- Ordinary service (tools, painting, and so forth) - 60 to 80 psig
- Soot blowing for boilers - 80 to 125 psig

1.2.0 Medium Pressure Systems

Medium-pressure systems provide compressed air within the range of 126 to 399 psig pressure. These systems are not extensive and are generally provided with individual compressors located near the loads. Medium-pressure systems are mainly used for the starting of diesel engines, soot blowing of boilers and high-temperature water (HTW) generators, and hydraulic lifts.

1.3.1 High-Pressure Systems

These systems provide compressed air within the range of 400 to 6,000 psig pressure. Hazards that increase with higher pressures and capacities can be minimized by the use of separate compressors for each required pressure. Systems operating at 3,000 psig may require small amounts of air at lower pressures, which is supplied through pressure-reducing stations.

Caution must be used with high-pressure systems because when high-pressure air enters suddenly into pockets or dead ends, the air temperature in the confined space increases dramatically. If there is any combustible material in the space and the air temperature increases to the ignition point of the material, an explosion may occur. This is known as auto ignition or diesel action. Explosions of this type may set up shock waves that travel through the compressed air system. This travel may cause explosions at remote points. Even a small amount of oil residue or a small cotton thread may be sufficient enough to cause ignition.

Some common pressure requirements for high-pressure systems may be as follows:

- Torpedo workshop - 600 to 3,000 psig
- Ammunition depot - 100, 750, 1,500, 2,000, and 4,500 psig
- Wind tunnels - Over 3,000 psig
- Testing laboratories - Up to 6,000 psig

2.0.0 AIR QUALITY REQUIREMENTS

The quality of air supplied from a compressed air system will vary with application. The installer and maintenance personnel should consider the class of air entrapment and specific air quality requirements for each application.

2.1.0 Classes of Air Entrapment

The classes of air entrapment may be subdivided into inert and chemical particulate, chemical gases, oil, and water. To prevent contamination of an air compression system by these types of entrapments, you should follow certain guidelines for each situation of possible contamination.

2.1.1 Particulate

Intake structures or openings should be free of shelves, pockets, or other surfaces that attract and accumulate particulate. Properly designed intakes are large enough to produce a low-velocity airflow. This limits the size of the particles that may be picked up by the intake suction.

Some particulate may contain active chemicals that may form acids or alkalines in the inevitable presence of water. These chemical particulate can accelerate damage to compressor surfaces.

Particulate are sized in microns or micrometers. This measurement is size, not weight. One micron is a unit of length equal to one millionth of a meter. Particles larger than 10 microns are visual to the naked eye. Filter systems are required for all air compressors. Generally, filters should be able to remove particles down to 1 to 3 microns in size.

2.1.2 Gases or Fumes

Gases or fumes are airborne and generally independent of air velocity. They can be strong acid, alkaline, or otherwise corrosive to the internal surfaces or lubricants of the compressor. In addition, gases or fumes may be prohibited by the end-use process, such as medical gases or breathing air and for environmental or odor reasons. Intakes near normal flow paths of engine exhausts should be avoided.

2.1.3 Oil

Oil fumes, vapor, or mist can be as difficult to handle as particulate or gases. Even though many types of compressors are oil lubricated, the oil ingested may not be compatible, and compressor load may be increased.

2.1.4 Water

Waste and water vapor are always present in air intakes. Installation of intakes should prevent the accumulation of free water. Free water ingested into the compressor causes damage to internal components.

Since water vapor with chemical content corrodes steel piping, precautions must be taken to protect materials from corrosion. Galvanizing, applying protective coatings, or using plastic or stainless steel piping for air intakes are some suggested methods to retard or prevent corrosion. Also, be sure to install intakes in a manner that excludes rainfall, snow, or spray by applying a weather hood.

2.2.0 Specific Air Quality Requirements

The diverse uses of air are accompanied by specific air quality requirements. These vary from high purity requirements through the need to introduce materials into a system to be carried along with the air. This section will discuss these specific air quality requirements.

2.2.1 Commercial Air

Commercial compressed air is graded according to its purity. The purest is grade A, running alphabetically to grade J, the least pure. The Compressed Gas Association has set guidelines for the grading of commercial compressed gas. The application of commercial compressed air is varied and generally specified for each individual installation by engineers. The full extent of the quality requirements for commercial compressed air applications can be located in the Compressed Air Association publication *Commodity Specification for Air,* G-7.1 (ANSI 286.1-1973).

2.2.2 Breathing Air

Breathing air must be of high quality for obvious reasons. Federal Specification BB-A-1034, shown in *Table 7-1,* outlines the specific requirements for breathing air.

Table 7-1 — Breathing air requirements.

	Source I (Pressurized Container Air)		Source II (Compressed Air)	
Component	Grade A	Grade B	Grade A	Grade B
Oxygen Percent *	20 to 22	19 to 23	20 to 22	19 to 23
Carbon dioxide	500	1,000	500	1,000
Carbon monoxide	10	10	10	10
Oil (mist and vapor) Particulate matter (weight/ volume)	0.005	0.005	0.005	0.005
Separated water	None	None	None	None
Total water (weight/volume)	0.02 mg/l	0.02 mg/l	0.02 mg/l	0.02 mg/l

Special attention must be given to eliminating carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons, odor, and water from breathing air. Carbon monoxide has first priority as its effects are cumulative and very small concentrations can cause problems. Whenever possible, carbon monoxide monitoring should be provided at the compressor intake. This monitoring equipment should sound an alarm or shut down the system when CO is detected.

Carbon dioxide is found in combustion flue gases, such as boiler stacks. Do not place compressor intakes near or downwind of the stacks.

Systems should be kept free of oil to limit the possible concentration of hydrocarbons or petroleum products. For breathing air, compressors should be oil free rather than using auxiliary petroleum removal equipment. The heat caused by compression may cause thermal breakdown of oil, or an explosion danger may exist as a result of drawing hydrocarbons into the air system.

Water content is kept below saturation to prevent condensation at points that cannot be cleaned. It is recommended that refrigerant or desiccant dryers be used to remove moisture from a breathing air system. This will limit the vapor clouding (fogging) of glasses and visors.

2.2.3 Medical Air

Medical air quality must be the same or better than breathing air. Whatever quality is established must be strictly adhered to.

2.2.4 Instrument and Control Air

Air quality requirements for instrument and control air should place emphasis on cleanliness and low moisture content. The Instrument Society of America (ISA) has established the following requirements:

- Dew point, exterior: 18°F (–7.8°C) below minimum recorded ambient temperature
- Dew point, interior: 18°F (–7.8°C) below minimum interior temperature but not higher than 35°F (1.7°C)
- Particle size: 3 microns maximum
- Oil content: As close to zero as possible but not over 1 ppm
- Contaminates: No corrosives or hazardous gases

- Water content must be low enough to prevent condensate accumulations. Special attention should be given to ensure that intake air is filtered and oil or water removed. A refrigerant dryer with a dew point at least as low as 30°F (–1.1°C) is recommended for these services.

2.2.5 Air for Pneumatic Tools

When compressed air is intended for use with pneumatic tools, it should be filtered for particulate, and water should be separated out. Oil is usually required to be ingested into the air for tool lubrication. Mist injection is preferred for tools to ensure dispersion and maximum settlement. Note that pressures in excess of 400 psig may cause compression combustion when oil is present.

2.2.6 High-Pressure Air Systems

Air quality must be carefully analyzed to minimize not only the normal hazards of high pressure, but also the internal explosive hazards that exist with high-pressure systems. Of particular danger is the introduction of oil and hydrocarbons during compression and their remaining and accumulating throughout the system. A high-pressure system of 500 psig or higher is subject to rapid local heat buildup whenever there is a rapid filling of a component or vessel. The heat buildup (combined with oil and foreign material) that permits the oil to wick or vaporize can readily cause an explosion or fire. Any explosion in the system may produce several shock waves to travel the system, compounding the damage. Because of this problem, special attention is required to clean the intake air, limit the introduction of lubrication oil, and remove oil after completion of the compression process.

Test your Knowledge (Select the Correct Response)

1. Low-pressure systems provide compressed air at a maximum of how many pounds per square inch gauge (psig)?

   A. 25
   B. 75
   C. 100
   D. 125

3.0.0 AIR COMPRESSORS and AUXILIARY EQUIPMENT

There are basically two types of compressors: positive displacement and dynamic. This section will discuss the reciprocating air compressors, the rotary air compressors, the helical screw compressors classed as positive displacement compressors, and the dynamic centrifugal compressors.

General auxiliary equipment will also be discussed. Auxiliary equipment consists of any device(s) that may be added to the system to improve its efficiency or provide a specific function. It provides a safe condition under which the compressor system will be operating.

3.1.0 Reciprocating Air Compressors

The most commonly used stationary air compressors are the reciprocating, positive displacement design. They may be single acting or double acting, single stage or multistage, and horizontal, angle, or vertical in design.

In a single-stage unit there is but one compressing element; it compresses air from the initial intake pressure to the final discharge pressure in one step. A multistage machine has more than one compressing element. The first stage compresses air to an intermediate pressure, and then one or more additional stages compress it to the final discharge pressure.

In the reciprocating compressor, the compression cycle is composed of three phases: intake, compression, and discharge.

During the intake stroke, the downward movement of the piston creates a partial vacuum inside the cylinder. The spring-operated intake valve is forced open by the differential pressure between free air on one side and the partial vacuum inside the cylinder. As the valve opens, air fills the cylinder. The piston now moves into the compression stroke, forcing the intake valve closed and raising the pressure of the air trapped in the cylinder. When the pressure of this air is great enough to overcome the force of the spring-operated discharge valve, the valve opens and the compressed air is discharged from the cylinder.

Compressors are classified as low pressure, medium pressure, or high pressure. Low-pressure compressors provide a discharge pressure of 150 psi or less. Medium-pressure compressors provide a discharge pressure of 151 psi to 1,000 psi. Compressors that provide a discharge pressure above 1,000 psi are classified as high pressure. Note that compressors are classified at pressures different from those for classifying total compressed air systems discussed earlier.

Most low-pressure air compressors are of the two-stage type with either a vertical or a vertical W arrangement of cylinders. Two-stage, V-type, low-pressure compressors usually have one cylinder that provides the first (low-pressure) stage of compression and one cylinder that provides the second (high-pressure) stage, as shown in *Figure 7-2.* W-type compressors have two cylinders for the first stage of compression and one cylinder for the second stage. This arrangement is illustrated in *Figure 7-3*.

Figure 7-2 — Two-stage, two-cylinder compressor.

Figure 7-3 — Two-stage, three-cylinder compressor.

Compressors may be classified according to a number of other design features or operating characteristics.

Medium-pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons, as shown in *Figure 7-4.* This type of piston provides more than one stage of compression on each piston.

Figure 7-4 — Differential piston with a two-stage vertical arrangement.

3.2.0 Rotary Air Compressors

Rotary sliding vane compressors are a machine in which longitudinal vanes slide radially in a slotted rotor that is mounted eccentrically in a cylinder. The rotor is fitted with blades or vanes that are free to slide in and out of longitudinal slots and maintain contact with the cylinder walls by centrifugal force. In operation, as the blades are forced outward by centrifugal force, compartments are formed in which air is compressed (*Figure 7-5*). Each compartment varies from a maximum volume on the suction side of the revolution to a minimum volume on the compression half of the revolution. This gives a positive displacement type suction and pressure effect.

Figure 7-5 — Compression cycle of rotary compressor.

Another type of rotary compressor is the twin lobe unit, sometimes referred to as a blower (*Figure 7-6*). This unit consists of two impellers mounted on parallel shafts that rotate in opposite directions within a housing. As the impellers rotate, they trap a quantity of air themselves in the blower housing and move the air around the casing to the discharge port. This action takes place twice each revolution of an impeller and four times per revolution of both impellers. The impellers are positioned in relation to each other by timing gears, located at the end of each shaft and external to the blower housing.

Figure 7-6 — Twin-lobe rotary compressor.

You should always use maintenance and service literature provided by manufacturers when you are working with rotary compressors. Maintenance information is given in *Operation and Maintenance of Compressed Air Plants,* NAVFAC MO-206.

3.3.0 Helical Screw Compressors

Helical screw compressors contain two mating rotating screws, one locked and one grooved, which provide the driving force. The unit's screws take in air, decreasing its volume as it progresses in a forward-moving cavity toward the discharge end of the compressor. *Figure 7-7* shows a typical single-stage helical screw compressor. These compressors are best used in booster or near constant-load conditions at low-pressure, oil-free application.

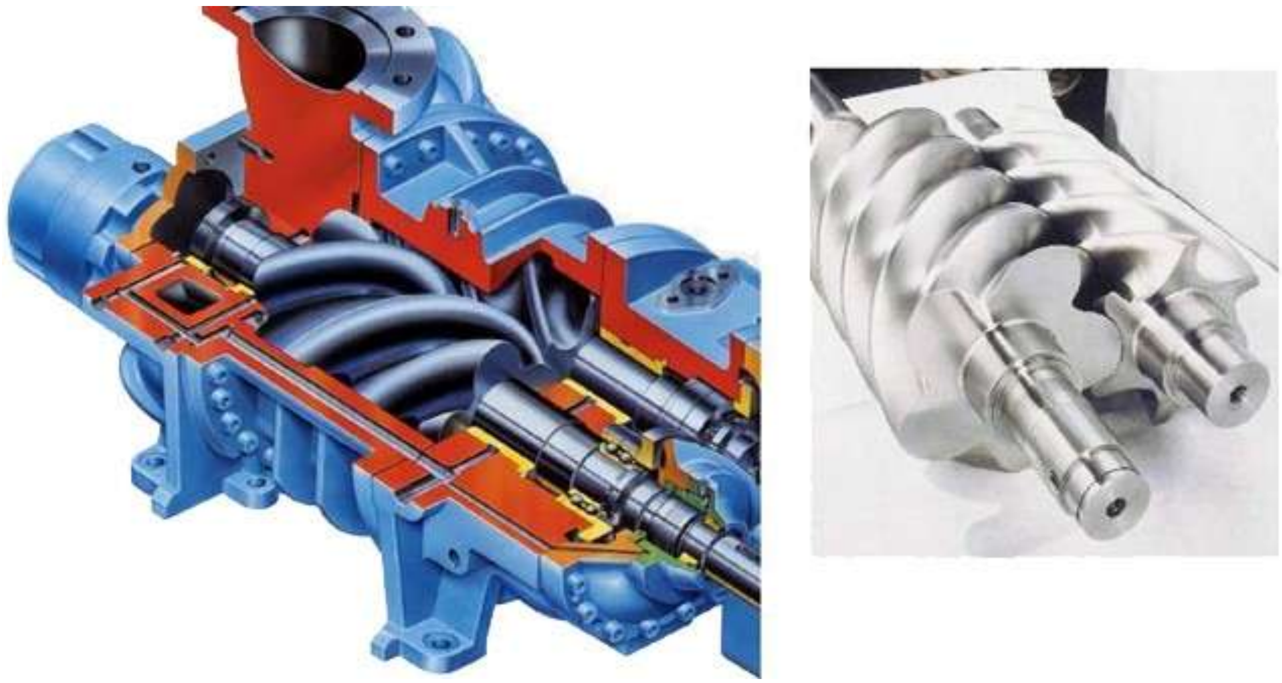


Figure 7-7 — Rotary helical screw compressor.

3.4.0 Dynamic Centrifugal Compressors

Dynamic compressors are high-speed rotating machines in which air is compressed by the action of rotating impellers or blades that impart velocity and pressure to the air through centrifugal force. *Figure 7-8* shows the internal parts of a multistage centrifugal compressor. This type will deliver air at an essentially constant pressure over a wide range of capacities. The direction of airflow is radial with respect to the axis of rotation.

Centrifugal compressors have a lower limit of stable operation called the surge point. Operation below this point results in pumping or surging of the airflow. Prime movers are normally electric motors or combustion engines.

Centrifugal compressors are intended for near continuous industrial air service when the load is reasonably constant. These compressors also work well when oil-free air is required and can be used for breathing air.

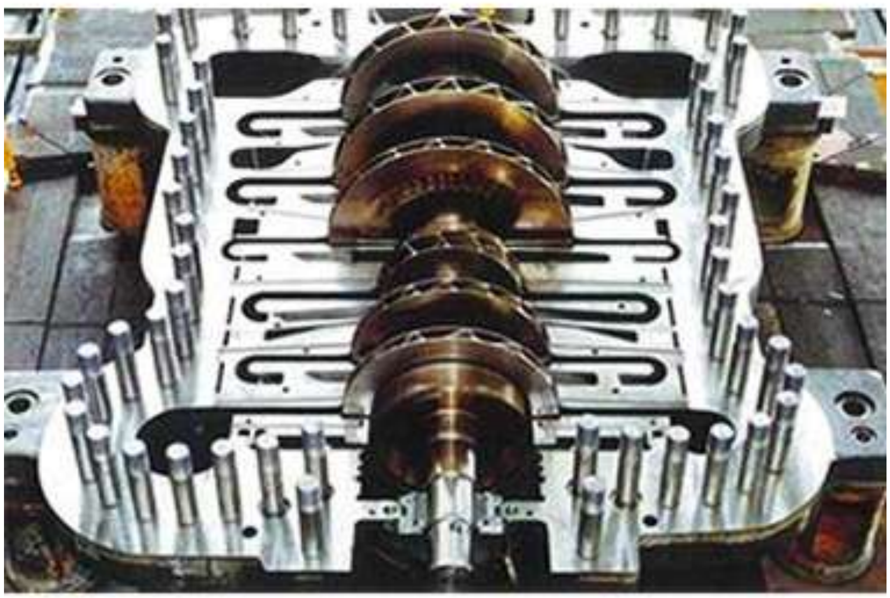


Figure 7-8 — Internal view of a multistage centrifugal compressor.

Table 7-2 shows typical application recommendations for both positive displacement and dynamic class compressors.

Table 7-2 — Summary application recommendations, types of compressors.

Type	Air Deliver Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, single stage, air cooled	L	100-125 psig, to 50 scfm, up to10 hp	Intermittent light duty
Reciprocating, two stage, air cooled	L	100-125 psig, to 200 scfm, up to 50 hp	Low volume requirements
Reciprocating, two stage air cooled	N	100-125 psig, to 50 scfm, up to 15 hp	Low volume requirements
Reciprocating, two stage water cooled	L	100-150 psig, 400-1,000 scfm, 75-200 hp	Wide application range
Reciprocating, two stage water cooled	N	100-125 psig, 400-1,000 scfm, 75-200 hp	Wide application where required
Reciprocating, two stage, water cooled, duplex and/or double acting	L	100-150 psig, 1,000-5,000 scfm, 200-1,200 hp	High volume requirements
Reciprocating, multi stage, water cooled	L, N	150-6,000 psig, 10-100 scfm, 3-1,000 hp	Medium and high pressure
Rotary, sliding vane, single-stage	L, N	5-50 psig, 50-3,000 scfm, 0.5-300 hp	Match to load only pressure booster
Rotary, sliding vane, two stage	L, N	60-100 psig, 100-3,000 scfm, 15-500 hp	Match to load only pressure booster
Rotary, sliding vane, single, or two stage oil injected	L	80-125 psig, 120-600 scfm, 15-200 hp	Wide application range
Helical screw, single stage, lubricated	L	To 35 psig, 30-12,000 scfm, up to 1,200 hp	Match to load only, single rating point
Helical screw, two stage, lubricated	L	60-100 psig, 30-12,000 scfm, up to 2,000 hp	Match load only, single rating point, aircraft air start, aircraft cooling
Helical screw, single stage, oil injected	L	To 125 psig, 40-1,500 scfm, 10-400 hp	Wide application range
Dynamic, centrifugal, single stage	N	To 35 psig, 1,500-15,000 scfm, 100-1,000 hp	Match load
Dynamic, centrifugal, two stage	N	35-70 psig, 1,500-15,000 scfm 100-2,000 hp	Match load, breathing air
Dynamic, centrifugal, three stage	N	70-125 psig, 1,500-15,000 scfm, 200-3,500 hp	High volume requirements, breathing air
Dynamic, centrifugal, four or more stage	N	125 psig or more, 1,500-15,000 scfm, up to 3,000 hp	Medium pressure high volume
Dynamic, axial or radial barrel, multistage	N	200 psig or more, 1,500 scfm or more, high horsepower	Medium and high pressure, high volume
* L=Lubricated N=Non-lubricated (1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 mm^3/min, 1 hp = 0.746 kW)			

3.5.0 Auxiliary Equipment

A system that functions to provide a continuous supply of usable compressed air requires certain auxiliary devices in addition to the air compressor. Most compressed air systems require a minimum of auxiliary equipment that should include air intakes, intake filters, silencers, intercoolers, after coolers, air discharge systems, separators, dryers, receivers, and so forth. These types of auxiliary equipment will be discussed in this section in addition to less common auxiliary equipment.

3.5.1 Air Intakes

Air intakes should be located high enough to eliminate intake of particles of dust, smoke, dirt, water, and snow. Carbon monoxide sources should not be able to discharge into compressor intakes. Special attention should be given to the elimination of flammable fumes into the compressed air system.

Whenever air intakes must be placed through a roof that is surrounded by parapets, they should be 8 to 10 feet above the roof.

Noise may be generated by air intakes and must be considered during installation. Reciprocating compressors are most likely to develop resonance through intake piping. If this possibility exists, the use of intake dampeners or surge chambers will help. High velocities present noise level problems. Intake pipe velocities should be limited to 1,000 fpm in open areas or 350 fpm across filters. Acoustical silencers combined with filters and/or pulse dampeners are available and should be used whenever potential noise level difficulties are anticipated.

Intake resistance to airflow should be no more than necessary to maintain air quality. The resistance created by the air intake system will reduce compressor performance and efficiency. Refer to the compressor manufacturer’s manual for maximum resistance requirements.

3.5.2 Intake Filters

Air filters are provided on compressor intakes to prevent atmospheric dust from entering the cylinders and causing scoring and excessive wear. The two most common types of elements in use are the viscous impingement and the oil bath. Both types are illustrated in *Figure 7-9*.

Figure 7-9 — Compressor intake filters.

In the oil bath type, air must pass through an oil seal that removes dirt particles, and then pass on through a wire mesh element, which is saturated by oil carry-over. Any remaining particles of dirt are removed by the wire mesh element. Captured dust particles settle to a sump at the bottom of the filter housing. Oil bath filters are recommended where dust concentrations are present in the atmosphere.

The viscous impingement filter consists of a wire mesh filter element, which is coated with oil. Air passing through the filter element must change directions many times, causing any dust to adhere to the oil film.

3.5.3 Silencers

Silencers are similar to mufflers and function simply to eliminate objectionable compressor suction noise. *Figure 7-10* illustrates a standard intake silencer. Some compressors are equipped with combination filter-silencer units that have the filter elements contained within the silencer housing.

Figure 7-10 — Intake silencer.

3.5.4 Intercoolers

When air is compressed to 100 psi without heat loss, the final temperature is about 485°F. The increase in temperature raises the pressure of the air under compression, thus necessitating an increase in work to compress the air. After the air is discharged into the receiver tank and lines, the temperature falls rapidly to near that of the surrounding atmosphere, thereby losing part of the energy generated during compression. The ideal compressor would compress the air at a constant temperature, but this is not possible. In multistage compressors, the work of compressing is divided between two or more stages, depending on the final discharge pressure required. An intercooler is used between the stages to reduce the temperature of compression from each stage. Theoretically, the intercooler should be of sufficient capacity to reduce the temperature between stages to that of the low-pressure cylinder intake. Actually, intercooling has three purposes: to increase compressor efficiency, to prevent excessive temperatures within the compressor cylinders, and to condense moisture from the air.

Most intercoolers are either the shell and tube, air-to-water heat exchangers or the air-cooled, radiator-type heat exchangers. *Figure 7-11* illustrates a typical water-cooled intercooler.

Figure 7-11 — Typical water-cooled intercooler.

3.5.5 Aftercoolers

Moisture carried in air transmission lines is undesirable because it causes damage to air-operated tools and devices. Aftercoolers are installed in compressor discharge lines to lower the air discharge temperature, thus condensing the moisture and allowing it to be removed. In addition, the cooling effect allows the use of smaller discharge piping. A water-cooled aftercooler is illustrated in *Figure 7-12*.

Figure 7-12 — Typical water-cooled aftercooler.

3.5.6 Air Discharge Systems

Some discharge systems require special consideration for the placement of auxiliary equipment. All positive displacement compressors require a relief valve on their discharge side to protect the equipment and piping upstream of the first shutoff valve. Relief valves should be sized for at least 125 percent of the maximum unit flow capacity and should carry the American Society of Mechanical Engineers (ASME) stamp, listing the capacity and pressure setting of the valve.

3.5.7 Separators

Water and oil separators are required to separate and free excess water from the discharge air or gas. This is necessary to prevent corrosion, deposit buildup, and water or oil buildup in the piping or service. For example, water will cause rust in piping, wash away lubricants, and plug nozzles. Oil will contaminate many industrial processes and may present an explosion hazard. The need for water or oil separators will be determined by the end use of the compressed air.

A centrifugal separator is illustrated in *Figure 7-13*. Air is directed into this unit in a manner that creates a swirling motion. Centrifugal force throws the

Figure 7-13 — Centrifugal-type moisture separator.

moisture particles against the wall, where they drain to the bottom.

A baffle-type separator is illustrated in *Figure 7-14*. In this unit, the air is subjected to a series of sudden changes in direction that result in the heavier moisture particles striking the baffles and walls, then draining to the bottom.

Figure 7-14 — Baffle-type moisture separator.

3.5.8 Dryers

Some compressed air supplies require dryers that ensure removal of all moisture that might otherwise condense in air lines, air-powered tools, or pneumatic instruments. Small amounts of moisture can cause damage to equipment from corrosion, freezing, and water hammer and can result in malfunctions of instruments and controls. The cost of dryers is often justified by the reduction in maintenance costs, production time lost in blowing down piping, and compressed air lost during blow down.

There are three basic designs of dryers: two absorption types and a condensation type. One type of absorption unit consists of two towers, each containing an absorbent material. Reactivation is accomplished by means of electric or steam heaters embedded in the absorbent material or by passing dried process air through it.

Another type of absorption unit consists of a single tank or tower containing a desiccant (drying agent) that dissolves as it absorbs moisture from the air and drains from the unit with the condensate. The drying agent must be replenished periodically.

