric and gravimetric dry feeders, including disk, oscillating, rotary gate, belt-type, screw, and loss-in-weight.

The basic maintenance operations that should be applied daily to all dry chemical feeders are as follows:

1. Clean the feeder, the feeder mechanism, and the feeder surroundings. Use a vacuum cleaner or brush to remove spilled chemicals or chemical dust. Make certain that the orifice, knife-edges, scrapers, shakers, and openings are free of chemical accumulations in volumetric feeders, and that both belt rolls and belt in gravimetric feeders are free of chemical accumulations.
2. Check the feeder for general performance. Note and investigate unusual noises.
3. Observe the condition of electrical wiring, fuses, and connections.
4. Check for oil drips and general deterioration.
5. Make necessary repairs to overcome deterioration and lack of good performance.
6. Wipe all parts of the feeder and inspect for loose bolts, cracks, defective parts, and leaks. Make the necessary repairs to eliminate undesirable conditions.

7. Check the solution tank for sediment or undissolved chemicals and remove accumulated material.

When the dissolver is lined with asphalt, check the lining, which should not be skinned away from the steel. Follow the manufacturer's instructions to repair such linings.

Quarterly, service moving parts and lubricate, following the manufacturer's instructions.

The maintenance operation frequency and schedule of inspections for dry chemical feeders are shown *Table 14-7*.

Table 14-7 — Maintenance Procedures for Dry Chemical Feeders.

Inspection	Action	Frequency
Dry feeders	Remove chemical dust accumulations; check feeder performance; check for loose bolts; clean solution tank of accumulated sediment; lubricate moving parts	D
Drive mechanisms and moving parts	Service and lubricate	Q
Calibration	Check feed-rate accuracy and adjust as necessary	M
Feeders out-of-service	Clean; remove all chemicals from hopper and feeder mechanism	V
Disk feeders	Clean rotating disk and plow	M
Oscillating feeders	Check and adjust mechanism and adjustable stroke rod	M
Rotary gate feeders	Clean pockets of star feeder and scraper	M
Belt-type feeders	Check vibratory mechanism, tare-balance, feeding gate belt drive, and belt; calibrate delivery	M
Loss-in-weight feeders	Check feeder scale sensitivity tare-weight and null balance	M
Screw feeders	Clean screw; check ratchet drive or variable speed drive	M
Lime slakers	Clean dust-removal and vapor-removal equipment; remove clinker; clean equipment; wipe off feeder; check operation of vapor-removal equipment; clean compartments	D
Dust collectors	Repair agitators, stirrers, and heat exchanger baffles	M
Motors	Lubricate motors	V
Dust collector filter bags	Check conditions and attachment; securely attach sound bags; replace damaged or tom bags	V
Symbols used for frequency are as follows: D = DAILY W = WEEKLY M = MONTHLY Q = QUARTERLY SA = SEMIANNUALLY A = ANNUALLY V = VARIABLE, AS CONDITIONS MAY INDICATE		

8.1.2 Solution Feeders

Maintenance procedures for pot-type solution feeders include the following:

- Daily operator inspection, which includes observations of the amount of chemical feed to determine whether flow through the post is effective
- Monthly cleaning of the sediment trap and check of the valve
- Cleaning of the chemical pot and orifice every 6 months
- Annual overhaul that includes cleaning and painting the pot feeder and accessories

With the decanter or swing-pipe feeder, the swing pipe should be checked monthly. The reducing gears, pawl, ratchet, and motor should be checked semiannually and overhauled annually, or as necessary. Overhauling includes cleaning, repairing, and painting all parts that require attention.

The maintenance operation frequency and schedules of inspection for liquid and solution chemical feeders are shown in *Table 14-8*.

Table 14-8 — Maintenance Procedures for Liquid and Solution Chemical Feeders.

Inspection	Action	Frequency
Pot feeders		
Flow through pot	Determine amount of chemical fed to ascertain if flow through pot is effective	D
Sediment trap	Clean trap and check needle valve	M
Chemical pot	Clean pot and orifice	SA
Differential solution feeders		
Chemical storage tank	Inspect and clean	SA
Oil volume	Check and replenish	SA
Pilot tubes and needle valve	Check and replace as necessary	A
All equipment	Paint as necessary	V
Decanter or swing-pipe feeder		
Swing-pipe	Check to make certain it does not bind	M
Motor ratchet, pawl reducing gears, and reducing gears	Check and lubricate	SA
Rotating dipper feeder		
Motor	Follow manufacturer's instructions	V
Transmission	Change oil after 100 hours operation drain and flush clean interior and refill	100 hrs
Shaft bearings	Lubricate	W
Drive chain	Clean, check alignment; check sprocket teeth; lubricate chain and sprockets	M
Agitator	If used, clean and lubricate according to manufacturer's instructions	V
Belt drives	Check alignment, tension, and inner cords of belt drives	M
Dipper and float valve	Check dipper clearance and adjust float valve setting	SA
Portioning pumps (Hypochlorinators)		
Operator inspection	Inspect sight feeders rate of flow piping joints	D
Feeder	Clean feeder	W
Solution tank	Clean tank	M
Linings	If cracks occur, special linings should be repaired	A
Symbols used for frequency are as follows: D = DAILY W = WEEKLY M = MONTHLY Q = QUARTERLY SA = SEMIANNUALLY A = ANNUALLY V = VARIABLE, AS CONDITIONS MAY INDICATE		

8.2.0 Maintenance of Ion Exchange Units

An ion-exchange unit is shown in *Figure 14-20*. Some of the maintenance procedures for this type of unit are given in the following sections.

Figure 14-20 — Ion-exchange unit.

8.2.1 Softener Unit

The softener unit itself consists of a steel shell that contains a supporting grid in the bottom, a layer of gravel, and a layer of ion-exchange resin. The shell is equipped with openings, valves, and fittings. Maintenance procedures for the unit are as follows:

- Annually, the exterior of the shell should be cleaned and brushed with a wire brush and then painted to protect it against corrosion.
- Quarterly, the fittings for the distribution of water and brine should be checked for possible obstructions, corrosion, and security fastness.
- Every 6 months, each individual valve should be inspected and tested for leaks and repacked, if necessary.

Where multiport valves are used, they should be serviced and lubricated under the manufacturer's instructions. Lubricate this type of valve with grease as follows:

1. Add grease by a pressure gun to each grease fitting while the valve is set in "service" or "wash" position.
2. Turn valve one-half turn and add more grease.
3. Give valve several full turns to spread the lubricant.

This lubrication does not require that the softener be removed from service, but when the water flow is stopped, no grease will get into the water.

Quarterly, flush ion-exchange beds with chlorinated water containing at least 2 ppm of chlorine. Do not use water with a hardness greater than 170 ppm, and be certain that the pH of the water is about neutral. Also, follow these directions:

1. Check the bed surface for dirt, fines, organic growths, and smoothness. Scrape excess foreign matter off and replace with new resin. When the surface is uneven, the gravel bed underneath is not distributing the wash water evenly. The remedy consists of removing the resin and gravel and replacing both in proper fashion.
2. Check the height of the ion-exchange bed surface; remove or add ion-exchange resin to maintain proper elevation. (A low elevation will allow excess fines and foreign matter to accumulate on the surface of the bed; a high elevation allows resin to be washed out during backwashing.) Extra ion-exchange resin may be added through a 2- or 3-inch half-coupling (with brass plug), provided in the upper head of the shell or through the manhole cover plate.
3. Replace the ion-exchange bed with new resin whenever the inspection indicates the need, or when the exchange capacity has decreased and cannot be restored by cleaning and or performing the special procedures recommended by the manufacturer.
4. Quarterly, probe through the resin bed to determine the surface of the supporting gravel. The surface should be relatively even with a maximum difference of 4 inches between high and low spots. Any indication of shifting gravel bed, caking, or other difficulties calls for repair efforts. Uneven gravel may be raked smooth through the open manhole during backwashing operations.

When gravel needs to be removed, it may be cheaper to install new gravel than to remove, wash, and regrade old gravel. New gravel should be lime-free (do not use ordinary river gravel). When old gravel is reused, screen out all resin particles. Spraying with water is the best method of removing the resin from the gravel on the screen.

Replace or add new gravel in four layers. Fill the shell with water to the depth desired, then add the coarsest grade first; level the gravel layer to fill low spots. Next, raise the water level to the next depth required and add the next smallest grade. Repeat the process. Add the resin to the desired depth and classify by backwashing the bed.

Annually, or as necessary, the condition of underdrains may be learned from the pressure drop across the underdrain system with a full backwash flow being discharged from the manhole. A greater pressure drop than that which existed at the time of installation shows plugging underdrains; a lesser pressure drop reveals displaced or corroded nozzles. Underdrains should be inspected, removed, cleaned, painted (where necessary), and replaced every 3 years.

Manifold-type underdrains should be inspected when gravel is removed. Remove several laterals at random and check for clogging. Where clogging is evident, remove all laterals and clean mechanically, or treat with inhibited muriatic acid.

Plate-type underdrains should be removed, inspected, painted, and replaced every 3 years; make certain that the clearance space between the plate and lower head is the same at all points.

8.2.2 generation Equipment

For regeneration equipment (*Figure 14-21*), the maintenance procedures are as follows:

1. The salt storage tank should be cleaned at varying periods, depending on the amount of insolubles in the salt, tank size, and the salt usage. Rock salt contains more insolubles than evaporated salt. (The greater the salt usage, the more frequent the cleaning required.)
2. The brine-measuring tank should be cleaned every 6 months, and both exterior and interior surfaces painted.
3. At annual intervals, the brine ejector should be cleaned, disassembled, and checked for erosion or corrosion; any clogging of piping should be removed before the ejector is reassembled and replaced.

Figure 14-21 — Regeneration equipment.

The maintenance operation frequency and schedule of inspections for ion-exchange softening units are shown in *Table 14-9*.

Table 14-9 — Maintenance Procedures for Ion-Exchange Softening Units.

Inspection	Action	Frequency
Softener unit		
Shell	Clean and wire brush; paint	A
Valves and fittings	Check for obstructions corrosion and fastness	Q
Multi-port valves	Check for leaks; repack, if necessary; lubricate with grease; follow directions for lubrication procedures	SA
Ion-exchange medium	Check bed surface for dirt fines and organic growths; remove foreign matter and resin to desired level	SA
Gravel	Probe through resin to determine gravel surface; level gravel surface with rake during backwash flow; replace gravel when caked or if resin is being lost to effluent; wash and grade gravel and place in four separate layers; use new lime-free gravel at discretion of inspector	Q
Underdrains	Check pressure drop through underdrains; if necessary, remove manifold or plate underdrains; clean and replace	A or V
Regeneration equipment		
Salt storage unit	Clean tank as necessary to remove dirt	V
Brine tank	Clean out dirt and insolubles; allow to dry; paint both exterior and interior surfaces	SA
Ejector	Clean; disassemble; check erosion and corrosion; clear clogged piping; assemble and replace	A
Operating conditions		
Flow rates	Check rate of flow through bed; adjust controls to optimum rate, depending on type of resin	Q
Backwash rates	Check rate and adjust controls to optimum rate	Q
Pressure	Check difference between inlet and outlet pressures; if undesirable changes in pressure drop have occurred, seek cause and remedy	Q
Efficiency	Compare total softening capacity with previous inspection; determine cause of decrease if any and remedy the situation	Q
Out-of-service softeners	Drain; keep synthetic resins damp; do not regenerate before draining	V
Symbols used for frequency are as follows: D = DAILY W = WEEKLY M = MONTHLY Q = QUARTERLY SA = SEMIANNUALLY A = ANNUALLY V = VARIABLE, AS CONDITIONS MAY INDICATE		

8.3.0 Maintenance of Clarification Equipment

Maintenance procedures for clarification equipment are discussed below. The equipment includes mixers, Flocculator basins, and sedimentation basins.

8.3.1 Mixers

Mixing basins, whether baffled or mechanically stirred (rapid or flash), require attention and cleaning semiannually. The maintenance requirements are as follows:

1. After draining, wash down the walls with a hose and flush the sediment to the drain. Repair spalled spots on walls or bottom as necessary.
2. Check the valves or sluice gates for corrosion and ease of operation; clean and lubricate; paint valves as necessary.

8.3.2 Flocculator Basins

The following maintenance procedures apply to Flocculator basins:

- Monthly, during operation, check paddle rotation to assure that all Flocculators are operating. Lower a light pole (bamboo fishing rod) into the water until the paddles strike the pole, revealing paddle operation. Broken shafts or chains may cause the paddles to become inoperative.
- Semiannually, drain and clean the basin, walls, and floor; inspect the Flocculator mechanism, drive, bearings, gears, and other mechanical parts; clean and lubricate. Especially check underwater bearings for silt penetration. Replace scored bearings. Paint mechanism parts where necessary.

8.3.3 Sedimentation Basins

All types of settling basins require the same basic maintenance, such as lubricating, cleaning, flushing, and painting. Basins, which have mechanical devices, should be maintained under the manufacturer's instructions.

Specific maintenance procedures for revolving sludge collector basins should agree with the manufacturer's instructions. The procedures described here are the minimum.

Regular lubrication is required where the basin is in continuous operation. Intermittent operation affects the lubrication schedule, making it possible to increase the interval between lubrication periods. When operating periods are intermittent and infrequent, the mechanism should be operated briefly between operating periods and lubricated. Devices subject to wide seasonal temperature changes must have seasonal changes in lubricant grades, especially where summer grade oils thicken below freezing and reduce the flow capability. Daily or weekly lubrication of operating units is a part of operator inspection. The choice of lubricant and its frequency of application are established by the manufacturer or by local command.

Other devices found in the equipment require attention on a regular basis. Some examples of these devices and required care are as follows:

1. The speed reducer should be inspected weekly to ensure that the oil is at the proper level, is free of water and grit, and has the right body. When a reducer runs hot during its operation, the oil level may be too high or too low. (Where the reducer is out of service for a long time, make certain it is filled above the level of the seals to prevent the seals from drying out. Be sure it is tagged to reflect this

condition. The reducer must be drained to proper level before being placed back in service.) Replace oil whenever necessary.

2. The drive head should be lubricated daily, but not too much.
3. The worm gear oil level should be checked at least weekly, and the water drained from the housing monthly.
4. The turntable bearings should be lubricated monthly and the oil changed twice yearly.
5. Lubrication procedures for chains depend on the design of the chain and chain guard. Inspect monthly and add oil as necessary; drain off the accumulated oil as necessary, and change the oil twice yearly.
6. Ball bearings and thrust bearings are lubricated annually. They should be inspected monthly for wear and proper lubrication.
7. Center bearings, shaft bearings, bushings, and so forth are lubricated under the manufacturer's instructions.

Tank equipment requires annual inspection. The steps for this inspection are as follows:

1. Check bolts and tighten nuts to maintain original alignments and adjustments.
2. Check for excessive wear of moving parts, including gears.
3. Flush and back blow the sludge withdrawal line by using high-pressure water or compressed air.
4. Check the plows or rakes and straighten them, if necessary.
5. Check the motor condition, couplings, and service shear pins.
6. Clean equipment and paint as necessary.

When the equipment has an overload alarm, check it for operation. If the alarm sounds at any time, shut off the equipment, locate the source of trouble, and correct it. Under no condition should the alarm switch be nullified to provide continuous operation. If the overload is caused by a sludge buildup leading to cutout of the starter switch or pin shearing, the tank must then be drained and the sludge flushed out.

Conveyor-Type Collector Basins

As with the revolving-sludge collectors, specific maintenance procedures in conveyor-type collector basins are in the manufacturer's instructions.

Maintenance procedures on the tanks and structures are the same for this type of sedimentation basin as they are for the circular-type basin. Generally, the maintenance procedures for gears, chains, sprockets, reducers, and so forth are also the same as those for circular-type basins.

Cathodic Protection

Where stubborn water problems exist in water supplies, the sedimentation tank equipment may be protected by cathodic protection. Cathodic protection is a method of protecting metal surfaces from corrosion through the use of a direct-current voltage.

The voltage is applied so that the current tends to flow from the direct-current source through the soil or water to the metal surface to be protected. This flow of current applies electrical energy that reverses the natural process of corrosion.

There are two well-known methods of cathodic protection: the impressed current system and the galvanic anode system. The impressed current system requires graphite rods and an external power source to establish enough voltage (*Figure 14-22*). The galvanic anode system, which requires no external power supply, uses metallic anodes, such as magnesium, zinc, or aluminum.

Cathodic protection systems may be maintained by activity personnel or by service contract. The field engineering officer will provide guidance in developing maintenance procedures or in contracting for such services.

Impressed Current System. Make inspections and necessary maintenance repairs at monthly intervals. The steps for the inspection include the following:

Figure 14-22 — Impressed current system.

1. Check exterior of enclosure for rust, corrosion, or mechanical damage; check hinges and locks for inadequate lubrication, rust, or other deficiencies; check wiring, fastenings, and rectifier for broken or damaged insulation and for rust or corrosion on conduit; and, check exposed wires, cables, and all electrical connections for insecurity, frayed or broken insulation, and other deficiencies.
2. Check interior of enclosure for rust, moisture, condensation, loose wiring, and signs of excessive heating. (Do not put hand tools inside the enclosure.)
3. Check anode suspensions for rust, corrosion, bent or broken suspension members, frayed or broken suspension lines or cables, loose bolts, loose cable connections, and frayed or broken wiring.
4. Whenever necessary, replace or repair any item that will not pass inspection for continued service, and paint switch cans, exposed rectifier housing, and other electrical gear as necessary.

Galvanic Anode System. The only maintenance required for a galvanic anode system or a sacrificial anode system is monthly inspection and potential tests to determine when replacement of anodes is necessary and to ensure continuity of the electric circuit. The procedures that apply are as follows:

1. When an abnormal decrease in current output (or potential of the protected structure) occurs, the anodes should be inspected for excessive disintegration.
2. Check terminals and jumpers of test leads for rust, corrosion, broken or frayed wires, loose connections, and similar deficiencies. Tighten all connections.
3. Check the bushing supporting the anode for rust and corrosion. Where resistors are installed in the circuit, examine these units for corrosion, broken and frayed wires, and loose connections. Tighten all connections.

4. Check the anode suspensions for rust, corrosion, bent or broken suspension members, frayed or broken suspensions lines or cables, loose bolts, loose cable connections, and frayed or broken wiring. Install new anodes when necessary.

8.4.0 Maintenance of Filtration Equipment

Maintenance procedures on both gravity and pressure filters are essentially the same, differing only in detail. Some of the maintenance operations for diatomite filters are similar to those for sand filters; others are not.

8.4.1 Gravity Filters

Regardless of the type of filter medium used (sand or anthracite coal), the material filtered out of the water must be removed from the filter at regular intervals (*Figure 14-23*).

Figure 14-23 — Gravity filter.

Filter Media

During daily backwashing, as an operating procedure, the operator should observe any conditions that may indicate a need for more complete inspection. The minimum procedures are as follows:

- At monthly intervals, drain the filter to the surface of the filter medium; inspect the surface for unevenness, sinkholes, cracks, algae, mud balls, or slime.

- When depressions or craters on the surface are of appreciable size, dig out the sand and gravel, and locate and repair any break in the underdrain system.

When a filter bed is not backwashed correctly, sand grains and foreign matter begin to stick together.

Over a period of time, large clumps, called mud balls, are formed. They lower the efficiency of the filter bed and must be removed. Surface washing usually breaks down these formations, and they can then be removed by backwashing. When the plant does not have surface wash equipment, mud balls may be removed by the steps of the procedure as follows:

1. Wash the filter bed completely clean at 2- to 3-week intervals by using about twice the usual amount of backwash to make sure the bed is cleaned thoroughly.

   When the wash water is clear, reduce the rate until the bed is expanded about 20 to 25 percent to expose mud balls on the sand surface.

   Remove the mud balls manually with a 10-mesh screen attached to a long handle.

   Where severe algae growths exist on sand or walls, remove the filter from service and treat the filter with a strong hypochlorite solution. Add enough hypochlorite to produce 2 to 4 ppm of free residual chlorine in a volume of water 6 inches deep above the filter surface. Draw down the filter until the water level is just above the bed surface. Allow it to stand for 6 to 8 hours, then backwash the surface; follow this by a complete backwashing. Repeat if necessary.

2. Quarterly, during a backwashing period, probe the filter for hard spots and uneven gravel. Examine the sand below the surface by digging to gravel with the water drawn down to the gravel level. When clogged areas are detected, clean the sand by treating the idle filter with an inhibited muriatic acid or sulfurous acid. The advice of the public works officer should be obtained if the operator is unfamiliar with the use of these chemicals.

   Add the inhibited muriatic acid at the surface and allow it to pass downward through the bed and out the filter drain, or “rewash” the line; or add it to an empty filter through a small tap on the bed side of the wash-water line.

   Use sulfurous acid as follows: Allow the sulfur dioxide gas from a cylinder to discharge into the filter wash waterline while slowly filling the filter bed with wash water. Use one 150-pound cylinder to 6,000 gallons of water to produce a 0.3-percent solution. Allow it to stand for 6 hours.

Semiannually, ascertain any change in the rate of wash water rise, as determined during operating procedures, and check sand expansion. Inspect the sand and, if you do not see the condition of the medium, locate the elevation of the top of the bed to determine if the bed has grown in depth.

Also, remove a sand sample and analyze it as follows:

1. Make a sampling tube 12 inches square by 36 inches deep. Force a tube to the gravel level and drain the bed. Remove the sand from within the tube.
2. Collect several such samples from well-scattered locations on the filter bed, mixing until about 2 pounds remain. Dry this sample; mix, quarter, and reduce to a usable sample size.
3. Determine loss of weight of a 10-gram sample during acid treatment. Treat the sample with 10 percent hypochloric acid in a Pyrex evaporating dish in a water

bath for 24 hours. Replace acid loss during treatment period. Wash, dry, and weigh the sand. Determine the weight loss and compare it to the previous analysis.

4. From the remainder of the sand sample, remove 100 grams and run a sieve test. Compare the results to previous tests.

When either inspection, weight loss, or sieve analysis shows growth of sand grains to a point where filtration efficiency is impaired, treat the sand as follows:

1. Add inhibited muriatic acid at the surface and allow it to pass downward through the bed and out the filter drain, or “rewash” the line; or add it to an empty filter through a small tap on the bed side of the wash waterline.
2. Adjust the water treatment process as necessary. If treatment is not effective, replace the filter medium.

Gravel Inspections

Gravel inspection procedures include the following:

- At monthly intervals, check the gravel bed surface for unevenness, using a garden rake or a pole as a probe during backwashing. When ridges or sinkholes are shown, the filter may need overhauling.
- Every 6 months, remove sand from an area about 3 square feet, taking care not to distribute the gravel. Examine the gravel by hand to determine if the gravel is cemented with incrustation or mud balls, or if it is not layered properly.
- When any undesirable conditions exist to a marked degree, the sand should be removed and the filter gravel re-laid. When unevenness or layer mixing is caused by a faulty underdrain system, repair it; when it is caused by faulty backwashing, correct the backwashing procedure.

Filter Underdrain Systems

Annually, or as observations indicate the need, the filter bottom should be inspected. Sand boiling during backwashing or sand craters on the surface indicate trouble in the underdrain system, as does marked unevenness of the gravel layers. Inspection and treatment procedures are as follows:

1. To inspect the bottom, remove the sand over an area of about 10 feet square. Select an area where sand boils or other indications of trouble have been noticed.
2. Place planking over the gravel to stand on, and remove the gravel from areas about 2 feet square. Check the underdrains for deterioration. When the underdrains need repair, remove all sand and gravel, make repairs to the underdrain, and replace the gravel and sand in proper layers.
3. Where the underdrains are porous plate and are clogged with alum floc penetration, flood the underdrain system with a 2-percent sodium hydroxide solution for 12 to 16 hours.

Wash Water Troughs

At quarterly intervals, the level and elevation of troughs should be checked. Water should be drawn below the trough lip, the wash water valve cracked, and any low points observed where water spills over the lip, before the lip is covered completely.

The troughs should be adjusted as necessary to produce an even flow throughout their lengths on both sides.

At 6-month intervals, metal troughs should be inspected for corrosion. When corrosion exists, the troughs should be allowed to dry, and then cleaned by wire brush and painted with a protective paint or coating.

Operating Tables

Operating controls for filter valves may be mounted on a console, panel, or table. The controls actuate the filter valves, which may be powered either by hydraulic or pneumatic means. The controls may be connected to the valve mechanism mechanically, electrically, hydraulically, or pneumatically.