The third type removes moisture from the air by condensation through the use of a mechanical refrigeration unit, or where available, cold water. Inlet air passes over cold coils, where moisture is condensed from the air and is drained from the unit by a trap. This process is illustrated in *Figure 7-15*.

Figure 7-15 — Flow process of refrigeration-type air dryer.

3.5.9 Receivers

Air receiver tanks in compressed air plants act as surge tanks to smooth the flow of air from the action of the compressor to discharge. They collect excessive moisture that may condense from the cooled air and provide a volume of air necessary to operate the pressure control system. A typical air receiver is shown in *Figure 7-16*. Related components include a relief valve, pressure gauge, drain valve, service valve, and inspection opening.

Figure 7-16 — Air receiver.

3.5.10 Lubrication

Compressors must receive adequate lubrication using clean oil of characteristics recommended by the compressor manufacturer. The manufacturer will usually specify oil requirements by characteristics, such as viscosity at one or more temperatures, pour point, flash point, and in some cases, by specific brands.

Typical compressor cylinder oils will have the following characteristics:

- Flash point, 350°F minimum
- Viscosity at 210°F, 45 minimum to 90 maximum
- Pour point, +35°F maximum
- Neutralization number, 0.10 maximum
- Conradson carbon residue, 2.0% maximum

Where cylinder lubrication is separate from frame and bearing lubricants, a modified set of characteristics may be specified. Synthetic oils must conform to the manufacturer's requirements and must be used with care because many synthetic oils may cause swelling and softening of neoprene and certain rubbers, or may not be compatible or separable from water.

Some special considerations for lubricants include the provision of a lubrication oil heater to ensure adequate viscosity during cold weather start-up. High compressor discharge temperatures require lubrication flows and characteristics that still lubricate when subjected to 300°F or higher discharge air temperature conditions. Finally, oil injection or oil-flooded compressors need adequate oil flow and characteristics to maintain lubrication of temperatures within the cylinders or screws.

A typical lubrication arrangement is shown in *Figure 7-17*.

Figure 7-17 — Typical pressure lubrication system.

3.5.11 Discharge Pulsation

Reciprocating compressor discharge lines are subject to pulsations caused by the compressor-forcing frequency. The pulsations set up a resonant frequency in the discharge piping, and the resulting vibration amplification will cause noise, support damage, and piping damage. There is no single solution to this problem, but some specific guidelines will be discussed below.

Pulsation dampeners serve as pulsation and noise mufflers by providing acoustical chambers with the dampener. Manufacturers generally provide dampeners to a specified discharge pulsation peak of ± 2 percent of line pressure. *Figure 7-18* shows several typical pulsation dampeners. These units should be used whenever reciprocating and centrifugal compressors serve the same compressed air main because the pulsations of the reciprocating compressor can transmit to and disturb the operation of the centrifugal compressor. Pulsation dampeners may not completely solve downstream resonance, but they will reduce the vibration amplitudes.

Figure 7-18 — Pulsation dampener.

Several other ways to decrease noise and amplification caused by discharge pulsation are available. Surge chambers can be used to change the equivalent length of the piping and increase the pulse-absorbing volume of the pipe. A surge chamber can be as simple as an increased diameter of discharge piping near the compressor discharge. An orifice plate or plates may be installed in conjunction with surge chambers to change the acoustical resonant frequency of the piping system. Piping support is also important at the compressor. The piping must not only be supported from top or bottom but also have lateral support. When piping is large, spring-loaded two-way lateral supports to absorb vibration are needed.

3.5.12 Controls

Compressor control systems generally include one or more controlling devices, such as safety controls, speed controls, and capacity controls. Such devices function in the system to regulate the output of the compressor as it meets the demand for compressed air.

On some small compressors, the simple Bourdon tube-type pressure switch serves as a controller by actuating the prime mover on and off over a predetermined pressure range. Compressors that are more complex require control systems that load and unload the compressor as air demands change. The constant speed type of controller is used with many compressors. It decreases or increases compressor capacity in one or more steps by the use of unloading devices, while allowing the prime mover speed to remain constant. Another type, referred to as the dual control, is a combination of the constant speed and an automatic start-stop control. It permits constant speeds when demands are continuous and an automatic stop or start when demands are light. There is still another system that enables the prime mover to idle and compressor suction valves to remain open when air pressure reaches a set maximum. As the pressure drops below a set minimum, the prime mover speed is increased, suction valves are closed, and air is compressed.

Generally, control systems include unloading devices that function to remove all but the friction loads on compressors; thus, starting is unaffected by compression loads. Various types of unloading devices are discussed below.

The inlet-valve-type unloader holds the inlet valve open mechanically during both the suction and compression strokes, thereby preventing compression. *Figure 7-19* illustrates a common inlet valve unloader. The unloader is positioned above the inlet valve. When air pressure rises to the preset unloading pressure, a pressure switch operates a solenoid unloader valve, which opens and allows receiver pressure to the inlet valve unloader. The pressure from the receiver, acting on the diaphragm of the inlet valve unloader, forces the yoke fingers against the inlet valve, holding it open. The intake air is pushed back out the inlet valve on the compression stroke so no compression takes place.

Figure 7-19 — Inlet valve unloader.

Figure 7-20 illustrates the thin plate, low-lift type of compressor valve. Most compressors use this type of valve.

Figure 7-20 — Thin plate, low lift, compressor valve assembly.

The use of a pressure switch with a solenoid unloader valve on each cylinder provides a step or sequenced capacity control. *Figure 7-21* illustrates a flow diagram of a five-step capacity control system applied to a two-stage, four-cylinder, double-acting, reciprocating compressor. Assuming that the compressor in the figure is required to maintain a pressure of 92 to 100 psi, the pressure switches should be set to load and unload as follows: switch 1, load at 93 psi and unload at 97 psi; switch 2, load at 94 psi and unload at 98 psi; switch 3, load at 95 psi and unload at 99 psi; and switch 4, load at 96 psi and unload at 100 psi. As the receiver pressure reaches the high limit of each pressure switch, 25 percent of the compressor capacity will unload. As receiver pressure falls to the low setting of each switch, 25 percent of the compressor capacity will load. Pressure switch 1 will therefore unload 25 percent of the compressor capacity at 97 psi and will load 25 percent at 93 psi, and so forth. As receiver pressure fluctuates between 93 and 100 psi, the compressor capacity varies in five steps: full, 75 percent, 50 percent, 25 percent, and zero capacity.

The compressor illustrated in *Figure 7-21* operates on the following principle: When it is started, air pressure switches are closed and the solenoids in the unloader valves become energized so that receiver pressure cannot enter the unloading lines, and compression is permitted. As the receiver pressure builds up and reaches 97 psi, pressure switch 1 breaks contact, de-energizing unloader 1, and allowing 97 psi receiver air to enter control line 1, actuating the inlet valve unloader. Twenty-five percent of the compressor has become unloaded and compression has reduced from full to 75-percent capacity. Control lines 2, 3, and 4 will operate in the same way as receiver pressure increases. At 100 psi, all cylinders will be unloaded. Air compression ceases, but the compressor continues to run under no load. As air is drawn off from the receiver, the pressure begins to drop. When the pressure falls to 96 psi, pressure switch 4 makes contact and energizes unloading valve 4, which cuts off receiver pressure from the inlet unloader and vents the unloader pressure to the atmosphere. The inlet valve unloader releases the inlet valve and normal compression takes place, loading the compressor to 25-percent capacity. If the demand for air increases and receiver pressure continues to decrease, control lines 3, 2, and 1 will load in sequence.

Figure 7-21 — Flow diagram of a five-step capacity control system applied to a two-stage, four-cylinder, double-acting, reciprocating compressor.

Another method of unloading a compressor is by the use of clearance pockets built into the cylinders. Normal clearance is the volume at the end of the piston and under the valves when the piston is at the end of the compression stroke. *Figure 7-22* shows an air cylinder with clearance pockets and clearance valves used with a five-step clearance control. Each end of the cylinder is fitted with two clearance pockets that are connected with or cut off from the cylinder by air-operated clearance valves. A regulated device, not shown, which is operated by receiver pressure, uses pilot valves to open and close the clearance pocket valve in the proper sequence. Each clearance pocket can hold one-quarter of the air compressed by the cylinder in one stroke. When both pockets at the end of the cylinder are open, no air is taken into that end of the cylinder. *Figure 7-23* illustrates the operation of clearance pockets under five-step clearance control.

Figure 7-22 — Clearance pockets.

Figure 7-23 — Five-step clearance control.

3.6.0 Prime Movers

Prime movers for compressors can be electrical, gasoline, or diesel driven. This section will address electrical prime movers only. Gasoline and diesel-driven prime movers are normally the responsibility of the Construction Mechanic. Several types of electric motors can be used to drive compressors: induction, synchronous-wound motor, and direct current (dc) motors.

Although electric motor drive is available for compressors of almost any capacity, an induction motor best drives certain types of machines; others may be driven by a synchronous motor. Generally, cost will rule out synchronous motors except in unusual cases. Direct current motors are seldom used.

The type of connection that is used between the motor and compressor may further identify motor-driven compressors. Any one of the following types of drives may be used: belt, direct connected, or speed reduction gears.

Induction motors can be used to power single-acting, reciprocating compressors ranging from fractional horsepower up to approximately 300 horsepower at a speed of 1,800 rpm. Speeds of 1,200 and 900 rpm and lower are sometimes used in higher horsepower applications. When sizing a motor, you must allow for belt or drive losses of power.

Caution must be exercised when large belted motors are used; manufacturers' recommendations should be applied. Most motors that are belted to compressors are rated as normal starting torque, low-starting current motors. Belt selection should be based on a continuous operation rating of at least 125 percent of motor size with 150 percent preferred. Other compressors that start under load may require motors rated as high-start torque, low-starting current. Consideration should be given to compressor inertia and load to avoid lengthy acceleration time. Whenever possible, it is best to arrange the compressor to be unloaded during start-up.

An induction motor may drive a reciprocating compressor with a speed reduction gear placed between the motor and compressor. This permits the use of a higher speed with a less costly motor. Gear-driven compressors should have the flywheel or inertia effect carefully checked. Couplings should have enough elasticity and dampening to allow for torque and current pulsations. Without this consideration, changes in torque caused by load variations or loading and unloading of a compressor could result in drive and motor damage.

4.0.0 DISTRIBUTION SYSTEMS

The development of a distribution system is dependent upon a combination of factors, such as location and size of each service, time rate demand of larger services, and concurrence or demand factor of larger services.

4.1.1 Types of Air Distribution Systems

The more common types of distribution systems or patterns (*Figure 7-24*) and their prime advantages are as follows:

- Radial, one-way system—used for isolated or individual service or where special requirements dictate a single path.
- Loop system—used for a closed route, such as throughout a building. The two-directional flow capacity represents an economical way to provide constant pressure to all services and permits selective isolation when necessary.
- Parallel system—used to provide dual service source to ensure at least one source will be available at all times.

Figure 7-24 — Types of air distribution systems.

4.2.0 Sizing Distribution Systems

Compressed air distribution systems are sized mainly by calculating the friction loss to be expected from piping, fittings, and valves as well as various accessories you may install.

Pipe diameters are determined from commercially available products, such as copper, stainless steel tubing, or steel piping. As contained pressure increases, the pipe wall thickness must increase and interior diameters decrease. This affects friction pressure loss; it should not exceed 15-percent pressure loss.

When you are determining total friction loss for a distribution system, the total length of the system piping plus the equivalent length of each fitting, valve, or device is summed to produce an equivalent hydraulic length. The equivalent lengths of fittings, valves, and other devices can be determined from *Table 7-3*. Friction loss in air hoses may be taken from *Table 7-4*.

Table 7-3 — Representative Equivalent Length in Pipe Diameters (L/D) of Various Valves and Fittings.

Description of Product				Equivalent Length in Pipe Diameters (L/D)
Globe Valves	Stem Perpendicular to Run	With no obstruction in flat, bevel, or plug-type seat With wing or pin-guided disk	Fully open Fully open	340 450
	Y-Pattern	(No obstruction in flat, bevel, or plug-type seat) —With stem 60 degrees from run of pipe line —With stem 45 degrees from run of pipe line	 Fully open Fully open	 175 145
Angle Valves		With no obstruction in flat, bevel, or plug-type seat With wing or pin guided disk	Fully open Fully open	145 200
Gate Valves	Wedge, Disk, Double Disk, or Plug Disk		Fully open Three-quarters open One-half open One-quarter open	13 35 160 900
	Pulp Stock		Fully open Three-quarters open One-half open One-quarter open	17 50 260 1200
Conduit Pipe Line Gate, Ball, and Plug Valves			Fully open	3**
Check Valves	Conventional Swing Clearway Swing Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern Angle Lift or Stop In-Line Ball		0.5†. . .Fully open 0.5†. . .Fully open 2.0†. . .Fully open 2.0†. . .Fully open 2.5 vertical and 0.25 horizontal†. . .Fully open	135 50 Same as Globe Same as Angle 150
Foot Valves with Strainer		With poppet lift-type disk With leather-hinged disk	0.3†. . .Fully open 0.4†. . .Fully open	420 75
Butterfly Valves (8-inch and larger)			Fully open	40
Cocks	Straight-Through	Rectangular plug port are equal to 100% of pipe area	Fully open	18
	Three-Way	Rectangular plug port are equal to 80% of pipe area (fully open)	Flow straight through Flow through branch	44 140
Fittings	90-Degree Standard Elbow 45-Degree Standard Elbow 90-Degree Long Radius Elbow			30 16 20
	90-Degree Street Elbow 45-Degree Street Elbow Square Corner Elbow			50 26 57
	Standard Tee	With flow through run With flow through branch		20 60
	Close Pattern Return Bend			50
**Exact equivalent length equal to the length between flange faces or welding ends		†Minimum calculated pressure drop (psi) across valve to provide sufficient flow to lift disk fully		

Table 7-4 — Loss of Air Pressure in Hose Caused by Friction

Pulsating flow															
Size of hose, coupled at each end (in.)	Gage pressure at line (lb)	Free air (cfm)													
		20	30	40	50	60	70	80	90	100	110	120	130	140	150
		Loss of pressure (psi) in 50 ft. lengths of hose													
½	50	1.8	5.0	10.1	18.1										
	60	1.3	4.0	8.4	14.8	23.4									
	70	1.0	3.4	7.0	12.4	20.0	28.4								
	80	0.9	2.8	6.0	10.8	17.4	25.2	34.6							
	90	0.8	2.4	5.4	9.5	14.8	22.0	30.5	41.0						
	100	0.7	2.3	4.8	8.4	13.3	19.3	27.2	36.6						
	110	0.6	2.0	4.3	7.6	12.0	17.6	24.6	33.3	44.5					
¾	50	0.4	0.8	1.5	2.4	3.5	4.4	6.5	8.5	11.4	14.2				
	60	0.3	0.6	1.2	1.9	2.8	3.8	5.2	6.8	8.6	11.2				
	70	0.2	0.5	0.9	1.5	2.3	3.2	4.2	5.5	7.0	8.8	11.0			
	80	0.2	0.5	0.8	1.3	1.9	2.8	3.6	4.7	5.8	7.2	8.8	10.6		
	90	0.2	0.4	0.7	1.1	1.6	2.3	3.1	4.0	5.0	6.2	7.5	9.0		
	100	0.2	0.4	0.5	1.0	1.4	2.0	2.7	3.5	4.4	5.4	6.6	7.9	9.4	11.1
	110	0.1	0.3	0.4	0.9	1.3	1.8	2.4	3.1	3.9	4.9	5.9	7.1	8.4	9.9
1	50	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2.0	2.6	3.5	4.9	7.0	…	…
	60	0.1	0.2	0.3	0.4	0.6	0.8	1.2	1.5	2.0	2.6	3.3	4.2	5.5	7.2
	70	…	0.1	0.2	0.4	0.5	0.7	1.0	1.3	1.6	2.0	2.5	3.1	3.8	4.7
	80	…	0.1	0.2	0.3	0.5	0.7	0.8	1.1	1.4	1.7	2.0	2.4	2.7	3.5
	90	…	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.4	2.8
	100	…	0.1	0.2.2	0.2	0.4	0.5	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4
	110	…	0.1		0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.8	2.1
1-1/4	50	…	…	0.1	0.2	0.2	0.3	0.4	0.5	0.7	1.1	…	…	…	…
	60	…	…	…	0.1	0.2	0.3	0.3	0.5	0.6	0.8	1.0	1.2	1.5	…
	70	…	…	…	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.7	0.8	1.0	1.3
	80	…	…	…	…	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0
	90	…	…	…	…	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.3	0.7	0.8
	100	…	…	…	…	…	0.1	0.2	0.2	0.3	0.4	0.4	0.2	0.6	0.7
	110	…	…	…	…	…	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
1-1/2	50	…	…	…	…	…	0.1	0.2	0.2	0.2	0.	0.3	0.4	0.5	0.6
	60	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5
	70	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.3	0.4
	80	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.4
	90	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3
	100	…	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2
	110	…	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2
(1 inch = 25.4 mm, 1 CFM = 0.0283 mm^3/min, 1 psi=6.90 kPA, 50 feet = 15.2 m)															

4.3.0 Layout Details

When installing compressed air systems, you must follow seven basic guidelines just as you must consider basic guidelines when installing any other type of piping or drainage system.

Compressed air lines should be installed as level as practical with a slight pitch in the direction of airflow. This pitch is generally placed at 3 inches per 100 feet of piping. In cases when pipes must be pitched upward causing condensate to flow against the flow of air, the pitch upward must be 6 inches or greater per 100 feet, and the piping size should be increased one pipe diameter.

The layout of the piping systems should always allow for the removal of dirt, water, oil, or other foreign material, which can accumulate over long periods of time. Because of this, pockets should be avoided and, where necessary, low points should be provided with drip legs. In addition to providing low points to drain foreign material from the system, the prevention of carryover of this material into branch lines is necessary. Carryover into branch lines can be prevented by making connections from the top of the distribution mains.

Piping must be placed with sufficient flexibility to prevent excessive strain or distortion caused by thermal expansion or sudden changes in pressure. By properly placing pipe supports, as shown in *Table 7-5*, movement of pipe can be accounted for. In addition, piping should be supported at all changes in direction and load concentrations, such as heavy valves. There are many other considerations in the layout of compressed air systems, which are beyond the scope of this manual. Refer to NAVFAC DM 3-5, *Compressed Air and Vacuum Systems,* for further information.

Table 7-5 — Maximum Span for Pipe.

Diameter (inches)	Standard Weight Steel Pipe 40S	Copper Tube Type K
1/2	5’-0”	3’-9”
3/4	5’-9”	4’-3”
1	6’-6”	5’-0”
1-1/2	7’-6”	5’-9”
2	8’-6”	6’-6”
2-1/2	9’-3”	7’-3”
3	10’-3”	7’-9”
3-1/2	11’-0”	8’-3”
4	11’-6”	9’-0”
5	12’-9”	10’-0”
6	13’-9”	10’-9”
8	15’-6”	
10	17’-0”	
12	18’-3”	
(1 inch = 25.4 mm, 1 foot = 0.3048 m)		

4.4.0 Test Procedures

After installation, the compressed air system must undergo testing. Generally, all piping and pressurized components should be tested at 150 percent of maximum working pressure. When testing, use clean, dry air or nitrogen. The system should be held at test pressure without loss for at least 4 hours.

5.0.0 MAINTENANCE REQUIREMENTS

As with any system, preventive maintenance conducted on a scheduled basis is an important factor in providing reliable service. Breakdown maintenance causes interruption in services that prove costly to the Navy. It also requires more extensive repair to system components. As a senior Utilitiesman, you must be able to coordinate maintenance efforts. An understanding of the maintenance required for each component will assist you in carrying out this type of duty.

5.1.0 Prime Mover Maintenance

Diesel, gasoline, and electrical prime movers can drive air compressors. These power-producing items of equipment require the same maintenance as any prime mover used to drive other equipment encountered by the Utilitiesman.

Establish a definite lubrication schedule. Normal oil levels in engines must be maintained at all times, using lubricants recommended by the manufacturer. The frequency of oil changes depends on the severity of service, atmospheric dust, and dirt. These factors also affect the filter and in the case of electrical motors, the need for regular lubrication of bearings.

Daily operator maintenance prevents most breakdowns. Following the suggested maintenance requirements of the manufacturer helps to reduce downtime caused by prime mover failure.

5.2.0 Air Compressor Maintenance

Taking into consideration the many types of air compressors the Utilitiesman may encounter in the field, it is impossible to cover all the maintenance requirements of air compressors in this section. Several common factors do apply to all compressors.

The establishment of a lubrication schedule is at the top of the list for ensuring trouble-free operation of compressors. A definite schedule and assignment of responsibility for maintenance personnel to follow are required. The manufacturer’s manual establishes minimum requirements that should be followed.

Bearings, packing, seals, and clearances between moving parts must be within the manufacturer’s specifications and be included on the maintenance schedule. Many compressors allow for adjustment, while others require overhaul when clearances are exceeded.

Visual inspections for dust, dirt, or leaks provide early detection of possible maintenance requirements. Operator maintenance, when conducted properly, can help you catch and correct potential problems early. Ensure all of your operators know how to operate the equipment. In all cases, you should use the manufacturer’s manual when making repairs or adjustments.

5.3.0 Auxiliary Equipment Maintenance

All auxiliary equipment that services the air compressor or is serviced by the compressor requires periodic scheduled maintenance. Air filters should be checked and cleaned at least once a month. Silencers should be checked twice a year for corrosion, paint, and gasket damage. Intercoolers and aftercoolers must be inspected for scale buildup in hub leaks. In general, all auxiliary equipment must be placed on a schedule for inspection and periodic maintenance.

5.4.0 Distribution System Maintenance

Distribution systems require a minimum of maintenance. Checking valve operation and hose connecters, draining condensation (manual or automatic), protecting piping from damage, and repairing leaks are the most common considerations in a maintenance plan.

Procedures applicable to the preventive maintenance inspections for compressed air plants can be found in NAVFAC MO 209, *Steam, Hot Water, and Compressed Air* and NAVFAC P- 717, *Preventive/Recurring Maintenance Handbook.* For more involved technical maintenance, such as overhauls, make sure competent personnel are trained before they are needed. Again, follow the manufacturer's instructions to repair any air compressor component.

Summary

You should now be more familiar with air compressor systems, their design, and the components that make up a system. You should now be capable of identifying and directing the proper construction techniques for installation of fittings and components. You should also have an understanding of the maintenance of previously installed systems. The chapter also discussed air quality requirements. Remember to always follow all safety requirements and use only the recommended maintenance techniques called for in the manufacturers' operator and repair manuals.

Review Questions (Select the Correct Response)

1. Medium-pressure systems provide compressed air from 126 psig to what maximum pressure?

   A. 299 psig
   B. 325 psig
   C. 399 psig
   D. 425 psig

2. High-pressure systems provide compressed air within what pressure range?

   A. 400 psig to 4,000 psig
   B. 400 psig to 6,000 psig
   C. 425 psig to 4,000 psig
   D. 425 psig to 6,000 psig

3. What type of shop or laboratory requires up to 6,000 psig of compressed air?

   A. Torpedo workshop
   B. Testing laboratory
   C. Wind tunnel
   D. Ammunition depot

4. Of the following grades of commercial compressed air, which one is the most pure?

   A. B
   B. D
   C. F
   D. H

5. A refrigerant dryer with a dew point at what maximum temperature should be used to remove moisture to meet air quality requirements for instrument and control air?

   A. 20°F
   B. 30°F
   C. 35°F
   D. 40°F

6. With pressure in excess of 400 psig, oil causes what compression phenomenon to occur?

   A. Burnout
   B. Blowout
   C. Combustion
   D. Recycling

7. In a reciprocating compressor, what are the three compression cycle phases?

   A. Intake, multistage pressurization, discharge
   B. Intake, impeller rotation, compression
   C. Intake, single-stage pressurization, discharge
   D. Intake, compression, discharge

8. In a W-type compressor, there are a total of how many cylinders in the (a) first and (b) second stages?

   A. (a) One (b) one
   B. (a) Two (b) two
   C. (a) Two (b) one
   D. (a) One (b) two

9. What type of compressor has two mating rotating screws, one locked and one grooved, to provide the driving force?

   A. Rotary
   B. Reciprocating
   C. Helical
   D. Centrifugal

10. When the load is reasonably constant, what type of compressor is intended for near-continuous industrial air service?

   A. Rotary
   B. Reciprocating
   C. Helical
   D. Centrifugal

11. When placed through a parapet roof, you should extend air intakes what approximate distance above the roof?

   A. 6 to 8 feet
   B. 8 to 10 feet
   C. 10 to 12 feet
   D. 12 to 14 feet

12. Of the following types of intake filters, which one(s) is/are best suited for use in locations where dust is prevalent in the atmosphere?

   A. Oil bath only
   B. Viscous impingement only
   C. Oil bath and viscous impingement
   D. Oil injected and centrifugal lubricated

13. The intercooler in a multistage compressor serves what purpose?

A. To lower the temperature of discharged air
B. To remove condensation and impurities from the air flow
C. To reduce the temperature of compressed air between each stage
D. To add cool air at the beginning of each cycle

14. Aftercoolers are used in compressor discharge lines for which of the following reasons?

A. To permit the use of larger discharge pipes
B. To lower the air discharge temperature only
C. To facilitate condensation and removal of moisture only
D. To lower the air discharge temperature and facilitate condensation and removal of moisture

15. Separators are used in conjunction with aftercoolers for what purpose?

A. To remove water and oil from the compressed air
B. To reduce working pressure in the distribution lines
C. To separate non-condensable gases from the compressed air
D. Each of the above

16. Compressor cylinder oil should have what minimum flash-point temperature?

A. 325°F
B. 350°F
C. 375°F
D. 400°F

17. Pulsation dampeners serve as pulsation and noise mufflers due to what feature within the dampener?

A. An injector
B. A vibration amplifier
C. An acoustical chamber
D. A sound resonator

18. The inlet valve unloading device functions mechanically to remove compression loads from the prime mover by _.

A. disengaging the drive clutch.
B. holding the inlet valve open during the suction and compression strokes.
C. opening the cylinder relief valve.
D. holding the inlet valve closed during the compression stroke.

19. The volume of air that can be released from a compressor cylinder into one clearance pocket is equal to what percentage of the cylinder volume?

    A. 25%
    B. 50%
    C. 75%
    D. 100%

20. When sizing a motor, you should take which of the following factors into consideration?

    A. Availability of a dc power source
    B. Availability of unleaded fuel
    C. Compressor size in rpm
    D. Belt or drive losses of power

21. Belt selection for a large motor should be based on what ideal percentage of motor size?

    A. 100%
    B. 125%
    C. 150%
    D. 175%

22. What type of air distribution system is used for isolated service or in situations where special requirements dictate a single path?