Maintenance operations that should be performed weekly are as follows:

1. Clean the table, the console, or the panel inside and out, using soap and water, if necessary.
2. When mechanically operated, check the tension on the cables or the chains used for connection to the valve operator or for connection to the valve-position indicators.
3. When hydraulically operated, inspect for leaks and stop any leakage; when pneumatically operated, check tubing for possible leakage.

Maintenance operations that should be performed monthly are as follows:

1. Transfer valves (four-way) and handles should be adjusted monthly to make certain that all filter valves open at the same rate. Packing glands should be tightened or new packing added, if needed.
2. Transfer valves should be lubricated monthly with grease. They should not be over lubricated; one-half turn of the grease screw (cup) should be enough.
3. The valve-position indicator should be inspected monthly and adjusted to ensure that it reads correctly in all positions.

Maintenance operations that should be performed annually are as follows:

1. The four-way transfer valves in the table should be disassembled annually and any worn parts, seats, or washers should be cleaned or replaced with new ones.
2. The inside of the table, console, or panel should be painted annually to protect against corrosion.

Rate Controllers

Rate-of-flow controllers may be either direct acting or indirect acting.

Maintenance procedures for a direct acting rate-of-flow controller are as follows:

- Weekly, clean the exterior, check for leakage through the diaphragm pot, and lubricate or tighten packing to stop any existing leakage. Also, ensure that both the diaphragm and the control gate move freely between zero differential and the open and closed positions.
- At intervals of 1 or more years, remove and disassemble the diaphragm pot, including the rubber diaphragm. When the water does not cause tubercles, this operation may not have to be done more than once every 3 to 5 years. The term ***tubercles*** refers to small, more or less hemispherical lumps on the walls of the pipe, caused by corrosive materials present in the water passing through the

pipe, which increase the friction loss and, by reducing the velocity, also reduce the capacity of the pipe.

- Every 3 years, disassemble and service the controller gate and mechanism. Inspect the venturi throat. Paint or apply protective coating as necessary. With indirect-acting controllers, the following maintenance procedures apply:
    1. At weekly intervals, clean the outside of the controller; adjust the packing; lubricate or tighten the fittings as necessary to stop any leakage from the hydraulic cylinder, the controller valve, the piping, or the pilot valve. Make sure that the knife-edges seat correctly and are free of paint or other foreign matter.
    2. Also, be sure that the piston has free vertical travel and does not bind. Replace packing, if necessary.
    3. Annually, disassemble, clean, and lubricate the pilot valve. Remove foreign matter from the piston with a cloth. Never use an abrasive to clean the piston. Make certain that no foreign matter enters the pilot valve during the cleaning operation. Check for leaks or cracks in the diaphragm.
    4. Every third year, disassemble and service the controller gate and mechanism; inspect the venturi throat and apply protective coatings where necessary.
    5. Check the hydraulic cylinders and maintain them under the manufacturer's instructions.

Gauges

Various types of indicating and recording instruments may be mounted on the operating table or control panel. Here, we will take up one device, the diaphragm-pendulum unit loss-of-head gauge. Where the actuating mechanism is this type, the general maintenance procedures given here apply. For a more detailed discussion of these procedures, consult the manufacturer's instructions. The following maintenance operations are required on a monthly basis:

1. Purge the diaphragm cases of air, and check the cable to be sure that it leaves the segment at a tangent to the lower end when a zero reading exists on the unit.
2. Remove dirt from the knife-edges; when necessary, tighten the cam hubs on their shafts.
3. Drain mud from the mud leg. In doing this, flush the mud out of the water pipeline running from above the sand to the loss-of-head gauge. Drain the mud leg until the water runs free of sediment.

Inspect the diaphragms annually for leakage, and replace when necessary.

NOTE

Diaphragms in stock should be stored underwater.

Also, disassemble the unit to clean and lubricate it when necessary. Check the working parts and the cables. (They should be free of knots, splices, or fraying.) Repack the stuffing box when it is leaking.

Make certain that the knife-edges rest solely on their edges where the pendulum is hung vertically, and be sure that all cable ends are knotted tightly.

8.4.2 Pressure Filters

Except where the filter medium is housed in an enclosed pressure shell, pressure filters are constructed like gravity filters with respect to the underdrain system, gravel, and the filter medium (sand or anthracite coal). Pressure filters need the same care and attention as gravity filters. Since their backwashing operations cannot be observed, the filter must be opened regularly and inspected carefully. The recommended maintenance procedures are as follows:

- Weekly, inspect piping and valves for leaks.
- Lubricate and repack valves if necessary.

Quarterly, open the pressure shell and inspect the filter bed surface. The inspection procedures are as follows:

1. Use a garden rake during backwashing while the manhole is open to test for mud balls in the lower part of the filter bed and for evenness of the gravel layer surface.
2. Determine when the sand bed level has changed since the last inspection by comparing the bed surface elevation with some reference point.
3. When the filter does not have a surface wash system and shows evidence of mud balls, backwash it at the highest rate possible while jetting the surface with a stream of water from a high-pressure hose nozzle.

Annual maintenance requirements are as follows:

1. Open the filter; remove the sand from an area large enough to permit the inspection of the gravel. When the sand or gravel distribution indicates nonuniform distribution of backwash water, the filter media and gravel may need to be removed, and the underdrain system checked.
2. Clean and paint the exterior of the shell. Every 3 years (or more often, if necessary), the filter medium and gravel should be removed and the underdrain system checked for the distribution of wash water and repaired, if necessary. Clean the underdrain system, and paint it or apply a protective coating to all parts subject to corrosion, including the inside shell. Replace the gravel and the filter medium.

8.4.3 Diatomite Filters

The most common diatomite filter installations in potable water supply plants are the pressure type, although there are vacuum-type filters that can be used in certain installations. In general, the maintenance procedures for cleaning the filter element are the same for both types. The following procedures apply:

- At monthly intervals, or as often as operating conditions show the need, check the filter elements.
- Cleaning is needed if the precoat has apparent bare spots on the elements. Causes of element clogging are iron oxide, manganese dioxide deposits, and algae growths.
- For iron oxide removal, treat the elements with a 0.5-percent solution of oxalic acid. Information is available from manufacturers on the amount of oxalic acid to use on different size units. The procedures used to remove iron oxide are as follows:

1. Start with an empty filter after a regular washing.
2. Close the drain valve and the main outlet valve; open the recirculation valve.
3. Fill the tank to a level covering the top of the elements.
4. Add the proper quantity of oxalic acid, and recirculate for 1 hour.
5. Drain and hose down the elements and the tank interior.
6. Close the drain valve; refill, circulate a few minutes, and then drain again. When the cleaning is not completely effective, repeat the procedure.

- The procedure for manganese dioxide removal is the same as for the removal of iron oxide, except that anhydrous sodium bisulfite must be added to the solution. (See the manufacturer's instructions for the correct amount.)
- To remove algae growths, add a 12 ½ percent hypochlorite solution to the tank volume after filling the tank to the proper level. (See the manufacturer's instructions for the proper amounts to use for different size units.)
- Semiannually, check the piping and valves and other equipment, including the body feed equipment. Make whatever adjustments the manufacturer's instruction says.
- Clean and paint all exterior surfaces annually, if necessary.

8.5.0 Maintenance of Aeration Equipment

Proper maintenance of aerators is another important area in water treatment activities.

8.5.1 Waterfall Aerators

The recommended maintenance procedures for waterfall-type aerators (cascade or step, and tray or splash pan) are as follows:

- Weekly, inspect the aerator surfaces for algae or other growths, precipitated iron oxide, non-uniformity of water distribution, and staining. Clean when necessary. Treat with copper sulfate or hypochlorite solution to destroy growths.
- Every 6 months, clean and repair tray aerators, removing the trays as necessary. Inspect the coke tray aerators for biological growths and coke deterioration. Replace the coke if the cleaning is not effective. Repair the screen and enclosures, if necessary.
- Annually, repair or replace the surfaces on cascade or step aerators.

8.5.2 Injection or Diffuser Aerators

Injection or diffuser aerators may be porous-medium design or injection nozzles.

Porous Ceramic Diffusers

The maintenance procedures for porous ceramic diffusers-plate or tube-is as follows:

- Upon evidence of the nonuniform distribution of air or clogging that impairs operation, dewater the tank; inspect and clean diffusers, if necessary.
- Every 6 months, drain the aeration tank and inspect the diffusers for joint leaks, broken diffusers, and clogging. Porous ceramic diffusers may suffer clogging of either the waterside or the air side (underside).

- For waterside (porous plate diffusers), use oxidizing acids to clean organic growths from the plate surface.

NOTE

Chlorine gas introduced into the air line at intervals between inspections will help hold down organic growths.

Removable plates should be soaked in 50 percent nitric acid. Plates grouted in place cannot be treated with nitric acid; use chromic acid (made by adding 1 gram of sodium dichromate to 50 ml of sulfuric acid). Pour approximately 2 fluid ounces on each plate 2 days in a row.

WARNING

Acids must be handled carefully. Do NOT pour water into sulfuric or chromic acid, as it will explode or splatter. Such acid will cause severe burns to the skin and clothes. Always pour acid slowly into the water, while stirring continuously. Acid treatment should only be done only upon the approval of the Public Works Officer under supervision of a chemist or other qualified personnel.

Air side (porous plate diffusers). When clogging is caused by iron oxide particles from pipes, treat this condition with a 30-percent solution of hydrochloric acid. If clogging is by soot, oil, or dust from improperly filtered air, remove the diffusers and burn off the extraneous material in a furnace.

Porous ceramic tubes. Tubes may be removed and cleaned by soaking in acids or by burning (as described for porous plate diffusers).

Porous Saran-Wound Tube Diffusers

These diffusers should be inspected and cleaned semiannually as necessary. This material cannot be subjected to strong acids or heat. It must be scrubbed with a brush and soap or detergent.

Injection Nozzles

Injection nozzles should be inspected and cleaned semiannually as necessary. Diffuser nozzles on header lines may become clogged from deposits inside from iron oxide particles, or on the outside from organic growths. Clogging from the inside may require removal of the individual nozzles for cleaning.

Chlorine gas injection into the air line header between inspections will hold down organic growths. At inspection periods, if growths are present, scrub them off with a brush and detergent solution to which hypochloride has been added.

8.5.3 Spray Nozzle Aerators

The maintenance procedures for spray nozzle aerators is as follows:

- At weekly intervals, check the nozzles for clogging, and clean when necessary. Remove the nozzles only when necessary. Check for adequate spread.
- Quarterly, check air line manifolds, remove caps, and clean out sediment; check for joint leaks.
- Check pipe supports, replace or repair, and paint as necessary.
- When spray fences exist, repair and paint them annually.

8.5.4 Blowers and Accessory Equipment

The procedures for injection aeration are as follows:

- Daily, lubricate the blower or compressor under the manufacturer's instructions. Check output pressures.
- Weekly, inspect the air filters; clean, repair, or replace them as necessary.
- Annually, open the blower or compressor and inspect for internal erosion or deterioration; repair as necessary. Paint exterior surfaces.

8.6.0 Safety and Emergencies

The operation of water treatment plants is a hazardous occupation, with dangers from noxious gases and vapors, physical injury, and infections. Work should be carried on only under the supervision of an experienced workman or operator who is trained in first aid and is familiar with the hazards of the work.

8.6.1 hlorination

Specific precautions in handling ammonia, chlorine, and chlorine-yielding compounds are given below.

- Provide self-generating oxygen-breathing apparatus or self-contained, oxygen-breathing apparatus designed to cope with chlorine.
- Maintain only the supply of chlorine in any chlorinator room that will do for normal daily demands. Store the main supply in a detached, noncombustible building or in a fireproof room that is vented only to the outside and that is separated from the main part of the building. Keep the chlorinator and chlorine storage buildings or rooms locked to prevent the entrance of unauthorized personnel and restrict these areas from any other use.
- Allow only reliable and trained personnel to handle chlorine.
- Handle containers carefully to avoid dropping or bumping them.
- Avoid hoisting containers as much as possible; when hoisting is necessary, use safe lifting clamps.
- Store cylinders in a cool place, away from dampness, steam lines, and fire, and in an upright position secured from tilting and falling.
- Keep protective valve caps on containers when not in use; never tamper with safety devices on containers.
- Never connect a full cylinder to a manifold with another cylinder unless temperatures of both are nearly the same.
- When not withdrawing chlorine or when cylinders are empty, keep the valves closed.
- Disconnect the valves as soon as the containers are empty, and check for chlorine leaks at the valve outlets. Test for leaks by passing an opened bottle of strong ammonia solution around the valve. White fumes of ammonium chloride will appear if there is any leakage. Leaks around fittings, connections, and lines can be detected in the same way. Do not apply ammonia solution to plated metal parts because it will remove the plating.

- When chlorine is noticed, workers should avoid panic, refrain from coughing, keep the mouth closed, avoid deep breathing, keep the head high, and get out of the affected area. Only qualified personnel with suitable respiratory equipment will be assigned to investigate and correct the cause of chlorine leaks. When chlorine is being discharged, close the container valve immediately. When chlorine is escaping in liquid form, turn the containers so the chlorine escapes as gas, which will reduce leakage. Do not apply water to the leak; this dangerous practice causes corrosion that may increase the leakage. Electronic chlorine gas detectors are widely used in water plants today.
- The handling of a persistent chlorine leak in a plant is best left to the chlorine supplier.
- Never apply a flame, blowtorch, or other direct heat to chlorine containers; discharge them in a room with a temperature of about 70°F.
- Never ship a defective or leaky cylinder unless it is completely empty. Paint Defective plainly on all such cylinders.
- Follow all regulations on shipping, storing, and using compressed gas cylinders.
- Provide proper means of exit from areas where chlorine is stored or used.
- Never use a chlorine cylinder except to hold chlorine gas.

Should any of the plant personnel become affected by chlorine gas or be overcome by its action, the steps for providing the victim first aid are as follows:

1. Remove the affected person at once to open air and away from gas fumes.
2. Call a physician.
3. Place the patient flat on the back with the head slightly elevated. Keep the patient warm and calm.
4. If conscious, give the patient one-half teaspoonful of essence of peppermint or a moderate stimulant. Do NOT give milk, as milk or cream will usually curdle in the stomach and cause vomiting, which adds to the discomfort of the patient.
5. If able, the person affected should try not to cough.
6. If the patient is unconscious and not breathing, apply artificial respiration.

In handling and storing chemicals, observe all safety precautions.

General:

- Wear appropriate-type chemical cartridge dust masks when bags of chemicals or bulk material are unloaded or otherwise handled. When the chemical is particularly irritating or dust is excessive, wear chemical goggles.
- In handling toxic solutions, a face shield, boots, gloves, and a rubber apron afford required protection from splashes or sprays.
- Store chemicals in a clean, dry place. Store bagged or mixed chemicals in single or double rows with access aisles around each stack for frequent fire inspection. This type of storage makes it easier to remove burning chemicals.
- Store chemicals in separate areas free from contact with flammable chemicals.
- Prohibit smoking when loading and unloading flammable chemicals.

- Do not store flammable chemicals where sparks from overhead electrical equipment can start a fire.
- Use explosion-proof wiring and electrical equipment where flammable chemicals are stored or handled.
- Provide adequate shower facilities for all personnel handling chemicals.
- Give all personnel who handle fluorides detailed safety instructions.

Fluorides:

- Avoid breathing fluoride dust; wash thoroughly after handling fluorides and clean up all spillage.
- All personnel likely to be exposed to sodium fluoride or sodium silicofluoride dust must wear respirators, chemical goggles, rubber gloves, and protective clothing. Rubber gloves, boots, and acid-proof aprons are necessary where acids, such as hydrofluoric, fluosilicic, and hydrofluosilicic, are handled. Wash protective equipment thoroughly before and after using.
- Take care to prevent dust or acids from entering open cuts, sores, or lesions.
- Provide all fluoride-handling equipment, such as storage bunkers, weight hoppers, and dry feed machines, with devices to keep the dust hazard down. Acid pumps will be provided with a clear plastic shield around glands and parts to protect personnel from acid spray.
- Store fluorides in a specific, well-identified area. Storage in various or changing locations may result in a mistake in identifying the chemical. All acid containers will be covered, well vented, and stored where there is no fire hazard.

Personnel protected as described above will dispose of containers that have held fluoride compounds.

8.6.2 ndling Lime

Operators must be particularly attentive to the commonsense rules of good housekeeping in handling lime. This chemical should be carefully stored in a dry area.

Other safety precautions for the handling of lime are as follows:

- An efficient dust-collecting system should be used whenever dust is present at handling points.
- A dry-pickup vacuum cleaner should be used for removing dust around unloading equipment and chemical feeders.
- Protective clothing should always be worn for personal safety in case bags break or the dust collection system fails. The proper dress is heavy-denim clothing with long sleeves, heavy gloves, bandanas, and trousers tied around the shoe tops. Chemical goggles and suitable dust masks should be worn. Any exposed skin areas should be covered with protective creams.

8.6.3 ndling and Storing Chemicals

In handling and storing chemicals, observe all safety precautions.

General:

- Wear appropriate-type chemical cartridge dust masks when bags of chemicals or bulk material are unloaded or otherwise handled. When the chemical is particularly irritating or dust is excessive, wear chemical goggles.
- In handling toxic solutions, a face shield, boots, gloves, and a rubber apron afford required protection from splashes or sprays.
- Store chemicals in a clean, dry place. Store bagged or mixed chemicals in single or double rows with access aisles around each stack for frequent fire inspection. This type of storage makes it easier to remove burning chemicals.
- Store chemicals in separate areas free from contact with flammable chemicals.
- Prohibit smoking when loading and unloading flammable chemicals.
- Do not store flammable chemicals where sparks from overhead electrical equipment can start a fire.
- Use explosion-proof wiring and electrical equipment where flammable chemicals are stored or handled.
- Provide adequate shower facilities for all personnel handling chemicals.
- Give all personnel who handle fluorides detailed safety instructions.

Fluorides:

- Avoid breathing fluoride dust; wash thoroughly after handling fluorides and clean up all spillage.
- All personnel likely to be exposed to sodium fluoride or sodium silicofluoride dust must wear respirators, chemical goggles, rubber gloves, and protective clothing. Rubber gloves, boots, and acid-proof aprons are necessary where acids, such as hydrofluoric, fluosilicic, and hydrofluosilicic, are handled. Wash protective equipment thoroughly before and after using.
- Take care to prevent dust or acids from entering open cuts, sores, or lesions.
- Provide all fluoride-handling equipment, such as storage bunkers, weight hoppers, and dry feed machines, with devices to keep the dust hazard down. Acid pumps will be provided with a clear plastic shield around glands and parts to protect personnel from acid spray.
- Store fluorides in a specific, well-identified area. Storage in various or changing locations may result in a mistake in identifying the chemical. All acid containers will be covered, well vented, and stored where there is no fire hazard.
- Personnel protected as described above will dispose of containers that have held fluoride compounds.

8.6.4 Housekeeping

Promote good housekeeping. Some good housekeeping rules to adhere to are as follows:

- Tools should be returned to their proper place when no longer needed.

- Empty bottles or other such objects should not be left around on the floor where someone is likely to trip or fall over them.
- See that the work area is kept neat and clean at all times.
- Among other things, ensure that passageways are kept free of grease and oil.
- Switchboards must not be used as clothes racks.
- Do not work around electrical apparatus or wiring with wet hands or in wet shoes or clothes.
- Workers on night watch or otherwise required to perform duties alone around water treatment plants should be capable of swimming at least 100 feet while dressed in the usual type of work clothing.
- An employee performing duties inside the tank guardrail should wear a safety belt and lifeline attached to the guardrail.
- Guardrails should be maintained around all water treatment plant open tanks. Handholds or suitable ladders should be maintained on one side wall of each open tank. Suitable handrails 8 to 12 inches above the waterline should be maintained on each side of open tanks.

Summary

This chapter gave a general understanding of the various types of utilities equipment, and the installation and maintenance procedures involved with these types of equipment. This chapter discussed galley equipment installation, troubleshooting, and maintenance. Emergency showers, eyewash stations, and fire hydrants were also discussed.

This chapter also covered the testing procedures associated with backflow prevention and maintenance procedures for miscellaneous equipment. The information covered here is by no means comprehensive, so always refer to the manufacturers' operating and maintenance manuals for detailed instructions and specifications.

Review Questions (Select the Correct Response)

1. What is the first thing you should do before installing an industrial food grinder?

    A. Clean the work area.
    B. Make sure you have all the parts needed for the job.
    C. Read the entire installation manual.
    D. Operational check all power tools.

2. What is the function of the impeller in a food grinder?

    A. Pulverize the garbage
    B. Spin the motor
    C. Flush the hopper
    D. Engage the flywheel

3. What diameter waste pipe is needed when installing an industrial sink?

    A. 1-inch
    B. 2-inch
    C. 3-inch
    D. 4-inch

4. What is the proper procedure for dislodging something stuck in the impeller?

    A. Use your hand.
    B. Use a broom stick.
    C. Use a chemical drain cleaner.
    D. Flush with hot water.

5. What are steam kettles commonly called?

    A. Hot pocket
    B. Copper
    C. Big man
    D. Chow pot

6. What is the temperature tolerance of a steam table thermostat?

    A. ± 2° F
    B. ± 3° F
    C. ± 4° F
    D. ± 5° F

7. How do you ensure the safe and efficient operation of a range?

    A. Immediately secure the gas supply after use.
    B. Observe a PM schedule.
    C. Ensure the range is level.
    D. Use approved chemical cleaners.

8. How often should preventative maintenance be performed on the M-59 Field Range?

A. 50 hours
B. 150 hours
C. 200 hours
D. 250 hours

9. What is the maximum time interval allowed before pumping out a grease trap?

A. 1 month
B. 2 months
C. 3 months
D. 4 months

10. What standard is used for all work concerning emergency eye/face wash equipment?

A. AWWA 101
B. ANSI Z358.1
C. NFPA
D. OSHA

11. What is sufficient water flow in gallons per minute from a fire hydrant for firefighting?

A. 50
B. 100
C. 200
D. 250

12. Why are dry hydrants preferable over wet hydrants in cold weather?

A. The outlet temperature of the water is higher.
B. They will not freeze.
C. They use a bigger valve system.
D. They are unpressurized.

13. Why is a breakaway flange used in the construction of a fire hydrant?

A. To help disconnect the fire hoses quickly
B. To ease maintenance on the main valve
C. To fracture should large stresses be applied to the hydrant
D. To protect the hydrant in case on an earthquake

14. **(True or False)** A traffic model fire hydrant is used near traffic because it is smaller than a standard fire hydrant.

A. True
B. False

15. In which manual are the criteria for fire hydrant locations found?

A. MIL-HDBK-1005
B. MIL-HDBK-1006
C. MIL-HDBK-1007
D. MIL-HDBK-1008

16. **(True or False)** Fire hydrants should be located at least 50 feet from a building but never closer than 25 feet.

A. True
B. False

17. What is the most common error made when installing a new fire hydrant?

A. Placing them too close to the street
B. Improper surface grading
C. Using the wrong diameter piping
D. Pointing the outlets in the wrong direction

18. What is the minimum distance any utility or equipment should be placed by a fire hydrant?

A. 1 foot
B. 2 feet
C. 3 feet
D. 4feet

19. **(True or False)** Utlitiesmen should only be concerned with hydrostatic testing of fire hydrants.

A. True
B. False

20. What is the minimum water pressure from a fire hydrant required for safe firefighting?

A. 20 psi
B. 40 psi
C. 60 psi
D. 80 psi

21. When performing hydrostatic testing, what is the recommended testing medium under pressure?

A. CO_2
B. O_2
C. H_2O
D. $ArCO_2$

22. What is the definition of backflow?

A. Flow of unintended liquids into the potable water supply
B. Grey water flow out of drains
C. Flow of liquids back out of septic systems
D. Reverse flow of water in a water main

23. What is the most common form of backflow?

A. Backpressure
B. Back-movement
C. Back-siphonage
D. Backwash

24. How is back-siphonage caused?

A. Positive pressure upstream
B. Positive pressure downstream
C. Negative pressure upstream
D. Neutral pressure downstream

25. What are the classes of water hazards?

A. Pollutant
B. Health Hazard
C. Lethal Hazard
D. All of the above

26. Which backflow device is the only acceptable means of protecting against lethal hazards?

A. Air gap
B. Pressure vacuum breaker
C. Atmospheric vacuum breaker
D. Double check valve

27. What is the hydraulic consideration when installing a backflow preventer?

A. Sizing
B. Water flow
C. Flow direction
D. Type of fluid

28. Which is NOT a type of volumetric dry feeder?

A. Disk
B. Screw
C. Belt
D. Turbine

29. What part of the regeneration unit should be cleaned thoroughly every 6 months?

A. The brine ejector
B. The brine measuring tank
C. The salt storage tank
D. The filter ejector

30. Baffled mixing basins require cleaning at what regular frequency?

A. Semiannually
B. Annually
C. Quarterly
D. Monthly

31. What intervals should you check the paddle rotation on flocculator basins to ensure all flocculators are working properly?