    A. Parallel
    B. Loop
    C. Radial, one-way
    D. Radial, two-way

23. What type of closed-route air distribution system can be used throughout a building?

    A. Parallel
    B. Loop
    C. Radial, one-way
    D. Radial, two-way

24. Normally, a compressed air distribution system is sized by calculating what factor?

    A. Friction loss
    B. Pipe size
    C. Compressor size
    D. Oil loss

25. In situations where compressed air pipes are pitched upward causing condensate to flow against the flow of air, the minimum pitch of how many inches per hundred feet should be allowed?

A. 10
B. 2
C. 6
D. 4

26. When testing a system with dry air or nitrogen, you should use what percentage of maximum working pressure for a minimum of 4 hours?

A. 75%
B. 100%
C. 125%
D. 150%

27. What maintenance program prevents most major prime-mover breakdowns?

A. Manufacturer
B. Operator
C. Equipmentman
D. Construction Mechanic

28. When a manufacturer's recommended tolerance level between two moving parts is exceeded on a compressor, you must perform which, if any, of the following actions?

A. A component adjustment only
B. An equipment overhaul only
C. A component adjustment or an equipment overhaul
D. None of the above

29. Air filters should be checked and cleaned a minimum of how often?

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

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.

Compressed Air and Vacuum Systems, NAVFAC DM-3.5, Naval Facilities Engineering Command, Alexandria, VA , 1983.

Maintenance of Steam, Hot Water and Compressed Air Distribution Systems, NAVFAC MO-209, Naval Facilities Engineering Command, Alexandria, VA, 1989.

Operation and Maintenance of Air Compressor Plants, NAVFAC MO-206, 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 8

Boilers

Topics

To hear audio, click on the box.

Overview

As a Utilitiesman (UT), you will be responsible for the general management of a boiler plant. You will be also be asked to supervise personnel in the installation, operation, and maintenance of boilers. This chapter describes the installation, plant operations, and maintenance of the scotch marine boiler, which is the most common type of boiler in the NCF. This chapter provides insight into many skills that you must develop to be a proficient boiler plant supervisor/manager.

Objectives

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

1. Describe the installation procedures associated with boilers.
2. Describe boiler plant operations.
3. Describe the maintenance procedures associated with boilers.

Prerequisites

None.

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

Air Conditioning and Refrigeration	↑	U
Duct and Ventilation Systems		T
Boilers		
Compressed Air Systems		A
Sewage Treatment and Disposal		D
Water Treatment and Purification		V
Fire Protection Systems		A
Interior Water Distribution and Interior Waste Systems		N C
Plumbing Planning and Estimating		E
Contingency Support		D

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.

1.1.1 INSTALLATION of BOILERS

“Scotch marine” is a generic term that refers to a boiler with a furnace, which forms an integral part of the boiler assembly. This configuration allows for compact construction requiring only a small space for the capacity produced. Scotch marine boilers are package units consisting of a pressure vessel, burner, controls, draft fan, and other components assembled into a fully factory fire-tested unit. They are engineered units equipped for quick installation and connection to services.

When preparing to install a boiler, you should consider the following three basic factors:

- Site location
- Accessories
- Fittings

Proper installation of a boiler helps to ensure successful operation. Always refer to the manufacturer’s manuals, and follow your prints and specifications closely. By being thorough in your planning and execution of plans, you can prevent many future problems for operators and maintenance personnel.

1.1.0 Site Location

Give careful consideration to site location for the construction of a boiler plant. Primarily, the cost in materials, manpower, and equipment is the most important factor affecting this selection. These costs can usually be reduced by locating the plant site as close as possible to the largest load-demand facility, such as a galley or laundry.

1.1.1 Location

When you are selecting a site for boiler installation, you must consider the availability of the following:

Water

Electricity

Fuel

Natural site drainage

Attempt to avoid high pedestrian and vehicle traffic areas for safety reasons. Another item you should consider is noise level. Noise pollution may cause discomfort for personnel, especially if the site being considered is adjacent to a berthing area.

These are factors that you must consider when you become involved in selecting a boiler plant site. Each situation may include all, part of, or more than these factors. You must look at each installation and evaluate the needs of that job.

1.1.2 oiler Foundation

Constructing the foundation or platform that a boiler sits on requires skilled engineering and development. Follow the manufacturer’s specifications. Boilers may vary in wet weight from 1.5 tons to more than 20 tons. A substantial foundation that can withstand the weight and absorb the vibration is essential.

Reinforced concrete slabs with runners provide for placing and anchoring the boiler. The runners should provide a level, uniform support and be of sufficient height to allow for maintenance and the installation of piping under the boiler. A raised platform also provides easier access for boiler room cleanup.

Generally, a sump in the slab between the runners provides a catchment area for boiler blow-down or draining of the boiler. This sump drains from the building to a suitable dispersal point.

1.1.3 Boiler Room

When considering the requirements of sheltering a boiler, you must ensure there is enough room for the boiler and all of the accessory equipment. This accessory equipment may include condensate tanks and pumps, chemical feeders, water makeup tanks and feeders, and blow-down tanks.

The boiler room must also be large enough to allow for boiler maintenance, for retubing, and for removing and replacing the boiler. The tube length of a boiler may be from 2 feet 6 inches to at least 10 feet, and possibly longer. To simplify the removal of the tubes, ensure the boiler room is long enough or has a door located behind the boiler. The most important source you need to check is the manufacturer's specifications, which will provide you with the proper dimensions for locating the boiler.

Fresh air inlets and louvers allow fresh air to enter and move across the boiler area. This fresh air entering the boiler room removes excess heat and provides adequate makeup air for combustion.

When planning for boiler room construction, you must always consider boiler requirements, maintenance requirements, and manufacturer's recommendations.

1.2.0 Accessories

As a boiler plant supervisor it is important that you know the special requirements for boiler accessory equipment. Select the boiler accessory number in *Figure 8-1* to view the special requirements for that accessory.

Figure 8-1 — Boiler accessory equipment.

	Item	Special Requirement
1	Boiler.	N/A
2	Main Steam Stop.	Must be outside yoke rising spindle type if it is over 2”. This allows the operator to distinguish the position of the valve by sight.
3	Guard Valve.	When two or more boilers are connected to a common header, the steam connection from a boiler with a manhole opening must be fitted with a main steam-stop and a guard valve.
4	Daylight Drain Valve.	When both eh main steam-stop and guard valves are required, install a daylight drain valve.
5	Main steam line.	Pitch horizontal piping 1/4” per 10’. Do not use galvanized piping.
6	Root Valve.	Normally of gate-valve design, fully opened or closed.
7	Pressure Regulating Valve (PRV).	N/A
8	Steam Trap.	Install traps with unions on both sides for easy replacement. Inlet and outlet piping of trap needs to be equal or larger than trap connections.
9	Drip Legs.	Place at intervals of not mover 200’ for horizontally pitched pipe and at intervals of not over 300’ for buried or inaccessible piping.
10	Temperature Regulating Valve (TRV).	When the valve throttles to a partially closed position, the pressure in the equipment can easily go into a vacuum. This is caused by condensing steam and it holds condensate in the equipment. Use a vacuum breaker to solve the problem.
11	Heat Exchanger.	N/A
12	Strainer.	N/A
13	Condensate Line.	Pitch lines toward boiler 1/4” per 10’. Do not use galvanized piping.
14	Condensate/Makeup Tank.	N/A
15	Feed Pump.	Pump must be capable of pumping higher pressures than that of the boiler pressure.
16	Feedwater Pipe.	Place relief valve, check valve, and stop valve in the feedwater pipe.
17	Relief Valve.	Relief valve opens gradually at a set pressure. Safety valves open fully at a set pressure. Do not use a relief valve in place of a safety valve.

1.2.1 Fittings

As a boiler plant supervisor, you must also know the American Society of Mechanical Engineers (ASME) requirements for boiler fittings. Select a boiler fitting name in *Figure 8-2* to view the ASME requirements for that fitting. *Figure 8-3* shows information applicable to a water column.

Figure 8-2 — Boiler fittings.

	Item	Special Requirement
1	Air Cock	Open valve when a boiler is initially filling with water during steam buildup and when emptying a boiler.
2	Water Column	Column must be connected to the steam and water space with a minimum size pipe and fittings of 1” and that each right angle turn be made with a cross to aid in inspection and cleaning.
3	Water Column Blowdown Line and Valve	Minimum permissible size for the blowdown piping and valve is 3/4".
4	Gauge Glass	Minimal size of gauge glass is 1/2". Boilers operating at 400 psi of pressure or greater require two gauge glasses and the lowest visible portion of the gauge glass must be at least 2” above the lowest permissible water level.
5	Gauge Glass Shutoff Valves	Gauge glass shutoff valves have a minimal size of 1/2". Some valves may be fitted with an automatic shutoff device, usually consisting of a nonferrous ball that functions to secure or prevent the escape of steam or hot water should the gauge glass break.
6	Glass Blowdown Line and Valve	When under pressure and the gauge glass blowdown line is opened and then closed, the water level should return promptly. If level returns slowly, a partial blockage may be present.

7	Try Cocks	Boilers not exceeding a diameter of 36” or heating surface of 110 square feet need only two try cocks and one gauge glass. Boilers that exceed the above diameter and heating surface require three try cocks regardless of the number of gauge glasses.
8	Pressure Gauge	Dial on gauge is graduated so it reads approximately twice the pressure at which the safety valve is set to open. Test every 6 months or whenever you doubt the accuracy of the gauge.
9	Fusible Plugs	Must be replaced every year.
10	Bottom Blowdown Piping	Minimum size blowdown and fittings for boilers having 100 square feet or less of heating surface require 3/4" pipe and fittings. If the boiler is in excess of 100 square feet, 1” is the minimum and 2 1/2" is the maximum.
11	Bottom Blowdown Valves	Every boiler must have one slow opening valve. A slow opening valve requires at least five complete 360° turns between fully opened and closed positions. Boilers exceeding 100 psi must provide two bottom blowdown valves. One may be of the quick closing type. When using the blowdown line, remember to always open the quick closing valve first and secure it last.
12	Safety Valve	No other valve is permitted to be between the safety valve and the boiler. Every boiler must have at least one. If heating surface is over 500 square feet, two safety valves are required. Lift valves monthly to blow away dirt and prevent disk from sticking. Ensure boiler pressure is at 75% of valve pop setting for removal of debris, and ensure the valve will re-seat.
13	Handhole Plates	N/A
14	Manhole Plates	N/A
15	Access Door	N/A
16	Breaching	N/A
17	Stacks	Stacks are required to be high enough to comply with health requirements.

Figure 8-3 — Water column.

1.3.1 Inspecting and Testing Responsibility

The commanding officer of an activity is responsible for ensuring that boilers and unfired pressure vessels installed at their facility are certified. Inspection and testing of boilers and unfired pressure vessels are done by a boiler inspector certified by Naval Facilities Engineering Command (NAVFACENGCOM) and/or licensed by a NAVFACENGCOM Engineering Field Division (EFD). This inspector is on the rolls, except for the following:

- Inspection responsibility has been assigned to the commanding officer of a Public Works Center.
- The commanding officer of a major or lead activity is responsible for doing the maintenance of public works and public utilities at adjacent activities.
- It is impractical to use qualified personnel for such inspections because of the limited work load. In such situations, assistance for inspection services should be obtained by an EFD inspector or an activity inspector located near the requested activity which has qualified perso nnel, or by contract. When assistance is required by the EFD, such assistance is on a reimbursable basis. The requesting activity is responsible for providing the finds to accomplish the inspections.

1.4.1 Frequency of Inspection and Tests

Table 8-1 provides a list of the different types of equipment and the frequency of boiler testing requirements. For frequency and testing requirements concerning unfired pressure vessels, refer to NAVFAC MO-324, *Inspection and Certification of Boilers and Unfired Pressure Vessels*.

Table 8-1 — Boiler Inspection and Test Frequencies.

ITEM	INTERNAL INSPECTION	EXTERNAL INSPECTION AND OPERATION TESTS	HYDROSTATIC TESTS
Boilers, wet or dry lay-up	At least annually. At resumption of active service.	At least annually. At resumption of active service.	Tightness test at resumption of active service.
Boilers, heating and LTW LTW boilers within at least once every 3 years if output is less than 5 million Btuh	At least annually. After any repair or alteration of pressure parts.	At least annually. After any alteration or modification to boilers, control equipment, or auxiliaries.	Strength test at least once every 6 years. Tightness test all other years. Strength test after repair or alteration of pressure parts. Additional times at the discretion of the inspector.
Boilers, power, high pressure, HTW, and MUSE	At least annually. After repair or alteration of pressure parts.	At least annually. After any alteration or modification to boilers, control equipment, or auxiliaries.	Strength test at least once every 3 years. Tightness test all other years. Strength test after repair or alteration. Additional times at the discretion of the inspector.

Notes:

1. Additionally, Mobile Utility Support Equipment (MUSE) boilers and other portable boilers must be inspected externally and internally and certified each time they are moved from one place to another. A MUSE steam coil type of boiler is exempt from annual inspections while in dry or wet lay-up.
2. All manhole and handhole gaskets must be replaced after a strength test unless they are made of non-compressible steel.

1.5.0 Preparing for Inspection

The activity that operates and maintains pressure vessels provides all of the material and labor required to prepare the vessels for inspection. You are responsible for providing the inspector with help during the inspection. An inspection on pressure vessels located on a naval base in a foreign country must comply with NAVFAC MO-324.

1.6.0 Waterside Inspection of Boiler Tubes

Regular waterside inspection of boiler tubes provides the information required to determine the effectiveness of water treatment, maintenance procedures, diagnosis of boiler operating troubles, and an overall condition of the boiler.

Tube failures generally occur in the outer half of the tube nest from external corrosion just above the water drum. When such failures have occurred, either in operation or under hydrostatic test, or when the examination of tubes in the exploring block shows that the tube thickness is less than half the original thickness, complete renewal must be made of all tubes from the center row to the outer row (inclusive) over a fore-and-aft length of the tube bank sufficient to completely cover the affected area. This renewal must be made regardless of the condition of the tubes that were not included in the exploring block.

The existence of slight scattered pitting does not necessarily require the complete retubing of the boiler, even if the thickness of the tubes at some of the pits is less than 50% of the original tube thickness. When pitting is observed, tubes should be split and examined to see whether the pitting is (1) moderately heavy, and (2) general throughout the boiler.

Internal pitting resulting from improper treatment of boiler water is most likely to occur in tubes that receive the most heat (screen tubes, fire row tubes, and so forth) and in areas that are particularly subject to oxygen pitting. In general, oxygen pitting tends to occur most commonly in down-comers, in superheaters, and at the steam drum ends of generating tubes. If active oxygen pits (that is, pits that are still scabbed over, rather than clean) are found when the boiler is inspected, or if oxygen pitting is suspected because of the past operating history of the boiler, one or two tubes should be removed from the areas in which oxygen pitting is most likely to be found.

After the tubes are removed, they should be split and examined. If as many as 25% of the pits are deeper than 50% of the tube wall thickness, and if at least a few of the pits are deeper than 65% of the tube wall thickness, a sample of about 20 tubes from the screen and last rows of the generating bank should be cut. These tubes should be split and examined, and their condition should be evaluated on the same basis as before. If as many as 25% of the pits are deeper than 50% of the wail thickness, and if at least a few are deeper than 65%, the oxygen pitting is considered to be general throughout the boiler and moderately heavy.

With these findings, complete tube renewal should be considered. However, it is possible that complete tube renewal may be postponed in the following cases:

1. The boiler can be successfully cleaned by a chemical cleaning.
2. The boiler can successfully withstand a 125% hydrostatic test.
3. Future boiler water treatment, use of blow-down, and laying-up procedures can be expected to be in strict accordance with NAVFAC requirements.

Before you make a detailed waterside inspection of boiler tubes, you should be familiar with some of the *waterside cavities* and *scars* that can be recognized by visual examination.

Localized pitting is the term used to describe scattered pits on the watersides. These pits are usually—though not always—caused by the presence of dissolved oxygen.

Figure 8-4 — Waterside grooving in a generating tube.

Waterside grooves are similar to localized pits in some ways, but they are longer and broader than the pits. These types of grooves tend to occur in the relatively hot bends of the tubes near the water drum; they may also occur on the external surfaces of the superheater tubes. Some waterside grooves are clean, but most contain islands of heavy corrosion scabs. A typical example of waterside grooving is shown in *Figure 8-4*.

Corrosion fatigue fissures are deep-walled, canyon-like voids. They have the appearance of being corroded rather than fractured, and they may be filled with corrosion products. These fissures occur in metal that has been fatigued by repeated stressing, thus making it more subject to corrosion than it would otherwise be.

General waterside thinning can occur if the boiler water alkalinity is too low over a long period of time, if the boiler water alkalinity is too high, or if acid residues are not completely removed from a boiler that has been chemically cleaned. The greatest loss of metal from general waterside thinning tends to occur along the side of the tube that is toward the flame. The entire length of the tube from steam drum to water drum may be affected. *Figure 8-5* shows general waterside thinning.

Waterside burning may occur if the temperature exceeds about 750°F in plain carbon steel tubes or about 1,000°F in most alloy superheater tubes. The effect of waterside burning is the oxidation of the tube metal to a shiny, black, magnetic iron oxide known as high-temperature oxide.

Waterside abrasion is the term used to describe waterside cavities that result from purely mechanical causes rather than from corrosion. For example, tube brushes or cutters may cause abrasion spots at sharp bends in economizer, superheater, and generating tubes. The surface markings of such abrasions indicate clearly that they result from mechanical abrasion rather than from corrosion.

Die marks appear as remarkably straight and uniform longitudinal scratches or folds on the watersides of the tube. They are the result of faulty fabrication. Die marks may extend for the full length of the tube (*Figure 8-6*). Localized corrosion occurs quite often along the die mark.

Figure 8-5 — General waterside thinning.

Figure 8-6 — Die marks on the waterside of a tube.

Tube corrugation is a peculiar type of heat blistering that occurs when the boiler water is contaminated with oil. Corrugation may consist of closely spaced, small-diameter, hemispherical bulges, as though the tube metal had been softened and then punched from the inside with a blunt instrument. It may also exist as a herring-bone or chevron pattern on the tube wall nearest the flame (*Figure 8-7*). It is not known exactly why oil contamination of the boiler water tends to cause this patterned corrugation.

Figure 8-7 — Tube corrugation resulting from oil on waterside.

1.6.1 Waterside Inspection of Drums and Headers

Whenever a boiler is opened for cleaning and overhaul, the internal surfaces of the drums and headers should be carefully inspected for evidence of cracking. Particular attention must be given to steam drum manhole knuckles, knuckles at corners of drum heads, corners of cross boxes and headers, superheater header vent nozzles, and handhole openings. Any defect found must be recorded in the boiler water treatment log and in the maintenance log. These defects should also be reported to the maintenance office so that appropriate repair action can be taken.

1.6.2 Hydrostatic Tests

Boilers are tested hydrostatically for several different purposes. In each case, it is important to understand why a test is being made and to use—but NOT to exceed—the test pressure specified for that particular purpose. In general, most hydrostatic tests are made at one of the following three test pressures:

1. Boiler design pressure
2. 125% of design pressure
3. 150% of design pressure

Other test pressures may be authorized for certain purposes. For example, a test pressure of 150 psi is required for the hydrostatic test given before a boiler undergoes chemical cleaning. The hydrostatic test at design pressure is required upon the completion of each general overhaul, cleaning, or repair that affects the boiler or its parts and at any other time when it is considered necessary to test the boiler for leakage.

The purpose of the hydrostatic test at design pressure is to prove the tightness of all valves, gaskets, flanged joints, rolled joints, welded joints, and boiler fittings. The test at 125% of design pressure is required after the renewal of pressure parts, after chemical cleaning of the boiler, after minor welding repairs to manhole and handhole seats, and after repairs to tube sheets, such as the correction of gouges and out-of-roundness. The “renewal of pressure parts” includes all tube renewals, rolled or welded, except down-comers and superheater support tubes.

The test at 150% of design pressure is required after welding repairs to headers and drums, including tube sheet cracks and nozzle repairs, after drain and vent nipple repairs, and after renewal or rewelding of superheater support tubes and down-comers. The hydrostatic test at 150% of design pressure is basically a test for strength. This test may be (but is not necessarily) required at the 5-year inspection and test.

Before making a hydrostatic test, rinse out the boiler with freshwater. Using at least 50-psi pressure, play the hose onto all surfaces of the steam drum, the tubes, the nipples, and the headers. Examine the boiler carefully for loose scale, dirt, and other deposits. Be SURE that no tools or other objects are left in the boiler. Remake all joints, being sure that the gaskets and the seating surfaces are clean. Replace the handhole and manhole plates, and close up the boiler.

Gag all safety valves. Boiler safety valves must NEVER, under any circumstances, be lifted by hydrostatic pressure. When gagging the safety valves, do not set up on the gag too tightly or you may bend the valve stems. As a rule, the gags should be set up only hand tight.

Close all connections on the boiler except to the air vents, the pressure gauges, and the valves of the line through which water is to be pumped to the boiler. Be sure the steam-stop valves are completely closed and that there will be no leakage of water through them.

After all preparations have been made, use the feed pump to fill the boiler completely. After all air has been expelled from the boiler, close the air vents and build up the hydrostatic pressure required for the particular test you are making. A hand boiler test pump can be used in building up the hydrostatic test pressure. If you do not have a hand test pump, build up the required test pressure by continuing to run the feed pump after the boiler has been filled. In any case, be very careful that you do not exceed the specified test pressure. After the boiler is full, it takes very little additional pumping to build up pressure.

To avoid complications arising from changes in pressure caused by changes in temperature, you should use water that is approximately the same temperature as the boiler and the fire room. In any case, the temperature of the water must be at least 70°F.

While the hydrostatic pressure is being built up, you should carefully check the boiler for signs of strain or deformation. If there is any indication of permanent deformation, stop the hydrostatic test and make the necessary repairs. If it is not possible to make the repairs right away, give a second hydrostatic test, progressing slowly up to 20 psi less than the pressure at which the first test was stopped.

If the boiler passes this second test successfully, the new working pressure of the boiler must be two-thirds of the test pressure reached on the second test, and all safety valves must be set accordingly.

Do not make any attempt to set up on leaky handhole or manhole plates until the pressure has been pumped up to within 50 psi of the test pressure. After all manhole and handhole leakage has been remedied, pump the pressure on up to test pressure. Check the pressure drop over a period of time. If all valves have been baked off, the maximum acceptable pressure drop is 1.5% of the test pressure over a period of 4 hours.

If connected valves are merely closed and left installed, a drop test will not indicate the true condition of the boiler. The pressure drop test is conducted at boiler design pressure.

A tube seat should not be considered tight unless it is bone dry at the test pressure. Any tube that cannot be made tight under a hydrostatic test should be renewed or rerolled. If there is an excessive pressure drop when there is only a slight leakage at tube joints, handholes, and manholes, the loss of pressure is almost certainly caused by leakage through valves and fittings. Valves and fittings should be overhauled and made tight.

1.6.3 Five-Year Inspection and Test

At 5-year intervals, each boiler must be inspected for integrity of welds and nozzle connections. Lagging must be removed from drums and headers sufficiently to expose the welded joints and the nozzle connections. The welds and nozzle connections must be inspected visually from both inside and outside. If there is any doubt about the welds, they should be inspected by magnetic particle inspection or dye penetrant inspection. After examination, if any area reveals that a 150-percent boiler design pressure hydrostatic test is warranted, and the area proves to be tight under test pressure, further investigation of the suspected area should be conducted. The investigation should continue until the true condition of the area is known, and if necessary, appropriate repairs are made.

1.7.0 Inspection of Firesides

Boiler firesides should be inspected for signs of damage to the refractory lining, tubes, protection plates, baffles, seal plates, support plates, and other metal parts. This type of inspection is usually conducted when the boiler is secured for fireside cleaning, but it should also be conducted each time the boiler is secured.

1.7.1 Refractory Inspection

Frequent inspection of refractories, together with early repair of any weak or damaged places, can do a lot to prevent refractory failure and to postpone the need for complete renewal. It is a good maintenance practice to inspect the refractories every time the boiler is opened up. Such inspections should be very detailed if you believe the boiler has been operated under the following severe service conditions:

- Steaming at high rates
- Burning low-grade or contaminated fuel
- Undergoing rapid fluctuations of temperature

Severe conditions cause rapid deterioration of refractories, increasing the need for frequent inspections.

To make a proper inspection of boiler refractories, you should have considerable knowledge of the causes of refractory deterioration. Also, you should know how to tell the difference between serious damage, which may require a complete renewal of brickwork, and less serious damage, which may be dealt with by patching.

Slagging and spalling are two of the main causes of refractory deterioration. Slag is formed when ash and other unburnable materials react with the brickwork. Although the ash content of fuel oil is low, there is always enough present to damage the refractories. The most damaging slag-forming materials are vanadium salts and sodium chloride.

If the slag that forms on the brickwork would remain in place, it would not cause any particular trouble; however, the slag does not remain in place. Instead, it peels off or melts and runs off, taking some refractory with it and exposing a fresh layer of refractory to further slag attack. When deterioration of the brickwork has progressed until only a 3-inch thickness of firebrick remains, the wall should be replaced. When sufficient slag has accumulated on the deck to cause striking with resultant deposits of carbon, the slag should be removed. The entire deck must be replaced if less than 1 ½ inches of firebrick remain after the slag has been removed.

Another type of slag that results from using contaminated fuel oil is usually more damaging than peeling slag. This type of slag is very glassy in appearance, and when this slag melts, it usually covers the entire wall or deck.

Firebrick shrinkage is another cause of furnace deterioration. True shrinkage (permanent shrinkage) is quite rare in firebrick approved for naval use. However, this defect can occur even in approved firebrick. In any case, it is important to recognize the appearance of true firebrick shrinkage because of the extremely dangerous condition it could create if it should occur. When the firebrick shrinks, the hot-face dimensions of each brick become measurably smaller than the cold-face dimensions. This condition leaves an open space around each brick, and the entire wall or floor becomes loose. A wall or floor having this appearance is DANGEROUS and should be completely renewed as soon as possible.

Also, during your inspection, look for signs of unequal stresses that are caused by rapid-raising of the furnace temperature while raising steam too rapidly. Emergencies may arise that require the rapid raising or lowering of furnace temperatures, but it is important to remember that the refractories cannot stand this treatment often. As a rule, you will find that raising the furnace temperature too rapidly causes the firebrick to break at the anchor bolts, and lowering the temperature too rapidly causes deep fractures in the firebrick.

Next, you should look for signs of mechanical strain caused by poor operation of the boiler. Continued panting or vibration of the boiler can cause a weakened section of the wall to be dislocated so that the bricks fall out onto the furnace floor. Improper oil-air ratio is the most common cause of boiler panting and vibration. Proper operation of the boiler, with particular attention to the correct use of the burners and forced draft blowers, generally prevents panting and vibration of the boiler.

Inspection should also be made of the lower side of the floor pan. Any overheating indicates a loss of insulation and excessive heat penetration. Under normal conditions, the brickwork in a boiler should last for a number of years without complete renewal.

Expansion joints should be inspected often for signs of incomplete closure. It is important to keep the joints free of grog, mortar, and refractory particles so that the joints can close properly when the boiler is fired. You can tell if an expansion joint is closing completely when it is heated by inspecting it when it is cold. If the inside of the expansion joint is light in color when the furnace is cold, the expansion joint is closing properly. If an expansion joint does not close properly when heated, the inside is dark and discolored.

The same method can be used to tell if cracks in refractory materials are closing properly when the furnace is fired. If the cracks are dark, showing that they do not close, they should be repaired.

Since the first firing of a plastic or castable burner front does more damage than any other single firing, the first inspection after installation is a very important one. The unfired burner front may appear to be in perfect condition while actually containing defects of material or workmanship that will show up immediately in the first firing.

After the boiler has steamed for several hours, slabs of plastic about 1/2 to 1 inch thick may separate from the burner's front surface and fall off. This is because the surface layer is more densely rammed during installation than the remainder of the material.

Radial cracks in the burner fronts may be found on the first inspection. These cracks are not harmful. They are caused by stresses resulting from the normal expansion and contraction of the refractory as it is heated and cooled. After the radial cracks occur, the stresses are relieved and there should be no further cracking of this type.

The cracks that eventually result in extensive damage run approximately parallel to the surface of the burner front, and they are called parallel cracks. Parallel cracks usually appear at or slightly behind the leading edge of the bladed cone. They are not dangerous until they actually loosen pieces of the burner front. Improper installation and boiler operation are usually the cause of parallel cracking.

A slanting crack in the narrow section between the burners sometimes joins a radial crack. When this occurs, pieces of plastic tend to break off. This type of damage can usually be repaired by a plastic patch.

If during your inspection you find that a castable burner front is breaking up after very little service, it is likely that too much water was used in mixing the material during installation. Sometimes the material is already partially set before installation; a common cause of this trouble is that the castable material, while in storage, reacted with moisture in the air and started to set. When castable material sets before it is used, it can never reach full strength.

Castable material is also subject to spalling after several hours of service. The peeling material, usually in 1/8-inch strips, should not be removed unless it is in the burner cone and is interfering with combustion. If a castable front is chalky or crumbly, find out how deep the condition goes. If no more than the surface can be rubbed off, the burner front is not seriously damaged. Do not remove the crumbly material. The condition is serious only if the burner cone is affected or if the casing shows signs of overheating.

Burner tile should be inspected for loose segments and broken pieces that might cause improper cone angles. The broken or damaged segments can be repaired by patching with plastic fireclay refractory. In some cases a new segment of tile can be installed.

When you inspect boiler refractories, it is a good idea to keep in mind the possibility that damage may occur because of operational problems. Although boilers must occasionally be operated under very severe and damaging conditions, a lot of damage to refractories (and, in fact, to other boiler parts as well) is caused by poor operating procedures that are really not necessary under the circumstances. It may be helpful to show operating personnel any refractory damage that appears to be directly related to poor operation of the boiler.

1.7.2 Tube Inspection

When inspecting the exterior of boiler tubes, look for signs of warping, bulging, sagging, cracking, pitting, scaling, acid corrosion, and other damage. All tube sheets should be inspected for signs of leakage, especially the superheater tube sheet.

Inspection of boilers sometimes shows an unexpected condition in which adjacent boiler tubes are warped in such a way that they touch each other. When this condition exists, the tubes are said to be married. Tube marriages can result either from overheating of the tubes or from stresses developed in the tubes during installation. For the latter reason, newly erected boilers and boilers that have been retubed should always be inspected for tube alignment after the initial period of steaming.

When inspection reveals one or more tube marriages, the decision as to whether or not the married tubes should be renewed is based on the following considerations:

1. If the tube marriage occurs in screen tubes 1 1/2 inches or larger, or if the furnace side wall or rear wall tubes are bowed, tube replacement is usually required.
2. If 1-inch or 1 1/4-inch tubes in the main bank of generating tubes are married, replacement is usually not required if the tube joints are tight under hydrostatic test.
3. Inspect the external surfaces of the tubes. If they show blistering or other signs of overheating, the tubes should be renewed.
4. Inspect the watersides. Wherever tube marriages exist, a poor waterside condition may indicate hard scale or oil within the affected tube. If hard scale or oil does exist, the married tubes should be replaced, and all appropriate steps should be taken to remove the scale or oil from the rest of the boiler. If the condition of the tubes is uncertain, or if a large number of tube marriages have occurred, remove one or more sample tubes, split them, and examine them carefully.
5. Tube marriages may cause gas laning, which can result in local overheating of the inner casing, the bottom part of the economizer, and other parts. Inspect the boiler carefully for signs of local overheating that might have been caused by gas laning resulting from the tube marriages. If the local overheating from this cause is found, renew the married tubes.
6. On single-furnace boilers, a lane more than 1 1/2 inches wide may allow overheating of the superheater and of the superheater supports. If a large lane (1 1/2 tubes-wide or wider) exists near the superheater outlet header end of the boiler, the married tubes that caused such a large lane should be renewed.

To identify the cause of the tube failure by visual inspection, you will need to know something about the various ways in which tubes rupture, warp, blister, and otherwise show damage. Tube failures must be reported, and they must be reported in standard terminology. The following sections of this chapter deal with the inspection techniques required for determining the causes of tube failure and with the various ways in which boiler tube damage is classified and identified.

The inspection techniques required for determining the cause of tube failure must naturally vary according to the nature of the problem. For example, a rupture in a fire row tube can usually be described adequately on the basis of simple visual observation, but the cause of damage to a tube that is deep in the tube bank cannot usually be determined without removing the intervening tubes. When a blistered tube suggests a waterside deposit, the nature and extent of the deposit can be determined only by removing and splitting the tube so that the waterside can be examined.

For a field inspection of damaged or fouled pressure parts, the following equipment is required:

- Devices for measuring tube diameters' depth of pits, and thickness of deposits
- Instruments for separating deposits and corrosion product, such as a sharp knife, chisel, steel scribe, or vise to crack deposits loose from the tube samples
- An approved type of portable light
- A supply of clean bottles for collecting samples of deposits
- A mirror for viewing relatively inaccessible places

Many of these items of equipment can be improvised if necessary. For example, a simple gauge for measuring the depth of waterside pits may be made by pushing a straight pin or a paper clip through a 3- by 5-inch card so that the point of the pin or clip projects beyond the card, at right angles to the card (*Figure 8-8*). A section of string can be wrapped around a deformed tube and then laid along a ruler to obtain a measure of tube enlargement or tube thinning.

Of course, special tools such as calipers, depth gauges, and scale thickness indicators give more accurate results and should be used if they are available, but the improvised tools, if used with care, can also give good results.

The four major classifications of boiler tube damage are the following:

1. Fireside cavities and scars
2. Waterside cavities and scars
3. Tube deformities and fractures
4. Tube deposits

Figure 8-8 — Improvised depth gauge.

Fireside cavities and scars on the tube firesides often indicate the reasons for tube failure. The term ***circumferential*** groove is used to describe the metal loss that occurs in bands or stripes around the circumference of a tube. Fireside grooving of this type often occurs at the header ends of horizontal tubes such as superheater tubes. The most common cause of this damage is leakage from tube seats higher in the tube bank. The grooving occurs as the water runs down the header and onto the tube ends, or as it drips directly onto the tubes. This kind damage is greater on the top of the tube than on the underside, but the groove may extend the entire circumference.

Fireside circumferential grooving may also occur on vertical generating tubes as a result of thin, damp deposits of soot on horizontal drums or headers. In fact, this kind of grooving can occur in any part of the boiler where leakage provides a sufficient supply of water. Large quantities of water trapped between the water drum and the boiler casing—as, for example, from a serious economizer leak—can produce general fireside grooving around the bottom of the rear generating tubes. *Figure 8-9* shows an example of general fireside circumferential grooving.

Figure 8-9 — General fireside circumferential grooving.

Craters are deep, irregular, straight-walled cavities in the tube metal. *Water tracks* are closely related to craters; the tracks consist of wandering, straight-walled, canyon-like cavities in the tube metal. Craters and water tracks are caused by water becoming trapped between the tube metal and the surrounding refractory. Both occur almost exclusively at the header ends of water wall tubes and division wall tubes that are surrounded by refractory. A frequent cause of craters and water tracks is water washing of boiler firesides without proper drying out. However, any leak higher in the boiler can also cause this type of damage. The size of the leak around and the angle of the tube upon which the water leaks determine, to a large extent, whether the resulting damage will be circumferential grooving, cratering, or water tracking. *Figure 8-10* shows examples of both craters and water tracks.

Figure 8-10 — Fireside craters and water tracks.

General fireside thinning consists of a uniform loss of metal over a relatively large area on the outside of the tube. Soot corrosion is by far the most common cause of general fireside thinning. The parts that are particularly subject to this kind of damage are superheater tube ends between the headers and the seal plates, water drum ends of generating tubes, and return bends in economizer tubes. *Figure 8-11* shows an example of general fireside thinning of a generating tube.

Figure 8-11 — General fireside thinning of a generating tube.

A rather unusual type of general fireside metal loss sometimes results from the combination of extremely high tube temperatures and the burning of fuel oil that contains vanadium compounds. The vanadium compounds carried in the flame can cause rapid oxidation of metal at high temperatures. This type of damage is unusual in water-cooled parts of the boiler, since critical temperatures are not usually attained. *Figure 8-12* shows a stainless steel superheater tube that has suffered this type of general thinning as a result of fuel ash damage.

Figure 8-12 — General fireside thinning of a stainless steel superheater tube (results of fuel ash damage).

Fireside burning occurs when the rate of heat transfer through the tube wall is so reduced that the metal is overheated. Waterside deposits can cause fireside burning, but most serious fireside burning occurs when a tube becomes steam-bound or dry. *Figure 8-13* shows the coarse, brittle appearance of tube metal that has suffered fireside burning.

Figure 8-13 — Fireside burning.

Steam gouging occurs when steam jets out of a hole in an adjacent tube. Steam gouging can be identified by the extremely smooth surface of the cavity, together with the irregular shape of the cavity. A steam gouge looks as though the metal has been blasted away and the cavity polished (*Figure 8-14*).

Tool marks, such as chisel cuts or hammer scars, can usually be identified without too much trouble. Tool marks do not resemble corrosion effects in any way (*Figure 8-15*).

Figure 8-14 — Fireside steam gouge.

Figure 8-15 — Fireside tool marks.

Tube deformities and fractures comprise another category of boiler tube damage that covers abnormal bends, blisters, bulges, cracks, warps, sags, and other breaks or distortions. Like the cavities and scars previously discussed, tube deformities and fractures are fairly easy to distinguish by visual observation.

Figure 8-16 shows a *thin-lipped rupture*, which is a fairly common tube deformity. The rupture resembles a burst bubble; the open lips are uniformly tapered to sharp, knifelike edges, with no evidence of cracking or irregular tearing of the metal. True thin-lipped ruptures occur in economizer tubes, in generating tubes, and, to a much lesser extent, in superheater tubes. Ruptures of this type indicate that the flow of steam or water was not adequate to absorb the heat to which the tube was exposed; consequently, the tube metal softened and flowed and then burst. Thin-lipped ruptures may be caused by a sudden drop in water level or by tube stoppage from plugs, tools, and so forth, that were accidentally left in the boiler.

Figure 8-16 — Thin-lipped rupture in a generating tube.

Serious *thick-lipped ruptures* resemble the thin-lipped ruptures except that the edges are thick and ragged rather than tapered and knifelike. Thick-lipped ruptures that occur in mild steel generating tubes indicate milder and more prolonged overheating than the overheating that leads to thin-lipped ruptures. Abnormal firing rates, momentary low water, flame impingement, gas laning, and many other causes can produce mild but prolonged overheating that can eventually lead to thick-lipped ruptures. *Figure 8-17* shows a typical thick-lipped rupture in a generating tube.

Figure 8-17 — Thick-lipped rupture in a generating tube.

Perforation is the term used to describe any opening in a tube (other than a crack) that is NOT associated with tube enlargement. The most common kind of perforation is probably the pinhole leak. In many cases, the first evidence of tube failure is a pinhole leak.

Thermal cracks or *creep cracks* result from prolonged mild overheating or repeated short-time overheating. Cracks of this type are found most often in alloy superheater tubes, but they can occur in mild steel tubes as well. The tube is not usually enlarged when a thermal crack exists; the cracked wall has normal thickness, and the break has a dark crystalline appearance. *Figure 8-18* shows a typical example of a thermal crack.

Figure 8-18 — Thermal crack in a superheater tube.

Tube enlargement is relatively common in superheater tubes but rare in generating tubes (*Figure 8-19*). This uniform enlargement of a portion of the tube is caused by milder overheating than that which produces cracks or ruptures. If an enlarged tube is continued in service, it will almost certainly crack or break.

Figure 8-19 — Enlarged tube.

Heat blisters differ from tube enlargements in that they affect only one side of the tube, usually the side toward the fires. Blisters appear as egg-shaped lumps on the fireside. They indicate that the tube has been heated to the softening point and has blown out under boiler pressure. Heat blisters always indicate the presence of waterside deposits. If the deposit is brittle, as scale or baked sludge, blistering breaks the deposit and allows the boiler water to quench the hot metal before the tube bursts. Heat blisters are most commonly found on fire row generating tubes; they are rarely found on superheater tubes or economizer tubes. *Figure 8-20* shows a typical heat blister.

Figure 8-20 — Heat blister on a fire row tube.

Sagging is the term applied to tubes that appear to have dropped downward toward the furnace under their own weight. This type of deformation results from semi-plastic flow of the tube metal, caused by extremely mild overheating. A momentary condition of low water is probably the most common cause of sagging. If the boiler has been cooled slowly, and if the distortion is not so severe as to interfere with the designed flow of combustion gases, sagged tubes may still be continued in service.

Warping is similar to sagging except that the distortion is haphazard rather than in one direction. Warping usually occurs as a result of sudden cooling of the tubes after they have been overheated. Cooling a boiler too rapidly after a low-water casualty is a typical cause of warped tubes.

Melting can occur as a result of a serious low-water casualty. If the tube temperature becomes high enough, the tube metal actually melts and runs down into the furnace. *Figure 8-21* shows a cluster of fused tubes that resulted from melting. Melting of aluminum economizer parts can cause tremendous damage to a boiler. The molten aluminum from overheated economizer parts reacts so violently with the iron oxide coating on the steel tubes below that the heat of the chemical reaction may melt the steel tubes even though the furnace temperature is not high enough to melt them.

Figure 8-21 — Melted cluster of tubes.

Mechanical fatigue cracks occasionally occur in boiler tubes from such purely mechanical processes as flexing. Cracks of this type can usually be identified by a clean, bright break through a major portion of the metal thickness. These cracks begin on the outside circumference of the tube.

Tube wall lamination is shown in *Figure 8-22*. This lamination or layering occurs during the fabrication of the tube. It is the most common material defect found in boiler tubes.

Figure 8-22 — Lamination of a tube wall (fabrication defect).

Folded or *upset tubes* are a result of defective fabrication (*Figure 8-23*). This defect resembles a heat blister in appearance, but the folded tube shows no wall thinning and has a depression on the side of the tube opposite the bulge.

Figure 8-23 — Tube fold (fabrication defect).

Stretched or *necked* tubes are also a result of defective fabrication. *Figure 8-24* shows a stretched or necked tube.

Figure 8-24 — Stretched or necked tube (fabrication defect).

Fireside tube deposits can produce many of the scars and deformities just described. Basically, tube deposits cause tube failure because they lead to localized overheating of the tube metal. The accurate identification of tube deposits is often a necessary part of determining the cause of tube failure. Fireside tube deposits include soot, slag, corrosion products, and high-temperature oxide.

- *Soot* is a broad term used to cover all of the ash products (other than slag) that result from combustion. These ash products include carbon, sand, salts such as sodium sulfate, and other materials. Soot deposits are usually powdery or ashy on the tube surfaces near the top of the boiler; however, they tend to be packed solid on drums, headers, and the lower ends of the tubes.
- *Slag* is not a powdery or packed ash-like soot; rather, it is a salt-like material that is fused to the tube surfaces. Slag is objectionable on boiler tubes because it retards the transfer of heat to the tube metal and because it may cause gas channeling, with consequent local overheating of tube metal that is not covered by the slag. Most slags on boiler tubes are soluble enough to be controlled by periodic washing of firesides. The main way to prevent slag is to avoid burning fuel oil that is contaminated with seawater.
- *Corrosion deposits* seldom form major fireside deposits. Occasionally, however, bulky deposits of ferrous sulfate may form as the result of the combination of soot and large amounts of water. These deposits have been known to travel away from their original location and adhere to remote rows of generating tubes. The deposits can usually be removed by water washing and mechanical cleaning. The source of the water leakage should be found and corrected. Also, the location of the original deposit should be found, and the area should be carefully inspected for signs of corrosion.
- *High-temperature oxide* is the term applied to heavy fireside layers of mixed iron oxides formed by overheating of the tube metal. Low water is a frequent cause of high-temperature oxide on the tube firesides. The high-temperature oxide has a rather layered appearance; it resembles corrosion products and is often wrongly called scale.

1.7.3 Exterior Inspection of Drums and Headers

The uptakes and smoke pipes are examined according to a maintenance system. Check the uptake expansion joints to be sure they are not clogged with soot. Look for ruptures and for loose reinforcing ribs or Z-bar stiffeners. Check the rain gutters to see that they are not plugged with soot. Check the top of the economizer to see if it is clean.

1.7.4 Inspection of Protection, Seal, and Support Plates

All corrosion-resisting steel plates such as baffle plates, seal plates, superheater support plates, steam drum protection plates must be carefully inspected whenever firesides are opened. These steel plates are subject to damage from overheating, particularly if clogged gas passages interfere with the designed flow of combustion gases and allow extremely hot gases to flow over the plates. Since failure of these parts could have extremely serious consequences, the plates should be inspected at every opportunity and should be renewed when necessary.

1.7.5 Inspection of Uptakes and Smoke Pipes

The uptakes and smoke pipes are examined according to a maintenance system. Check the uptake expansion joints to be sure they are not clogged with soot. Look for ruptures and for loose reinforcing ribs or Z-bar stiffeners. Check the rain gutters to see that they are not plugged with soot. Check the top of the economizer to see if it is clean.

1.8.0 Operational Inspection and Tests

Following the hydrostatic test, the boiler should be fired and brought up to operating pressure and temperature. All automatically and manually operated control devices provided for control of steam and water pressure, hot-water temperature, combustion, and boiler water level should be inspected and caused to function under operating conditions. All associated valves and piping, pressure- and temperature-indicating devices, metering and recording devices, and all boiler auxiliaries should be inspected under operating conditions. All safety valves and water-pressure relief valves should be made to function from overpressure.

Inspections and tests may be made with the main steam or hot-water distribution valves closed or open as necessary to fire the boiler and operate it under normal operating conditions. Testing the function of automatically or manually controlled devices and apparatus that may interfere with distribution requirements should be done with main steam or hot-water distribution valves closed, as applicable.

The purpose of these inspections and tests is to discover any inefficient operation or maintenance of the boiler or its auxiliaries that may be observed under operating conditions. All deficiencies requiring adjustment, repair, or replacement, and all conditions indicating excessive operating costs and maintenance costs should be reported.

1.8.1 Firing Equipment

The operation of all firing equipment, including oil burners, gas burners, fuel injectors, fuel igniters, coal stokers and feeders, and other such equipment provided to introduce fuel into the boiler furnace and ignite the fuel should be inspected for any deficiency that may be observed under operating conditions. In particular, igniters and burners should be checked to ensure that burner protrusion, angle, setting, and so forth are such that light off and operation are as effective as possible.

1.8.2 ontrols

Inspect the operation of combustion controls, steam pressure controls, water temperature controls, and feed-water controls. Assure that the ability of the combustion control and steam pressure control to maintain proper steam pressure (or water temperature in high-temperature water installations) and air-fuel ratio is demonstrated throughout the capacity range of the boiler. Air-fuel ratio should be checked by CO^2 or O^2 measuring devices. On smaller boilers the appearance of the fire may be used as a guide for inspection of air-fuel ratio.

Check the automatic boiler controls for proper programming sequence and timing with respect to pre-purge, ignition, pilot proving, flame proving, and post-purge periods, Check the operation of flame failure and combustion air failure devices to assure that they properly shut off the supply of fuel; do this by simulating a flame failure (manually shutting off the fuel or by other means) and observing the operating of the controls, solenoid valves, and diaphragm-operated valves that are to operate during a flame failure. Inspect feed-water controls and check the ability of the controls to maintain proper water level throughout the range of capacity with first load swings.

Check the operation of low-water fuel cutoff and automatic water-feeding devices by draining the float bowl, lowering the boiler water level, or by performing other necessary steps to cause these devices to function, to assure they operate properly. The low-flow cutout on high-temperature water boilers should be tested by reducing the flow until cutout occurs.

For additional information on the inspection of the operating conditions of the controls, refer to the section of this RTM that deals with *water columns* and *gauge classes*.

1.8.3 Steam and Water Piping

While the boiler is operating, examine all steam and water piping, including connections to the column, for leaks. If you find any leaks, determine if they are the result of excessive strains caused by expansion and contraction or other causes. Listen for water hammer, and if found, determine the cause. Look for undue vibration, particularly in piping connections to the boiler. When you find excessive vibration of piping, examine the connections and parts for crystallization.

1.8.4 Water Columns and Gauge Glasses

With steam on the boiler, blow down the water columns and gauge glasses, and observe the action of the water in the glass to determine if the connection to the boiler or the blowoff piping is restricted or not properly free. This will help you determine the true condition of high- and low-water alarms and of the automatic combustion equipment.

1.8.5 Devices

While the boiler is operating, cause the individual mechanisms of *low-water fuel cutoff* and/or *water-feeding devices* to operate to assure they function properly.

Where a float-operated, low-water cutoff or water-feeding device or a combination low-water fuel cutoff and water-feeding device is provided, test its operation by opening the drain to the float bowl and draining the bowl to the low-water level of the boiler. When the low-water point is reached, the mechanism of the low-water fuel cutoff should function and shut off the fuel supply to the boiler until boiler water is added to the proper level. Also, at the low-water point, the mechanism controlling the feed-water supply should function to start the feed-water.

Where there is a low-water fuel cutoff device controlled by excess temperature generated in a temperature element located inside the boiler, you can test its operation by blowing off the boiler to its allowable low-water level. On or before the low-water level is reached, the device should function to shut off the boiler fuel supply until boiler water is added to the proper level.

On high-temperature water boilers, the flow through the boiler should be restricted to the minimum allowed, as shown by the manufacturer’s operating data. Note the point at which fuel cutoff takes place and make adjustments as required.

With steam on the boiler, observe the *steam gauge pointer* for sticking or restriction of its movement. Blow down the pipe leading to the gauge to assure that it is free. Attach an approved test gauge to the pipe nipple provided for this purpose, and compare the accuracy of each steam gauge on the boiler with that of the test gauge.

When inaccuracy of any gauge is evidenced or suspected, it should be removed and calibrated by means of a deadweight gauge tester or other device designed for this purpose. When several boilers are in service and connected to a common steam main, compare the readings of the separate gauges. All *temperature-indicating devices* should be observed for indications of excessive temperature, particularly during and immediately after the time high-load demands are made on the boiler.

While the boiler is operating under normal conditions, observe the operation of all *metering* and *recording devices*. When there is evidence that any such device is not functioning properly, it should be adjusted, repaired, or replaced as necessary.

1.8.6 Blowoff Valves

Test the freedom of each blowoff valve and its connections by opening the valve and blowing off the boiler for a few seconds. Determine if the valve is excessively worn or otherwise defective and if there is evidence of restrictions in the valve, or connected piping preventing proper blowoff of the boiler.

1.8.7 Stop and Check Valves

While the boiler is operating, inspect the operating condition of each stop and check valve where possible. Serious defects of externally controlled stop valves may be detected by operating the valve when it is under pressure. Similarly, defects in check valves maybe detected by listening to the operation of the valve or observing any excessive vibration of the valve as it operates under pressure.

1.8.8 Pressure-Reducing Valves

While there is pressure on the system, open and then close the bypass valve as safety and operating conditions permit. Also, observe the fluctuation of the pressure gauge pointer as an aid in determining possible defects in the operation of the pressure-reducing valve or the pressure gauge. Look for any evidence that may indicate improper condition of the relief or safety valves provided for the pressure-reducing valves.

1.8.9 Boiler Safety and Water-Pressure Relief Valves

Test the blowoff setting of each safety valve for steam boilers and each water-pressure relief valve for hot-water boilers by raising the boiler pressure slowly to the blowoff point. In turn, test the releasing pressure of each valve, gagging all other safety or relief valves except the one being tested. Observe the operation of each valve as blowoff pressure is reached. Compare the blowoff setting with setting requirements specified in paragraph 1 or 2 of this section, and make adjustments where necessary. When the steam discharge capacity of a safety valve is questionable, it should be tested by one of the methods given in paragraph 3 of this section. When the pressure-relieving capacity of a pressure-relief valve is questionable, it should be tested according to the procedures given in paragraph 4 of this section.

1. *Safety Valve—Setting Requirements*. <u>Note this word of caution</u>: Before adjusting safety valves on electric steam generators, be sure that the electric power circuit to the generator is open. The generator may be under steam pressure, but the power line should be open while the necessary adjustments are being made. At least one safety valve should be set to release at no more than the maximum allowable working pressure of the steam boiler. Safety valves are factory set and sealed. When a safety valve requires adjustment, the seal should be broken, adjustments made, and the valve resealed by qualified personnel only. When more than one safety valve is provided, the remaining valve or valves may be set

within a range of 3% above the maximum allowable working pressure. However, the range of the setting of all the safety valves on the boiler should not exceed 10% of the highest pressure to which any valve is set. Each safety valve should reseat tightly with a blow-down of not more than 2 psig or 4% of the valve setting, whichever is greater.