A. Weekly
B. Monthly
C. Bimonthly
D. Quarterly

32. What part(s) of a flocculator basin should be checked for silt penetration?

A. The underwater bearings
B. The flocculator gears
C. The drive mechanism
D. The flocculator floor

33. Cathodic protection fights corrosion in what manner?

A. Current flows from the ac source directly to the metal surface to be protected.
B. Current flows from the dc source through the soil or water to the metal to be protected.
C. The flow of current applies electrical energy that reverses the process of corrosion.
D. The flow of current applies electrical energy that parallels the process of corrosion.

34. How often should wash water troughs be inspected for corrosion?

A. Quarterly
B. Semiannually
C. Annually
D. Every 2 years

35. Most diatomite filter installations in potable water supply plants are of what type?

A. Pressure
B. Vacuum
C. Hydraulic
D. Pneumatic

36. A 30-percent solution of hydrochloric acid should be used to clean porous plate diffusers clogged with_ .

A. dust, soot, or oil
B. manganese oxide
C. grease or debris
D. iron oxide

Trade Terms Introduced in This Chapter

None

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

FM 10-23 Basic Doctrine for Army Filed Feeding and Class 1 Operations Management, Headquarters, Department of the Army, Washington, DC, 18 April 1996

UFC 3-190-07N Unified Facilities Criteria (UFC) Food Service Equipment Operation and Maintenance, Naval Facilities Engineering Command, Philadelphia, PA, 16 January 2004

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

APPENDIX I

MATHEMATICS

The purpose of this mathematics appendix is twofold; first, it is a refresher for the Seabees who have encountered a time lapse between his or her schooling in mathematics; second, and more important, this section applies mathematics to the tasks that can not be accomplished without the correct use of mathematical equations.

Linear Measurement

Measurements are most often made in feet (ft) and inches (in). It is necessary that a Seabee know how to make computations involving feet and inches.

Changing Inches to Feet and Inches

To change inches to feet and inches, divide inches by 12. The quotient will be the number of feet, and the remainder will be inches.

Changing Feet and Inches to Inches

To change feet and inches to inches, multiply the number of feet by 12 and add the number of inches. The results will be inches.

Changing Inches to Feet in Decimal Form

To change inches to feet in decimal form, divide the number of inches by 12 and carry the result to the required number of places.

Changing Feet to Inches in Decimal Form

To change feet in decimal form to inches, multiply the number of feet in decimal form by 12.

Addition of Feet and Inches

A Seabee often finds it necessary to combine or subtract certain dimensions which are given in feet and inches.

Arrange in columns of feet and inches and add separately. If the answer in the inches column is more than 12, change to feet and inches and combine feet.

Subtraction of Feet and Inches

Arrange in columns with the number to be subtracted below the other number. If the inches in the lower number are greater, borrow 1 foot (12 Inches) from the feet column in the upper number. Subtract as in any other problem.

Multiplication of Feet and Inches

Arrange in columns. Multiply each column by the required number. If the inches column is greater than 12, change to feet and inches then add to the number of feet.

Division of Feet and Inches

In dividing feet and inches by a given number, the problem should be reduced to inches unless the number of feet will divide by the number evenly.

To divide feet and inches by feet and inches, change to inches or feet (decimals).

Angles

When two lines are drawn in different directions from the same point, an angle is formed.

Angles are of four types:

- Right angle is a 90° angle.
- Acute angles are angles less than 90°.
- Obtuse angles are angles greater than 90°, but less than 180°.
- Reflex angle is an angle greater than 180°.

Measurement of Angles

Observe that two straight lines have been drawn to form four right angles. Refer to *Figure A-1*.

In order to have a way to measure angles, a system of angle-degrees has been established. Assume that each of the four right angles is divided into 90 equal angles. The measure of each is 1 angle degree; therefore, in the four right angles, there are 4 x 90°, or 360 angle degrees. For accurate measurement, degrees have been subdivided into minutes and minutes into seconds.

1 degree= 60 minutes (’).

1 minute= 60 seconds (“).

Figure A-1 — Right angles.

Relationship of Angles

Figure A-2 — Relationship of angles.

1. ∠ZOY and ∠ZOX are supplementary angles and their total measure in degrees is equal to 180°. When one straight line meets another, two supplementary angles are formed. One is the supplement of the other. Refer to *Figure A-2, View 1*.

2. ∠DAC and ∠CAB are complementary angles and their total is a right angle or 90°. Refer to *Figure A-2, View 2*.

Two angles whose sum is 90° are said to be complementary, and one is the complement of the other.

3. ∠MOP and ∠RON are a pair of vertical angles and are equal. Refer to *Figure A-2, View 3*.

When two straight lines cross, two pairs of vertical angles are formed. Pairs of vertical angles are equal.

Bisecting Angles

To bisect an angle merely means to divide the angle into two equal angles. This may be done by use of a compass.

Perpendicular Lines

Lines are said to be perpendicular when they form a right angle (90°).

Parallel Lines

Two lines are said to be parallel if they are equidistant (equally distant) at all points.

Facts about parallel lines:

Two straight lines lying in the same plane either intersect or are parallel.

Through a point there can be only one parallel drawn to a given line.

If two lines are perpendicular to the third, and in the same plane, they are parallel.

Plane Shapes

A plane shape is a portion of a plane bounded by straight or curved lines or a combination of the two.

The number of different types of plane shapes is infinite, but we are concerned with those which are of importance to you as a Seabee. We will cover the circle, triangle, quadrilateral, other polygons, and ellipses.

Circles

Definitions:

A CIRCLE is a closed curved line in which any point on the curved line is equidistant from a point called the center. (Circle O). Refer to *Figure A-3*.

A RADIUS is a line drawn from the center of a circle to a point on a circle. (As OA, OB, OX, and OY). Refer to *Figure A-3.*

A DIAMETER is a line drawn through the center of a circle with its ends lying on the circle. Refer to *Figure A-3*.

A DIAMETER is twice the length of a radius. (AB is a diameter of circle O) Refer to *Figure A-3*.

A CHORD is a line joining any two points lying on a circle. (CD is a chord of circle O.) Refer to *Figure A-3*.

Figure A-3 — Circle.

An ARC is a portion of the closed curved lines which forms the circle. It is designated by CD. An arc is said to be subtended by a chord. Chord CD subtends arc CD. Refer to *Figure A-3*.

A TANGENT is a straight line which touches the circle at one and only one point. (Line MZ is a tangent to circle O.) Refer to *Figure A-3*.

A CENTRAL ANGLE is an angle whose vertex is the center of a circle and whose side are radii of the circle. (As XOY, YOA, and XOB.) Refer to *Figure A-3*.

CONCENTRIC CIRCLES are circles having the same center and having different radii.

The CIRCUMFERENCE of a circle is the distance around the circle. It is the distance on the curve from C to A to X to Y to B to D and back to C. Refer to *Figure A-3*.

Triangles

A triangle is a plane shape having 3 sides. Its name is derived from its three (tri) angles.

1. Equilateral - all sides are equal, all angles are equal, and all angles are 60°. Refer to *Figure A-4*.
2. Isosceles - two sides are equal and two angles are equal. Refer to *Figure A-4.*
3. Scalene - all sides are unequal and all angles are unequal. Refer to *Figure A-4.*
4. Right - one right angle is present. Refer to *Figure A-4*.

Figure A-4 — Types of triangles.

Altitudes and Medians

The altitude and median of a triangle are not the same; the difference is pointed out in the following definitions:

1. The altitude of a triangle is a line drawn from the vertex, perpendicular to the base. Refer to *Figure A-5, View 1*.
2. The median of a triangle is a line drawn from the vertex to the midpoint of the base. Refer to *Figure A-5, View 2*.

Figure A-5 — Altitude and median of a triangle.

Construction of Triangles

There are many ways to construct a triangle, depending upon what measurements are known to you. The following definitions will assist you.

1. A triangle may be constructed if the lengths of three sides are known.
2. A triangle may be constructed if two sides and the included angle (angle between the sides) are known.
3. A triangle may be constructed if two angles and the included side are given.
4. A right triangle may be constructed if the two sides adjacent to the right angle are known.
5. A right triangle may be constructed by making the sides 3, 4, and 5 inches or multiples or fractions thereof.

Quadrilaterals

A quadrilateral is a four-sided plane shape. There are many types, but only the trapezoid, parallelogram, rectangle, and square are described here.

Trapezoid is a quadrilateral having only two sides parallel. If the other two sides are equal, it is an isosceles trapezoid. BF is the altitude of the trapezoid. See *Figure A-6*.

Figure A-6 — Trapezoid.

Parallelogram is a quadrilateral having opposite sides parallel. Refer to *Figure A-7*.

1. AB is parallel to CD.
2. AC is parallel to BD.
3. AD and CB are diagonals.
4. Diagonals bisect each other so CO = OB and AO = OD.
5. Opposite angles are equal. ACD = DBA and CAB = BDC.
6. If two sides of a quadrilateral are equal and parallel, the figure is a parallelogram.
7. A parallelogram may be constructed if two adjoining sides and one angle are known.

Figure A-7 — Parallelogram.

Rectangle is a parallelogram having one right angle. Refer to *Figure A-8*.

1. ABCD is a parallelogram having one right angle. This, of course, makes all angles right angles.
2. AC and BD are diagonals.
3. O is the midpoint of AC and BD and OB = OC = OD = OA.
4. O is equidistant from BC and AD and is also equidistant from AB and CD.
5. A rectangle may be constructed if two adjoining sides are known.

Figure A-8 — Rectangle.

Square is a rectangle having its adjoining sides equal. Refer to *Figure A-9*.

1. ABCD is a square.
2. AC and BD are diagonals.
3. O is the geometric center of the square. AO = OC = OB = OD.
4. O is equidistant from all sides.
5. A square may be constructed if one side is known.

Figure A-9 — Square.

Polygons

A polygon is a many-sided plane shape. It is said to be regular if all sides are equal and irregular when they are not. Only regular polygons are described here.

Triangles and quadrilaterals fit the description of a polygon and have been covered previously. Three other types of regular polygons are shown in *Figure A-10*. Each one is inscribed in a circle. This means that all vertices of the polygon lie on the circumference of the circle.

Note that the sides of each of the inscribed polygons are actually equal chords of the circumscribed circle. Since equal chords subtend equal arcs, by dividing the circumference into an equal number of arcs, a regular polygon may be inscribed in a circle. Also note that the central angles are equal because they intercept equal arcs. This gives a basic rule for the construction of regular polygons inscribed in a circle as follows:

To inscribe a regular polygon in a circle, create equal chords of the circle by dividing the circumference into equal arcs or by dividing the circle into equal central angles.

Dividing a circle into a given number of parts has been discussed, so construction should be no problem. Since there are 360 degrees around the center of the circle, you should have no problem in determining the number of degrees to make each equal central angle.

Figure A-10 — Types of polygons.

Methods for Constructing Polygons

The three methods for constructing polygons described here are the pentagon, hexagon, and octagon.

The Pentagon is a developed by dividing the circumference into 5 equal parts.

The Hexagon is developed by dividing the circumference into 6 equal parts.

The Octagon method has been developed by creating central angles of 90° to divide a circle into 4 parts and bisecting each arc to divide the circumference into 8 equal parts.

Ellipses

An ellipse is a plane shape generated by point P, moving in such a manner that the sum of its distances from two points, F_1 and F_2, is constant. Refer to *Figure A-11.*

$BF_1 + PF_2 = C$ = (a constant)

AE is the major axis.

BD is the minor axis.

Figure A-11 — Ellipses.

Perimeters and Circumferences

Perimeter and circumference have the same meaning; that is, the distance around. Generally, circumference is applied to a circular object and perimeter to an object bounded by straight lines.

Perimeter of a Polygon

The perimeter of a triangle, quadrilateral, or any other polygon is actually the sum of the sides.

Circumference of a Circle

Definition of Pi: Mathematics have established that the relationship of the circumference to the diameter of a circle is a constant called Pi and written as π. The numerical value of this constant is approximately 3.141592653. For our purposes 3.1416 or simply 3.14 will suffice.

The formula for the circumference of a circle is $C = 2\pi D$ where C is the circumference and D is the diameter since D = 2R where R is the radius, the formula may be written as $C = 2\pi R$.

Areas

All areas are measured in squares.

The area of a square is the product of two of its sides and since both sides are equal, it may be said to be square of its side.

NOTE

The area of any plane surface is the measure of the number of squares contained in the object. The unit of measurement is the square of the unit which measures the sides of the square.

Area of Rectangle

$$A = L \times W$$

Where:

A = area of a rectangle

L = length of a rectangle

W = width of a rectangle

Area of a Cross Section

The cross section of an object is a plane figure established by a plane cutting the object at right angles to its axis. The area of this cross section will be the area of the plane figure produced by this cut.

The area of the cross section is L x W.

The most common units are square inches, square feet, square yards and in roofing, “squares.”

1 square foot = 144 square inches

1 square yard = 9 square feet

1 square of roofing = 100 square feet

Common Conversions

1. To convert square inches to square feet, divide square inches by 144.
2. To convert square feet to square inches, multiply by 144.
3. To convert square feet to square yards, divide by 9.
4. To convert square yards to square feet, multiply by 9.
5. To convert square feet to squares, divide by 100.

Conversion of Units of Cubic Measure

It is often necessary to convert from one cubic measure to another. The conversion factors used are as follows:

1. 1 cubic foot = 1,728 cubic inches
2. 1 cubic yard = 27 cubic feet
3. 1 cubic foot = 7.48 US gallons (liquid measure)
4. 1 us gallon (liquid measure) = 231 cubic inches
5. 1 bushel (dry measure) = 2,150.42 cubic inches

Area of a Circle

The formula for the area of a circle is:

$$A = \pi r^2$$

Where:

A = area of circle

r = radius of circle

π = 3.1416

Since r = d/2 where d is the diameter of a circle, the formula for the area of a circle in terms of its diameter is:

$$A = \pi(\frac{d}{2})^2 = \frac{\pi d^2}{4}$$

Geometric Solids

In describing plane shapes, you use only two dimensions: width and length; there is no thickness. By adding the third dimension, you describe a solid object.

Consider the solids described below.

Prism - is a figure whose two bases are polygons, alike in size and shape, lying in parallel planes and whose lateral edges connect corresponding vertices and are parallel and equal in length. A prism is a right prism if the lateral edge is perpendicular the base. The altitude of a prism is the perpendicular distance between the bases.

Cone - is a figure generated by a line moving in such a manner that one end stays fixed at a point called the “vertex.” The line constantly touches a plane curve which is the base of the cone. A cone is a circular cone if its base is a circle. A circular cone is a right circular cone if the line generating it is constant in length. The altitude of a cone is the length of a perpendicular to the plane of the base drawn from the vertex.

Pyramid - is a figure whose base is a plane shape bounded by straight lines and whose sides are triangular plane shapes connecting the vertex and a line of the base. A regular pyramid is one whose base is a regular polygon and whose vertex lays on a perpendicular to the base at its center. The altitude of a pyramid is the length of a perpendicular to the plane of the base drawn from the vertex.

Circular Cylinder - is a figure whose bases are circles lying in parallel planes connected by a curved lateral surface. A right circular cylinder is one whose lateral surface is perpendicular to the base. The altitude of a circular cylinder is the perpendicular distance between the planes of the two bases.

Measurement of Volume

Volume is measured in terms of cubes.

Common Volume Formulas

All factors in the formulas must be in the same linear units. As an example, one term could not be expressed in feet while other terms are in inches.

Volume of a Rectangular Prism

$$V = L \times W \times H$$

Where:

V = Volume in cubic inches

W = Width of the base in linear units

L = Length of base in linear units

H = Altitude of the prism in linear units

Volume of a Cone

$$V = \frac{A x h}{3}$$

Or

$$V = \frac{\pi r^2 h}{3}$$

Or

$$V = \frac{\pi d^2 h}{12}$$

Where:

V= Volume of a cone in cubic units

A = Area of the base in square units

h = Altitude of a cone in linear units

r = Radius of the base

d = Diameter of the base

Volume of a Pyramid

$$V = \frac{Ah}{3}$$

Where:

V = Volume in cubic units

A = Area of base in square units

h = Altitude in linear units

Volume of a Cylinder

V = Ah

Or

$$V = \pi r^2 h$$

Or

$$V = \frac{\pi d^2 h}{4}$$

Where:

V = Volume in cubic units

A = Area of the base in square units

h = Altitude in linear units

r = Radius of the base

d = Diameter of the base

Volume of the Frustum of a Right Circular Cone

The frustum of a cone is formed when a plane is passed parallel to the base of the cone. The frustum is the portion below the plane. The altitude of the frustum is the perpendicular distance between the bases.

$$V = 1/3\,\pi h\left(r^2 + R^2 + Rr\right)$$

Where:

h = Altitude in linear units

r = Radius of the upper base in linear units

R = Radius of the lower base in linear units

Volume of a Frustum of a Regular Pyramid

A frustum of a pyramid is formed when a plane is passed parallel to the base of the pyramid. The frustum is the portion below the plane. The altitude is the perpendicular distance between the bases.

$$V = 1/3h\ (B + b + \sqrt{Bb}\ )$$

Where:

V = Volume of the frustum in cubic units

h = Altitude in linear units

B = Area of the lower base in square units

b = Area of the upper base in square units

Ratio

The ratio of one number to another is the quotient of the first, divided by the second. This is often expressed as a:b, which is read as the ratio of a to b. More commonly, this expressed as the fraction a/b.

Ratio has no meaning unless both terms are expressed in the same unit by measurement.

Percentage

Percentage (%) is a way of expressing the relationship of one number to another. In reality, percentage is a ratio expressed as a fraction in which the denominator is always one hundred.

Proportion

Proportion is a statement of two ratios which are equal.

Example: 1/3 = 5/15 or 1:3 = 5:15

Solving proportions is done by cross multiplying.

Example: $\frac{a}{b} = \frac{c}{d}$ = a x d = b x c

Law of Pythagoras

The Law of Pythagoras is the square of the hypotenuse of a right triangle equals the sum of the two legs. It is expressed by the formula $a^2 + b^2 = c^2$.

Right Triangle: a triangle having one right angle

Hypotenuse: The hypotenuse of a right triangle is the side opposite the right angle

Leg: The leg of a right triangle is a side opposite and acute angle of a right triangle.

METRIC CONVERSION TABLES

Length Conversion

When You Know:	You Can Find:	If You Multiply By:
inches	millimeters	25.4
inches	centimeters	2.54
feet	centimeters	30
feet	meters	0.3
yards	centimeters	90
yards	meters	0.9
miles	kilometers	1.6
miles	meters	1609
millimeters	inches	0.04
centimeters	inches	0.4
centimeters	feet	0.0328
meters	feet	3.3
centimeters	yards	0.0109
meters	yards	1.1
meters	miles	0.000621
kilometers	miles	0.6
meters	nautical miles	0.00054
nautical miles	meters	1852

Weight Conversion

When You Know:	You Can Find:	If You Multiply By:
ounces	grams	28.3
pounds	kilograms	0.45
short tons (2000 lbs)	megagrams (metric tons)	0.9
grams	ounces	0.0353
kilograms	pounds	2.2
megagrams (metric tons)	short tons (2000 lbs)	1.1

Temperature Conversion

When You Know:	You Can Find:	If You Multiply By:
Degrees Fahrenheit	Degree Celsius	Subtract 32 then multiply by 5/9
Degrees Celsius	Degree Fahrenheit	Multiply by 9/5 then add 32
Degrees Celsius	Kelvins	Add 273.15°

Volume Conversion

When You Know:	You Can Find:	If You Multiply By:
teaspoons	milliters	5
tablespoons	milliters	1 5
fluid ounces	milliters	3 0
cups	liters	0.24
pints	liters	0.47
quarts	liters	0.95
gallons	liters	3.8
milliters	teaspoons	0.2
milliters	tablespoons	0.067
milliters	fluid ounces	0.034
liters	cups	4.2
liters	pints	2.1
liters	quarts	1.06
liters	gallons	0.26
cubic feet	cubic meters	0.028
cubic yards	cubic meters	0.765
cubic meters	cubic feet	35.3
cubic meters	cubic yards	1.31

Area Conversions

When You Know:	You Can Find:	If You Multiply By:
Square inches	Square centimeters	6.45
Square inches	Square meters	0.000 6
Square feet	Square centimeters	929
Square feet	Square meters	0.0929
Square yards	Square centimeters	8.360
Square yards	Square meters	0.836
Square miles	Square kilometers	2.6
Square centimeters	Square inches	0.155
Square meters	Square inches	1550
Square centimeters	Square feet	0.001
Square meters	Square feet	10.8
Square centimeters	Square yards	0.00012
Square meters	Square yards	1.2
Square kilometers	Square miles	0.4

Table A-1 — Decimal Equivalents.

Fraction	16th	32nd	64th	Decimal	Fraction	16th	32nd	64th	Decimal
			1	.015625				33	.515625
		1	2	.03125			17	34	.53125
			3	.046875				35	.54875
	1	2	4	.0625		9	18	36	.5625
			5	.078125				37	.578125
		3	6	.09375			19	38	.59375
			7	.109375				39	.609375
1/8	2	4	8	.125	5/8	10	20	40	.625
			9	.140625				41	.640625
		5	10	.15625			21	42	.65625
			11	.171875				43	.671875
	3	6	12	.1875		11	22	44	.6875
			13	.203125				45	.703125
		7	14	.21875			23	46	.71875
			15	.234375				47	.734375
1/4	4	8	16	.25	3/4	12	24	48	.75
			17	.265625				49	.765625
		9	18	.28125			25	50	.78125
			19	.296875				51	.796875
	5	10	20	.3125		13	26	52	.8125
			21	.328125				53	.818225
		11	22	.34375			27	54	.84375
			23	.359375				55	.859375
3/8	6	12	24	.375	7/8	14	28	56	.875
			25	.390623				57	.890625
		13	26	.40625			29	58	.90625
			27	.421875				59	.921875
	7	14	28	.4375		15	30	60	.9375
			29	.453125				61	.953125
		15	30	.46875			31	62	.96875
			31	.484375				63	.984375
1/2	8	16	32	.5	1	16	32	64	1.0

Table A-2 — Metric measures of length.

10 millimeters	=	1 centimeter (cm)
10 centimeters	=	1 decimeter (dm)
10 decimeters	=	1 meter (m)
10 meters	=	1 decameter (dkm)
10 decameters	=	1 hectometer (hm)
10 hectometers	=	1 kilometer (km)

Table A-3 — Conversion of inches to millimeters.

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
1	25.4	26	660.4	51	1295.4	76	1930.4
2	50.8	27	685.8	52	1320.8	77	1955.8
3	76.2	28	711.2	53	1346.2	78	1981.2
4	101.6	29	736.6	54	1371.6	79	2006.6
5	127	30	762	55	1397	80	2032
6	152.4	31	787.4	56	1422.4	81	2057.4
7	177.8	32	812.8	57	1447.8	82	2082.8
8	203.2	33	838.2	58	1473.2	83	2108.2
9	228.6	34	863.6	59	1498.6	84	2133.6
10	254	35	889	60	1524	85	2159
11	279.4	36	914.4	61	1549.4	86	2184.4
12	304.8	37	939.8	62	1574.8	87	2209.8
13	330.2	38	965.2	63	1600.2	88	2235.2
14	355.6	39	990.6	64	1625.6	89	2260.6
15	381	40	1016	65	1651	90	2286
16	406.4	41	1041.4	66	1676.4	91	2311.4
17	431.8	42	1066.8	67	1701.8	92	2336.8
18	457.2	43	1092.2	68	1727.2	93	2362.2
19	482.6	44	1117.6	69	1752.6	94	2387.6
20	508	45	1143	70	1778	95	2413
21	533.4	46	1168.4	71	1803.4	96	2438.4
22	558.8	47	1193.8	72	1828.8	97	2463.8
23	584.2	48	1219.2	73	1854.2	98	2489.2
24	609.6	49	1244.6	74	1879.6	99	2514.6
25	635	50	1270	75	1905	100	2540

Table A-4 — Conversions of fractions and decimals to millimeters.

Fraction of inch (64ths)	Decimal of Inch	Millimeters	Fraction of inch (64ths)	Decimal of Inch	Millimeters
1	.015625	.3968	33	.515625	13.0966
2	.03125	.7937	34	.53125	13.4934
3	.046875	1.1906	35	.546875	13.8903
4 (1/16")	.0625	1.5875	36	.5625	14.2872
5	.078125	1.9843	37	.578125	14.6841
6	.09375	2.3812	38	.59375	15.0809
7	.109375	2.7780	39	.609375	15.4778
8 (1/8")	.125	3.1749	40 (5/8")	.625	15.8747
9	.140625	3.5817	41	.640625	16.2715
10	.15625	3.9686	42	.65625	16.6684
11	.171875	4.3655	43	.671875	17.0653
12	.1875	4.7624	44	.6875	17.4621
13	.203125	5.1592	45	.703125	17.8590
14	.21875	5.5561	46	.71875	18.2559
15	.234375	5.9530	47	.734375	18.6527
16 (1/4")	.25	6.3498	48 (3/4")	.75	19.0496
17	.265625	6.7467	49	.765625	19.4465
18	.28125	7.1436	50	.78125	19.8433
19	.296875	7.5404	51	.796875	20.2402
20	.3125	7.9373	52	.8125	20.6371
21	.328125	8.3342	53	.818225	21.0339
22	.34375	8.7310	54	.84375	21.4308
23	.359375	9.1279	55	.859375	21.8277
24 (3/8")	.375	9.5248	56 (7/8")	.875	22.2245
25	.390623	9.9216	57	.890625	22.6214
26	.40625	10.3185	58	.90625	23.0183
27	.421875	10.7154	59	.921875	23.4151
28	.4375	11.1122	60	.9375	23.8120
29	.453125	11.5091	61	.953125	24.2089
30	.46875	11.9060	62	.96875	24.6057
31	.484375	12.3029	63	.984375	25.0026
32 (1/2")	.5	12.6997	64 (1")	1.0	25.3995

Table A-5 Conversions of measurements.

Conversion Chart for Measurement								
inches								centimeters
Cm							inches	
Feet						meters		
Meters					feet			
Yards				meters				
Meters			yards					
Miles		kilometers						
km	miles							
1	0.62	1.61	1.09	0.91	3.28	0.30	0.39	2.54
2	1.21	3.22	2.19	1.83	6.56	0.61	0.79	5.08
3	1.86	4.83	3.28	2.74	9.81	0.91	1.18	7.62
4	2.49	6.44	4.37	3.66	13.12	1.22	1.57	10.16
5	3.11	8.05	5.47	4.57	16.40	1.52	1.97	12.70
6	3.73	9.66	6.56	5.49	19.68	1.83	2.36	15.24
7	4.35	11.27	7.66	6.4	22.97	2.13	2.76	17.78
8	4.97	12.87	8.75	7.32	26.25	2.44	3.15	20.32
9	5.59	14.48	9.84	8.23	29.53	2.74	3.54	22.86
10	6.21	16.09	10.94	9.14	32.81	3.05	3.93	25.40
12	7.46	19.31	13.12	10.97	39.37	3.66	4.72	30.48
20	12.43	32.19	21.87	18.29	65.62	6.10	7.87	50.80
24	14.91	38.62	26.25	21.95	78.74	7.32	9.45	60.96
30	18.64	48.28	32.81	27.43	98.42	9.14	11.81	76.20
36	22.37	57.94	39.37	32.92	118.11	10.97	14.17	91.44
40	24.37	64.37	43.74	36.58	131.23	12.19	15.75	101.60
48	29.83	77.25	52.49	43.89	157.48	14.63	18.90	121.92
50	31.07	80.47	54.68	45.72	164.04	15.24	19.68	127.00
60	37.28	96.56	65.62	54.86	196.85	18.29	23.62	152.40
70	43.50	112.65	76.55	64	229.66	21.34	27.56	177.80
72	44.74	115.87	78.74	65.84	236.22	21.95	28.35	182.88

Table A-6 — Cubic conversion chart.

Cubic Conversion Chart					
Cubic Meters				Cubic Feet	Cubic Yard
Cubic Yard			Cubic Meters		
Cubic Feet		Cubic Meters			
Cubic Inches	Cubic Centimeters				
1	16.39	0.028	0.76	35.3	1.31
2	32.77	0.057	1.53	70.6	2.62
3	49.16	0.085	2.29	105.9	3.92
4	65.55	0.113	3.06	141.3	5.23
5	81.94	0.142	3.82	176.6	6.54
6	98.32	0.170	4.59	211.9	7.85
7	114.71	0.198	5.35	247.2	9.16
8	131.10	0.227	6.12	282.5	10.46
9	147.48	0.255	6.88	317.8	11.77
10	163.87	0.283	7.65	353.1	13.07
20	327.74	0.566	15.29	706.3	26.16
30	491.61	0.850	29.94	1059.4	39.24
40	655.48	1.133	30.58	1412.6	52.32
50	819.35	1.416	38.23	1765.7	65.40
60	983.22	1.700	45.87	2118.9	78.48
70	1174.09	1.982	53.52	2472.0	91.56
80	1310.96	2.265	61.16	2825.2	104.63
90	1474.84	2.548	68.81	3178.3	117.71
100	1638.71	2.832	76.46	3531.4	130.79
Example: 3 cu. Yd = 2.29 cu. M Volume: The cubic meter is the only common dimension used for measuring the volume of solids in the metric system.					

Table A-7 — Gallon and liter conversion chart.

Gallon	Liter	Gallon	Liter	Gallon	Liter
.1	.38	1	3.79	10	37.85
.2	.76	2	7.57	20	57.71
.3	1.14	3	11.36	30	113.56
.4	1.51	4	15.14	40	151.42
.5	1.89	5	18.93	50	189.27
.6	2.27	6	22.71	60	227.12
.7	2.65	7	26.50	70	264.98
.8	3.03	8	30.28	80	302.83
.9	3.41	9	34.07	90	340.69
NOTE: 1 us Gallon = 3.785412 Liters 100 us Gallons = 378.5412 Liters					

Table A-8 — Weight conversion chart.

Weight Conversion Chart						
Ounces						Grams
Grams					Ounces	
Pounds				Kilograms		
Kilograms			Pounds			
Short Ton		Metric Ton				
Metric Ton	Short Ton					
1	1.10	0.91	2.20	0.45	0.04	28.1
2	2.20	1.81	4.41	0.91	0.07	56.7
3	3.31	2.72	6.61	1.36	0.11	85.0
4	4.41	3.63	8.82	1.81	0.14	113.4
5	5.51	4.54	11.02	2.67	0.18	141.8
6	6.61	5.44	13.23	2.72	0.21	170.1
7	7.72	6.35	15.43	3.18	0.25	198.4
8	8.82	7.26	17.64	3.63	0.28	226.8
9	9.92	8.16	19.81	4.08	0.32	255.2
10	11.02	9.07	22.05	4.54	0.35	283.5
16	17.63	14.51	35.27	7.25	0.56	453.6
20	22.05	18.14	44.09	9.07	0.71	567.0
30	33.07	27.22	66.14	13.61	1.06	850.5
40	44.09	36.29	88.14	18.14	1.41	1134.0
50	55.12	45.36	110.23	22.68	1.76	1417.5
60	66.14	54.43	132.28	27.22	2.12	1701.0
70	77.16	63.50	154.32	31.75	2.17	1981.5
80	88.18	72.57	176.37	36.29	2.82	2268.0
90	99.21	81.65	198.42	40.82	3.17	2551.5
100	110.20	90.72	220.46	45.36	3.53	2835.0
NOTE: 1 pound = 0.4535925 KG; 1 US Short Ton = 2,000 pounds; and 1 Metric Ton = 1,000 KG						

FORMULAS

Conversion Factors and Constants

$\pi = 3.14$	$2\pi = 6.28$
$\pi^2 = 9.87$	$(2\pi)^2 = 39.5$
$\varepsilon = 2.718$	$\sqrt{2} = 1.414$
$\sqrt{3} = 1.732$	LOG = 0.497

Sinusoidal Voltages and Currents

Effective Value	=	0.707 x Peak Value
Average Value	=	0.637 x Peak Value
Peak Value	=	1.414 x Effective Value
Effective Value	=	1.11 x Average Value
Peak Value	=	1.57 x Average Value
Average Value	=	0.9 x Effective Value

Temperature

(F to C) C = 5/9 (F – 32)

(C to F) F = 9/5 C = 32

(C to K) K = C + 73

Power

1 kilowatt = 1.341 horsepower

1 horsepower = 746 watts

Trigonometric Formulas

sin A = $\frac{a}{c} = \frac{\text{Opposite Side}}{\text{Hypotenuse}}$

cos A = $\frac{b}{c} = \frac{\text{Adjacent Side}}{\text{Hypotenuse}}$

tan A = $\frac{a}{b} = \frac{\text{Opposite Side}}{\text{Adjacent Side}}$

cot A = $\frac{b}{a} = \frac{\text{Adjacent Side}}{\text{Opposite Side}}$

Figure A-12 — Trapezoid.

Ohm’s Law- Direct Current

Figure A-13 — Direct Current.

Ohm’s Law- Alternating Current

Figure A-14 — Alternating Current.

Speed vs. Poles Formulas

$F = \frac{NP}{120}$ N = $\frac{F\ 120}{P}$ P = $\frac{F\ 120}{N}$

F = frequency

N= speed of rotation

P = number of poles

120 = time constant

Power Factor

$PF = -\frac{\text{actual power}}{\text{apparent power}} = \frac{\text{watts}}{\text{volts x amperes}} = \frac{kW}{kVA} = \frac{R}{Z}$

Single-Phase Circuits

$kVA = \frac{EI}{1{,}000} = \frac{kW}{PF}$ $kW = kVA \times PF$

$I = \frac{P}{E \times PF}$ $E = \frac{P}{I \times PF}$ $PF = \frac{P}{E \times I}$

P = E x I x PF

Two-Phase Circuits

$I = \frac{P}{2 \times E \times PF}$ $E = \frac{P}{2 \times I \times PF}$ $PF = \frac{P}{E \times I}$

$kVA = \frac{2 \times E \times I}{1{,}000}$ $\frac{kW}{PF}$ $kW = kVA \times PF$

P = 2 x E x I x PF

Three-Phase Circuits, Balanced Wye

I phase = I line

$E_L = \sqrt{3}\, E_P = 1.73\, E_P$

$E_P = \frac{E_L}{\sqrt{3}} = 0.577\, E_L$

Three-Phase Circuits, Balanced Wye

E phase = E line

$I_L = \sqrt{3}\, I_P = 1.73\, I_P$

$I_P = \frac{I_L}{\sqrt{3}} = 0.577\, I_L$

Power: Three-Phase Balanced Wye or Delta Circuits

P = 1.732 x E x I x PF VA = 1.732 x E x I

$E = \frac{P}{PF \times 1.73 \times I} = \frac{0.577 \times P}{PF \times I}$

$I = \frac{P}{PF \times 1.73 \times E} = \frac{0.577 \times P}{PF \times E}$

$PF = \frac{P}{PF \times 1.73 \times E} = \frac{0.577 \times P}{I \times E}$

VA = apparent power (volt-amperes)

P = actual power (watts)

E = line voltage (volts)

I = line current (amperes)

WEIGHTS AND MEASURES

Dry Measure

2 cups = 1 quart (pt)

2 pints = 1 quart (pt)

4 quarts = 1 gallon (gal)

8 quarts = 1 peck (pk)

4 pecks = 1 bushel (bu)

Liquid Measure

3 teaspoons (tsp) = 1 tablespoon (tbsp)

16 tablespoons = 1 cup

2 cups = 1 pint

16 fluid ounces (oz) = 1 pint

2 pints = 1 quart

4 quarts = 1 gallon

31.5 gallons = 1 barrel (bbl)

231 cubic inches = 1 gallon

7.48 gallons = 1 cubic foot (cu ft)

Weight

16 ounces = 1 pound (lb)

2,000 pounds = 1 short ton

2,240 pounds = 1 long ton

Distance

12 inches = 1 foot (ft)

3 feet = 1 yard (yd)

5-1/2 yards = 1 rod (rd)

16-1/2 feet = 1 rod

1,760 yards = 1 statute mile (mi)

5,280 feet = 1 statute mile

Area

144 square inches = 1 square foot (sq ft)

9 square feet = 1 square yd (sq yd)

30- ¼ square yards = 1 square rod

160 square rods = 1 acre (A)

640 acres = 1 square mile (sq mi)

Volume

1,728 cubic inches = 1 cubic foot

27 cubic feet = 1 cubic yard (CU yd)

Counting Units

12 units = 1 dozen (doz)

12 dozen = 1 gross

144 units = 1 gross

24 sheets = 1 quire

480 sheets = 1 ream

Equivalents

1 cubic foot of water weighs 62.5 pounds (approx) = 1,000 ounces

1 gallon of water weighs 8-1/3 pounds (approx)

1 cubic foot = 7.48 gallons

1 inch = 2.54 centimeters

1 foot = 30.4801 centimeters

1 meter = 39.37 inches

1 liter = 1.05668 quarts (liquid) = 0.90808 quart (dry)

1 nautical mile = 6,080 feet (approx)

1 fathom = 6 feet

1 shot of chain = 15 fathoms

Feet	x.00019	= miles
Feet	x 1.5	= links
Yards	x .9144	= meters
Yards	x .0006	= miles
Links	x .22	= yards
Links	x .66	= feet
Rods	x 25	= links
Rods	x 16.5	= feet
Square inches	x .007	= square feet
Square inches	x 6.451	= square centimeters
Square centimeters	x 0.1550	= square inches
Square feet	x .111	= square yards
Square feet	x .0929	= centares (square meters)
Square feet	x 929	= square centimeters
Square feet	x 144	= square inches
Square yards	x .0002067	= acres
Acres	x 4840.0	= square yards
Square yards	x 1,296	= square inches
Square yards	x 9	= square feet
Square yards	x 0.8362	= centares
Square miles, statute	x 640	= acres
Square miles, statute	x 25,900	=ares
Square miles, statute	x 259	= hectares
Square miles, statute	x 2,590	= square kilometers
Cubic inches	x .00058	= cubic feet
Cubic feet	x .03704	= cubic yards
Tons (metric)	x 2,204.6	= pounds (avoirdupois)
Tons (metric)	x 1,000	= kilograms
Tons (short)	x 2,000	= pounds (avoirdupois)

Tons (short)	x 0.9072	= metric tons
Tons (long)	x 2,240	= pounds (avoirdupois)
Tons (long)	x 1.016	= metric tons
π	= 3.14592654	
1 radian	= 180°/ π = 57.2957790°	= approx. 57° 17' 44.8"
1 radian	= 1018.6 miles	
1 degree	= 0.0174533 radian	
1 minute	= 0.0002909 radian	
1 mil	= 0.0009817	
π radians	= 180°	
π /2 radians	= 90°	
Radius	= arc of 57.2957790°	
Arc of 1° (radius $=1$)	= .017453292	
Arc of $1'$(radius $=1$)	= .000290888	
Arc of $1'$ (radius $=1$)	= .000004848	
Area of sector of circle	= ½ Lr	(L= length of arc; r = radius)
Area of segment of parabola	= 2/3 cm	(c = chord; m = mid. ord.)
Area of segment of circle	= approx 2/3	
Arc – chord length	= 0.02 foot per 11 ½ miles	
Curvature of earth's surface	= approx. 0.667 foot per mile	

APPENDIX II

Hand Signals

Emergency Stop
Stop all motion as quickly as possible.

Stop

Kill Engine
Secure engine as prescribed

Manuever Forward Slowly
When manuevering in close quarters or to move a foot or two at a time.

Slow Down

Guide On Me
Hand open and palm facing inward.

Increase Speed

Raise Hoist Slowly
Hurry up and move out, double time, etc.

Lower Hoist Slowly

Raise Load

Lower Load

Raise Boom

Lower Boom

Raise Boom and Hold Load

Lower Boom and Hold Load

Lower Boom Slowly

Raise Boom Slowly

Lower Boom and Raise Load

Raise Boom and Lower Load

Swing In Direction Finger Points

Close Bucket

Open Bucket

Use Whip Line For Preceding Signals
(Auxilliary Hoist)
Tap elbow then use regular signals

Make Left Turn

Make Right Turn

Travel Both Tracks

Cut, Fill, or Drag Road
Point to road to be dragged or bladed, then rub palms together.
Applies to scrapers, motor graders, and bulldozers.

Raise a Little

Lower a Little

Dump Load Now
Start dumping and spreading load to proper depth if given.

Rehaul or Retract

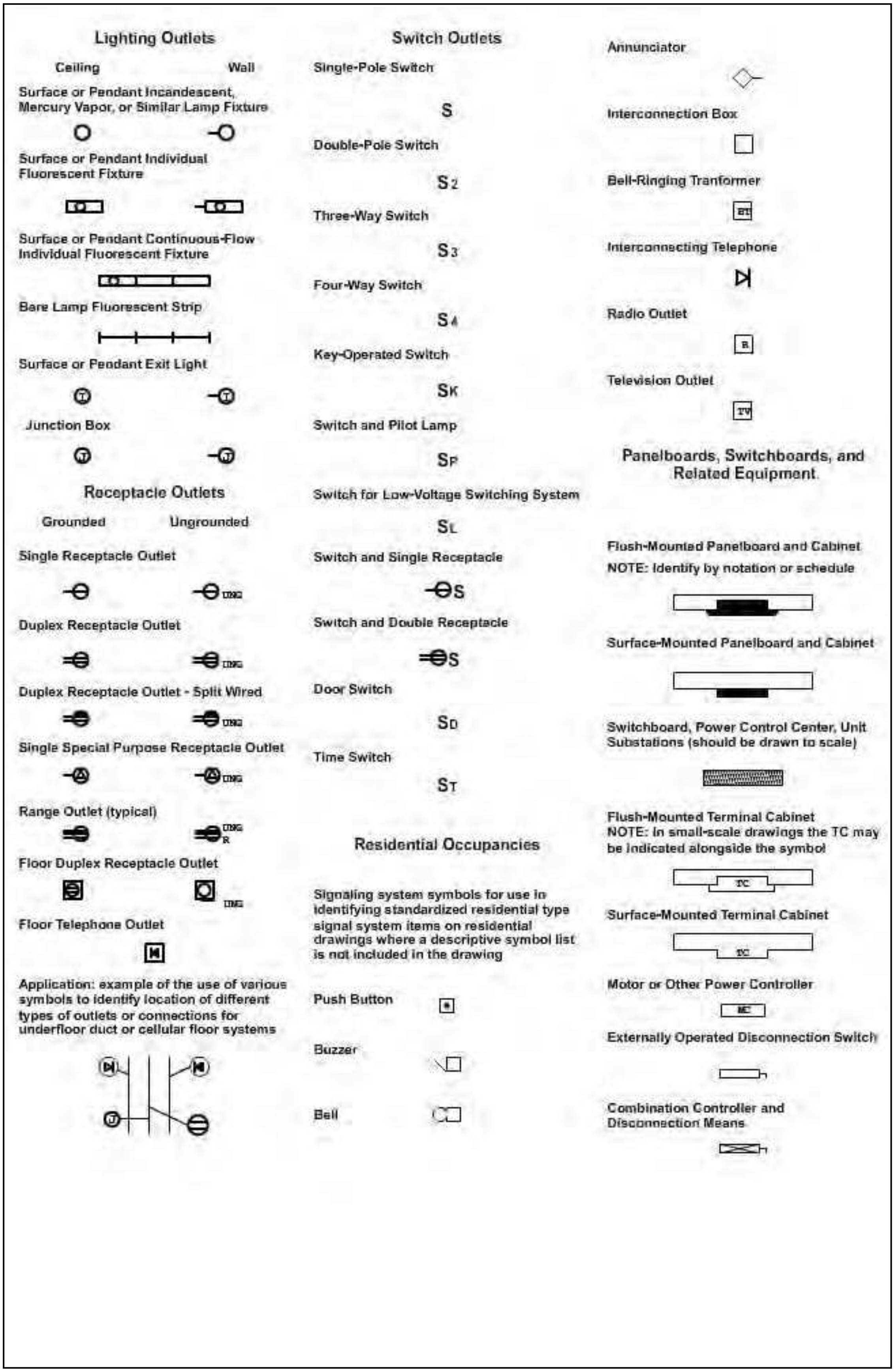
Crowd or Extend

Turn Right (Operator's Right)

Turn Left (Operator's Left)

APPENDIX III

Common Construction Symbology



Remote Control Stations for Motors or Other Equipment

Push-button Stations in General

Float Switch - Mechanical

F

Limit Switch - Mechanical

L

Pneumatic Switch - Mechanical

P

Electric Eye - Beam Source

Electric Eye - Relay

Thermostat

T

Circuiting

Wiring method identification by notation on drawing or in specifications.

Wiring Concealed in Ceiling or Wall

Note: Use heavy weight line to identify service and feed runs

Wiring Concealed in Floor

Wiring Exposed

Branch Circuit Home Run to Panelboard

Number of arrows indicates number of circuits. (A numeral at each arrow may be used to identify circuit number.)

2 1

NOTE: Any circuit without further identification indicates a 2-wire circuit. For a greater number of wires, indicate with cross lines.

Application:

3 wires;
4 wires; etc

Unless indicated otherwise, the wire size of the circuit is the minimum size required by the specification.
Indicate size in inches and identify different functions of wiring system, such as signaling, by notation or other means.

Wiring Turned Up

Wiring Turned Down

Manhole

M

Handhole

H

Transformer Pad

TP

Underground Direct Burial Cable

Indicate type, size, and number of conductors by notation or schedule.

Underground Duct Line

Indicate type, size, and number of ducts by cross section identification of each run by notation or schedule. Indicate type, size, and number of conductors by notation or schedule.