In those cases where the boiler is supplied with feedwater directly from the pressure main without the use of feeding apparatus (not including return traps), no safety valve should be set at a pressure greater than 94% of the lowest pressure obtained in the supply main feeding the boiler.

2. *Pressure-Relief Valve—Setting Requirements*. At least one pressure-relief valve should be set to release at not more than the maximum allowable working pressure of the hot-water boiler. When more than one relief valve is provided on either hot-water heating or hot-water supply boilers, the additional valve (or valves) may be set within a range not to exceed 20% of the lowest pressure to which any valve is set. Each pressure-relief valve should reseat tightly with a blow-down of not more than 25% of the valve setting.
3. *Safety Valve—Capacity Test*. When the relieving capacity of any safety valve for steam boilers is questioned, it may be tested by one of the three following methods:
   - Performing an accumulation test, which consists of shutting off all other steam-discharge outlets from the boiler and forcing the fires to the maximum. The safety valve capacity should be sufficient to prevent a pressure in excess of 6% above the maximum allowable working pressure. This method should not be used on a boiler with a superheater or re-heater.
   - Measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity (steam-generating capacity) upon the basis of the heating value of this fuel. These computations should be made as outlined in the code.
   - Measuring the feedwater capacity to determine the maximum evaporative capacity.

When any of the above methods are employed, the sum of the safety valve capacity should be equal to or greater than the maximum evaporative capacity (maximum steam-generating capacity) of the boiler.

If you discover that the relieving capacity is inadequate because of deficiencies in the valve, the valve should be repaired or replaced. If the relieving capacity of the valve is found to be satisfactory within the proper relieving range of the valve but inefficient for the steam-generating capacity of the boiler, additional safety valve capacity should be provided.

4. *Pressure-Relief Valve—Capacity Test*. When the relieving capacity of any pressure-relief valve for hot-water boilers is questioned, the capacity can be tested by turning the adjustment screw until the pressure-relief valve is adjusted to the fully open position. The pressure should not rise excessively. When the test is completed, reset the pressure-relief valve to the required setting. This test is made with all water discharge openings closed except the pressure-relief valve being tested. When the discharge is led through a pipe, determine at the time the valve is operating if the drain opening in the discharge pipe is not properly free, or if there is evidence of obstruction elsewhere inside the pipe. If deemed necessary to determine the freedom of discharge from the valve, the discharge

connection should be removed. After completing tests and adjustments, the inspector should seal the safety adjustment to prevent tampering.

1.8.10 Boiler Auxiliaries

While the boiler is operating under normal conditions, observe the operation of all boiler auxiliaries for any defects that may prevent proper functioning of the boiler or indicate a lack of proper maintenance of auxiliary equipment. The unnecessary use of multiple auxiliaries or the use of a large auxiliary during a light-load period (when a smaller auxiliary could be substituted) should be discouraged. The maximum use of steam-driven auxiliaries short of atmospheric exhaust should be encouraged. Steam leaks, wastage to atmosphere, and so forth should be called to the attention of operating personnel. Particular attention should be given to de-aerator venting practice. Venting should be held to the minimum required to preclude oxygen entrainment in the feedwater.

When intermittently operating condensate pumps are used, look for any tendency toward creation of a vacuum when a pump starts. If this happens, recommend installation of a small, continuously operating, float-throttled, condensate pump (in parallel with intermittently operating pumps) to assure a condensate flow at all times. If there are a number of intermittently operating condensate pumps, it may be possible to convert one of them (if of small enough capacity) to continuous throttled operation.

Test your Knowledge (Select the Correct Response)

1. **(True or False)** When selecting a site for boiler installation, the availability of water, electricity, fuel, and natural drainage should be considered.

   A. True
   B. False

2. When must boilers be inspected for integrity of welds and nozzle connections?

   A. Once every year
   B. Every 5 years
   C. Every 6 months
   D. None of the above

2.0.0 PLANT OPERATION

To operate boilers or be a plant supervisor, you need to know all the mechanical details of the boiler you are operating and its associated auxiliaries. However, just knowing this information is not enough. To be a professional boiler operator or plant supervisor, you must develop a keen eye for trouble, a finely tuned ear, and an overall sense of awareness concerning boiler plant operation at all times.

As an operator and/or supervisor of a boiler plant, you must learn to tell the difference between normal and abnormal operating conditions. By training yourself to notice and analyze strange noises, unusual vibrations, abnormal temperatures and pressures, and other indications of trouble, you will be better able to prevent any impending trouble or casualty to the plant.

2.1.0 Operators

During the hours that a boiler plant operator is on duty, it is very important that you ensure that the operator is maintaining accurate records.

2.1.1 Logs

Logs provide a means of recording continuous data on boiler plant performance and analysis of operation. Logs are arranged for use over a 24-hour period, consisting of three 8-hour shifts. Log entries should be carefully made in columns. Commands will establish information required but the following info is typical of the info found in boiler logs.

2.1.2 Turnover and Watch Relief

When an operator comes on duty, an operational inspection should be done to ensure that everything is operating normally. The points that the operator should check are as follows:

- Check the water level in the gauge glass on each boiler by opening and closing the try cocks.
- Check the low-water cutoffs and the boiler feed equipment by blowing down the water columns on each boiler.
- Check the steam pressure and compare it with the steam pressure that the plant should deliver.
- Check the boilers for leaks or other conditions that can affect plant operation.
- Check for proper operation of the boiler room accessories.
- Check the fuel supply and the firing equipment.
- Check the condition of the fires to determine if they are clean.
- Check the general appearance of the boiler room, fixtures, piping, and insulation.
- Check the boiler room record sheets to determine if any troubles were encountered by the previous shift operator.
- Question the operator being relieved about plant operation and the troubles encountered.
- Check for any verbal or written orders with which you are to comply.

2.2.1 Plant Supervisor

As a boiler plant supervisor you are expected to organize and manage the overall operation of the boiler. Your duties and responsibilities include but are not limited to the following:

- Ensuring that daily logs are maintained by operators
- Submitting monthly operation reports and logs
- Checking maintenance requirements
- Providing personnel with required training

Each boiler plant has its unique requirements. Only through operating your specific plant and completely familiarizing yourself with it can you establish a comprehensive management program.

This chapter cannot cover all the aspects of supervising a boiler plant. You must refer to current Navy publications, command instructions and manufacturer’s manuals that pertain to your specific plant. When you are assigned as a boiler plant supervisor, you should establish an on-site library of the required publications and manuals.

2.3.0 Water Chemistry

The effects of inadequate or improper water conditioning can cause major problems in the operation of boilers. Manufacturer's specifications must be strictly adhered to. *Table 8-2* outlines the effects and results of poor water treatment of boiler water. By establishing an aggressive water-treatment program, you can greatly reduce inefficient boiler operation and high maintenance costs.

Table 8-2 — Effects of Inadequate or Improper Water Conditioning.

EFFECT	CONSTITUENT	REMARKS
Scale	Silica	Forms a hard, glassy coating on internal surfaces of the boiler. Vaporizes in high-pressure boilers and forms deposits on turbine blades.
	Hardness	$CaSo_4$, $MgSo_3$, $CaCO_3$, and $MgCO_3$ form scale on the boiler tubes.
Corrosion	Oxygen	Causes pitting of metal in boilers, and steam and condensate piping.
	Carbon dioxide	Major causes of deterioration of condensate return lines.
	$O_2 – CO_2$	Combination is more corrosive than either by itself.
Carryover	High boiler water concentrations	Causes foaming and priming of the boiler and carryover in steam, resulting in deposits on turbine blades and valve seats.
Caustic embrittlement	High caustic concentration	Causes inter-crystalline cracking of boiler metal.
Economic losses	Repair of boilers	Repair of pitted boilers and cleaning of heavily scaled boilers are costly.
	Outages	Reduce efficiency and capacity of plant.
	Reduced heat transfer	High fuel bills.

2.4.0 Chemical Makeup of Water

Water is called the *universal solvent.* The purer the water, that is, the lower its dissolved solids content, the greater the tendency to dissolve its surroundings. If stored in a stainless steel tank after a short contact time, pure water has a very small amount of iron, chromium, and nickel from the tank dissolved in it. This dissolving of the tank does not continue indefinitely with the same water.

The water, in a sense, has satisfied its appetite in a short time and does not dissolve any more metal. Pure water, if exposed to air, immediately absorbs air and has oxygen from the air dissolved in it. A glass of tap water at 68°F contains 9.0 ppm of oxygen. Tap water heated to 77°F contains 8.2 ppm of oxygen, because some oxygen is driven out of the water. The higher the temperature of the water, the less dissolved oxygen it can hold.

Conversely, the higher the pressure imposed on the water, the greater the dissolved oxygen it can hold. Water, when boiled, produces steam. The steam contains some liquid water. There is never a perfect separation of pure steam from the boiling water. The steam above the boiling water always has some boiling water entrained with it. These three concepts—that water is a universal solvent, that water dissolves oxygen when in contact with air, and that boiling water is always entrained with steam--should help you understand the nature of feedwater.

As it enters the boiler steam drum, the feedwater is now considered boiler water. Complete understanding of the nature of boiler water can be gained by temporarily making the assumption that no water treatment, chemical addition, or blowdown is applied to the boiler water. The character of the boiler water continually changes as the boiler operates. The dissolved and suspended solids contained in the feedwater concentrate in the boiler water at the rate of eightfold every hour if the boiler is producing steam at 50 percent of its normal capacity. Three damaging conditions arise in the boiler as the boiler water continues to steam without treatment. *Scale formation* on the steam generating surfaces, *corrosion* of the boiler metal, and boiler water *carry-over* with the steam due to foaming are the three results of untreated boiler water.

To prevent scale formation on the internal water-contacted surfaces of a boiler and to prevent destruction of the boiler metal by corrosion, you must 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 when no scale deposits occur.

2.5.0 Chemical Treatment (External and Internal)

The method of using chemicals may take the form of external treatment, internal treatment, or a combination of both. The principal difference between these forms of treatment is that in external treatment the raw water is changed or adjusted by chemical treatment outside of the boiler so a different type of feedwater is formed. In internal treatment, the water is treated inside the boiler by feeding chemicals into the boiler water, usually through the feed lines. Again, in external treatment the main chemical action takes place outside the boiler, while in internal treatment the chemical action takes place within the boiler.

2.6.0 Internal Treatment and Prevention

At many Navy installations, the boilers are not large and do not operate at high pressure. When the makeup water is not too high in hardness or dissolved solids, good operation is possible with only internal treatment. Under this condition, external treating equipment is unnecessary. Chemical treatment covered in this chapter applies primarily to internal treatment.

2.6.1 Scale

When water evaporates in a boiler, the hard components that were in the water, such as calcium salts, magnesium salts, and other insoluble materials, form deposits on the tubes and other internal surfaces. These deposits are known as scale. Actually, the temperature of the water determines how well the different salts dissolve and how long they remain dissolved. Some salts are such that the hotter the water, the better they stay dissolved. Other salts stay dissolved while the water is at a relatively low temperature but form solid crystals (scales) that come out in increasing amounts as the water gets closer to becoming steam.

The scale-forming salts stay dissolved in the water and in the cooler parts of the boiler, but when the water reaches the hot tubes, these salts start forming solid particles that come out of the water and stick to the hot metal parts as scale deposits. These deposits are highly objectionable because they are poor conductors of heat, actually reduce efficiency, and are frequently responsible for tube failures. Some of the principal scale-forming salts to be considered in most cases are as follows:

- Calcium sulfate $CaSO_4$
- Calcium silicate $CaSiO_3$
- Magnesium silicate $MgSiO_3$
- Calcium hydroxide $Ca(OH)_2$
- Calcium carbonate $CaCO_3$
- Magnesium hydroxide $Mg(OH)_2$

Scale is made up of three main parts: calcium sulfate, calcium carbonate, and silicates of calcium and magnesium. Scales that are principally calcium sulfate or chiefly of the aforementioned silicates are very hard; those scales that are principally calcium carbonate with little silicate are somewhat softer. A scale consisting chiefly of calcium carbonate may appear only as a thin, porous, soft scale that does not build up in thickness.

Scale can be prevented by the intelligent use of proper water treatment, and that is one of the objectives of the boiler water test and treatment program.

2.6.2 Prevention and Treatment for Scale Control

Scale-forming substances cannot always be prevented from entering the boiler, but they can be made to form a fluid sludge. The problem then is simply one of proper chemical treatment and blowdown.

The selection of chemicals for internal treatment is determined by many factors: the kind of feedwater hardness (whether carbonate or sulfate); the ability of feedwater to build up required causticity; the type of external treatment, if used; the pH and percentage of condensate returns; the location of chemical feed injection; and the cost and availability of chemicals.

The first two chemicals to be considered for boiler water treatment of shore-based boilers are caustic soda and sodium phosphate (*Table 8-3*).

Table 8-3 — Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers.

CHEMICAL	PURPOSE	COMMENT
Sodium hydroxide NaOH (caustic soda)	Increase alkalinity, raise pH, precipitate calcium sulfate as the carbonate.	Contains no carbonate, therefore does not promote CO_2 formation in steam.
Sodium carbonate Na_2CO_3 (soda ash)	Increase alkalinity, raise pH, precipitate magnesium.	Lower cost, more easily handled than caustic soda. But some carbonate breaks down to release CO_2 with steam.
Sodium phosphates HaH_2PO_4, $HaHPO_4$, Na_3PO_4, $NaPO_3$	Precipitate calcium as hydroxyapatite ($Ca_{10}(OH)_2(PO_4)_6$).	Alkalinity and resulting pH must be kept high enough for this reaction to take place (pH usually above 10.8).
Sodium aluminate $NaA1_20_4$	Precipitate calcium, magnesium.	Forms a flocculent sludge.
Sodium sulfite Na_2SO_3	Prevent oxygen corrosion.	Used to neutralize residual oxygen by forming sodium sulfate. At high temperatures and pressures, excess may form H_2S in steam.
Hydrazine hydrate $N_2H_4.H_2O$ (35%).	Prevent oxygen corrosion.	Remove residual oxygen to form nitrogen and water. One part of oxygen reacts with three parts of hydrazine (35% solution).
Filming amines; Octadecylamine, etc.	Control return-line corrosion by forming a protective film on the metal surfaces.	Protects against both oxygen and carbon dioxide attack. Small amounts of continuous feed will maintain the film. Do not use where steam contacts foods.

Table 8-3 — Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers (cont.).

CHEMICAL	PURPOSE	COMMENT
Neutral amines; morpholine, cyclohexylamine, benzylamine	Control return-line corrosion by neutralizing CO_2 and adjusting pH of condensate.	About 2 ppm of amine is needed for each ppm of carbon dioxide in steam. Keep pH in range of 7.0 to 7.4 or higher.
Sodium nitrate $NaNO_3$	Inhibit caustic embrittlemerit.	Used where the water may have embrittling characteristics.
Tannins, starches, glucose and lignin derivatives	Prevent feed line deposits, coat scale crystals to produce fluid sludge that will not adhere as readily to boiler heating surfaces.	These organics, often called protective colloids, are used with soda ash and phosphates. They also distort scale crystal growth, help inhibit caustic embrittlement.
Seaweed derivatives (sodium alginate, sodium mannuronate	Provide a more fluid sludge and minimize carryover.	These organics are often classified as reactive colloids since they react with calcium and magnesium and absorb scale crystals.
Antifoams (polyamides, etc.)	Reduce foaming tendency of highly concentrated boiler water.	Usually added with other chemicals for scale control and sludge dispersion.
Proprietary compounds (of ball or brick type)	Do not use for water treatment. May be used for water treatment.	Boilers 125 psig and above, all power plant boilers, all boilers using intermittent blowdown. Low makeup boilers (under 125 psig) for space heating. High makeup boilers (under 125 psig) with continuous blowdown and stable feedwater, if cost saving is affected.

The caustic soda prepares the way by making the water definitely alkaline (high pH). The sodium phosphate can then attack the calcium magnesium and silica salts and convert them into a fluid sludge that can be removed by blowdown.

Caustic soda is used when the feedwater cannot build up the required causticity residual in the boiler water. Use of soda ash (Na_2CO_3) is not authorized in steaming boilers because it breaks down under heat to form undesired carbon dioxide (CO_2). This gas is corrosive to condensate return lines. The Navy boiler compound customarily used aboard ship is not authorized because it contains about 39% soda ash.

Sodium phosphate ($NaPO_4$) has a special affinity (attraction) for calcium, and in boiler water the phosphate joins with calcium to precipitate calcium phosphate ($CaPO_4$). Phosphate prevents the formation of calcium scales, such as calcium sulfate, calcium carbonate, or calcium silicate. The precipitate of calcium phosphate develops as a finely divided fluid material that can readily be removed by blowdown. The sodium phosphate dosage should be regulated to maintain a residual reading of 30 ppm to 60 ppm.

2.6.3 Sludge

Another source of tube coating is *baked sludge*. This sludge comes from dirt, oil, or water-treatment chemicals that are suspended in dirty feedwater. The solids settle on tube surfaces and absorb the heat intended to be transferred to the water. The heat then cooks the sludge into a hard coating on the tube walls. These deposits are as hard or harder to remove, than *true scale* and should be recognized as a completely different problem. Methods of preventing and combating baked sludge are different from methods of preventing and combating scale.

Baked sludge is very hard to remove by mechanical means, and boiler compound has no effect on it at all. The best method found to combat sludge is to know where it comes from, make it gather by proper treatment, and blow it out before it cooks.

2.6.4 Prevention and Treatment for Sludge Control

When the proper causticity residual is maintained and phosphate is fed in correct amounts, the scale-forming impurities in boiler water become sludge and should be easy to blow out. Sometimes, however, the characteristics of the precipitated chemicals are such that the sludge formed does not go along with the water and leave the boiler with the blowdown. It has been discovered that additives called sludge conditioners cause the sludge to flow better.

Most sludge conditioners are organic substances that act as dispersants. They keep the sludge in a fluid state by holding the precipitates as finely divided particles. As the precipitated chemicals settle, a loose fluid mass that is easy to blow out is formed. The only sludge dispersant approved by NAVFAC for use in shore-based boilers is ***quebracho tannin***.

Generally, when quebracho tannin is used, sufficient quantities are fed to the boiler to give the boiler water a medium tea color. If the causticity residual is high, a darker color should be maintained. This darker color for high causticity aids in preventing hardening of metal in the boiler. As the tannin particles become part of the sludge and are blown out, the brown color, given to the water by the initial dose of tannin, becomes a lighter color, and more tannin must be added.

Proper blowdown is important because some sludges are almost always in the boiler water. When only parts of the boiler are badly sludged, blowdown may not be complete or there may be areas of poor circulation. The boiler design may be such that even good blowdown does not clear all the parts. Another concern is that frequency, time, and the kind of blowdown being used may not be complete or correct to maintain optimum conditions.

A small amount of seawater in the feedwater causes heavy sludging. Where seawater is likely to contaminate feedwater or where evaporated seawater is used for feedwater, every precaution should be taken to prevent saltwater contamination of the feedwater.

Regular daily boiler water tests will show up contaminated feedwater so that it can be corrected before serious harm is done.

Where makeup water is clean and not much sludge shows at bottom blowdown, tannin may not be necessary. Where there is a lot of sludge, the addition of tannin is a big help in keeping the boiler free and clean. Also, much less sludge-forming materials are required when the raw water makeup is upgraded by external treatment.

2.6.5 Corrosion

Corrosion is the deterioration of metal by chemical action. When dissolved oxygen is present in the boiler water, corrosion begins and continues until all metal has been transformed into iron oxide or, commonly stated, rust. When rust forms in the boiler, it may drop out as sludge or cling to other metal surfaces. It is not economically possible to prevent at least some of the iron in the boiler from going into solution. All iron not protected by a coating or film of something that keeps out moisture and air is sooner or later going to become *rust*. The idea is to slow down the process as much as possible by *keeping oxygen out* and by maintaining a proper causticity residual.

The pH level of boiler water is also a factor in corrosion. The active agent in the corrosion of the internal water surface of boilers is oxygen; however, the combined action of oxygen and the acid action of the water are required for the corrosion process. To suppress the acid action of the water, you can raise the pH value of the water by adding caustic soda. The lower the pH value the stronger the acid concentration. The higher the pH value the weaker the concentration. Economically, acid corrosion cannot be stopped completely, but it can be suppressed by keeping oxygen out of the boiler and by maintaining a proper pH value and causticity range.

2.6.6 Prevention and Treatment for Oxygen Corrosion

The chemical most commonly used in oxygen removal is sodium sulfite, and it is quite often referred to as an oxygen scavenger. It is an example of a chemical that actually reacts with the harmful constituent. It reacts with oxygen, forming a neutral compound—sodium sulfate.

When enough sodium sulfite is fed into a boiler so that a surplus of the chemical is maintained, any of the oxygen getting into the boiler water is taken up by the chemical, and the boiler water is kept virtually free of oxygen. By maintaining a suitable residual, little, if any, corrosion due to oxygen occurs. Common practice in feeding sodium sulfite is to maintain a surplus residual of about 20 ppm to 50 ppm in the boiler water. This is generally enough sodium sulfite to react with normal amounts of oxygen that might get into the boiler. Higher concentrations of sodium sulfite are unnecessary.

Sodium sulfite dissolves readily in water and must be fed at a point between the feed heater and the boiler so that it is used to take up only the oxygen that gets by the deaerator or heater. If the sodium sulfite is fed through the feed lines by continuous feeding, it is always present in the feed lines and takes up oxygen in the feedwater in addition to maintaining a surplus in the boilers.

Another advantage of using sodium sulfite is that if, for any reason, a feedwater heater or deaerator becomes inoperative or efficient operation is temporarily interrupted, the sodium sulfite residual present in the boiler water can take up the larger amounts of the oxygen getting in. At the same time, the concentration of sodium sulfite drops.

This is shown by test analysis of the boiler feedwater. This test gives the operator ample warning of an existing malfunction within the boiler feedwater supply system. Immediate steps should be taken to correct this off-standard condition.

Feedwater or makeup water tanks should be heated to a temperature of 180°F to 200°F. This heat alone helps to dispense of most of the dissolved oxygen before it can enter the boiler. It also allows for more economical use of sodium sulfite.

The prevention of corrosion in the boiler means regulating the alkalinity of the water, producing protective films, and removing dissolved oxygen. These preventive measures are accomplished by maintaining the proper chemical residuals in the boiler water and by proper deaeration.

2.6.7 Carryover—Foaming and Priming

The word *priming* is used rather loosely to express the action of the water and steam in a boiler when an unusual amount of water is being carried over with the steam. For a given boiler installation, a certain amount of water or moisture in the steam is tolerated. The amount depends upon the use of the steam, the boiler construction, and the facilities for removing the water from the steam. The mechanical causes include the following:

- Deficiency in boiler design
- High water level
- Improper method of firing
- Overloading
- Sudden load changes

A poorly designed boiler may have insufficient steam-disengaging space. It is fairly obvious that the faster the steam is produced in a given vessel, such as a boiler, the more violent is the boiling effect. But when the steam space above the water level is large enough, the steam leaving the boiler does not show any evidence of carryover. The size of the steam header and the velocity of steam leaving the boiler are, therefore, important elements in boiler design.

As the rate of steam production goes up, so does the tendency for steam contamination. The sudden opening of a steam valve or the cutting in of a boiler too quickly speeds up the production of steam, which can cause violent bubbling and carryover. The primary chemical causes of carryover are high concentrations of totally dissolved and suspended solids in the boiler water, excessive alkalinity, and the presence of oil.

Foaming is the production of froth or unbroken bubbles on the surface of the boiler water. The froth may be thin, with few bubbles overlying each other, or it may build up throughout the steam space. Under such conditions it is difficult to free the steam of the liquid films, and the moisture content increases. When certain substances are dissolved in water, they concentrate somewhat more in the body of the liquid than on the surface; others concentrate more on the surface than in the body. In either case, the surface tension of the water is affected, and bubble film develops.

The formation of froth depends upon the tenacity of the films of liquid that form the shells of the bubbles. A tough film can develop that refuses to break and release the steam. Apparently, finely divided solids in suspension increase the stability of the film so that the combination of salts in solution and finely divided solids cause foaming to develop more readily than when either one is present by itself.

Soaps getting into the boiler from outside sources or formed within the boiler from oils or animal greases intensify the foaming action. Water can be carried over in the steam without formation of froth. When pure water that does not foam is boiled, it frequently "bumps" as unstable steam bubbles are formed. These rapidly reach the surface of the water and instantaneously burst through. Parts of the water tend to become superheated and suddenly turn to steam. Fine solid particles released in water under these conditions cause the immediate production of much steam. This may occur in a boiler when particles of scale suddenly become loose.

When a boiler is foaming or priming, it is difficult and quite often impossible to read the true level of the boiler water on the gauge glass. The slugs of boiler water can wreck turbines or engines. The carryover of boiler water solids usually caused by foaming and priming disrupts operation of the equipment coming in contact with the steam. Deposits form in steam piping, valves, superheaters, engines, or turbines. These solids erode the turbine blades and frequently create out-of-balance conditions to the rotor. They often clog tubing, a pipe, and other apparatus following the boiler.

When live steam is used for processing purposes or for cooking, the solids can seriously damage the final product. It is important for you to remember, any moisture carryover with the steam is an additional heat loss through the steam line.

2.6.8 Prevention and Treatment for Carryover—Foaming and Priming

There are two kinds of solids present in most boiler water—the dissolved solids, or substances that are in solution, and suspended solids. Suspended solids are finely divided solid particles floating around in the water. This is material left over after the scale-forming and corrosive salts have been changed into sludge by chemical treatment.

When a boiler is steaming, the feedwater continuously carries dissolved mineral matter into the boiler. However, the steam leaving the boiler carries very little mineral matter with it. The concentration of dissolved solids in the boiler water, therefore, keeps building up unless properly controlled by continuous or intermittent blowdown.

In water tube boilers, concentrations are generally highest at the place where the mixture of steam and water from the tubes spills over into the steam drum. Where total concentrations are not reduced sufficiently by the bottom blow, another blowdown line should be installed to remove water from the drum at the point where TDS (total dissolved solids) concentrations are the highest. This blowdown is generally operated continuously when the boiler is in service and is called a continuous blowdown.