Streetlight Standard Fed from Underground Circuit

Electrical Distribution or Lighting Systems, Aerial

Pole

Pole, with Streetlight

Pole, with Down Guy and Anchor

Transformer

Transformer, Constant-Current

Switch, Manual

Circuit Recloser, Automatic

R

Circuit, Primary

Circuit, Secondary

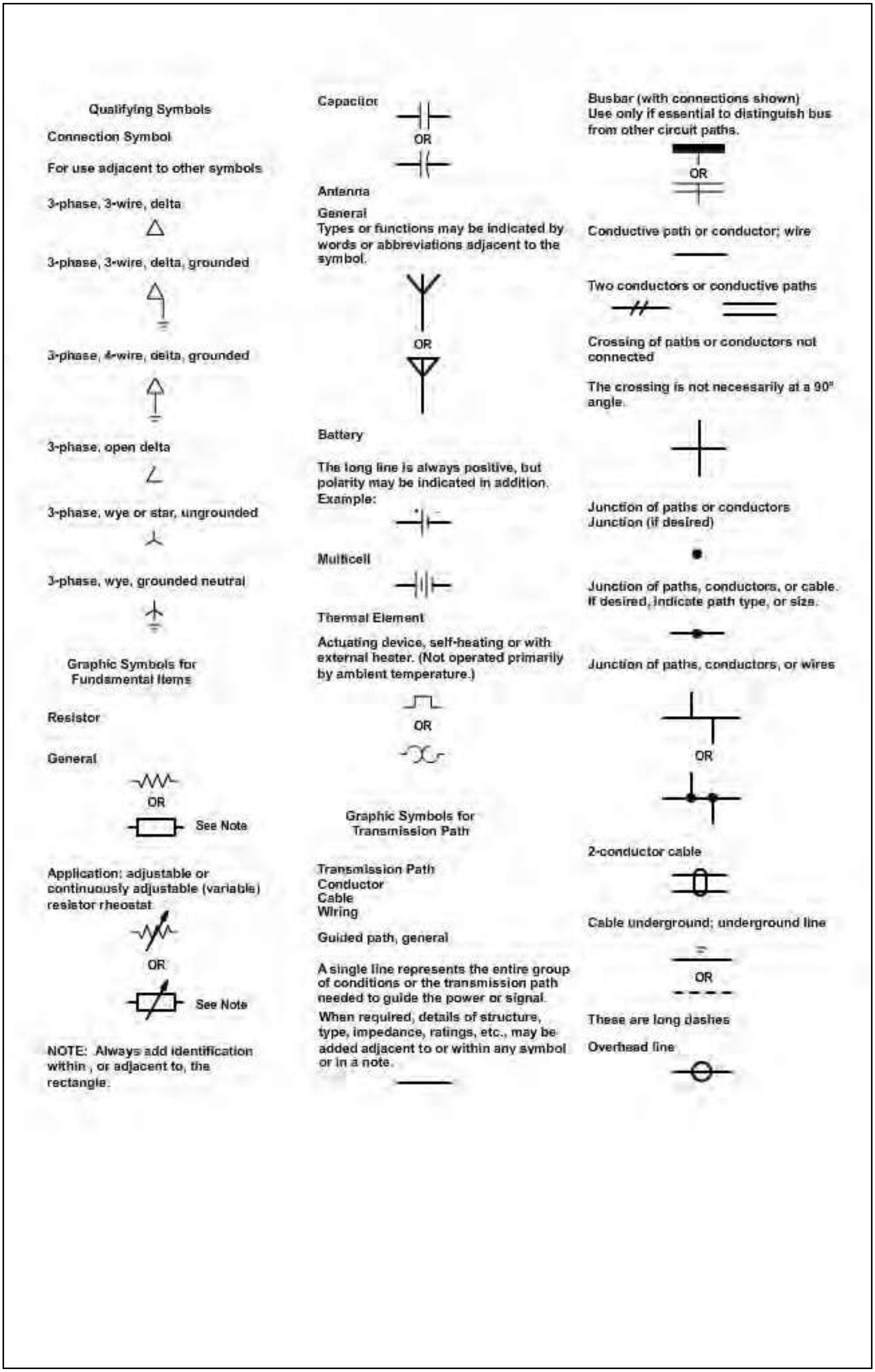
Circuit, Series Street Lighting

Down Guy

Head Guy

Sidewalk Guy

Service Weather Head


Qualifying Symbols
Connection Symbol
For use adjacent to other symbols
3-phase, 3-wire, delta
3-phase, 3-wire, delta, grounded
3-phase, 4-wire, delta, grounded
3-phase, open delta
3-phase, wye or star, ungrounded
3-phase, wye, grounded neutral
Graphic Symbols for Fundamental Items
Resistor
General
OR
See Note
Application: adjustable or continuously adjustable (variable) resistor rheostat
OR
See Note
NOTE: Always add identification within , or adjacent to, the rectangle.
Capacitor
OR
Antenna
General
Types or functions may be indicated by words or abbreviations adjacent to the symbol.
OR
Battery
The long line is always positive, but polarity may be indicated in addition. Example:
Multicell
Thermal Element
Actuating device, self-heating or with external heater. (Not operated primarily by ambient temperature.)
OR
Graphic Symbols for Transmission Path
Transmission Path
Conductor
Cable
Wiring
Guided path, general
A single line represents the entire group of conditions or the transmission path needed to guide the power or signal.
When required, details of structure, type, impedance, ratings, etc., may be added adjacent to or within any symbol or in a note.
Busbar (with connections shown)
Use only if essential to distinguish bus from other circuit paths.
OR
Conductive path or conductor; wire
Two conductors or conductive paths
Crossing of paths or conductors not connected
The crossing is not necessarily at a 90° angle.
Junction of paths or conductors
Junction (if desired)
Junction of paths, conductors, or cable. If desired, indicate path type, or size.
Junction of paths, conductors, or wires
OR
2-conductor cable
Cable underground; underground line
OR
These are long dashes
Overhead line

Circuit Return

Ground general symbol

NOTE: Supplementary information may be added to define the status or purpose of the earth if this is not readily apparent.

(1) A direct conducting connection to the earth or body of water that is a part therof.

(2) A conducting connect to a structure that serves a function similar to that of an earth ground (that is, a structure such as a frame of an air, space, or land vehicle that is not conductively connected to earth).

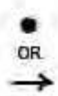
Chassis or frame connection, equivalent chassis connection (of printed-wiring boards)

A conducting connection to a chassis of frame (or equivalent chassis connection of a printed-wiring board) may be at substantial potential with respect to the earth or structure in which this chassis or frame (or printed-wiring board) is mounted.

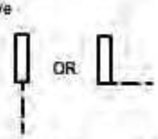
Graphic Symbols for Contacts, Switches, Contacts, and Relays

Electrical Contact

Fixed contact for jack, key, relay, switch, etc.



‡ Sleeve



‡ The broken line - - - indicates where line connection to a symbol is made and is not part of the symbol.

Moving Contact

Adjustable or sliding contact for resistor, inductor, etc.

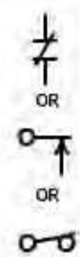
Locking

Nonlocking

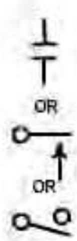
Basic Contact Assemblies

The standard method of showing a contact is by a symbol indicating the circuit condition it produces when the actuating device is in the de-energized or nonoperated position. The actuating device may be of a mechanical, electrical, or other nature, and a clarifying note may be necessary with the symbol to explain the proper point at which the contact functions; for example, the point where a contact closes or opens as a function of changing pressure, level, flow, voltage, current, etc. In cases where it is desirable to show contacts in the energized or operated condition and where confusion may result, a clarifying note shall be added to the drawing.

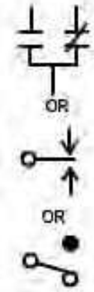
Closed contact (break)



Open contact (make)

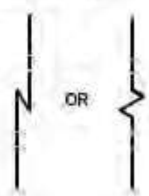


Transfer



Make-before-break

Magnetic Blowout Coil



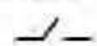
Operating Coil

Relay Coil

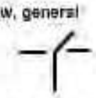
Switch

Fundamental symbols for contacts, mechanical connections, etc, may be used for switch symbols.

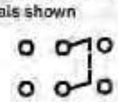
Single-throw, general



Double-throw, general



2-pole double-throw switch with terminals shown

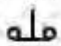


NOTE: The asterisk is not part of the symbol. Always replace the asterisk by a device designation.

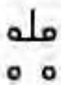
Push button, Momentary or Spring-Return

Circuit closing (make)

Circuit opening (break)



Two-circuit



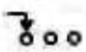
Selector or Multiposition Switch

The position in which the switch is shown may be indicated by a note or designation of switch position.

General (for power and control diagrams)

Any number of transmission paths may be shown.

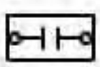
OR



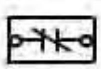
Limit Switch
Sensitive Switch

NOTE: Identity by LS or other suitable note.

Track-type, circuit-closing contact



Track-type, circuit-opening contact



Flow-Actuated Switch

Closes on increase in flow

Opens on increase in flow

Liquid-Level-Actuated Switch

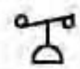
Closes on rising level

Opens on rising level

Pressure-or Vacuum-Actuated Switch

Closes on rising pressure

Opens on rising pressure



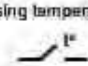
Temperature-Actuated Switch

Closes on rising temperature

Opens on rising temperature

Thermostat

Closes on rising temperature



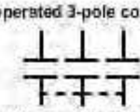
* See Note

Contactor

See also CIRCUIT BREAKER

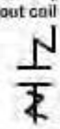
Fundamental symbols for contacts, coils, mechanical connections, etc. are the basis of contactor symbols and should be used to represent contactors on complete diagrams. Complete diagrams of contactors consist of combinations of fundamental symbols for control coils, mechanical connections, etc. in such configurations as to represent the actual device. Mechanical interlocking should be indicated by notes.

Manually operated 3-pole contactor

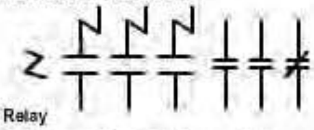


NOTE: The t° symbol shall be shown or be replaced by data giving the nominal or specific operating temperature of the device.

Electrically operated 1-pole contactor with series blowout coil



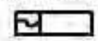
Electrically operated 3-pole contactor with series blowout coils; 2 open and 1 closed auxiliary contacts (shown smaller than the main contacts)



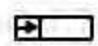
Relay

Fundamental symbols for contacts, mechanical connections, coils, etc. are the basis of relays on complete diagrams.

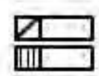
The following letter combinations or symbol elements may be used with relay symbols. The requisite number of these letters or symbol elements may be used to show what special features a relay possesses.



- AC Alternating-current or ringing relay
- D Differential
- DB Double-biased (biased in both directions)
- DP Dashpot
- EP Electrically polarized
- FO Fast-operate
- FR Fast-release
- L Latching
- MG Marginal
- ML Magnetic-latching (remanent)
- NB No bias
- NR Nonreactive



- P Magnetically polarized using biasing spring, or having magnet bias
- SA Slow-operate and slow-release

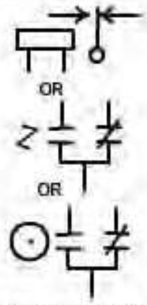


- SO Slow-operate
- SR Slow-release
- SW Sandwich-wound to improve balance to longitudinal currents

The proper poling for a polarized relay shall be shown by the use of + and - designations applied to the winding leads. The interpretation of this shall be that a voltage applied with the polarity as indicated shall cause the armature to move toward the contact shown nearer the coil on the diagram. If the relay is equipped with numbered terminals, the proper terminal numbers shall also be shown.

Basic

Relay with transfer contacts



Graphic Symbols for Terminals and Connectors

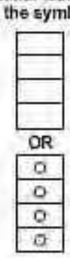
Terminals

Circuit terminal

Terminal board or terminal strip, with 4 terminals shown; group of 4 terminals

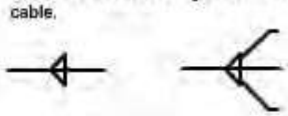
Number and arrangement as convenient.

NOTE: Internal lines and terminals may be omitted if terminal identifications are shown within the symbol.



Cable Termination

Line shown on left of symbol indicates cable.



Connector
Disconnecting Device
Jack
Plug

The contact symbol is not an arrowhead. It is larger and the lines are drawn at a 90-degree angle.

Female contact 

Male contact 

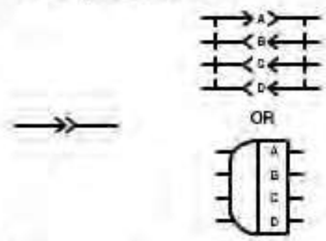
Receptacle or jack (usually stationary)

NOTE: The asterisk is not part of the symbol. If desired, indicate the type of contacts: male (⟶) or female (—<).

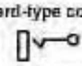
Plug (usually movable) OR

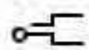
Separable connectors (engaged)

Engaged 4-conductor connectors; the plug has 1 male and 3 female contacts with individual contact designations shown in the complete-symbol column



Communication switchboard-type connector

2-conductor (jack) 

2-conductor (plug) 

Graphic Symbols for Transformers, Inductors, and Windings

Core

General or air core

If it is necessary to identify an air core, a note should appear adjacent to the symbol of the inductor or transformer

NO SYMBOL

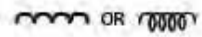
Magnetic core of inductor or transformer

Not to be used unless it is necessary to identify a magnetic core.

Inductor
Winding (machine or transformer)
Reactor
Radio-Frequency Coil
Telephone Retardation Coil

See also OPERATING COIL

General



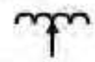
Magnetic-core inductor

Telephone loading coil

If necessary to show a magnetic core

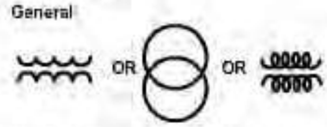
Tapped 

Adjustable inductor



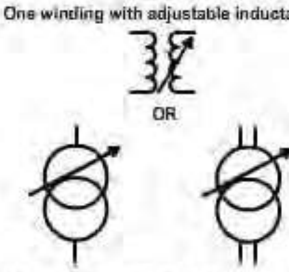
Transformer

General

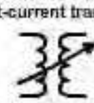


Shielded transformer with magnetic core shown

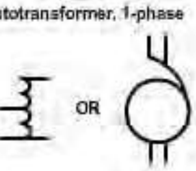
One winding with adjustable inductance

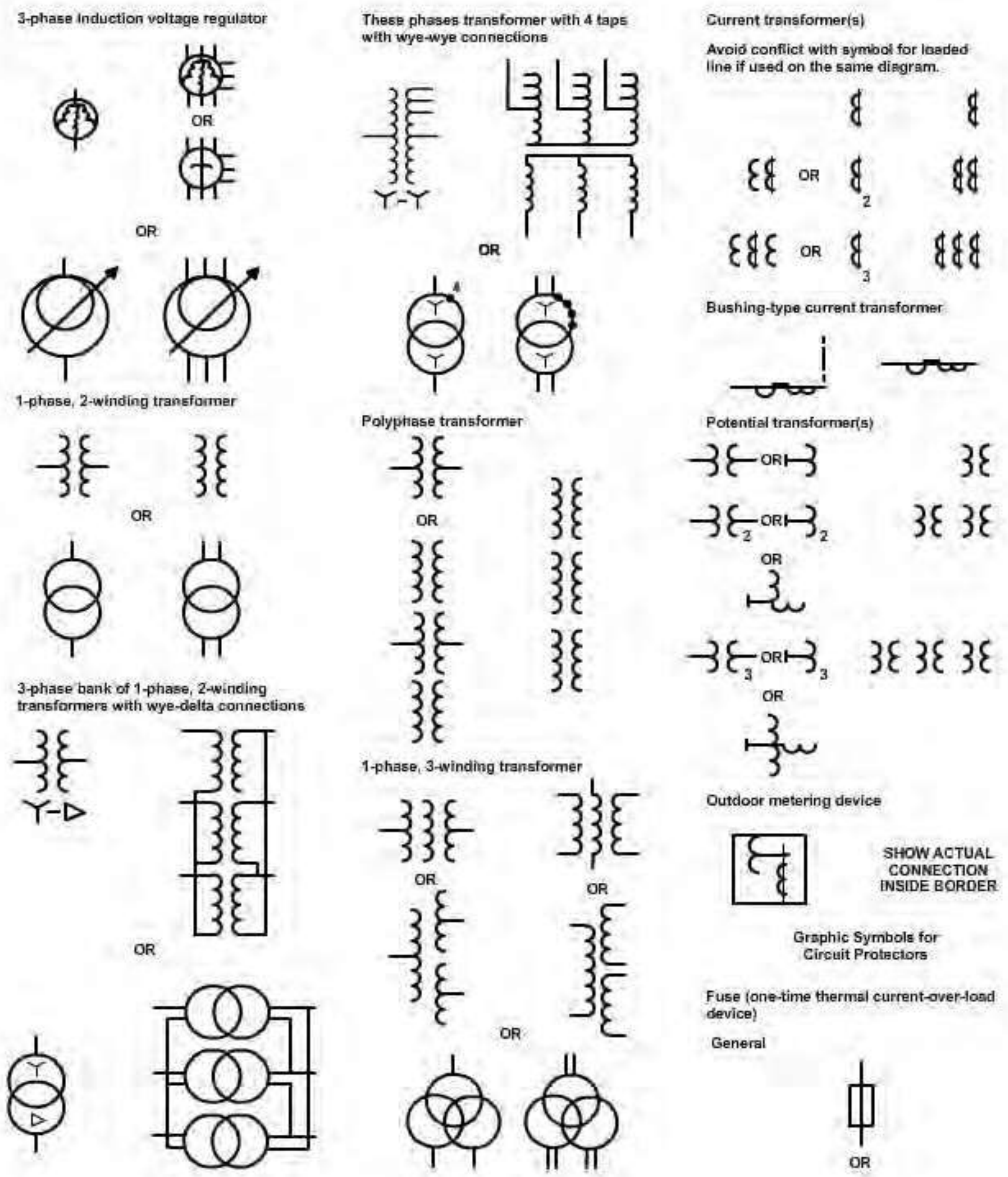


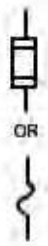
Adjustable mutual inductor; constant-current transformer



Autotransformer, 1-phase

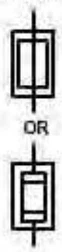



3-phase induction voltage regulator
OR
OR
These phases transformer with 4 taps with wye-wye connections
OR
Current transformer(s)
Avoid conflict with symbol for loaded line if used on the same diagram.
OR
2
OR
3
Bushing-type current transformer
1-phase, 2-winding transformer
OR
Polyphase transformer
OR
Potential transformer(s)
OR
2
OR
2
OR
OR
3
OR
3
OR
3-phase bank of 1-phase, 2-winding transformers with wye-delta connections
1-phase, 3-winding transformer
OR
OR
Outdoor metering device
SHOW ACTUAL CONNECTION INSIDE BORDER
OR
Graphic Symbols for Circuit Protectors
Fuse (one-time thermal current-over-load device)
General
OR
OR



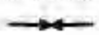
Isolating fuse-switch: high-voltage primary fuse cutout, dry

High-voltage primary fuse cutout, oil



Current Limiter (for power cable)

The arrowheads in this case are filled.

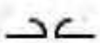


Lightning Arrester
Arrester (electric surge, etc)
Gap

General

Carbon block; telephone protector block

Horn gap



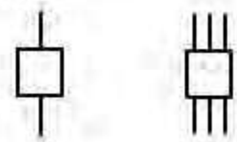
Circuit Breaker

Air circuit breaker, if distinction is needed; for alternating-current circuit breakers rated at 1,500 bolts or less and for all direct-current circuit breakers

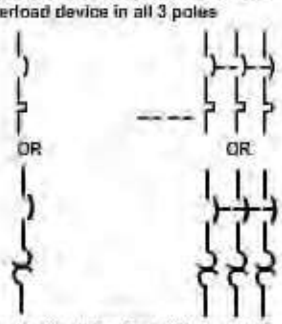
Network protector

Circuit breaker, other than covered by the above symbol

The symbol in the right column is for a 3-pole breaker.

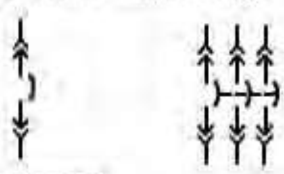


3-pole circuit breaker with thermal-overload device in all 3 poles



3-pole circuit breaker with magnetic-overload device in all 3 poles

3-pole circuit breaker, drawout type



Protective Relay

Fundamental symbols for contacts, coils, mechanical connections, etc, are the basis or relay symbols and should be used to represent relays on complete diagrams.

See RELAY COIL; OPERATING COIL and RELAY

Graphic Symbols for
Acoustic Devices

Audible-Signaling Device

Bell, electrical; telephone ringer

NOTE: If specific identification is required, the abbreviation AC or DC may be added within or adjacent to the symbol.

Single-stroke

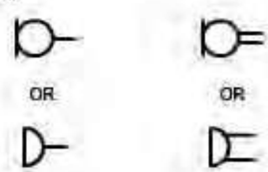
Buzzer

Loudspeaker
Horn, Electrical
Sirem

General

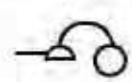
Microphone
Telephone Transmitter

General



Handset
Operator's Set

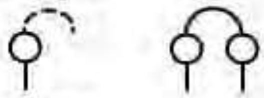
General



Telephone Receiver
Earphone

General

Headset, double

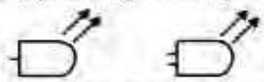


Headset, single

Graphic Symbols for Lamps and Visual-Signaling Devices

Lamp

Lamp, general; light source, general



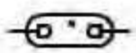
NOTE: This symbol may be used to represent one or more lamps with or without operating auxiliaries.

NOTE: If it is essential to indicate the following characteristics, the specified letter or letters may be inserted within or placed adjacent to the symbol.

A	Amber
B	Blue
C	Clear
G	Green
O	Orange
OP	Opalescent
P	Purple
R	Red
W	White
Y	Yellow
ARC	Arc
EL	Electroluminescent
FL	Fluorescent
HG	Mercury vapor
IN	Incandescent
IR	Infrared
NA	Sodium vapor
NE	Neon
UV	Ultraviolet
XE	Xenon
LED	Light-emitting diode

Fluorescent lamp

2-terminal



4-terminal

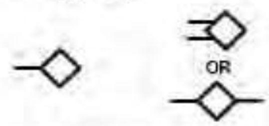
Incandescent lamp (incandescent-filament illuminating lamp

Ballast lamp; ballast tube

The primary characteristic of the element within the circle is designed to vary non-linearity with the temperature of the element.

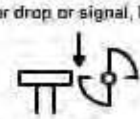
Visual-Signaling Device

Annunciator (general)

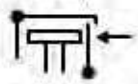


Annunciator drop or signal, shutter or grid type

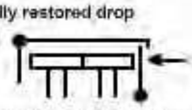
Annunciator drop or signal, ball type



Manually restored drop



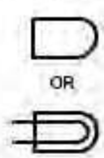
Electrically restored drop

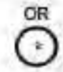


Communication switchgoard-type lamp; indicating lamp

Indicating, pilot, signaling, or switch-board light; indicator light signal light

If confusion with other circular symbols may occur, the D-shape symbol should be used.





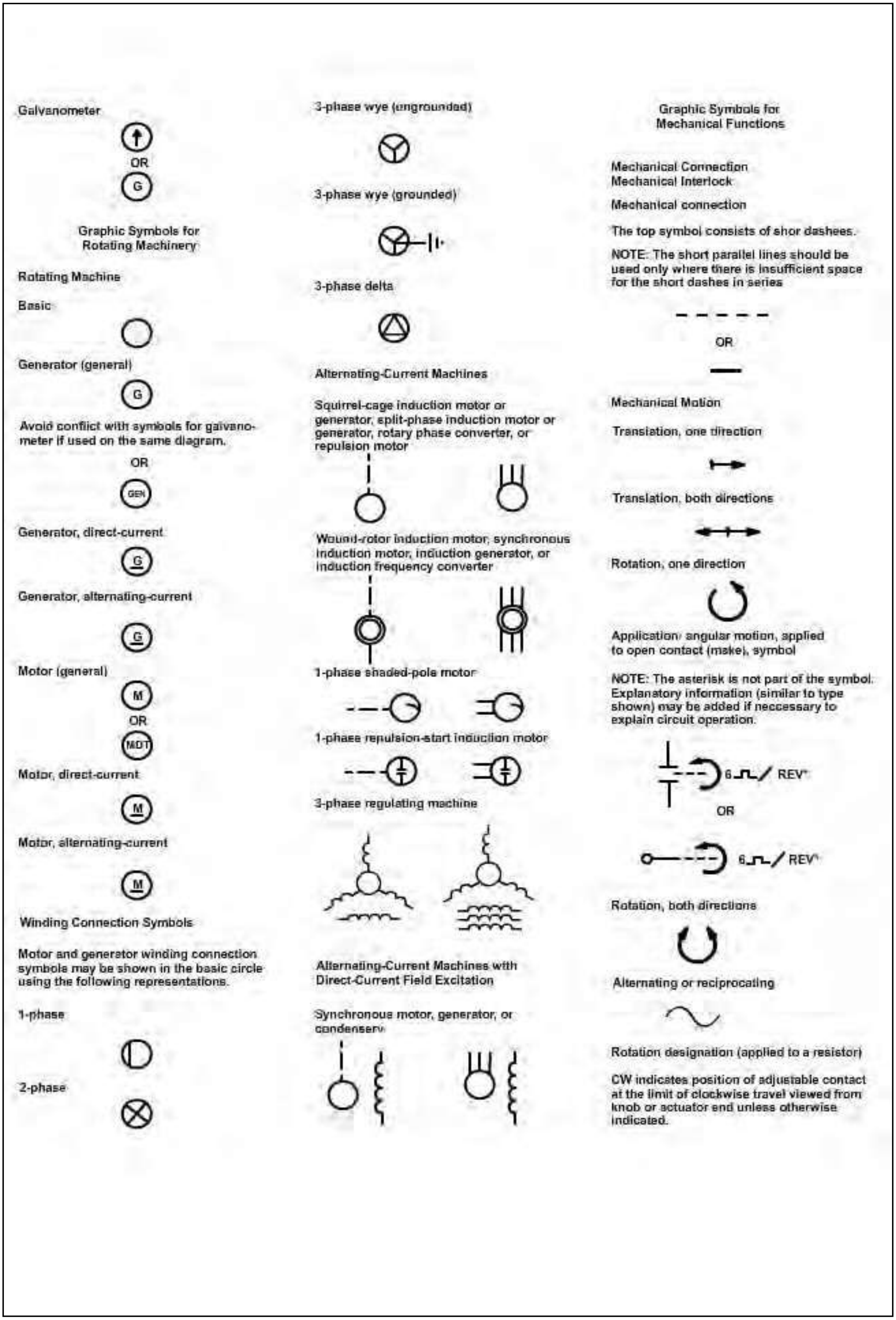
Jeweled signal light

Graphic Symbols for Readout Devices

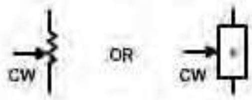
Meter Instrument

NOTE: The asterisk is not part of the symbol. Always replace the asterisk by one of the following letter combinations, depending on the function of the meter or instrument, unless some other identification is provided in the circle and explained on the diagram.

A	Ammeter
AH	Ampere-hour meter
C	Coulombmeter
CMA	Contact-making (or breaking) ammeter
CMC	Contact-making (orbreaking) clock
CMV	Contact-making (or breaking) voltmeter
CRO	Oscilloscope Cathode-ray oscillograph
DB	DB (decibel) meter Audio level/meter
DBM	DBM (decibels referred to 1 milliwatt) meter
DM	Demand meter
DTR	Demand-totalizing relay
F	Frequency meter
GD	Ground detector
I	Indicating meter
μ A or UA	Microammeter
MA	Milliammeter
NM	Noise Meter
OHM	Ohmmeter
OP	Oil pressure meter
OSCG	Oscillograph
PF	Power factor meter
PH	Phasemeter
PI	Position indicator
RD	Recording demand meter
REC	Recording meter
RF	Reactive factor meter
SY	Synchroscope
t°	Temperature meter
THC	Thermal converter
TLM	Telemeter
TT	Total time meter Elapsed time meter
V	Voltmeter
VA	Volt-ammeter
VAR	Varmeter
VARH	Varhour meter
VI	Volume indicator Audio-level meter
VU	Standard volume indicator Audio-level meter
W	Wattmeter
WH	Watthour meterv


Galvanometer
OR
G
Graphic Symbols for Rotating Machinery
Rotating Machine
Basic
Generator (general)
G
Avoid conflict with symbols for galvanometer if used on the same diagram.
OR
GEN
Generator, direct-current
G
Generator, alternating-current
G
Motor (general)
M
OR
MOT
Motor, direct-current
M
Motor, alternating-current
M
Winding Connection Symbols
Motor and generator winding connection symbols may be shown in the basic circle using the following representations.
1-phase
2-phase
3-phase wye (ungrounded)
3-phase wye (grounded)
3-phase delta
Alternating-Current Machines
Squirrel-cage induction motor or generator, split-phase induction motor or generator, rotary phase converter, or repulsion motor
Wound-rotor induction motor, synchronous induction motor, induction generator, or induction frequency converter
1-phase shaded-pole motor
1-phase repulsion-start induction motor
3-phase regulating machine
Alternating-Current Machines with Direct-Current Field Excitation
Synchronous motor, generator, or condenser
Graphic Symbols for Mechanical Functions
Mechanical Connection
Mechanical Interlock
Mechanical connection
The top symbol consists of shor dashees.
NOTE: The short parallel lines should be used only where there is insufficient space for the short dashes in series
OR
Mechanical Motion
Translation, one direction
Translation, both directions
Rotation, one direction
Application angular motion, applied to open contact (make), symbol
NOTE: The asterisk is not part of the symbol. Explanatory information (similar to type shown) may be added if neccessary to explain circuit operation.
6 REV*
OR
6 REV*
Rotation, both directions
Alternating or reciprocating
Rotation designation (applied to a resistor)
CW indicates position of adjustable contact at the limit of clockwise travel viewed from knob or actuator end unless otherwise indicated.

NOTE: The asterisk is not part of the symbol. Always add identification within or adjacent to the rectangle.



Manual Control

General

Operated by pushing

Operated by pushing and pulling (pudh-pull)

Graphic Symbols for Composite Assemblies

Circuit Assembly
Circuit Subassembly
Circuit Element

NOTE: The asterisk is not part of the symbol. Always indicate the type of apparatus by appropriate words or letters.

NOTE: The use of a general circuit-element symbol is restricted to the following:

a. Diagrams drawn in block form.
b. A substitute for complex circuit elements when the internal operation of the circuit element is not important of the purpose of the diagram.

General

Accepted abbreviations from ANSI Z32.13-1950 may be used in the rectangle.

The following letter combinations may be used in the rectangle:

CLK	Clock
EQ	Equalizer
FAX	Facsimile set
FL	Filter
IND	Indicator
PS	Power supply
RG	Recording unit
RU	Reproducing unit
DIAL	Telephone dial
TEL	Telephone station
TPR	Teleprinter
TTY	Teletypewriter

Amplifier

General

The triangle is pointed in the direction of transmission.

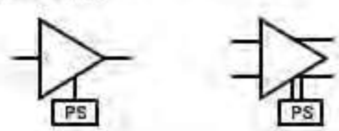
The symbol represents any method of amplification (electron tube, solid-state device, magnetic device, etc).

NOTE: If identification, electrical values, location data, and similar information must be noted within symbol, the size or aspect ratio of the original symbol may be altered providing its distinctive shape is retained.

Amplifier use may be indicated in the triangle by words, standard abbreviations, or a letter combination from the following list:

BOG	Bridging
BST	Booster
CMP	Compression
EXP	Direct-current
LIM	Limiting
MON	Monitoring
PGM	Program
PRE	Preliminary
PWR	Power
TRQ	Torque

Application: amplifier with associated power supply

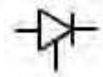


General

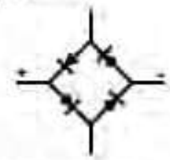
NOTE: Triangle points in direction of forward (easy) current as indicated by a direct-current ammeter, unless otherwise noted adjacent to the symbol. Electron flow is in the opposite direction.

NOTE: This symbol represents any method of rectification (electron tube, solid-state device, electrochemical device, etc).

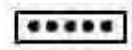
Controlled



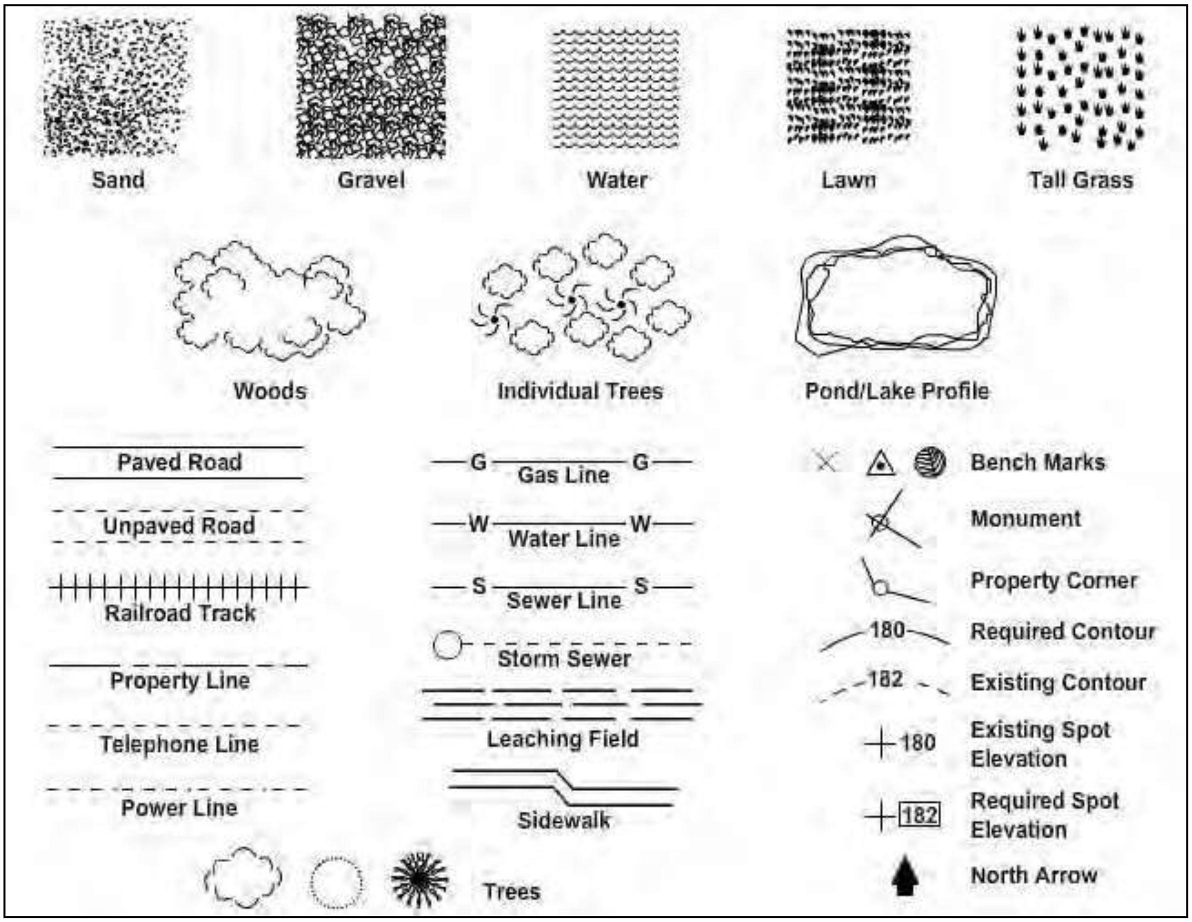
Bridge-type rectifier



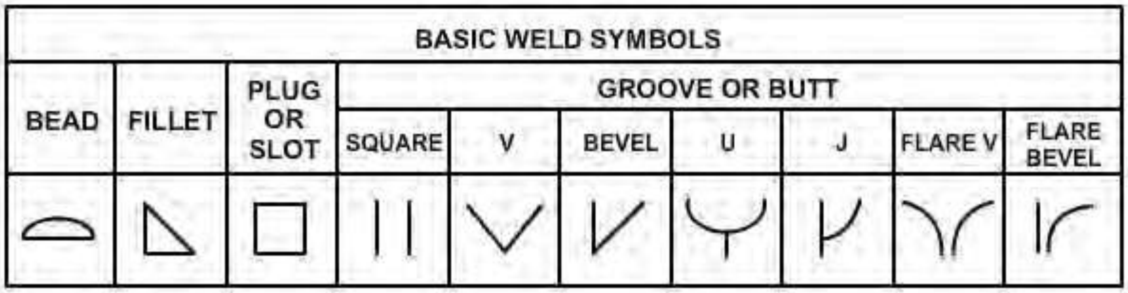
On connection or wiring diagrams, rectifier may be shown with terminals and plarity marking. Heavy line may be used to indicate nameplate or positive-polarity end.

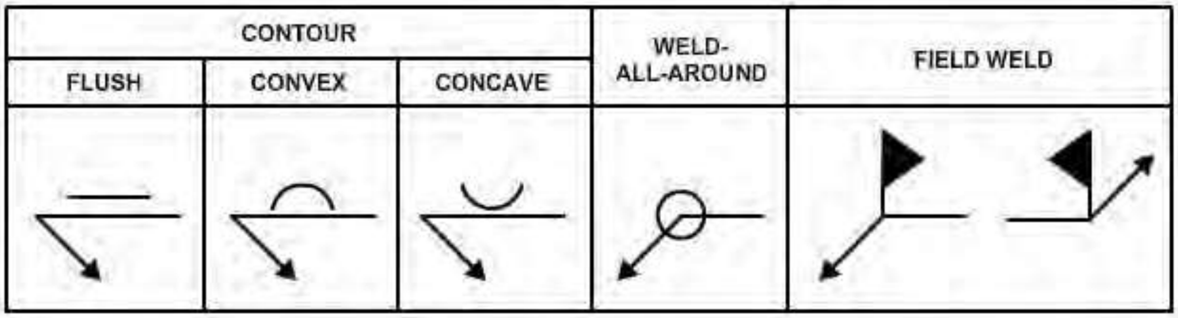


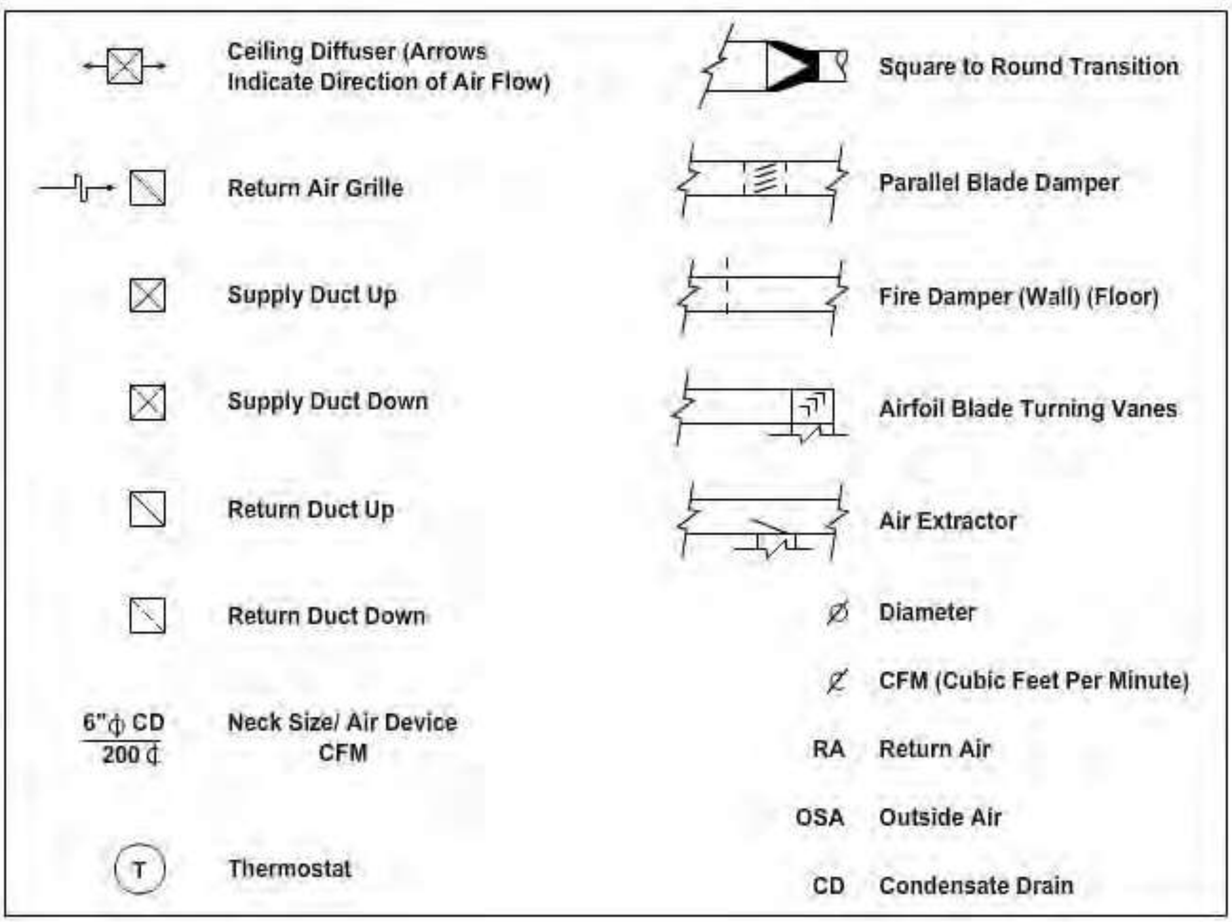
For connection or wiring diagram

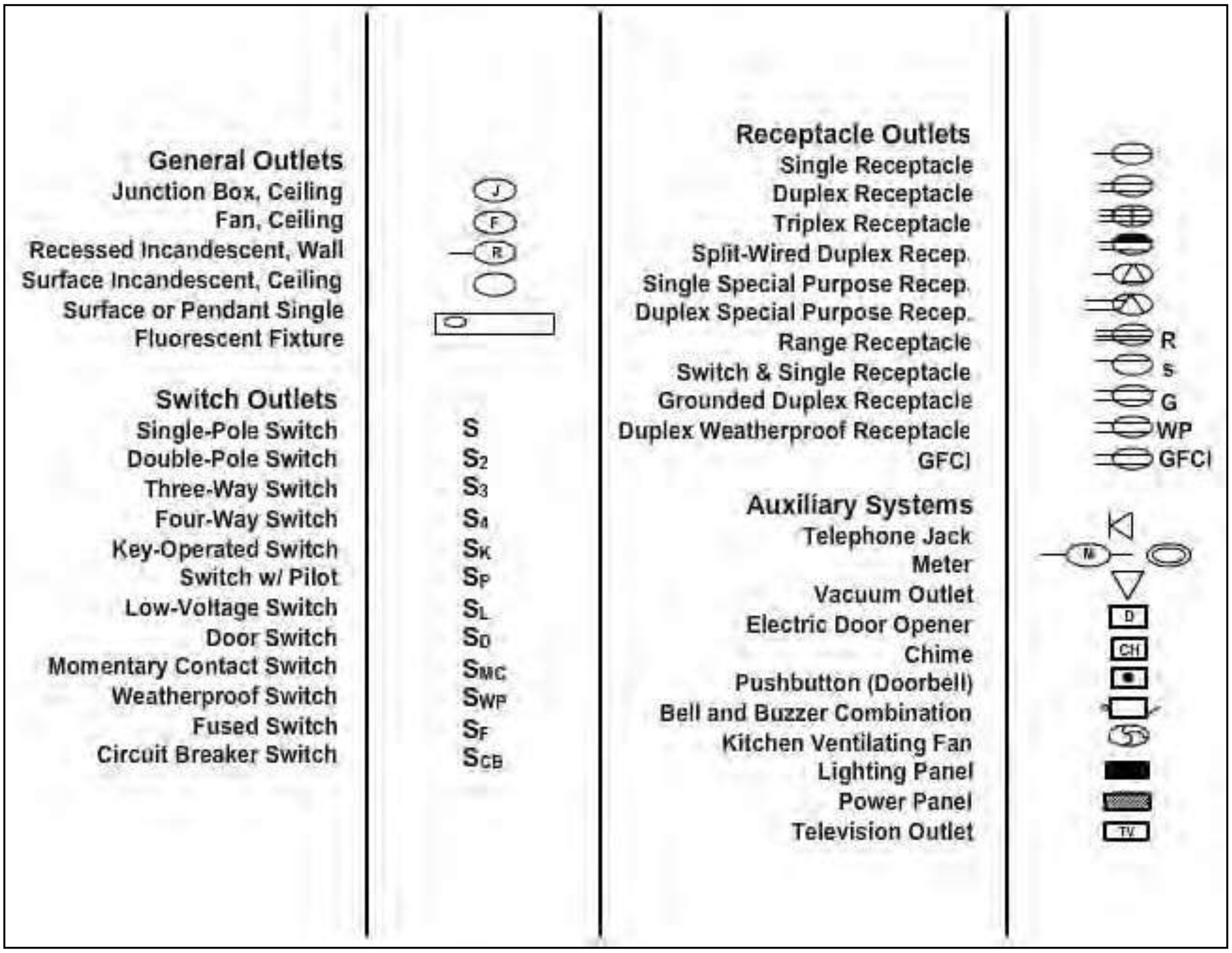


Description	Example	Symbol	Illustrated Use
W- Shape (Wide Flange)		W	W24 x 78
Bearing Pile		BP	BP14 x 73
S-Shape (American STD I-Beam)		S	S15 x 42.9
C-Shape (American STD Channel)		C	C9 x 13.4
M-Shape (Misc Shapes Other Than W, BP, S, & C)		M	M5 x 34.3 M5 x 17 M7 x 5.5
MC-Shape (Channels Other Than American STD)		MC	MC12 x 45 MC 12 x 12.8
Angles:			3x 3x
Equal Leg		L	L 3x 3x 1/4
Un-equal Leg		L	L 7x 4x 1/2
Tees, Structural: Cut From W-Shape		WT	WT 12x38
Cut From S-Shape		ST	ST 12x38
Cut From M-Shape		MT	MT 12x38
Plate		PL	PL 1/2x18"x30"
Flat Bar		BAR	BAR 2 1/2 x 1/4
Pipe, Structural			Pipe 4 STD Pipe 4x-STRG Pipe XX-STRG

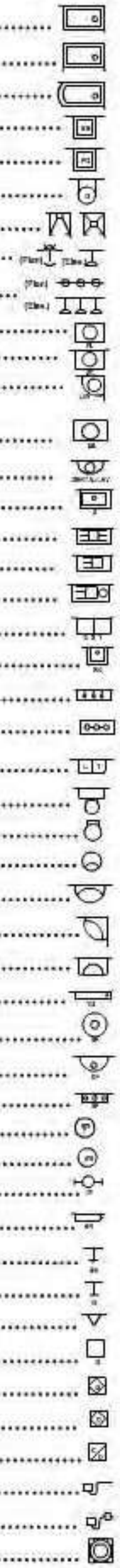

BASIC WELD SYMBOLS
BEAD
FILLET
PLUG OR SLOT
GROOVE OR BUTT
SQUARE
V
BEVEL
U
J
FLARE V
FLARE BEVEL


CONTOUR
FLUSH
CONVEX
CONCAVE
WELD-ALL-AROUND
FIELD WELD


Ceiling Diffuser (Arrows Indicate Direction of Air Flow)
Return Air Grille
Supply Duct Up
Supply Duct Down
Return Duct Up
Return Duct Down
6"ϕ CD
200 ¢
Neck Size/ Air Device CFM
T
Thermostat
Square to Round Transition
Parallel Blade Damper
Fire Damper (Wall) (Floor)
Airfoil Blade Turning Vanes
Air Extractor
Ø Diameter
¢ CFM (Cubic Feet Per Minute)
RA Return Air
OSA Outside Air
CD Condensate Drain

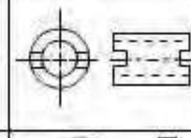
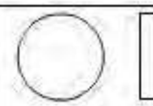
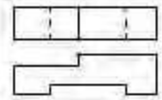
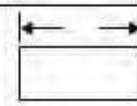
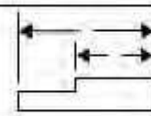
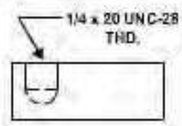
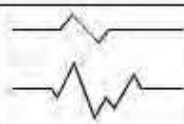
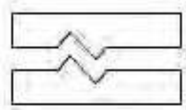
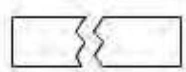
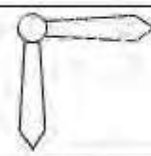
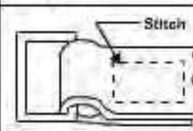
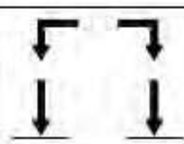
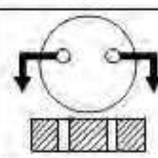
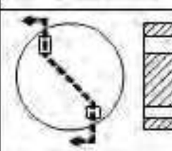

General Outlets
Junction Box, Ceiling
Fan, Ceiling
Recessed Incandescent, Wall
Surface Incandescent, Ceiling
Surface or Pendant Single
Fluorescent Fixture
J
F
R
Switch Outlets
Single-Pole Switch
Double-Pole Switch
Three-Way Switch
Four-Way Switch
Key-Operated Switch
Switch w/ Pilot
Low-Voltage Switch
Door Switch
Momentary Contact Switch
Weatherproof Switch
Fused Switch
Circuit Breaker Switch
S
S2
S3
S4
SK
SP
SL
SD
SMC
SWP
SF
SCB
Receptacle Outlets
Single Receptacle
Duplex Receptacle
Triplex Receptacle
Split-Wired Duplex Recep.
Single Special Purpose Recep.
Duplex Special Purpose Recep.
Range Receptacle
Switch & Single Receptacle
Grounded Duplex Receptacle
Duplex Weatherproof Receptacle
GFCI
R
S
G
WP
GFCI
Auxiliary Systems
Telephone Jack
Meter
Vacuum Outlet
Electric Door Opener
Chime
Pushbutton (Doorbell)
Bell and Buzzer Combination
Kitchen Ventilating Fan
Lighting Panel
Power Panel
Television Outlet
M
D
CH
TV

Plumbing



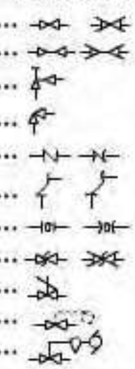
Corner Bath	
Recessed Bath	
Roll Rim Bath	
Sitz Bath	
Floor Bath	
Bidet	
Shower Stall	
Shower Head	
Overhead Gang Shower	
Pedestal Lavatory	
Wall Lavatory	
Corner Lavatory	
Manicure Lavatory	
Medical Lavatory	
Dental Lavatory	
Plain Kitchen Sink	
Kitchen Sink, R & L Drain Board	
Kitchen Sink, L H Drain Board	
Combination Sink and Dishwasher	
Combination Sink & Laundry Tray	
Service Sink	
Wash Sink (Wall Type)	
Wash Sink	
Laundry Tray	
Water Closet (Low Tank)	
Water Closet (No Tank)	
Urinal (Pedestal Type)	
Urinal (Wall Type)	
Urinal (Corner Type)	
Urinal (Stall Type)	
Urinal (Trough Type)	
Drinking Fountain (Pedestal Type)	
Drinking Fountain (Wall Type)	
Drinking Fountain (Trough Type)	
Hot Water Tank	
Water Heater	
Meter	
Hose Rack	
Hose Bibb	
Gas Outlet	
Vacuum Outlet	
Drain	
Grease Separator	
Oil Separator	
Cleanout	
Garage Drain	
Floor Drain With Backwater Valve	
Roof Sump	