The best remedy for foaming and priming carryover is the proper blowdown of TDS. The continuous blowdown should be regulated to maintain the TDS at 3,000 to 4,000 ppm. The greater the number of TDS that can be carried without trouble, the less water, fuel, and chemicals are required or wasted in the TDS blowdown.

2.7.1 Chemical Treatment Determination

Because raw water conditions vary so greatly with locale, it is impossible to recommend a single, specific water treatment. Whenever possible, you should consult with a water treatment chemist and follow their recommendations concerning chemical treatment of boiler water. The degree of success of any water treatment program depends upon how well the recommendations for treatment are monitored.

When the services of a qualified water treatment chemist are obtained, their recommendations should include the following:

- The treatment formula
- The treatment ingredients
- Instructions to the boiler operator in the use of the treatment
- Periodic visits to the plant to check on the results of the treatment plan

When the operator follows instructions and uses the proper blowdown procedure, scale and sludge in the boiler are reduced to a minimum. Blowdown limits the amount of dissolved and suspended solids in the boiler water.

Consulting a chemist is an ideal situation. Seabees seldom operate under ideal situations, particularly during contingency operations. Below are some general guidelines to follow in order to determine the initial chemical treatment for a boiler, and how to establish an effective treatment program.

The first determination you have to make is the steaming rate of the boiler, expressed in pounds per hour. This is a fairly simple computation. You first determine the boiler horsepower (bhp), and then multiply the result by 4.5 pounds. For example, if you have a 100 horsepower boiler operating at one-half fire, your steaming rate is 1,725 pounds of steam per hour.

- 1 BHP = 34.5 lb steam/hour
- 100 x 34.5 = 3,450 steam/hour at high fire
- 3,450 ÷ 1/2 = 1.725 lb steam/hour at one-half fire

To determine the initial chemical dosage, you must know the hardness of the raw water. A chemist can tell you this; however, in the field you must determine it by experimentation. The harder the water, the more phosphates you must add during treatment to obtain correct phosphate residuals. The example that follows assumes zero hardness of the raw water and uses a 1,725-pound steaming rate.

1. Mix the following chemicals in 28 gallons of water:
    - 1 1/4 pounds of sodium sulfate
    - 1/2 pound of trisodium phosphate
    - 1/2 pound of caustic soda
2. Adjust the chemical feed rate to 3 gallons per hour (allows for 8 to 10 hours of steaming).

The chemical dosage varies with the steaming rate of the boiler. To establish your water treatment program, use the following steps every hour of operation for the duration of your initial chemical batch.

1. Determine the hourly steaming rate.
2. Test for phosphate residual (30-60 ppm).
3. Test for sulfite residual (25-50 ppm).
4. Test for pH (9.5 to 11.5).
5. Test for TDS (3,000 to 4,000 ppm).

You should make a log entry of these test results every hour. This establishes a history of the test results. At the completion of the initial chemical dosage, you can either add or subtract chemicals, based on your log. It may take several batches fed over an 8 to 10-hour period to get a consistent chemical requirement for boiler water treatment. Once the boiler has stabilized and treatment test results remain reasonably balanced, testing may be required only every 4 hours.

At this time you can chart your chemical requirements based on load demand of the boiler. By establishing this history through experimentation, your operators are able to treat the boiler water with fairly accurate results. At this time note that boiler blowdown has a big effect on your treatment program. Proper blowdown practices cannot be overemphasized. Too little blowdown causes TDS readings to be high; too much blowdown causes a high demand for chemicals and results in lost efficiency of the boiler.

Test your Knowledge (Select the Correct Response)

3. Operator boiler plant logs are arranged for use over a 24-hour period, consisting of how many shifts?

   A. Two 6-hour
   B. Three 8-hour
   C. Four 10-hour
   D. Five 12-hour

4. What effect of inadequate or improper water conditioning causes pitting of metal in boilers, and steam and condensate in piping?

   A. Carryover
   B. Scale
   C. Corrosion
   D. Caustic embrittlement

5. What chemical is used for internal boiler water treatment to prevent oxygen corrosion in boilers?

   A. Sodium sulfite
   B. Sodium carbonate
   C. Sodium aluminate
   D. Sodium nitrate

3.0.0 MAINTENANCE

As a boiler plant supervisor/manager, you need to know that boiler maintenance covers a wide range of topics.

Major repairs that involve welding of pressure parts of the boiler are done by Steelworkers in strict adherence to the procedures in section IX of the ASME, *Boiler and Pressure Vessel Code*. This section is concerned with operator and preventive maintenance and major considerations for the maintenance and care of firesides and watersides. Procedures for laying up idle boilers are also discussed.

3.1.1 Operator Maintenance

Operator maintenance is the necessary, routine, recurring maintenance work performed by the operators to keep the equipment in such condition that it may be used continuously at its original or designed capacity and efficiency for its intended purpose. The operator is actually the most important member of the boiler plant maintenance team. A well informed and responsible operator can do the following:

1. Keep equipment in service for maximum periods of time.
2. Detect any flaws so equipment can be removed from service in time to prevent serious damages.
3. Perform minor repairs on equipment removed from service to minimize outage time.

It is sometimes difficult to determine where operator duties end and maintenance crew work begins. However, the operator must realize that he or she has the keenest interest in the condition of the equipment. A well kept plant not only reflects the operator's interest (and the desire to better his or her position) but it also is vital to the safety of equipment and personnel. It is essential for every person in the operating aisle to perform the following duties:

1. Clean. Dirt is the principal cause of equipment failure. Whether it is fly ash in the switch gear, oil on the deck, cloth lint, or dust, it causes trouble. No matter the form in which dirt appears, it should be removed immediately by the operator.
2. Lubricate. Any two surfaces brought together develop friction. If not properly lubricated, these surfaces wear one another down, change clearances, and cause equipment breakdowns. A well placed drop of oil or a thin layer of grease can go a long way toward keeping a much used piece of equipment in good condition.
3. Cool. Every piece of equipment has an operating temperature range. The operator should be informed on this matter. An unusual change in temperature that the operator cannot correct should be reported immediately to the plant supervisor. When the temperature of a piece of equipment rises rapidly, an immediate shutdown is recommended.
4. Tighten. Vibration is another major source of equipment failure. A simple step taken in time, such as tightening bolts, can prevent a serious failure. Equipment that is not secured properly vibrates, causes an unbalance, vibrates further, and compounds a cycle that can only lead to further trouble. In making rounds, the operator should put his or her hand on the bearings, touch the fan housing, and feel the motor casing. When any unusual sound is heard, vibration felt or motion seen, the proper steps should be taken by the operator to correct the condition.

3.2.0 Preventive Maintenance

Preventive maintenance inspection (PMI) is a system of routine inspections of equipment recorded for future reference on some type of inspection record. The purpose of PMI is to anticipate and prevent possible equipment failures by making periodic inspections and minor repairs in advance of major operating difficulties. Preventive maintenance directed specifically toward maintaining boiler efficiency is the exception rather than the rule. Rising fuel costs have placed an increasing emphasis on conscientious maintenance because it results in higher boiler operating efficiency. Preventive maintenance practices are easily justified from an economical and safety standpoint. *Tables 8-4* and *8-5* reflect NAVFACENGCOM recommendations for PMI.

Table 8-4 — PMI Checklist for Steam Boilers 350,000 Btuh or Less.

STEP	IF	THEN	WHEN
Observe condition of flame.	Flame is smoky, flame impinges on furnace walls or burner starts with a puff	Make appropriate repairs or adjustments.	Weekly
Test low water and fuel cutoff.	Boiler does not secure during tests	Locate problem and repair.	Weekly
Test water column or gauge glass.	Gauge glass is dirty, has an obstruction, or leaks are present including gauge cocks	Clean, remove obstruction or repair leaks, or replace.	Weekly
Observe operation of condensate of vacuum pumps.	Pump is defective or leaking	Repair or replace defective equipment.	Weekly
Check operation of chemical feed pots and pumps.	Leaks or improper operation exists	Repair or replace defective equipment	Weekly
Test flame detection devices and associated automatic fuel cutoff valves.	Loss of flame does not shut off fuel to burner	Repair or replace defective equipment.	Monthly
Inspect steam supply and condensate return piping.	Problems with valves, radiators, trap leaks, or excessive rust	Repair or replace defective equipment.	Monthly
Inspect fuel supply systems and piping. Include adjustment of oil pressure and ensure both oil supply and return lines have a fusible in-line valve.	Discrepancies are leaks, or insulation is missing	Repair or replace for corrective action.	Monthly
Check condition of safety valves.	Valves are obstructed to flow, are inoperative, or fail to meet code requirements	Repair or correct problem.	Monthly
Check boiler room drains.	Drains are not operating properly	Repair.	Monthly
Inspect burner assembly.	Evidence of improper fuel nozzle wear, plugging, or carbon building exists	Replace nozzle and adjust equipment after new nozzle is installed.	Monthly
Check transformer.	Transformer is replaced for any reason	Do not interchange transformers of different capacities.	Annually

Table 8-4 — PMI Checklist for Steam Boilers 350,000 Btuh or Less (cont.).

STEP	IF	THEN	WHEN
Inspect burner assembly, replace fuel filters and nozzle on oil burning equipment, clean and adjust electrodes.			Annually
Make internal and external inspection of heating surfaces after cleaning.			Annually
Inspect gas piping valves for proper support and tightness.	Leaks are present	Secure piping to the boiler and contact the gas company.	Annually
Remove trash.			Annually
Check draft, manifold pressure, and combustion. Over-fire draft should be .02" water gauged for oil burners.	Deficiencies are noted	Repair, adjust, or replace defective mechanism.	Annually
Inspect control equipment for proper sequence and operation.	Covers are missing, controls are dirty, or electrical contacts are fouled	Replace, clean, or repair.	Annually
Calibrate and check operation of gauges and meters.	Gauges are defective, cracked, have broken glass, or bent pointers	Have gauges calibrated or repaired, or replace.	Annually
Check shell for cleanliness, excessive rust, corrosion streaks, deformations, and cracks.			Annually
Check stack and breaching for integrity and tightness.			Annually

Table 8-5 — PMI Checklist for Hot-Water Boilers.

STEP	WHEN
Observe condition of flame.	Weekly
Check fuel supply and note oil level.	Weekly
Observe operation of circulating pumps. Lubricate pump motor bearing assembly and flex coupling.	Weekly
Test flame detection devices and associated automatic fuel cutoff valves.	Monthly
Inspect fuel supply systems and piping in boilers for leaks and loss of insulation.	Monthly
Check boiler room drains for proper functioning.	Monthly
Inspect burner assembly.	Monthly
Make internal and external inspection of heating surfaces after cleaning.	Annually
Inspect gas piping and valves regularly for proper support and tightness.	Annually
Check transformer.	Annually
Inspect area around boiler for cleanliness.	Annually
Inspect hot water supply and return piping and valves.	Annually
Check expansion tank and air eliminator equipment.	Annually
Check control equipment for proper sequence and operation.	Annually
Calibrate and check operation of gauges and meters.	Annually
Check breaching and stack for integrity.	Annually
Check shell for cleanliness, excessive rust, corrosion streaks, deformations and cracks.	Annually

3.3.0 Efficiency Maintenance

Efficiency-related boiler maintenance is directed at correcting any condition that increases the amount of fuel required to generate a given quantity of steam. Thus, at a specified boiler load, any condition that leads to an increase in flu-gas temperature, flue-gas flow, combustible content of flue gas or ash, convection or radiation losses from the boiler exterior, ductwork, or pipe, or blowdown rates is considered an efficiency-related maintenance item. Generally, attention to items can eliminate more serious consequences, such as damage to equipment and/or injury to personnel.

The boiler tune-up is the best method of improving efficiency. The primary objective of a tune-up is to achieve efficient combustion with a controlled amount of excess air, thus reducing the dry gas loss and the power consumption of forced- and induced-draft fans.

3.4.0 Care of Boiler Firesides

The boiler firesides must be kept clean. The burning of any petroleum product tends to be incomplete, thus leaving soot and carbon deposits on the boiler firesides. These deposits seriously reduce the efficiency of the boiler. Slag contributes greatly to failure of such parts as superheater support plates, baffles, protection plates, and soot blowers. Deposits also act as insulation and prevent the transfer of heat to the water or steam in the tubes.

Soot and slag accumulations that block the gas passages through the tube banks require the use of high air pressures to force the combustion gases through the boiler, thus reducing fire-room efficiency. Accumulations that block the gas passages also interfere with the designed flow of combustion gases and cause extremely hot gases to pass over protection plates, baffles, seal plates, and other parts that are not designed for such high-temperature gases; in some cases, early failure of these parts can be blamed directly on blocked gas passages and the resulting overheating of the parts.

When soot is allowed to remain on the boiler firesides for any length of time, the sulfur in the soot combines with moisture and forms sulfuric acid. This acid attacks tubes, drums, and headers. The extent of the damage caused by acid attack depends upon the length of time the soot remains on the tubes and upon the amount of moisture present during this interval. Moisture may be present as a result of high atmospheric humidity, rain or snow coming down the stack, leaky boiler tubes, and steam or water leakage through the boiler casing joints, particularly from machinery and piping installed above the boiler.

One indication of soot corrosion is the development of pinhole leaks at the point where the tubes enter the water drums and headers and at other points where it is difficult to clean the tubes properly. When soot corrosion is allowed to proceed unchecked, extensive deterioration of the boiler metals results.

You will find that keeping the firesides clean actually saves work, as well as saves the boiler. Clean tubes do not collect deposits as readily as dirty tubes do. It is a good deal easier to clean the firesides several times when they are only slightly dirty than to clean them once when they are heavily coated with soot and carbon.

Local instructions usually specify steaming intervals after which the boiler firesides must be cleaned. In addition to this upkeep, the firesides are normally cleaned just before the annual internal inspection.

Although there are a number of cleaning methods available (such as hot water washing, wet steam lancing, and so forth), mechanical cleaning should be considered the basic and preferred method of cleaning firesides. The other methods are generally used only when mechanical cleaning cannot adequately remove the fireside deposit.

Mechanical cleaning is accomplished within the boiler, in the furnace, and from outside the boiler through access doors by using various types of scrapers, probes, and wire brushes to remove soot and other deposits. In most instances, these cleaning tools can be obtained from the boiler manufacturer.

In addition to scrubbing and cleaning the firesides of the generating tubes, other areas of the firesides should receive scrupulous cleaning as well. Give particular care to those more or less inaccessible portions of the firesides that are not cleansed by the soot blowers. Remove any encrusted soot from burner impeller plates, bladed cones, and drip pans.

The furnace refractory must also be cleaned. This operation is perhaps best done last to remove not only original deposits from the brickwork but also soot and dust deposited after other parts of the boiler were cleaned. It is important to keep the brickwork clean for two reasons: first, soot and foreign matter lodged in expansion joints can prevent proper expansion of refractories when hot, and can ultimately cause serious cracking of the brickwork; second, soot and other deposits left on the brickwork will lower the melting point of the refractories.

3.5.1 Care of Boiler Watersides

Failure to keep boiler watersides clean reduces the efficiency of the boiler and contributes to overheating, and can lead to serious damage. Experience has shown that tube failures resulting from defective materials or poor fabrication are rare. The majority of all tube failures, other than those associated with water-level casualties, are caused by waterside deposits or accumulations.

Some tube failures are caused by waterside deposits of hard scale. More frequently, however, tube failures occur as the result of an accumulation of relatively soft materials such as metal oxides, the residue of chemicals used for boiler water treatment, the solids formed as a result of the reactions between scale-forming salts or other impurities, and the chemicals used for boiler water treatment.

As in the case of fireside cleaning, waterside cleaning is usually accomplished after specified steaming intervals and also before the annual internal inspection.

The need for cleaning watersides or firesides is often signaled by a gradual rise in the stack gas temperature. In other words, deposits on either the firesides or watersides of generating tubes reduce heat transfer from the furnace to the water. A good part of the non-transferred heat is, as you know, retained by the fireside or waterside deposit. However, some of the heat not properly carried away by the water and not absorbed by the deposits remains with the combustion gases. Therefore, the temperature of the stack gas rises.

When working in the watersides of a boiler, you should take all possible precautions to keep tools, nuts, bolts, cigarette lighters, and other small objects from sliding down into the tubes. Some advisable precautions are as follows:

1. Remove all small objects from your pockets before entering the boiler.
2. Keep an inventory of all the tools and equipment you take into the boiler. Ensure that you remove each item and check it off the inventory before closing up the boiler.
3. Do NOT set tools or other articles down in places where you are likely to forget them. For example, you should not leave tools on top of the steam separators or in other places that are easy to reach but hard to see.
4. When an article is lost in the boiler watersides, you must NOT close up or operate the boiler until the article has been located and removed. Even a very small article can interfere with boiler circulation and cause tube ruptures.

Additional precautions for waterside work include the following:

1. Close, wire, and tag all steam, water, and air valves that could possibly admit fluid to the boiler. Disconnect (or otherwise render inoperative) the remote operating valves as well.

2. Ensure that adequate ventilation is provided before entering the waterside of a boiler.
3. Ensure that all portable extension lights are of the watertight globe type, with the globe encased in a rubberized, metal cage. Be sure all lights are grounded and wires are not broken. Examine the wires from end to end to be sure that the insulation is not broken or cracked, exposing the bare wire.
4. Station a person outside the drum whose ONLY duty is to act as tender and to assist personnel working in the drum.

Boiling out is a special waterside cleaning technique. There are two approved methods for boiling out boilers—the sodium metasilicate pentahydrate method and the trisodium phosphate method. The method used depends upon the purpose of the boiling out. The sodium metasilicate pentahydrate method is used to remove rust-preventive compounds and other preservatives; consequently, this method is used for boiling out (1) newly erected boilers, (2) reactivated boilers, and (3) boilers that have had major tube renewals. The trisodium phosphate method is used when you are boiling out for the removal of oil and for scale softening in preparation for mechanical cleaning.

3.6.0 Laying-Up Idle Boilers

Many operators carefully follow all boiler water treatment procedures and regulations only to find that the watersides may still experience corrosion and pitting. It should come as no great surprise that the fault is not with the treatment methods, but rather with the manner in which the boiler is permitted to stand idle. After the pressure drops within an idle boiler, air gradually seeps into the boiler, carrying oxygen with it.

The air also contains carbon dioxide that combines with the boiler water to form carbonic acid, which lowers the residual causticity of the boiler water. Gradual in-leakage of feedwater can dilute and lower the causticity of the boiler water even further. In addition, condensation within the boiler, on both waterside and firesides, can produce water droplets that are saturated with oxygen and contain no causticity. Conditions within the boiler are now ideal for active and rapid corrosion. This means the need for protecting boilers that are left idle for any length of time is very important.

3.6.1 Laying-Up a Boiler by the Wet Method

A wet lay-up is done after a thorough cleaning of both firesides and watersides. The feedwater used to fill the boiler is deaerated as much as possible. While the boiler is being filled, add caustic soda in sufficient quantities to maintain a pH reading of 9.5 to 11. Additionally, add approximately 0.03-0.06 pounds of sodium sulfite per 1,000 gallons of boiler holding capacity to maintain 30-60 ppm. When equipment is installed in a plant and used in acid treatment of feedwater, it should never be used to fill a boiler for idle standby; this results in a low pH in the boiler as concentration by boiling is taking place. To ensure the boiler is filled completely, you should add water until it overflows at the top of the boiler through any convenient outlet, and then close the outlet. When there is a superheater on the boiler, add water to fill it completely. If appreciable air is dissolved in the water, you should boil the water to vent out any air after the boiler is nearly filled.

When the installed chemical feeding system is not suitable for continuous feeding and it is necessary to slug feed the chemical while the boiler is being filled, the boiler water must be mixed to obtain uniform distribution of the chemical throughout the boiler. This can be achieved by pumping water from one section of the boiler to another using a circulating pump. When such a pump is not available, mixing can be accomplished by heating the boiler just enough under low fire to set up natural circulation.

After a boiler has been filled for standby, it must be kept filled as long as it is idle with no water flowing in or out. Leakage out, as through a leaky blowdown valve, can admit air and form a waterline in the boiler. A method sometimes used for keeping a boiler completely full consists of using a small tank placed above the boiler with a line connected to any outlet of the boiler or the superheater header. This method also shows when any leakage occurs into or out of the boiler. The small tank is provided with a vent and a water column. When the boiler is filled, water is added up into the tank. Then, if water leaks out of the boiler, water from the tank flows in, keeping the boiler full. When the level in the tank rises, it shows that water is leaking into the boiler, either through the feed line or the steam line.

Water in an idle boiler should be sampled and analyzed weekly. When the causticity or the concentration of sulfite drops considerably, you should ensure additional chemical is fed and the boiler water circulated to distribute the chemical uniformly.

One disadvantage of using the wet method is when the temperature of the water in the boiler is lower than the outside temperature, condensation or moisture occurs on the outside of a metal boiler, causing corrosion. Some engineers coat the outside of a metal boiler with light oil to help protect it from corrosion.

3.6.2 Laying-Up a Boiler by the Dry Method

Dry lay-up should be used when a boiler is scheduled to be out of service for a long period of time or when a boiler is in danger of freezing. The first step is to clean both firesides and watersides of the boiler thoroughly. After the boiler is cleaned, the watersides must be completely dried because any moisture remaining on the surface will cause corrosion. Take precautions to preclude entry of moisture in any form from steam lines, feed lines, or surrounding air.

To start this method, place a moisture-absorbing material such as quicklime in the boiler at a rate of 2 pounds, or silica gel at the rate of 5 pounds, for 30 cubic feet of boiler volume. Place the chemical-absorbing material in trays and insert it in the drums or manholes. Remember, air carries moisture so make sure you close all of the manholes and handholes. This method requires that you check the moisture-absorbing material every 3 months.

One method of dry lay-up for a large utility type of boiler is to simply feed nitrogen through the boiler vents while draining the boiler. With using this method, you should maintain the nitrogen pressure at 5 psig during the storage period.

Test your Knowledge (Select the Correct Response)

6. What boiler operator maintenance responsibility is required to keep a boiler running continuously at its original capacity and efficiency?

   A. Keeping equipment in service for maximum periods of time.
   B. Determining any flaws so equipment can be removed in time to prevent serious damage.
   C. Performing minor repairs on equipment that has been removed from service to minimize outage time.
   D. All of the above

7. How often should a PMI be done on the boiler room drains of a hot-water boiler?

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

8. **(True or False)** Water that is contained in an idle boiler should be sampled and analyzed monthly.

   A. True
   B. False

Summary

This chapter covered the procedures for boiler installation, plant operations, and maintenance. You were also provided information on the purpose, types, and components of gaseous and chemical extinguishing systems.

Ensuring the installation, operation, and maintenance procedures for boilers meet the necessary standards is an important requirement for fulfilling your duties as a boiler plant worker, supervisor, and manager.

Review Questions (Select the Correct Response)

1. How often should the internal inspections of wet or dry lay-up boilers be conducted?

    A. Semi-annually
    B. Monthly
    C. Annually
    D. Weekly

2. What waterside damage is the result of mechanical causes and not corrosion?

    A. Die marks
    B. Abrasion
    C. Corrosion
    D. None of the above

3. What action should be taken when defects are discovered during a waterside inspection of drums and headers?

    A. Report defects to the maintenance officer.
    B. Record defects in the maintenance log.
    C. Record defects in the boiler water treatment log.
    D. All of the above

4. Boiler firesides are inspected for signs of damage and deterioration when the boiler is secured for fireside cleaning. At what other intervals should this type of inspection be conducted?

    A. Each day the boiler is secured
    B. Every time the boiler is secured
    C. When material inspection is inevitable
    D. When NAVFAC requests an inspection

5. What two types of slag-forming materials cause the most damage to boiler refractories?

    A. Calcium sulfate and sodium hydroxide
    B. Hydrazine hydrate and sodium aluminate
    C. Caustic soda and sodium phosphate
    D. Vanadium salts and sodium chloride

6. What term is used to describe any opening in a tube that is not associated with tube enlargement?

    A. Thick-lipped rupture
    B. Crater
    C. Perforation
    D. Fatigue

7. What term is applied to tubes that appear to have dropped downward toward the furnace under their own weight?

   A. Warping
   B. Folded
   C. Sagging
   D. Stretched

8. Which condition should be looked for when conducting a steam and water piping inspection?

   A. Excessive expansion and contraction
   B. Undue vibration in piping connections to the boiler
   C. Leaking water column connections
   D. All of the above

9. What step should be taken to test the operation of a float-activated low-water fuel cutoff device?

   A. Drain the float bowl to the low-water level.
   B. Close the fuel oil solenoid valve.
   C. Blow down the steam drum.
   D. Disconnect the low-water control circuitry.

10. Venting should be held to a minimum to preclude what condition in the feedwater?

   A. Deaerator venting
   B. Hydrogen entrainment
   C. Oxygen entrainment
   D. Oxygen venting

11. What indications of trouble should the boiler plant supervisor be able to identify?

   A. Strange noises
   B. Unusual vibrations
   C. Abnormal temperatures
   D. All of the above

12. What term is commonly used to describe the universal solvent?

   A. Oxygen
   B. Water
   C. Sodium phosphate
   D. Caustic soda

13. What term is used for deposits on tubes and other internal surfaces caused by calcium salts, magnesium salts, and insoluble materials?

A. Caustics
B. Crystals
C. Solids
D. Scales

14. What is the only sludge dispersant approved by NAVFAC for use in shore-based boilers?

A. Magnesium silicate
B. Calcium sulfate
C. Quebracho tannin
D. Sodium phosphate

15. Which condition inside a boiler is caused by a small amount of seawater in the feedwater?

A. Steam carryover
B. Heavy sludge
C. Baked sludge
D. Warping

16. Feedwater or makeup water tanks should be maintained within what temperature range?

A. 125°F to 135°F
B. 140°F to 160°F
C. 165°F to 175°F
D. 180°F to 200°F

17. What two types of solids are present in most boiler water?

A. Dissolved and floating
B. Suspended and floating
C. Dissolved and scale-forming
D. Suspended and dissolved

18. How many pounds of steam per hour are produced by one boiler horsepower?

A. 32.45
B. 34.50
C. 36.35
D. 38.50

19. What person is the most important member of a boiler plant maintenance team?

A. Operator
B. Watch chief
C. Supervisor
D. Laboratory technician

20. What is formed when soot mixes with water?

    A. Slag
    B. Sulfur dioxide
    C. Sulfuric acid
    D. Hydrogen sulfide

21. Which component will have a lower melting point if soot and other deposits are left on boiler brickwork?

    A. Boiler tube
    B. Header
    C. Burners
    D. Refractories

22. What two methods can be used to boil out the watersides of a boiler?

    A. Sodium metasilicate pentahydrate and trisodium silicate
    B. Sodium pentahydrate and sulfuric acid
    C. Sodium silicate and trisodium metasilicate pentahydrate
    D. Sodium metasilicate pentahydrate and trisodium phosphate

23. What chemical should be added to the water when laying-up a boiler using the wet method?

    A. Sodium sulfite
    B. Sodium hydroxide
    C. Sodium silicate
    D. Sodium electrolyte

24. **(True or False)** Laying-up a boiler by the dry method should be used when a boiler is scheduled to be out of service because it could freeze.