LINE STANDARDS

Name	Convention	Description and Application	Example
Center Lines		Thin lines made up of long and short dashes alternately spaced and consistent in length. Used to indicate symmetry about an axis and location of centers.	
Visible Lines		Heavy unbroken lines Used to indicate visible edges of an object	
Hidden Lines		Medium lines with short evenly spaced dashes Used to indicate concealed edges	
Extension Lines		Thin unbroken lines Used to indicate extent of dimensions	
Dimension Lines		Thin lines terminated with arrow heads at each end Used to indicate distance measured	
Leader		Thin line terminated with arrowhead or dot at one end Used to indicate a part, dimension or other reference	
Break (Long)		Thin, solid ruled lines with freehand zigzags Used to reduce size of drawing required to delineate object and reduce detail	
Break (Short)		Thick, solid free hand lines Used to indicate a short break	
Phantom or Datum Line		Medium series of one long dash and two short dases evenly spaced ending with long dash Used to indicate alternate position of parts, repeated detail or to indicate a datum plane	
Stitch Line		Medium line of short dases evenly spaced and labeled Used to indicate stitching or sewing	
Cutting or Viewing Plane Viewing Plane Optional		Thick solid lines with arrowhead to indicate direction in which section or plane is viewed or taken	
Cutting Plane for Complex or Offset Views		Thick short dashes Used to show offset with arrowheads to show direction viewed	

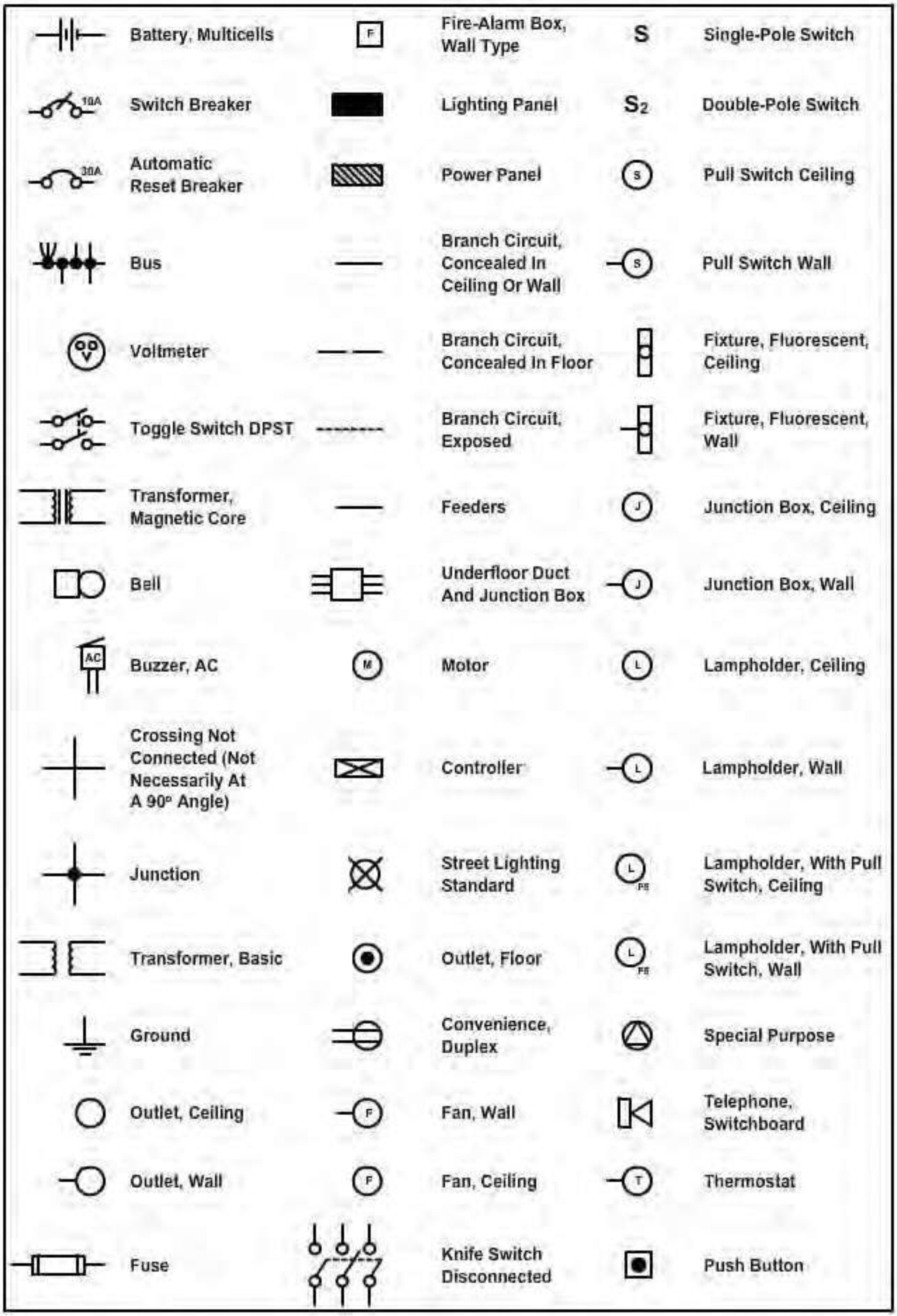
Valves

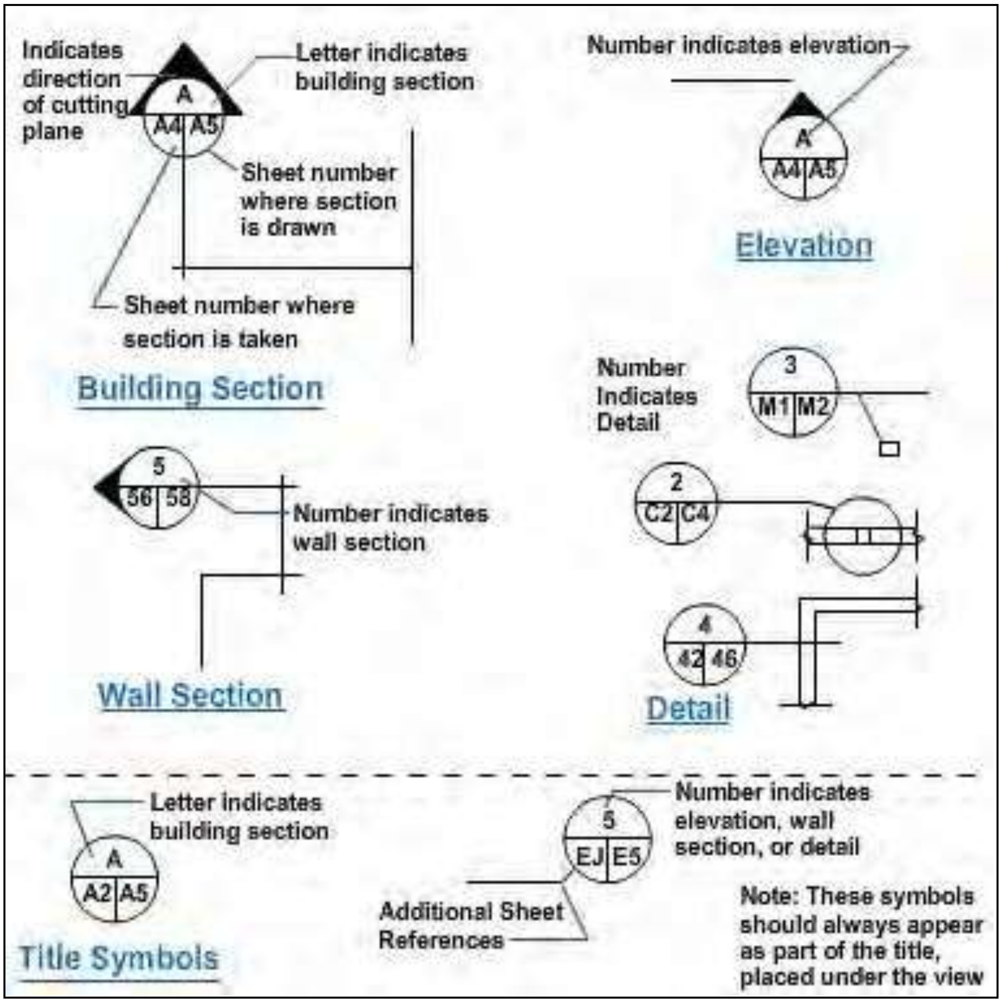
	Screwed	Soldered
Gate Valve		
Globe Valve		
Angle Glove Valve		
Angle Gate Valve		
Check Valve		
Angle Check Valve		
Stop Cock		
Safety Valve		
Quick Opening Valve		
Float Opening Valve		
Motor Operated Gate Valve		

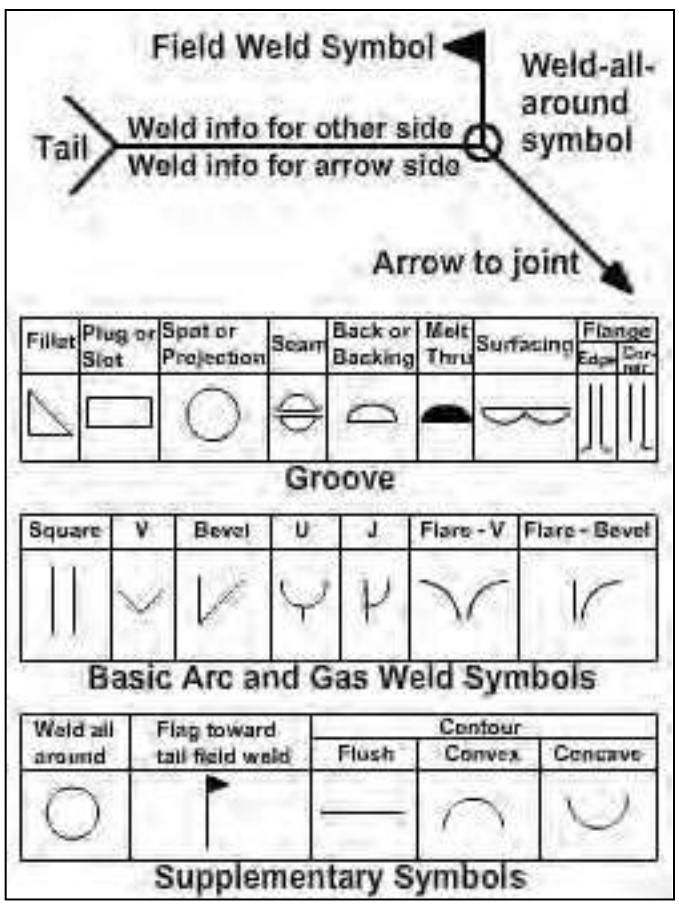


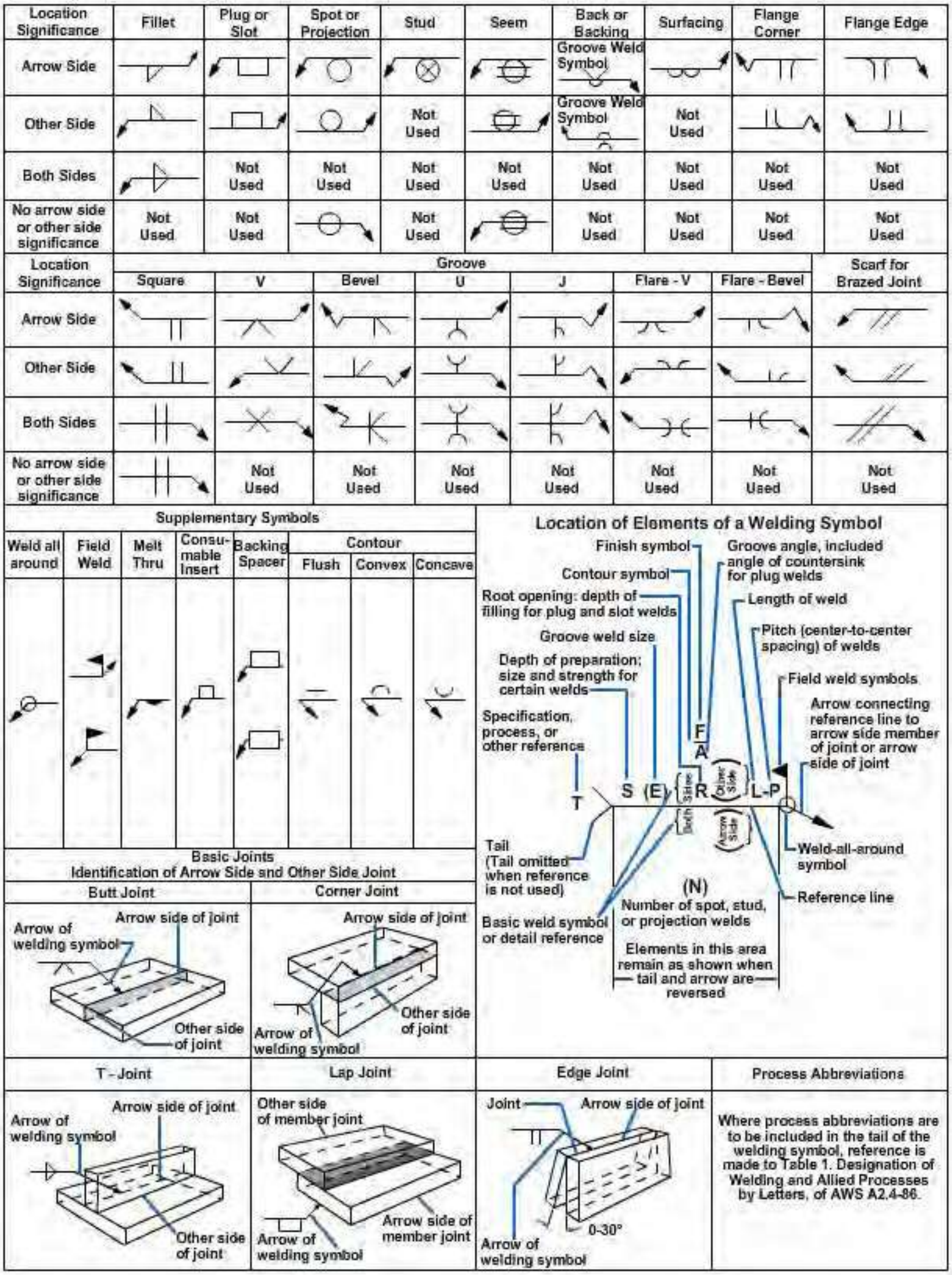
Pipe Fittings

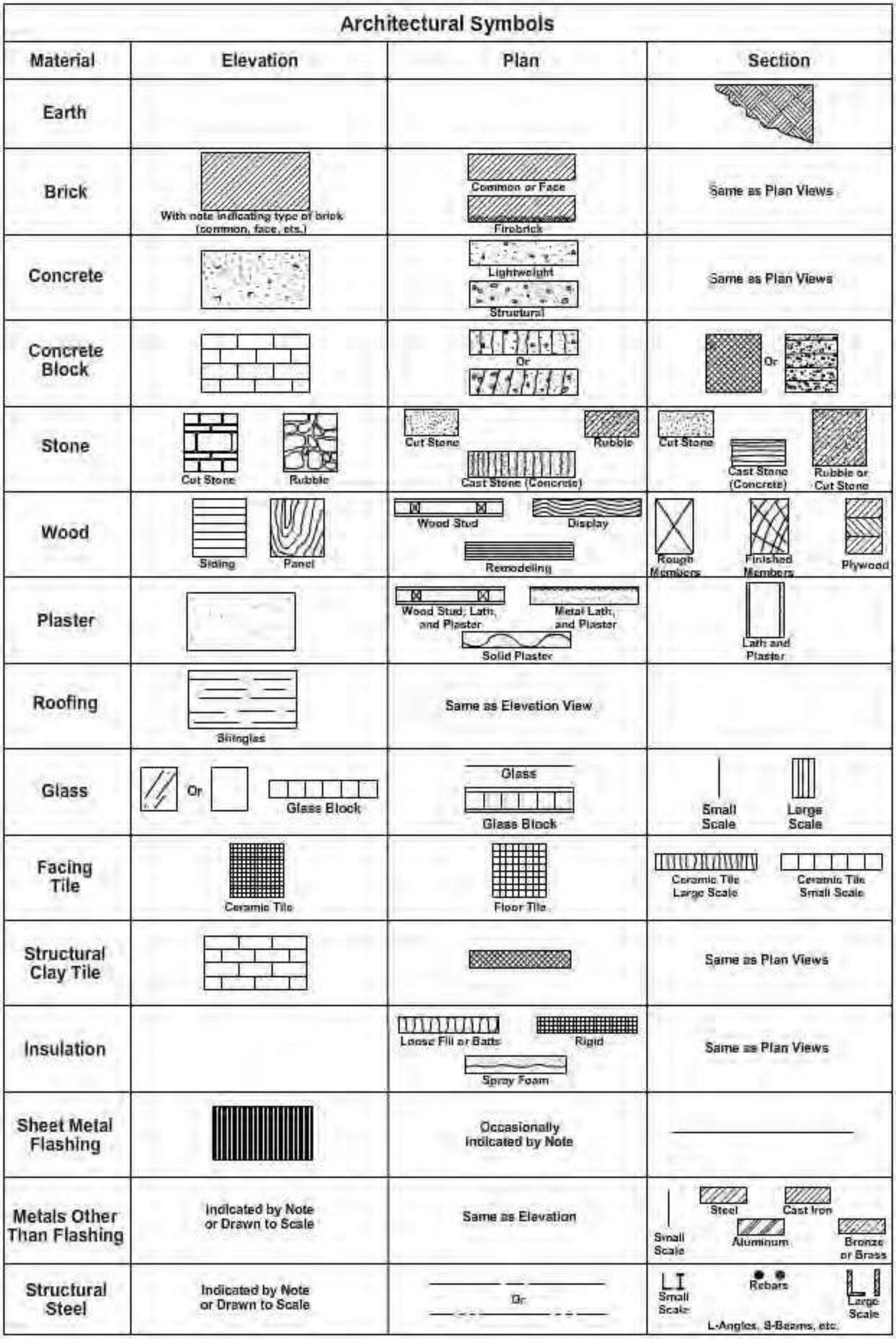
	Screwed	Soldered
Joint		
Elbow - 90		
Elbow - 45		
Elbow - Turned Up		
Elbow - Turned Down		
Elbow Long Radius		
Side Outlet Elbow- Outlet Down		
Side outlet Elbow - Outlet Up		
Base Elbow		
Double Branch Elbow		
Single Sweep Tee		
Double Sweep Tee		
Reducing Elbow		
Tee		
Tee - Outlet UP		
Tee - Outlet Down		
Side Outlet Tee - Outlet Up		
Side Outlet Tee - Outlet Down		
Cross		
Reducer		
Eccentric Reducer		
Lateral		
Expansion Joint Flanged		

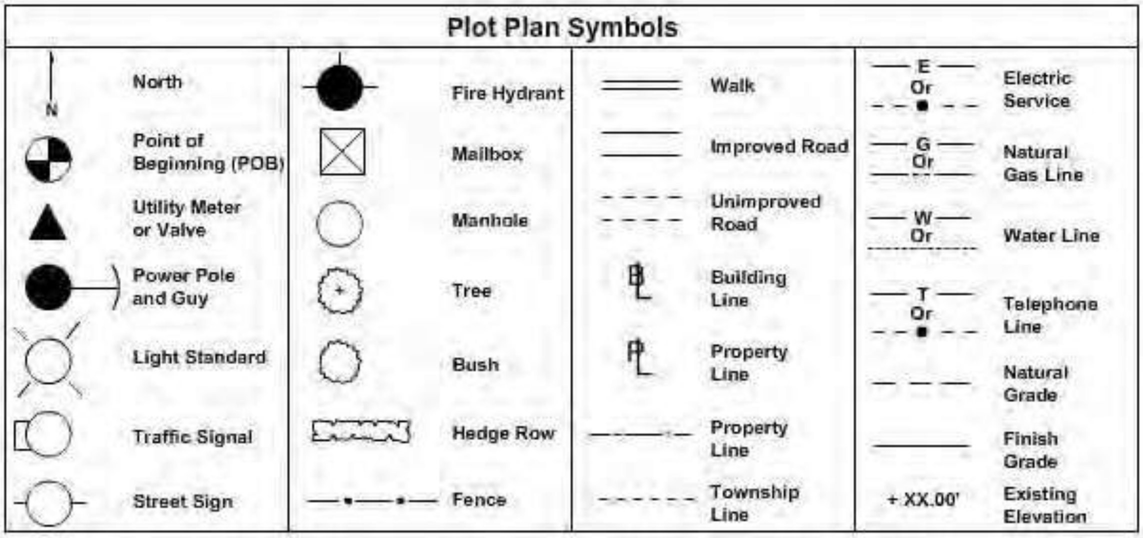

Battery, Multicells
Fire-Alarm Box, Wall Type
S
Single-Pole Switch
10A
Switch Breaker
Lighting Panel
S2
Double-Pole Switch
30A
Automatic Reset Breaker
Power Panel
Pull Switch Ceiling
Bus
Branch Circuit, Concealed In Ceiling Or Wall
Pull Switch Wall
Voltmeter
Branch Circuit, Concealed In Floor
Fixture, Fluorescent, Ceiling
Toggle Switch DPST
Branch Circuit, Exposed
Fixture, Fluorescent, Wall
Transformer, Magnetic Core
Feeders
Junction Box, Ceiling
Bell
Underfloor Duct And Junction Box
Junction Box, Wall
AC
Buzzer, AC
Motor
Lampholder, Ceiling
Crossing Not Connected (Not Necessarily At A 90° Angle)
Controller
Lampholder, Wall
Junction
Street Lighting Standard
Lampholder, With Pull Switch, Ceiling
Transformer, Basic
Outlet, Floor
Lampholder, With Pull Switch, Wall
Ground
Convenience, Duplex
Special Purpose
Outlet, Ceiling
Fan, Wall
Telephone, Switchboard
Outlet, Wall
Fan, Ceiling
Thermostat
Fuse
Knife Switch Disconnected
Push Button

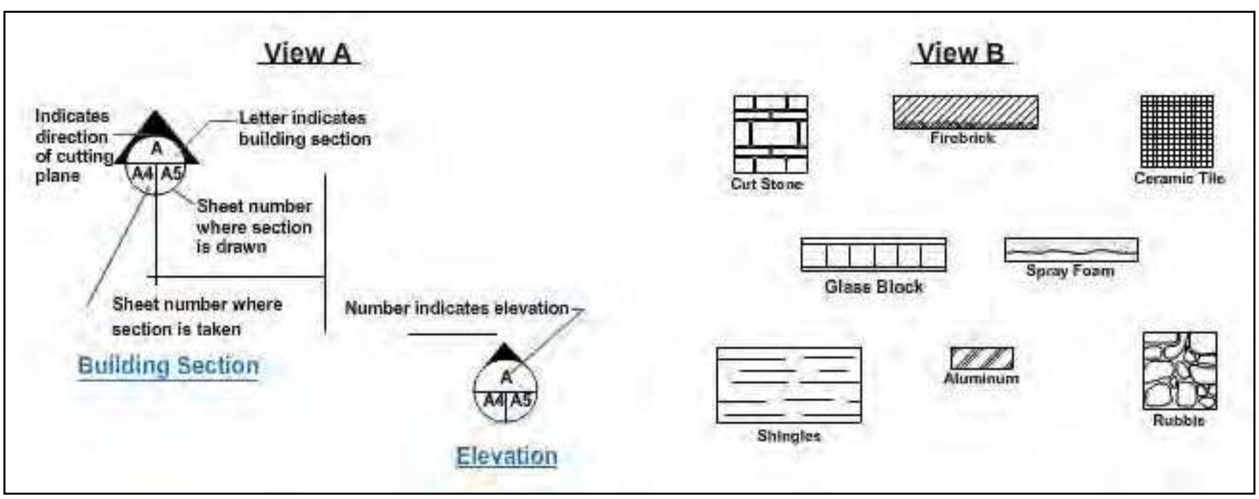

Indicates direction of cutting plane
Letter indicates building section
A
A4 A5
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
Elevation
Number Indicates Detail
3
M1 M2
2
C2 C4
4
42 46
Detail
5
56 58
Number indicates wall section
Wall Section
Letter indicates building section
A2 A5
Title Symbols
Number indicates elevation, wall section, or detail
EJ E5
Additional Sheet References
Note: These symbols should always appear as part of the title, placed under the view