    A. True
    B. False

Trade Terms Introduced in this Chapter

Circumferential	The line bounding a circle, a rounded surface, or an area suggesting a circle.
Quebracho tannin	Sludge dispersant derived from the bark of the sumac family of trees found in South America.

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.

Inspection and Certification of Boilers and Unfired Pressure Vessels, NAVFAC MO-324

American Society of Mechanical Engineers (ASME), *Boiler and Pressure Vessel Code*

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 9

Duct and Ventilation Systems

Topics

To hear audio, click on the box.

Overview

As a Utilitiesman (UT), you can expect to become involved in the installation of duct and/or ventilation systems designed to provide conditioned air or to remove less desirable air from a given space or facility. When sheet metal is to be fabricated into system components, the Steelworker (SW) provides the expertise. When duct board is used, fabrication and installation may be tasked to the UT exclusively.

This chapter provides some key knowledge to aid you in the identification of types of duct and ventilation systems, their installation, and factors you must be aware of in determining the sizes required to meet specified building requirements. Keep in mind that the term *air conditioned* refers to air that has been cooled, heated, dehumidified or humidified, or any combination of these.

Objectives

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

1. Describe the different types of duct systems.
2. Describe procedures for balancing duct systems.
3. Describe the different types of ventilation systems.

Prerequisites

None.

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

Air Conditioning and Refrigeration	↑	U
Duct and Ventilation Systems		T
Boilers		
Compressed Air Systems		A
Sewage Treatment and Disposal		D
Water Treatment and Purification		V
Fire Protection Systems		A
Interior Water Distribution and Interior Waste Systems		N C
Plumbing Planning and Estimating		E
Contingency Support		D

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 DUCT SYSTEMS

To deliver air to the conditioned space, you need air carriers. These carriers are called ducts. They are made of sheet metal or some structural material that is noncombustible.

Duct systems are also classified as high-pressure or high-velocity ductwork and low-pressure or low-velocity ductwork. The term *high-pressure* or *high-velocity* ductwork includes ductwork systems and ***plenums*** from the fan discharge to the final high-velocity mixing boxes, or other final pressure-reducing devices or any air supply system served by a fan operating with a static pressure range of 3 inches to 7 inches of water column (WC).

High-velocity or high-pressure systems with fan static pressures of 3 inches WC or greater are defined as high pressure. Usually the static pressure is limited to a maximum of 7 inches WC, and duct velocities are limited to 4,000 feet per minute (fpm). Systems requiring pressures more than 7 inches WC are normally unwarranted and could result in very high operating costs. Systems with velocities more than 4,000 fpm performs satisfactorily when all duct fittings are carefully designed and installed. However, velocity pressure losses are excessive and velocities more than 4,000 fpm are not recommended.

A high-velocity double-duct system begins with a high-pressure fan of class II or III design any conveys air through sound-treated high-velocity ductwork connected to sound and pressure-attenuating mixing units. Connections to the outlets of the reduction units are treated as low velocity.

Smaller sized ductwork, using higher velocities, permits conveyance of air to areas limited by construction and reduces floor-to-floor height. Round ductwork generally provides the greatest strength, tightness, and economy, while oval and rectangular ducts can be used when large risers are involved. *Figure 9-1* shows the three types of ductwork.

A necessary component of the high-pressure system is the mixing box or unit. Its function is to blend air at two different temperatures for proper delivery to the rooms. This requires special pressure-reducing air valves at both hot and cold inlets, mixing baffles to prevent stratification of air, and sound attenuation treatment to absorb noise generated by the air valves.

Figure 9-1 — Types of ductwork.

The term *low-pressure* or *low-velocity* ductwork applies to systems with fan static pressures less than 3 inches WC. Generally, duct velocities are less than 2,000 feet per minute.

The choice between using low versus high-velocity systems requires you to study architectural, mechanical, and structural considerations. Installation cost, temperature control, and operating cost should also be studied.

Low-velocity double duct systems are many years old. It was not until after World War II that their use became extensive. Space for the installation of the double ducts is a main consideration for this system and must be provided during initial planning. Difficulties in providing for this space in modern structures with low floor-to-floor heights and flush ceilings, together with the need for developing a compact distribution system for existing buildings, has brought about the development of high-velocity double duct systems. High velocity saves ceiling space and duct shaft space, but requires greater attention in the selection of fans and equipment with regard to sound levels.

Also, higher duct velocities require increased fan static pressures; therefore, increased operating costs. On the other hand, high-velocity systems are easy to balance and control and have much greater flexibility for partition changes and so forth.

Generally, high-velocity systems are applicable to large multistory buildings; primarily because the advantage of saving in duct shafts and floor-to-floor heights is more substantial. Small two- and three-story buildings are normally low velocity; however, both systems should be analyzed for each building. *Table 9-1* shows outlet velocities for the range of optimum performance of typical ventilation fans.

Ducts are made of many types of materials. Pressure in the ducts is small, so materials with a great deal of strength are not needed. Originally, hot air ducts were thin, tin sheet steel. Later, galvanized sheet steel, aluminum sheet, and finally, insulated ducts made from materials, such as asbestos and fiberboard, were developed. Passageways, formed by studs or joists, are sometimes used for return air when a fire hazard does not exist.

Ducts made of asbestos are no longer legal. Asbestos may still be encountered when performing preventative and corrective maintenance in older facilities. If you have any doubt, inform you COC immediately. Naval guidance for asbestos handling, demolition, and disposal are covered by OPNAVINST 5100.23(series), *Navy Safety and Occupational Health (SOH) Program Manual*. However, you should also learn the local laws and restrictions pertinent to your work location. These federal, state, and local laws are important. In an overseas location, the laws of the host country must be researched and clearly understood in the construction planning phase. It is inevitable that somewhere in the disposal cycle, transporting of this type of material to a disposal site will take place over roads not directly under Navy control.

Table 9-1 — Outlet Velocities for Optimum Performance of Fans

Static Pressure Inches of Water	Centrifugal Fans Outlet Velocity fpm	Tube Axial and Vane Axial Fans Outlet Velocity at Wheel Dia. fpm
1/4	400 - 100	950 – 1,500
1/2	550 – 1,450	1,350 – 1,900
3/4	700 – 1,750	1,650 – 2,350
1	800 – 2,000	1,900 – 2,700
1 1/2	1,000 – 2,500	2,350 – 3,300
2	1,150 – 2,800	2,700 – 3,800
2 1/2	1,250 – 3,200	3,000 – 4,300
3	1,400 – 3,500	3,300 – 4,700
4	1,600 – 4,050	
6	2,000 – 4,950	
8	2,300 – 5,700	
10	2,500 – 6,400	

The material you use for the construction of ductwork depends on the application of the duct. Use *Table 9-2* as a guide in the selection of duct material. The thickness of the material depends primarily on the pressure developed within the duct, the length of the individual sections, and the cross-sectional area of the duct. The developed length of a section for a particular gauge can be increased if you install angle bracing around the duct.

It is beyond the scope of this chapter to include the technical details necessary for the selection of proper metal thickness and section length for different pressures and for different cross-sectional areas of duct material. However when you make repairs, the same thickness and type of metal that was originally included in the system must be installed. Where the original ductwork was destroyed by pressure, repairs may include increasing metal thickness or adding of angle bracing.

Ducts are either round or rectangular in cross section. Rectangular ducts usually have the advantage of saving room space and being easier to install in walls. However, whenever possible you should use round ducts, which provide less resistance to air flow.

Additionally, round ducts require less material to construct; thus, by using round ducts, you can save both money and material during installation.

Initially, an air-handling duct is usually sized for round ducts. Then, if rectangular ducts are wanted or required, duct sizes can be selected to provide flow rates equivalent to those of the round ducts originally selected.

Table 9-2 — Materials for Ductwork

Application	Material
Normal system handling dray air: 1. Air conditioning 2. Ventilating	Galvanized steel Fiberboard
Systems handling air at very high temperature: 1. Kitchen exhaust	Black steel
System handling partially saturated air: 1. Outside air intake ductwork 2. Exhaust ductwork near discharge outlet 3. Ductwork exposed to weather elements	Aluminum
Systems handling completely saturated air: 1. Shower exhaust 2. Dishwasher exhaust 3. Ductwork exposed to salty atmosphere	Copper

Table 9-3 is a ready reference to determine the size of a rectangular duct that equals the carrying capacity of a predetermined round duct. To use this chart, convert a rectangular duct with sides of 17 inches by 16 inches, respectively. First, come down the left-hand column until you reach 17 inches; then trace the line horizontally across the columns until you reach the column headed by 16 inches. At the center of these intersecting lines is 18.0 inches. This is the round duct size equivalent. In the second example, following the same procedure, it is clearly shown that a 22-inch by 17-inch rectangular duct has a 21-inch round duct equivalent.

Table 9-3 — Duct Capacity Conversions

(The dimensions in this chart are in inches)

Side Rectangular duct	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
3.0	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1	5.2	5.5	5.7	6.0	6.2	6.4	6.6	6.8	7.0
3.5	4.1	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.4	7.6
4.0	4.4	4.6	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4	6.8	7.1	7.3	7.6	7.8	8.1	8.3
4.5	4.6	4.9	5.2	5.4	5.6	5.9	6.1	6.3	6.5	6.9	7.2	7.5	7.8	8.1	8.4	8.6	8.9
5.0	4.9	5.2	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.3	7.6	8.0	8.3	8.6	8.9	9.1	9.4
5.5	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.6	8.0	8.4	7.8	9.0	9.4	9.6	9.8

Side Rectangular duct	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30
6	6.6																			
7	7.1	7.7																		
8	7.5	8.2	8.8																	
9	8	8.6	9.3	9.9																
10	8.4	9.1	9.8	10.4	10.9															
11	8.8	9.5	10.2	10.8	11.4	12														
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1													
13	9.5	10.3	11.1	11.8	12.4	13	13.6	14.2												
14	9.8	10.7	10.5	12.2	12.9	13.5	14.2	14.7	15.3											
15	10.1	11	11.8	12.6	13.3	14	14.6	15.3	15.8	16.4										
16	10.4	11.4	12.2	13	13.7	14.4	15.1	15.7	16.3	16.9	17.5									
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6								
18	11	11.9	12.9	13.7	14.5	15.3	16	16.6	17.3	17.9	18.5	19.1	19.7							
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19	19.5	20.2	20.8						
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	17.5	18.2	18.8	19.5	20.1	20.7	21.3	21.9					
22	12	13.1	144.1	15	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21	21.7	22.3	22.9	24.1				
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2	23.9	25.1	26.2			
26	12.8	14.1	15.2	16.2	17.2	18.1	19	19.8	20.6	21.4	22.1	22.8	23.5	24.1	24.8	26.1	27.2	28.4		
28	13.2	14.5	15.6	16.7	17.7	19	18.7	19.6	200.8	21.3	2.1	22.9	23.6	24.4	25	25.7	27.1	28.2	29.5	30.6
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22	22.9	23.7	24.4	25.2	25.9	26.7	28	29.3	30.5	31.6	32.8
32	14	15.3	16.5	17.7	18.8	20.8	20.8	21.8	22.7	23.6	24.4	25.2	26	26.7	27.5	28.9	31	32.3	33.6	33.8
34	14.4	15.7	17	18.2	19.3	19.3	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	32.3	33.6	33.8	34.8
36	14.7	16.1	17.4	18.6	19.8	19.8	21.9	23	23.9	24.8	25.8	26.6	27.4	28.3	29	30.5	32	33	34.6	35.8

This chart depicts sizes of rectangular duct that are equal in carrying capacity to round ducts. To use this chart find the diameter of round duct in the chart. Then find one side of rectangular duct by reading up. Find the other side by reading left to the first row of numbers representing the other side of the rectangular duct.

1.1.0 Types of Duct Systems

In this section, the advantages and disadvantages of a double-duct system are discussed. Since there are many possibilities for an adequate duct system, one such system is modified to fit the needs of two different residential configurations.

A double duct system generally consists of a blow-through fan unit discharging filtered air through stacked or adjacent heating and cooling coils into separate plenums and ductwork with thermostatically controlled mixing dampers at various room locations.

The inherent advantage of a double duct system is that individual room conditions can be maintained from a central system, within the limitations of supply air temperatures. This is done by the blending of hot and cool air through automatically controlled mixing devices. Another important credit is flexibility. In this regard, individually controlled rooms can be easily incorporated, at modest cost, after the building is completed.

In modern buildings of multiple exposures designed for variable functions and changing occupancy, individual room control is essential and a double duct system should be seriously considered.

Double duct systems for low pressure are usually tiered hot and cold ducts within the furred space. They are generally located above corridors. The manner of distributing proper temperature air to the room is through right angle, interlinked mixing dampers operated by motors controlled through thermostats. In general, this type of system uses the same corridor plenum area around the ducts for conveyance of return or exhaust air. The residual volume of space left for this purpose is too often neglected. Inevitably, this results in insufficient relief for the rooms.

The main disadvantage of a double duct system is lack of stability of air quantities supplied to areas (rooms) because of varying duct static pressures.

All duct elbows, including supply, exhaust, and return, should be made with a center line radius of 1.5 times the duct width, parallel to the radius wherever possible. In no case should the center line radius be less than the width of the duct parallel to the radius. Where space does not permit the above radius, or where square elbows are indicated on plans, turning vanes of an approved type should be used.

Additionally, there are numerous adaptations and modifications of duct systems. *Figure 9-2* shows a residential duct system with the furnace and central air unit located in the basement.

In *Figure 93*, the same basic system is shown in a single-story house. The duct system is located in the overhead and the return air enters through the bottom of the central air-handling unit. When the duct system is located in a crawl space, basement, or attic, it should be insulated to maintain the existing temperature.

Figure 9-2 — Basement residential duct system.

Figure 9-3 — Overhead residential duct system.

1.2.0 Duct Construction

This section will discuss the basic round and rectangular sheet metal ducts. Emphasis is placed on layout and pattern requirements. Fiberboard duct construction and its use will also be discussed.

1.2.1 ound Duct

Straight sections of round duct are usually formed from sheets rolled to a proper radius and assembled with a longitudinal grooved seam. Each end of a round section is swaged and assembled with the larger end of the adjoining section butting against the swage. Sections are held together by rivets, by sheet metal screws, or by solder. Where solder is not used, duct tape or liquid rubber (duct sealer) should be used as a covering at all joints. Rectangular ducts are generally constructed by bending corners and by grooving along the longitudinal seam.

The duct system should be constructed in a way that avoids abrupt changes in size, direction, or other resistance conditions that can create unnecessary noise and reduce the air volume. The normal noise level of air flowing through a duct depends on the velocity of the air moving through the duct. This can be further reduced by lining or covering the duct with sound absorbing material. The exterior of ducts that carry conditioned air can be covered with heat insulation materials to prevent heat transfer between ducts and the surrounding air. All materials used for duct lining and coverings must be noncombustible.

Ducts should be constructed for easy maintenance. They should have access plates or doors included to facilitate cleaning and inspection (*Figure 9-4*). It is important that the correct size duct (as specified on the prints or drawings) be used for the construction of the duct system.

Figure 9-4 — Duct access door.

The amount of air to be carried depends on the size of the duct. This determines the pressure loss in the system—the larger the quantity of air moving through a duct of a given cross-sectional area, the greater the friction loss. Similarly, with a given quantity of air to be delivered, the friction loss increases in inverse proportion to the sizes of ducts provided to carry the air. Therefore, the power required at the fan for delivering a given quantity of air increases rapidly as the duct size is decreased. It is important to keep these facts in mind, when you have to replace or change sections of ducts. The same size new duct should be used unless proper design provisions are made for a change in size.

1.2.2 Rectangular Duct

Straight sections of rectangular duct are normally formed by personnel in the Steelworker rating. This is normally accomplished on bending-brake type of equipment. Then the rectangular ductwork is joined together as mentioned earlier. Straight sections of ducts can usually be laid out without a pattern. However, a pattern is required for elbows, transitions, and jump fittings. Steelworkers perform the task, but you are the planner, so you need to be aware of the time required to draw and fabricate the required patterns. Also bear in mind that if this is a one-time job, you can make the pattern of paper or cardboard. If there are large numbers of fittings to be constructed with the same size and dimension, you should make the pattern of sheet metal.

1.2.3 Fiber Glass Duct

A fiber glass duct is constructed of molded glass fibers covered with a thin film coating. This coating is usually of aluminum, but vinyl or other plastic coatings are sometimes used. Since they are made of glass fibers, the ducts are inherently insulated. Also, they are primarily used where insulation is a factor. Fiber glass meets military specifications for a flame spread rating of less than 25 and a smoke development rating of less than 50 for insulating material. The fiber glass ducts allowed for use on Navy installations must range between 3/4 inch to 2 inches thick, depending upon the size of the duct.

The nature of a fiber glass duct requires that it be supported with 1-inch by 1/16-inch galvanized steel strap hangers shaped to fit the duct. For round ducts, these supports must be on not less than 6-foot centers. Rectangular and square ducts up to 24-inch spans may be supported on 8-foot centers. Ducts larger than 24 inches require support on 4-foot centers.

The applicability of fiber glass ducts on heating systems is sometimes limited by the adhesive used on the protective outer covering to cause it to adhere to the fiber glass material. Unless aluminum surface duct is used, the specification of the duct should be checked carefully to ensure that it does not fail when heated over 250°F.

Fiber glass ducts can be molded into a variety of shapes for special uses. Round ducts and reducers are available from manufacturers' stock. For most purposes, however, the duct is supplied flat in the form of a board, with V-grooves cut into the inner surface to allow folding to make a rectangular section. The ends of the boards are molded so that when the rectangular duct is formed, two sections of the same size fit together in a shiplap joint to ensure a tight joint in positive alignment. It is important to exercise care in selecting a board of adequate size to complete the desired duct before beginning cutting and grooving operation. In all cases, the inside diameter of the duct is the determining factor for board size. To determine board size, see *Table 9-4*.

Table 9-4 — Duct Board Length Selection Chart

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76
7	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78
8	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
9	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
10	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
11	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86
12	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
13	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
14	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
15	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94
16	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96
17	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98
18	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
19	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102
20	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104
21	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106
22	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108
23	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
24	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112
25	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114
26	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
27	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118
28	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
29	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	
30	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	102		
31	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120			
32	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120				
33	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120					
34	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120						
35	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120							
36	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120								
37	94	96	98	100	102	104	106	108	110	112	114	116	118	120									
38	96	98	100	102	104	106	108	110	112	114	116	118	120										
39	98	100	102	104	106	108	110	112	114	116	118	120											
40	100	102	104	106	108	110	112	114	116	118	120												
41	102	104	106	108	110	112	114	116	118	120													
42	104	106	108	110	112	114	116	118	120														
43	106	108	110	112	114	116	118	120															
44	108	110	112	114	116	118	120																
45	110	112	114	116	118	120																	
46	112	114	116	118	120																		
47	114	116	118	120																			
48	116	118	120																				
49	118	120																					
50	120																						

* For 1 1/2 -inch board – ADD 4 INCHES to these dimensions.
* for 2-inch board – ADD 8 INCHES to these dimensions.

To form a rectangular duct, the flat duct board is measured accurately and grooves are cut at the proper locations. The board is then folded into a rectangular shape. When the board is cut, an overlapping tab is left and this is then pulled tight and stapled. Tape is applied and the joint is heat sealed. Joints between sections are made by pulling the shiplap end sections together. The joint is then completed by stapling, taping, and heat sealing the junction (*Figure 9-5*).

Sheet metal ducts expand as they become hot and contract as they become cold. The degree to which expansion and contraction becomes an installation factor depends upon the temperature of the air surrounding the ducts and the temperature of the air moving through the ducts. Fabric joints are often used to absorb this duct movement. Additionally, fan noise and furnace or air-conditioner noise tends to travel along the metal ducts. Therefore, fabric joints (usually constructed of heavy canvas) are used to join the branch ducts to the plenum.

Figure 9-5 — Forming rectangular fiberglass ducts from duct board.

1.3.1 Sizing Duct Systems

There are numerous factors that you need to consider when sizing duct systems. These factors cause you to make modifications and adjustments throughout the planning and installation process to develop an efficient working system. First, you must calculate the air volume required for heating and cooling the required space. This will assist you in determining the necessary duct size, fan size, fan speed, and so forth, that is needed to circulate the conditioned air. While determining the heating and the cooling factors, you should think in terms of air circulation throughout the building and in each individual room or space. Remember, air movement is determined by the type of return airflow that you use.

Four other important duct system components are diffusers, grilles, registers, and dampers. Each of these components has a direct correlation between functional design, amount of air accommodated, and the air movement pattern.

The elbows within the duct system are a major source of airflow restriction. Whenever possible, you can gain efficiency by installing long sweeping elbows. Short 90-degree elbows should be used sparingly on long duct runs. However, they can be used very effectively with a minimum of air turbulence and airflow restriction when installed just before diffusers, grilles, and registers.

Your final duct calculations involve taking unit pressure drops and total pressure drops throughout the system. Some of the major contributing factors to these pressure drops are as follows:

- Length of duct
- Duct material and interior finish
- Changes in duct size
- Number of elbows

Normally, you will be installing a duct system according to pre-established blueprints and drawings. Occasionally you may need to refer to other sources and review trade association standards. The *ASHRAE Handbook of Fundamentals* has three chapters dedicated to methods and procedures for selecting proper duct sizes. You should become familiar with the contents of these three chapters; particularly, if you are involved in the design phase of an air-conditioning system.

Test your Knowledge (Select the Correct Response)

1. It is now illegal to use what type of material for making ducts?

   A. Steel
   B. Aluminum
   C. Asbestos
   D. Fiber glass

2. **(True or False)** The first step to follow, when sizing a duct systems, is to calculate the air volume required for heating and cooling the required space.

   A. True
   B. False

2.0.0 BALANCING DUCT SYSTEMS

A duct system is always installed to fulfill specific requirement features related in some way to the health and welfare of human beings. Equally important is the fact that a properly balanced operating system results in lower operating costs and significant utilities conservation. Consequently, it is important that these systems, regardless of the function, operate properly. When a duct system is initially installed, the required pressures and performance data are available from the construction drawings and the manufacturer's instructions. After installation, pressures and performance requirements should be measured to ensure proper airflow at different locations. Once the proper airflows are established, little change should take place within the system. Maintenance personnel must ensure that the system is operating correctly by conducting certain periodic tests. Tests are used for the initial and subsequent setting of grilles, diffusers, dampers, and registers to obtain the necessary airflow required by specifications, codes, regulations, or trade association standards.

It is important to understand the pressure in a duct carrying a moving stream of air. Certain changes in an existing duct system are often necessary and you should be able to accomplish these changes. In addition, malfunctioning duct systems require immediate attention, and an understanding of the basic elements of the system is required before troubleshooting and corrective action can be undertaken. Furthermore, you need to have an essential knowledge of airflow, before a duct system can be properly balanced.

Static pressure is a measure of the outward push of air on the walls of a duct. When air is not moving within a duct because a damper at the outlet is closed, the static pressure can be measured by means of a pressure gauge installed in the wall of the duct. If the damper in the duct is then opened and the air is flowing, static pressure continues to be present. It will be reduced when the damper is opened, but the static pressure can still be read on the gauge.

When air is flowing in a duct, there is another pressure that can be measured, in addition to the static pressure. This is the pressure exerted by the moving airstream. This pressure acts in a plane perpendicular to the direction of airflow. To illustrate, imagine a horizontal duct without any air flowing in it. When a thin, flat piece of metal is suspended with a movable hinge from the top of the duct, it will hang straight down when air is not moving. When air is flowing, the hinged piece of metal swings upward toward the top of the duct. The velocity pressure is the force that causes the deflection of the hinged vane (obviously, the greater the air velocity, the greater the pressure acting on the hinged vane and the greater its deflection from the perpendicular).

The velocity pressure cannot be measured as easily as the static pressure. When a hollow tube is inserted in the moving airstream, and a gauge is connected to the end of the tube, the gauge registers a certain pressure. This pressure is larger than the static pressure because the gauge indicates the sum of the static and the velocity pressure. This sum is known as the total pressure. Since total and static pressure can be easily measured, the velocity pressure can be found by subtracting static from total pressure. In most problems concerning duct systems, air pressure is expressed in terms of inches of water (1 pound per square inch = 27.74 inches of water.)

It is important that the design data be recorded when the duct system is initially installed. After initial start-up, the system should be balanced so that each air outlet is adjusted to the design rate of flow. During the initial balancing procedure, the actual design rate of flow is sometimes not achieved, but the flow is within the range of acceptable standards. When such conditions exist, they should be noted on the design data sheet where they may be considered by maintenance personnel during repairs or the rebalancing of the system.

Static pressure measurements should be taken throughout the system after the system is balanced and proper operation is assured. Also, the total pressure difference across the fan (the difference between the suction total pressure and the discharge total pressure) is noted. Although these initial measurements can be used for checking the design of the system, their main function is to serve as reference data for future tests. If the system fails to function properly at any time, another set of measurements should be taken and compared to the original set.

2.1.0 Air Balancing Instruments

There are numerous instruments designed for air balancing requirements which are available from different manufacturers. The ones most commonly used will be discussed in this section.

2.1.1 Velometer

This instrument is particularly adaptable to maintenance work because of its portability, wide scale range, and instantaneous reading features. Its accuracy is suitable for most air velocity and static pressure readings. Since velometers are made by several manufacturers, the instruction sheets for any instrument should be thoroughly understood before attempting to use it. A functional velometer set consists of the basic meter with hoses and accessories (*Figure 9-6*).

2.1.2 Manometer

A manometer is an instrument that indicates air pressure by employing the principle of balancing a column of liquid of known weight against air pressure. The units of measure used are pounds per square inch, inches of mercury using mercury as the fluid, and inches of water using water as the fluid.