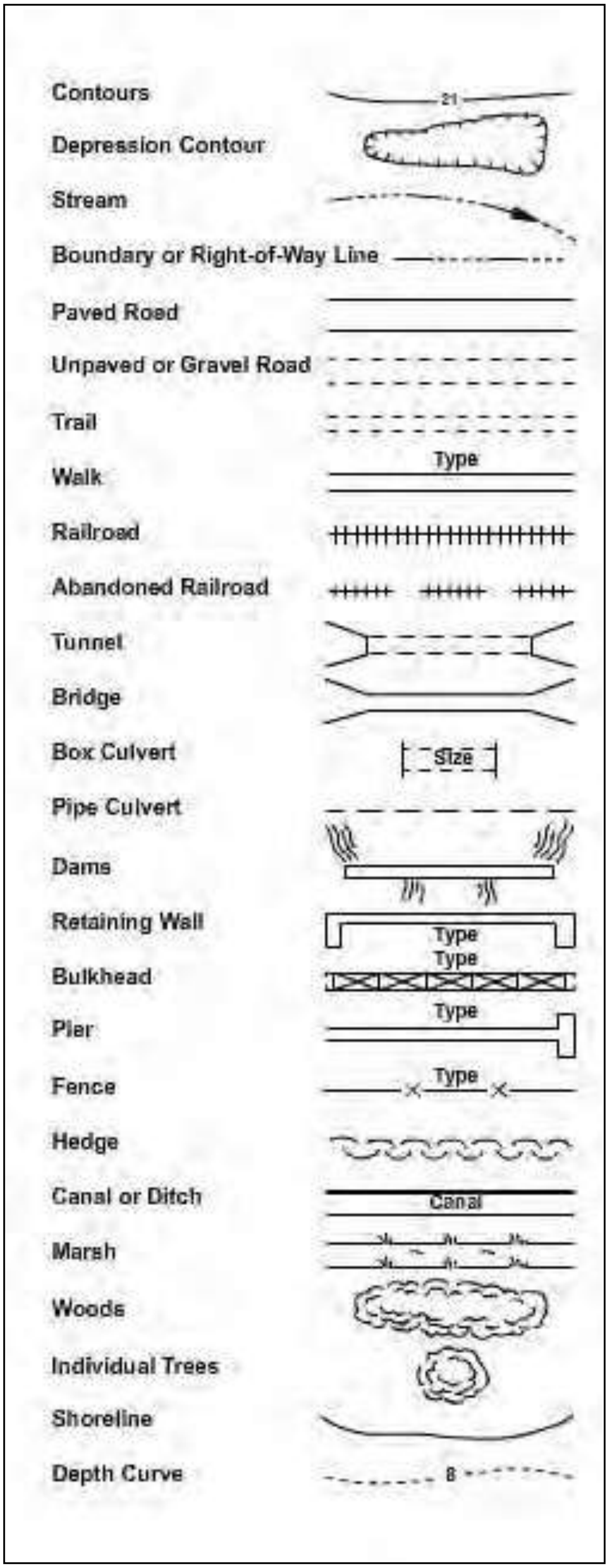

Field Weld Symbol
Weld-all-around symbol
Tail
Weld info for other side
Weld info for arrow side
Arrow to joint
Fillet
Plug or Slot
Spot or Projection
Seam
Back or Backing
Melt Thru
Surfacing
Flange
Edge
Corner
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Basic Arc and Gas Weld Symbols
Weld all around
Flag toward tail field weld
Contour
Flush
Convex
Concave
Supplementary Symbols

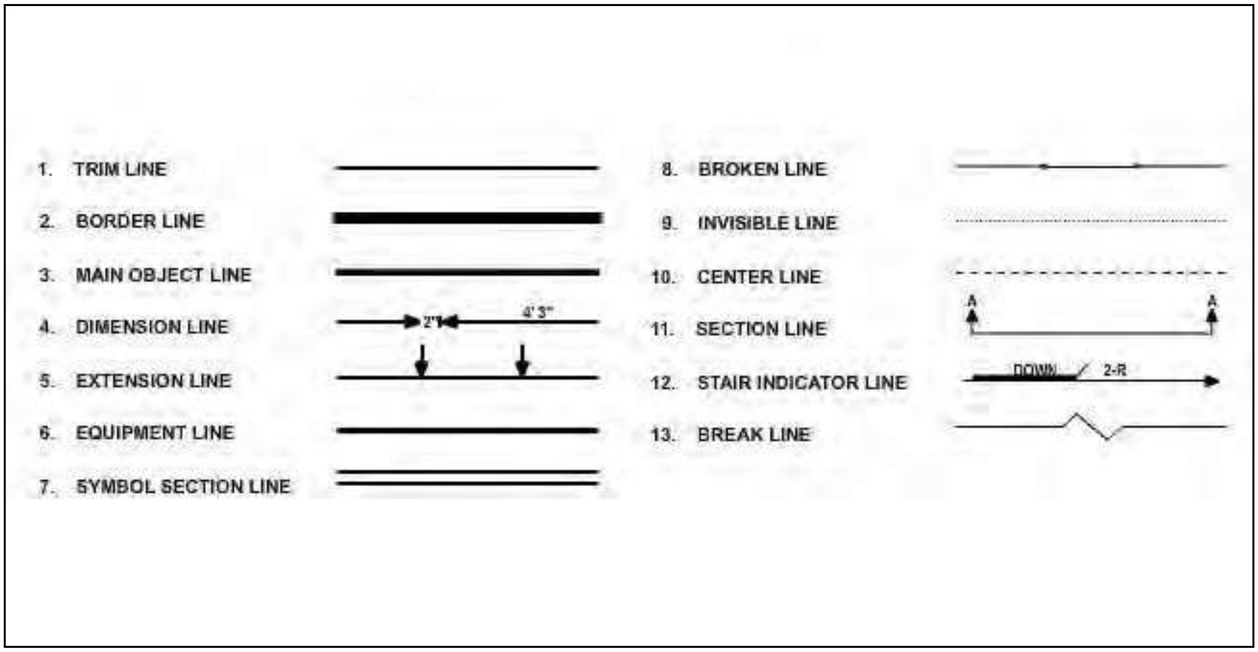

Location Significance
Fillet
Plug or Slot
Spot or Projection
Stud
Seem
Back or Backing
Surfacing
Flange Corner
Flange Edge
Arrow Side
Groove Weld Symbol
Other Side
Not Used
Groove Weld Symbol
Both Sides
No arrow side or other side significance
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Scarf for Brazed Joint
Supplementary Symbols
Weld all around
Field Weld
Melt Thru
Consu-mable Insert
Backing Spacer
Contour
Flush
Convex
Concave
Location of Elements of a Welding Symbol
Finish symbol
Groove angle, included angle of countersink for plug welds
Contour symbol
Root opening: depth of filling for plug and slot welds
Length of weld
Groove weld size
Pitch (center-to-center spacing) of welds
Depth of preparation; size and strength for certain welds
Field weld symbols
Arrow connecting reference line to arrow side member of joint or arrow side of joint
Specification, process, or other reference
F
A
S (E)
R
L-P
T
Both Sides
Other Side
Arrow Side
Tail
(Tail omitted when reference is not used)
Weld-all-around symbol
(N)
Number of spot, stud, or projection welds
Reference line
Basic weld symbol or detail reference
Elements in this area remain as shown when tail and arrow are reversed
Basic Joints
Identification of Arrow Side and Other Side Joint
Butt Joint
Arrow of welding symbol
Arrow side of joint
Other side of joint
Corner Joint
Arrow side of joint
Other side of joint
Arrow of welding symbol
T - Joint
Arrow of welding symbol
Arrow side of joint
Other side of joint
Lap Joint
Other side of member joint
Arrow side of member joint
Arrow of welding symbol
Edge Joint
Joint
Arrow side of joint
0-30°
Arrow of welding symbol
Process Abbreviations
Where process abbreviations are to be included in the tail of the welding symbol, reference is made to Table 1. Designation of Welding and Allied Processes by Letters, of AWS A2.4-86.

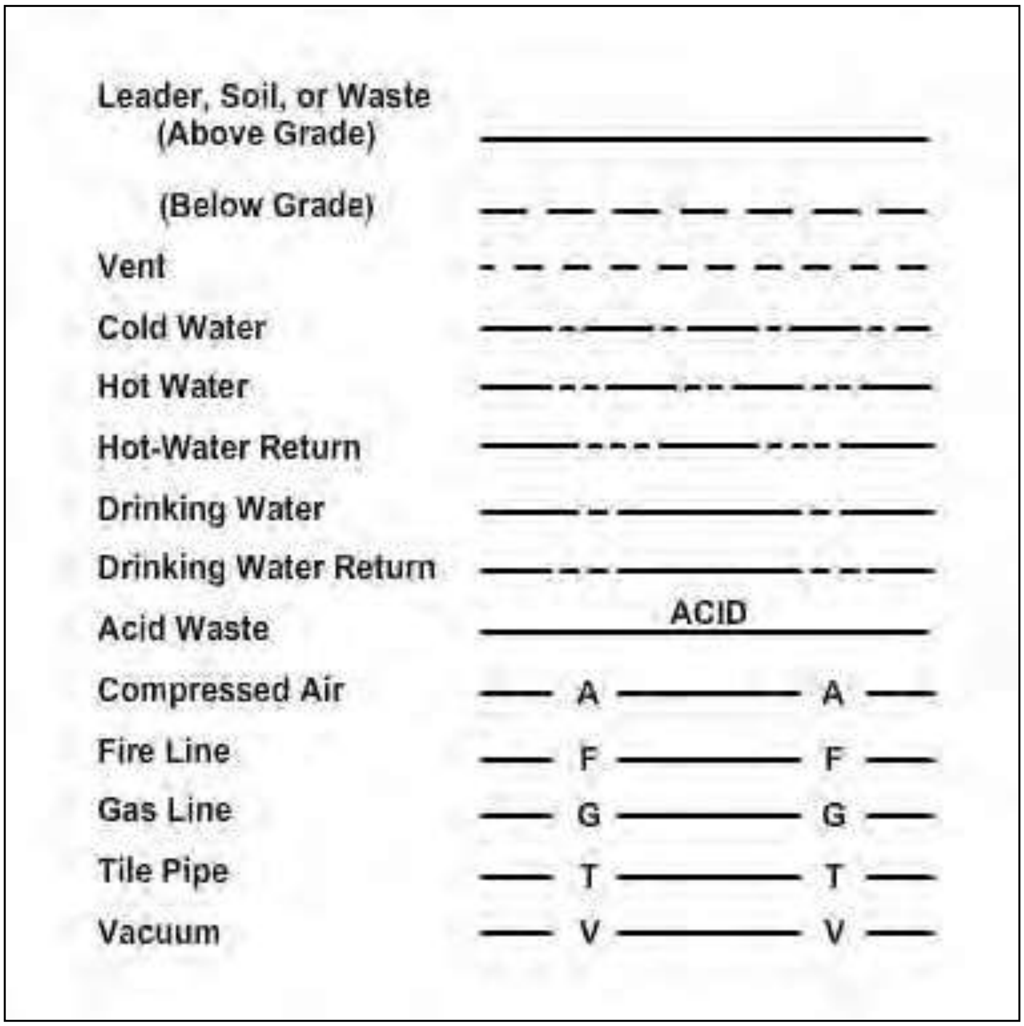

Architectural Symbols
Material
Elevation
Plan
Section
Earth
Brick
With note indicating type of brick (common, face, etc.)
Common or Face
Firebrick
Same as Plan Views
Concrete
Lightweight
Structural
Same as Plan Views
Concrete Block
Or
Or
Stone
Cut Stone
Rubble
Cut Stone
Rubble
Cast Stone (Concrete)
Cut Stone
Cast Stone (Concrete)
Rubble or Cut Stone
Wood
Siding
Panel
Wood Stud
Display
Remodeling
Rough Members
Finished Members
Plywood
Plaster
Wood Stud, Lath, and Plaster
Metal Lath, and Plaster
Solid Plaster
Lath and Plaster
Roofing
Shingles
Same as Elevation View
Glass
Or
Glass Block
Glass
Glass Block
Small Scale
Large Scale
Facing Tile
Ceramic Tile
Floor Tile
Ceramic Tile Large Scale
Ceramic Tile Small Scale
Structural Clay Tile
Same as Plan Views
Insulation
Loose Fill or Batts
Rigid
Spray Foam
Same as Plan Views
Sheet Metal Flashing
Occasionally Indicated by Note
Metals Other Than Flashing
Indicated by Note or Drawn to Scale
Same as Elevation
Steel
Cast Iron
Small Scale
Aluminum
Bronze or Brass
Structural Steel
Indicated by Note or Drawn to Scale
Or
Small Scale
Rebars
Large Scale
L-Angles, S-Beams, etc.

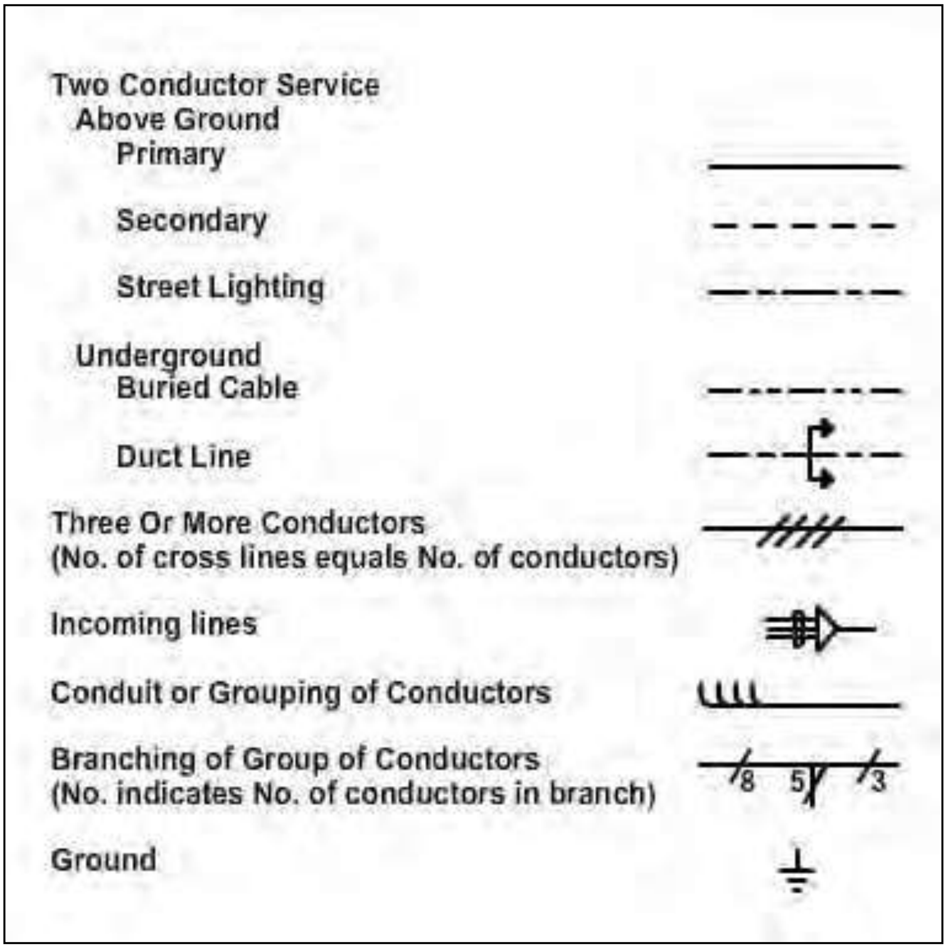

Plot Plan Symbols
North
N
Point of Beginning (POB)
Utility Meter or Valve
Power Pole and Guy
Light Standard
Traffic Signal
Street Sign
Fire Hydrant
Mailbox
Manhole
Tree
Bush
Hedge Row
Fence
Walk
Improved Road
Unimproved Road
Building Line
Property Line
Property Line
Township Line
E
Or
Electric Service
G
Or
Natural Gas Line
W
Or
Water Line
T
Or
Telephone Line
Natural Grade
Finish Grade
+ XX.00'
Existing Elevation

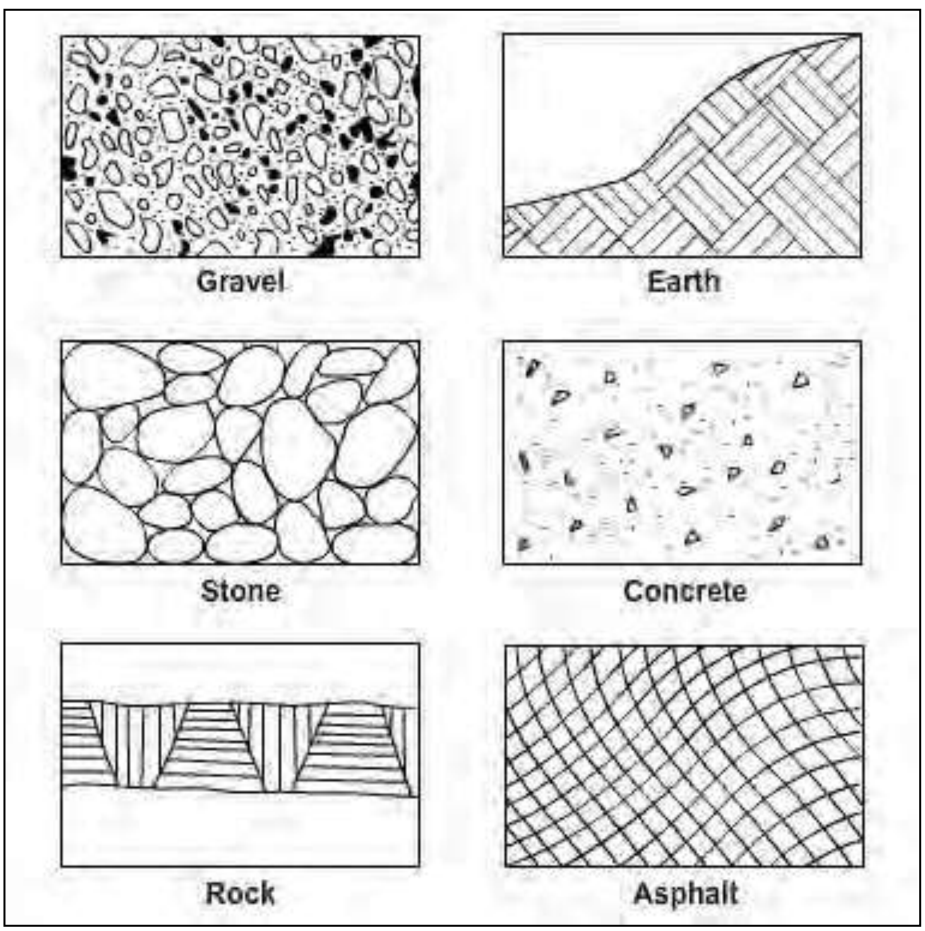

View A
Indicates direction of cutting plane
Letter indicates building section
A
A4
A5
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
A
A4
A5
Elevation
View B
Cut Stone
Firebrick
Ceramic Tile
Glass Block
Spray Foam
Shingles
Aluminum
Rubble

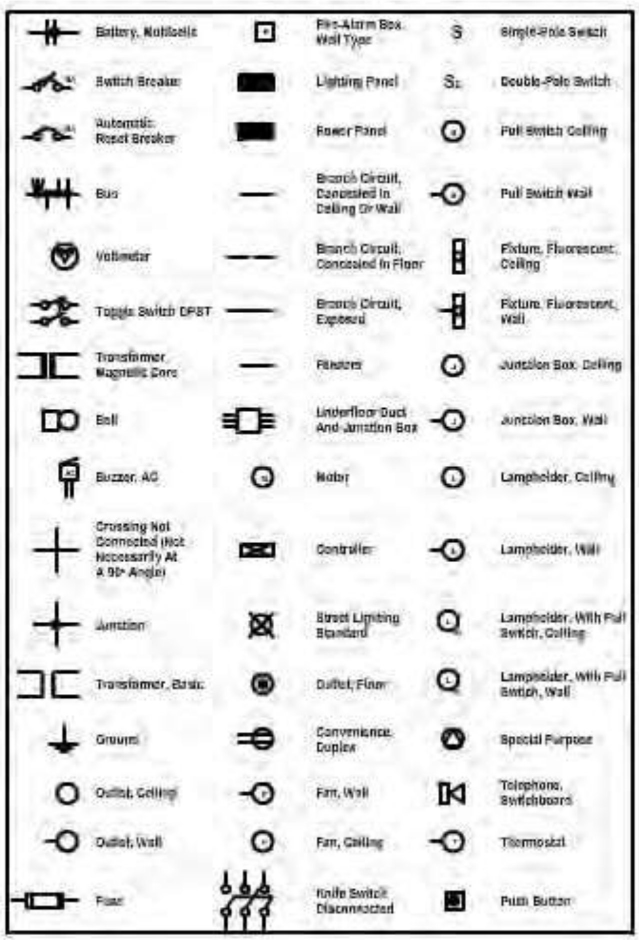

Contours
21
Depression Contour
Stream
Boundary or Right-of-Way Line
Paved Road
Unpaved or Gravel Road
Trail
Walk
Type
Railroad
Abandoned Railroad
Tunnel
Bridge
Box Culvert
Size
Pipe Culvert
Dams
Retaining Wall
Type
Bulkhead
Type
Pier
Type
Fence
Type
Hedge
Canal or Ditch
Canal
Marsh
Woods
Individual Trees
Shoreline
Depth Curve
8


1. TRIM LINE
2. BORDER LINE
3. MAIN OBJECT LINE
4. DIMENSION LINE
5. EXTENSION LINE
6. EQUIPMENT LINE
7. SYMBOL SECTION LINE
8. BROKEN LINE
9. INVISIBLE LINE
10. CENTER LINE
11. SECTION LINE
12. STAIR INDICATOR LINE
13. BREAK LINE
A
A
DOWN
2-R


Leader, Soil, or Waste (Above Grade)
(Below Grade)
Vent
Cold Water
Hot Water
Hot-Water Return
Drinking Water
Drinking Water Return
Acid Waste
ACID
Compressed Air
A
A
Fire Line
F
F
Gas Line
G
G
Tile Pipe
T
T
Vacuum
V
V


Two Conductor Service
Above Ground
Primary
Secondary
Street Lighting
Underground
Buried Cable
Duct Line
Three Or More Conductors
(No. of cross lines equals No. of conductors)
Incoming lines
Conduit or Grouping of Conductors
Branching of Group of Conductors
(No. indicates No. of conductors in branch)
8
5
3
Ground


Gravel
Earth
Stone
Concrete
Rock
Asphalt


Battery, Multicells
Switch Breaker
Automatic Reset Breaker
Bus
Voltmeter
Toggle Switch DPST
Transformer Magnetic Core
Bell
Buzzer, AC
Crossing Not Connected (Not Necessarily At A 90° Angle)
Junction
Transformer, Basic
Ground
Outlet, Ceiling
Outlet, Wall
Fuse
Fire-Alarm Box Wall Type
Lighting Panel
Power Panel
Branch Circuit, Concealed In Ceiling Or Wall
Branch Circuit, Concealed In Floor
Branch Circuit, Exposed
Feeders
Underfloor Duct And Junction Box
Motor
Controller
Street Lighting Standard
Outlet, Floor
Convenience Duplex
Fan, Wall
Fan, Ceiling
Knife Switch Disconnected
Single-Pole Switch
Double-Pole Switch
Pull Switch Ceiling
Pull Switch Wall
Fixture, Fluorescent, Ceiling
Fixture, Fluorescent, Wall
Junction Box, Ceiling
Junction Box, Wall
Lampholder, Ceiling
Lampholder, Wall
Lampholder, With Pull Switch, Ceiling
Lampholder, With Pull Switch, Wall
Special Purpose
Telephone, Switchboard
Thermostat
Push Button