Figure 9-6 — Velometer set.

The simplest form of manometer is the basic U-tube type. Several variations of the basic type are presently used in air movement applications, for example, the inclined type (draft gauge) and the combination inclined and vertical type. *Figure 9-7* shows an inclined manometer with a pitot probe. Many commercially installed central duct systems have permanently mounted manometers connected to duct interiors with static pressure tips.

Figure 9-7 — Inclined monometer with pitot probe.

2.1.3 Rotating Vane Anemometer

The rotating vane anemometer (*Figure 9-8*) consists of a propeller or revolving vane connected through a gear train to a set of recording dials that indicate the number of linear feet of air passing in a measured length of time. It requires correction factors and frequent calibrations, and it is not as accurate as the velometer.

The primary application for a rotating vane anemometer is the measurement of grille velocities on heating, cooling, and ventilating installations; however, it may not be suitable for exhaust measurements or for measurements on very small grilles.

Figure 9-8 — Rotating vane anemometer.

2.1.4 Miscellaneous Instruments

In addition to the air balancing instruments, there are other miscellaneous devices required. Thermometers are necessary for making temperature measurements at various duct and room locations; a tachometer is needed to determine fan speeds; and a multimeter is needed to check fan motors for proper operation.

2.2.1 Preparation for Balancing

The following preliminary procedure is necessary before proper balancing can begin. These steps are general in nature and should apply to most situations.

1. Review applicable mechanical drawings and job specifications. This review will provide necessary data on the ducts, air handlers, and outlets. Information pertaining to design airflow can also be taken from these drawings.
2. Prepare a simple working sketch of the entire duct system showing dimensions, airflow volumes and velocities, and the location of all components such as dampers, fans, coils, and filters. Duct outlets should be numbered on the sketch starting at the farthest one from the fan and working back toward the fan. (*See Figure 9-9*) The type of diffuser and the air delivery design of each outlet should be noted.
3. Obtain data pertinent to motors, fans, diffusers, and grilles that are not given on drawings. This can usually be taken from the manufacturer's identification plate located on the component. This information is useful during the balancing process for comparing measured results with design conditions.

4. Make a visual check of the system to ascertain that all fans are rotating correctly. Also, that air filters are clean and properly installed.
5. Place all dampers in the open position. This includes volume balancing dampers, splitter dampers, outlet dampers, and fire dampers.
6. Check all necessary instruments *prior* to starting the balancing procedure. Always follow the manufacturer's recommendations for checking the calibration of instruments.

2.3.0 Procedures for Balancing

The procedures required for balancing most systems are similar. Balancing is a rigorous technique that, if properly done, yields excellent results. As with any set of procedures, each operation is necessary and must be performed in the correct sequence. The following procedures are general in nature and apply to most systems.

2.3.1 Determine Fan Performance

The first step of the procedure is to determine fan performance. The purpose for this is to ensure that there is sufficient static pressure and air volume being handled at the fan before balancing is started. The fan's revolutions per minute (rpm), the voltage and amperage of the fan motor, the fan static pressure, and the system's total airflow are indications of fan performance.

Figure 9-9 — Duct system working sketch.

The fan rpm can be measured by a tachometer (*Figure 9-10*). You should take several readings to ensure an accurate reading. The results can be compared with the design conditions to determine performance.

You should use a multimeter to determine if the operating voltage and amperage of the fan motor are within the range of rated voltage and amperage indicated on the motor nameplate. The measured results can either be compared or used to calculate the brake horsepower. Use the manufacturer's recommended calculation to determine the brake horsepower.

You can determine the fan static pressure by attaching a velometer and static pressure probe to test tap holes located on the inlet and discharge duct of the fan (*Figure 9-11*). Fan static pressure is the static pressure at the outlet minus the total pressure in the fan inlet. This test may not be necessary in the field; however, if it is, the results can be compared with the manufacturer's fan curve and system specifications to determine fan performance.

Figure 9-10 — Measuring fan rpm.

Figure 9-11 — Fan static pressure measurement.

You can quickly locate problems caused by blockages in duct systems by performing static pressure readings. The total air volume in cubic feet per minute (cfm) for a fan can be determined by the following procedures:

1. Downstream of the air handler, establish a point along the duct that has the longest straight run and drill test holes into the duct. Holes should be far enough downstream from any elbows or from the fan discharge to minimize the effect of turbulence. The holes must be closed and sealed after the test is completed.
2. Take velocity pressure readings using a pitot probe and manometer or velometer. For rectangular ducts, velocity readings are taken at the center of equally divided areas. On round ducts, readings are taken across each of two diameters on lines at right angles to each other. (*See Figure 9-12*)
3. Calculate the cubic feet of air per minute by multiplying the average velocity pressure in feet per minute found in the above reading by the cross-sectional area of the duct in square feet. Total airflow in cfm = Average velocity in fpm x duct cross-sectional area in square feet.

The results are compared with design conditions to determine performance. Measured cfm should be approximately equal to design cfm plus 10 percent to allow for leakage.

In the event that fan performance is not consistent with design conditions, the necessary adjustments or repairs should be made at this point in the balancing procedure. For example, the fan speed can be changed by adjusting the variable diameter motor pulley. Be careful to avoid operating the fan at a speed that overloads the motor. After adjustments or repairs, tests should be repeated to verify that the design conditions have been attained. Total air volume measurements should be repeated for all air-handling units on branch, return, and exhaust duct systems.

Figure 9-12 — Velocity pressure measurement.

2.4.0 Duct and Outlet Adjustments

You should use the same procedure for measuring total air volume to set the main splitter dampers on systems containing branch ducts. When main ducts, zone ducts, and branches are set for design air, the tests necessary for adjusting individual outlets can begin. When available, always follow the manufacturer’s recommended procedure.

The final balancing procedure involves the adjustment of individual outlets to correspond with the manufacturer's design flow and system specifications. Begin with the last outlet on the branch farthest from the fan discharge and measure the velocity (or cfm). You can use either a velometer with the diffuser probe or an anemometer. If the cfm is below design, leave the damper open and proceed to the next outlet. If the cfm is greater than design, close the damper to obtain the desired results. In the same branch go to the next closest outlet and repeat the procedure. Then continue the process with each outlet, until you reach the main duct.

If applicable, you should complete the same procedure on the remaining branch ducts. Finally, total cfm of all outlets should agree with total cfm of all branches, and this grand total should agree with the air volume for the fan or fans. These figures should be within 3 to 7 percent of design conditions. You should check fan outputs and motor amperages to ensure that the motor is not in an overloaded condition. At this point, fan speed and horsepower, fan total air by velocity measurement, and total air by outlet volume measurements have been established for the specific operating condition of the system during the procedure. The system should be balanced for those conditions.

Test your Knowledge (Select the Correct Response)

3. What air balancing instrument can be permanently connected to duct interiors using static pressure tips?

   A. Manometer
   B. Velometer
   C. Tachometer
   D. Rotating van anemometer

4. **(True or False)** When balancing a duct system, the first step is to determine the type of fan that is being used in the system.

   A. True
   B. False

3.1.1 VENTILATION SYSTEMS

Normally air contains about 21 percent oxygen. The air in a ventilation system that serves human beings must have a certain oxygen content to maintain life and to ensure comfort.

If a room is tightly sealed, any person in that room would slowly consume the oxygen and increase the amounts of carbon dioxide, water vapor, and various impurities. This could cause that person to become drowsy or even result in death.

You must remember that the space where people live must have air with good oxygen content and be kept at a reasonable temperature. It is of utmost importance that fresh air be admitted to provide the oxygen.

In the past, this fresh air entered the space by infiltration (leakage) from the outside at door and window openings and through cracks in the structure. However, modern construction is reducing this air leakage, which means air conditioning systems must provide fresh air. Modern units have a controlled fresh-air intake. This fresh air is conditioned and mixed with the re-circulated air before it reaches the room.

Some conditioned air leaves a building through doors, windows, and other construction joints. Some also leaves by ***exfiltration***. Any kind of exhaust fan removes conditioned air. Some of this air is replaced by infiltration on those sides of the building exposed to wind pressure. It is best to bring in replacement fresh air through a makeup air system. The following occurs when this is done:

- The makeup air can be cleaned, cooled and heated
- A positive pressure can be maintained in the building to keep out airborne dirt, dust, and pollen. (A negative pressure reduces the efficiency of exhaust fans and fuel-fired furnaces.)
- A definite amount of fresh air is brought into the building for health purposes (oxygen content).

Certain areas of a building should have a slightly less positive pressure (5 to 10 percent) than the rest of the building to reduce the spread of odors. Such areas would include the kitchen, lavatories, and where certain industrial operations produce fumes.

The amount of fresh air required depends on the use of the space and the amount of fresh air admitted by infiltration. One basic rule is to provide at least 4 cfm of fresh air per person to provide enough oxygen and to remove carbon dioxide. If six people occupy a 1,000-square foot space with a 10-foot ceiling, there is 10,000 ÷ 6, or 1,667 cubic feet per hour for each person, or 1,667 ÷ 60 = 27.7 cfm (.78m3 /min). This meets or exceeds ventilating code requirements.

It is important for you to remember that the air can be handled either to produce positive pressure (higher than atmospheric pressure) in a building or negative pressure (below atmospheric pressure). A positive pressure eliminates infiltration of air from the outside or from other spaces. Positive pressure is produced by using special air intakes to the blowers. A positive pressure assures -that all air entering a building can be filtered and cleaned before reaching the occupied space. For example, hospitals use positive air pressure and require a 100- percent fresh air intake.

Negative pressure increases the infiltration at windows and doors. This air is untreated and may be dirty. If the amount of impurities in the inside air-such as odor, smoke, and bacteria—is great enough to require air cleaning, the remedy may be either more ventilation (using fresh air) or improved air cleaning.

Ventilation for a conditioned space is usually based on air changes per hour. If the space is 10,000 cubic feet there would be three changes per hour at 3,000 cubic feet per hour or 50 cfm. Three changes every hour is the minimum for a residence during the heating season. As high as 12 changes per hour (in the above case, 200 cfm), are recommended for cooling.

It is a good practice to keep the air blowers running at all times to provide good ventilation to all parts of the building. When heating and cooling systems are turned off, variable speed blowers are sometimes used to provide more air movement.

An adequate air supply is the best way to control comfort. Body comfort is controlled by evaporation, convection, radiation, and respiration. That means you must control the temperature of the walls, floors, or ceilings to make sure they are not too warm or too cold (radiation). You must also supply enough air to promote good respiration, evaporation, and convection.

If the specified conditions are not known, it is best to design for 2 cubic feet per minute per square foot and/or 12 changes of air per hour. It is also very important to remember that people occupying a closed space give off considerable heat. A sleeping person gives off about 200 Btu/hr; a person doing heavy work gives off up to 2,400 Btu/hr.

Another way to determine ventilation requirements is to design for 4 cfm to 6 cfm of fresh air per person and for about 25 cfm to 40 cfm of re-circulated air per person. This means the system should handle a total of 29 cfm to 46 cfm per person. (1 cfm = 0.0283 cu m/min.)

3.1.1 Natural Ventilation

Natural ventilation, or gravity ventilation, uses the natural forces of wind, stack effect, and breathing of structures caused by the interior-exterior temperature difference to induce air circulation and removal. Generally, air enters through openings at or near the floor level in a building and escapes through openings high in the walls or ventilators on the roof.

Natural ventilation is used only where the necessary quantity of ventilation can be induced by natural forces. Applications that require a continuous supply of outdoor air for human comfort, or the safe use of space (or process) should not be designed for natural ventilation. In such cases, natural ventilation is not reliable because of wide variations in the natural forces, such as wind velocity and direction and the inside-outside temperature difference.

For an installation using natural ventilation, you should consider the location and control of ventilation openings. Locate the air inlet openings on the side of the building facing directly into the prevailing winds. Locate the air outlets where prevailing winds movements would create low-pressure areas; that is, on the side directly opposite the prevailing wind direction.

Outlets may also be placed on a roof in the form of individual gravity ventilators or ridge ventilators. Calculate the ventilation rate due to wind velocity and the stack effect as detailed in criteria established by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE). When natural ventilation is provided for temperature control, you should provide a means for closing the openings during the heating season.

The use of gravity ventilators is another method. A roof-mounted gravity ventilator may be a stationary, a pivoting wind-directional, or a rotating-turbine type of ventilator. You should select gravity ventilators based on the rating tables for the mounting height involved and a wind velocity of 4 miles per hour. Natural ventilation has limited uses. In general, natural ventilation is inadequate for the following examples:

- Offices having an open window area less than 5 percent of the floor area
- Offices over 24 feet deep and without cross ventilation
- Offices having cross ventilation but having occupied space more than 35 feet from a window or an air inlet
- Dining rooms having a window area less than 6 percent of the floor area

In using natural ventilation, you should consider local building and safety codes and the minimum requirements of the *Occupational Safety and Health Standards, part 1910*.

3.2.1 Mechanical Ventilation

Mechanical ventilation uses mechanical forces to induce air circulation within buildings or spaces. Air movement is created by fans or by fans combined with a supply air and/or exhaust air duct system. You should provide mechanical ventilation equipment when the necessary quantity of outside air cannot be supplied continuously by natural forces. The quantity of air supplied should be kept to an acceptable minimum. You should install mechanical ventilation equipment in the following cases:

You should provide mechanical ventilation equipment when the necessary quantity of outside air cannot be supplied continuously by natural forces. The quantity of air supplied should be kept to an acceptable minimum. You should install mechanical ventilation equipment in the following cases:

- For a supply of outside air and the removal of bad air or air contaminated by smoke, body odors, and so forth, in areas having a high occupancy level (auditoriums, assembly halls, and cafeterias).
- For processes giving off noxious or hazardous fumes, dust, or vapor, resulting in unsafe or unhygienic conditions (paint spray booths, electroplating plants, welding booths, and other similar applications).
- For limited comfort of operators as in laundries, projection booths, and kitchens.
- For spaces containing fumes and vapor with specific gravity higher than air, such as garages and some refrigeration rooms. In these cases, provide exhaust intakes at floor level.
- For electronic or electric equipment installed in confined spaces where the operating temperatures of the equipment may exceed the safe limit.
- For spaces having explosive vapors or dust, use explosion proof ventilation equipment regardless of the concentration of explosive substances.
- For odor removal in bathrooms.

Test your Knowledge (Select the Correct Response)

5. How many ventilation air changes are considered the minimum for a residence during the heating season?

   A. 1
   B. 2
   C. 3
   D. None of the above

6. **(True or False)** Hospitals use positive air pressure and require a 75- percent fresh air intake.

   A. True
   B. False

Summary

In this chapter you were introduced to the types of duct systems, duct system construction, and how duct systems are sized. This chapter also provided you with information on how duct systems are balanced , the two types of ventilation systems, and the tools and materials used to evaluate system operation.

Review Questions (Select the Correct Response)

1. The velocity of a high-pressure duct system is usually limited to how many feet per minute (fpm)?

   A. 4,000
   B. 5,000
   C. 6,000
   D. 7,000

2. The velocity of a low-pressure duct system is generally less than how many feet per minute (fpm)?

   A. 5,000
   B. 4,000
   C. 3,000
   D. 2,000

3. What type of material is used to make duct systems?

   A. Galvanized sheet steel
   B. Fiberboard
   C. Aluminum sheets
   D. All of the above

4. **(True or False)** Rectangular ducts usually have the advantage of saving room space and are easier to install in walls.

   A. True
   B. False

5. What type of duct system allows individual room conditions to be maintained from a central system, by blending hot and cool air through automatically controlled mixing devices?

   A. Single
   B. Parallel
   C. Double
   D. Inline

6. **(True or False)** Fiber glass duct constructed of molded-glass fibers should never be coated with vinyl or other plastic coatings.

   A. True
   B. False

7. What air balancing instrument indicates air pressure by employing the principle of balancing a column of liquid of know weight against air pressure?

   A. Manometer
   B. Velometer
   C. Rotating vane anemometer
   D. Tachometer

8. **(True or False)** The third step for duct system balancing preparation is to obtain data pertinent to motors, fans, diffusers, and grilles that are not given on drawings.

   A. True
   B. False

9. When balancing a duct system, what are balancing instrument, along with a pressure probe, can be used to determine fan static pressure?

   A. Rotating van anemometer
   B. Multimeter
   C. Velometer
   D. Manometer

10. **(True or False)** Certain areas of a building, such as hallways and bedrooms, should have a slightly less positive pressure to reduce the spread of odors.

   A. True
   B. False

11. What type of blower can be used to provide more air movement when heating and cooling systems have been turned off?

   A. Variable-speed
   B. High-speed
   C. Low-speed
   D. None of the above

12. What type of gravity ventilator may be roof-mounted?

   A. Stationary
   B. Pivoting wind-directional
   C. Rotating-turbine
   D. All of the above

Trade Terms Introduced In This Chapter

Exfiltration	This means leaking out or being blown out by mechanical means.
Plenums	A space within the building created by building components, designed for the movement of environmental air (a space above a suspended ceiling or below an access floor).

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.

Navy Safety and Occupational Health (SOH) Program Manual, OPNAVINST 5100.23 (series), Naval Safety Center, Norfolk, Va.

American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Handbook of Fundamentals.

Occupational Safety and Health Standards (Part 1910), Occupational Safety & Health Administration (OSHA).

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

Air Conditioning and Refrigeration

Topics

To hear audio, click on the box.

Overview

As an Utilitiesman (UT) supervisor/manager, you are expected to know technical information about the air conditioning of buildings and the refrigeration of perishable products. This chapter covers the aspects of selecting and installing air-conditioning and refrigeration equipment. Also discussed will be the individual components required in air-conditioning and refrigeration systems. Finally, this chapter will provide you with the fundamental electrical knowledge needed to install, maintain, and repair air-conditioning and refrigeration equipment.

Objectives

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

1. Describe the selection and installation procedures associated with air-conditioning systems.
2. Describe the selection and installation procedures associated with refrigeration systems.
3. Identify the different special types of refrigeration systems.
4. Describe the process of mechanical component selection.
5. Describe the purpose and function of single phase hermetic motors.

6. Describe the purpose and function of single phase hermetic motor windings and terminals.
7. Describe troubleshooting methods associated with electrical systems.
8. Describe testing procedures associated with motor windings.
9. Identify the different types of electrical circuit components.
10. Identify the equipment utilized in testing electrical circuit components.
11. Interpret hermetic electrical schematic wiring diagrams.

Prerequisites

None.

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

Air Conditioning and Refrigeration	↑	U
Duct and Ventilation Systems		T
Boilers		
Compressed Air Systems		A
Sewage Treatment and Disposal		D
Water Treatment and Purification		V
Fire Protection Systems		A
Interior Water Distribution and Interior Waste Systems		N C
Plumbing Planning and Estimating		E
Contingency Support		D

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 SELECTION and INSTALLATION of AIR-CONDITIONING SYSTEMS

There are two types of air-conditioning systems that you must consider before selecting and installing equipment. These two systems consist of the forced air system and the hot and chilled water system. This chapter will only discuss the forced-air system.

1.1.1 Forced Air

Forced air units are used when the areas to be air-conditioned are close to each other, are being used for similar purposes, or have the same humidity and comfort zone requirements. A few examples are office spaces, single-dwelling homes, and single-purpose shops. Some characteristics of the system that you must take into consideration during the planning phase are the following:

- Keep the units centrally located
- Ensure return air is drawn from the area being cooled
- Ensure that one thermostat controls the system.

See *Figure 10-1* for two examples of a forced air unit with accompanying ductwork.

Figure 10-1 — Arrangements for package-type air-conditioning units and air ducts.

If you are involved in designing an air-conditioning system or desire more information, refer to NAVFAC DM 3.3, *Heating Ventilating Air-Conditioning and Dehumidifying Systems.*

1.2.0 Heat Load Calculations and Air Movement

Once the type of air-conditioning system has been chosen, the next step is to figure out its appropriate size. There are two primary factors that must be considered. The first factor is heat load calculation. Humidity comfort temperature and ***psychometrics*** are the three primary considerations necessary for calculating heat load. The second factor is air movement. Velocity, pressure, and drafts are the three main factors that are important when you are designing and planning the size of an installation. *Figure 10-2* shows the relationship between humidity, temperature and air movement.

Figure 10-2 — Humidity, temperature and air movement relationship.

Test your Knowledge (Select the Correct Response)

1. **(True or False)** Once the type of air-conditioning system has been chosen, the next step is to figure out its appropriate size.

    A. True
    B. False

2.1.1 SELECTION and INSTALLATION of REFRIGERATION SYSTEMS

In a refrigeration system, the major consideration is the heat load calculation. The following five general factors affect the refrigeration heat-load estimate required for a particular application:

- *Heat transmission load*. This leakage occurs through walls, doors, ceilings, and floor space into the space being refrigerated.
- *Insulation factor*. This is the rate of heat transfer that occurs through insulating material.
- *Air change load*. This factor is determined by the frequency with which a door is opened and closed and the length of time a door is left open.
- *Product load factor*. This is determined by the types of products being stored and product temperature at time of storage.
- *Miscellaneous factor*. This includes such factors as exposure to direct sunlight and ambient temperature surrounding the system.

There are several charts and graphs available that depict the relationship between the factors listed above. To do the job right, you must take into consideration the total effect of the factors before selecting a particular refrigeration system.

3.0.0 SPECIAL TYPES of REFRIGERATION SYSTEMS

There are certain applications where an electrically powered refrigeration system cannot be used. This requires knowledge of special applications and selection of a refrigeration system that will work effective. The absorption and the expendable refrigeration systems are discussed in this section.

3.1.0 Absorption Refrigeration System

An absorption system uses either, water, ammonia or lithium bromide as the refrigerant. The system can range from very simple (small refrigerator) to complex (commercial freezer). This type of system is used in domestic and industrial refrigeration and air-conditioning applications. The absorption system is also used in recreational vehicles. Normally, these systems are identified by the type of heat source being used to power them, such as kerosene, natural gas, steam, or electricity.

Because of the high pressure (400 psi), you should remember that welded steel tube construction must be used throughout the system. Also, because of the reaction between ammonia and copper or brass, you need a set of steel manifold gauges. *Figure 10-3* shows an absorption refrigeration cycle using ammonia as the refrigerant.

Figure 10-3 — Absorption refrigeration cycle.

3.2.0 Expendable Refrigeration System

An expendable refrigeration system is for used in trucks, railroad cars, and shipping containers that transport perishable items. The three types of refrigerants presently being used in an expendable system are liquid nitrogen, carbon dioxide, and liquid helium. The evaporator system and the spray system are two types of expendable systems commonly used in the Navy.

3.2.1 Evaporator Systems

In the expendable evaporator system, liquid refrigerant is stored in large metal insulated cylinders. These cylinders are normally located in the front of the cargo vehicle. Each cylinder is equipped with a temperature control to provide a temperature range of –20°F to 60°F. The temperature control is connected to a temperature sensor. As the temperature rises, the switch operating the control valve opens and liquid refrigerant flows into the evaporator. The evaporator can be blower coils, plates, or eutectic plates. As it passes through the evaporator, the refrigerant vaporizes. The vapor is pushed through the evaporator by the pressure difference between the cylinder and the vent. When the selected temperature is attained, the refrigerant valve closes. The vapor that has been used is then discharged from the evaporator at about the same temperature as the air in the cargo vehicle. With this system, the refrigerant does not mix with air in the vehicle space.

An example of the expendable evaporator system is shown in *Figure 10-4*. This example shows two nitrogen cylinders located inside a truck body connected by a manifold to regulators and to temperature control solenoid valves. The vaporizing liquid nitrogen flows into the vaporizers or cold plates to refrigerate the true box.

3.2.2 Spray Systems

In the expendable refrigerant spray system, liquid nitrogen or carbon dioxide is sprayed directly into the vehicle space that is to be cooled. This system uses liquid containers, a control box, a fill box, spray headers, emergency switches, and safety vents. The fill box is normally located on the front of the vehicle. It contains the valves, gauges, and connections that allow the liquid containers to be filled. The liquid containers are insulated cylinders similar to thermos bottles. The control box contains the valves, gauges, and thermostats that are necessary for safe release of the liquid to the spray headers. Once the liquid is received at the spray headers, the nozzles spray it into the vehicle.

Figure 10-4 — Expendable evaporation refrigeration system.

The remaining two components are primarily safety devices. These emergency interlock switches are attached to each door. That means, whenever a door is opened, the system shuts down. The safety vent is a small trapdoor that vents air directly to the atmosphere whenever the air inside the truck box exceeds atmospheric pressure.

A benefit of this system is that liquid nitrogen or carbon dioxide replaces the oxygen inside the space being refrigerated. Therefore when fruits, vegetables, meats, and fish are being refrigerated, they are also preserved by the inert atmosphere.

A vehicle equipped with this type of system must display the following safety sign:

CAUTION

THE TEMPERATURE OF LIQUID NITROGEN, AS IT COMES FROM THE SPRAY NOZZLES, IS BLOW (0°F).

Liquid nitrogen will instantly freeze any part of the human body that it touches. Since liquid nitrogen can be dangerous, you should always inspect the refrigerated space before closing the doors. An expendable spray system for a refrigeration truck is shown in *Figure 10-5*. In this system, the liquid nitrogen is in an insulated container that is installed vertically inside the truck body. Another similar type of spray system with the refrigerant container mounted horizontal under the truck body is shown in *Figure 10-6*.

Figure 10-5 — Vertically installed expandable spray system.

Figure 10-6 — Horizontally installed expandable spray system.

3.3.0 Thermoelectric Refrigeration Systems

This type of system is used to move heat from one area to another by use of electrical energy. The electrical energy, rather than the refrigerant, serves as an "*earner*." The primary use of thermoelectric systems has been in portable refrigerators, water coolers, cooling of scientific apparatus used in space exploration, and in aircraft. The main advantage of this system is there are no moving parts. The system is compact, quiet, and requires little service.

3.4.1 Multistage Refrigeration System

Multistage refrigeration systems are used where ultralow temperatures are required but cannot be obtained economical through the use of a single-stage system. The reason for this is the compression ratios are too high to attain the temperatures required to evaporate and condense the vapor. The following two general types of systems are presently in use:

- Cascade
- Compound

3.4.1 Cascade System

The cascade system has two separate refrigerant systems interconnected in such a way that the evaporator from the first unit cools the condenser of the second unit. This allows one of the units to be operated at a lower temperature and pressure than would otherwise be possible with the same type and size of single-stage system. It also allows two different refrigerants to be used, and it can produce temperatures as low as −50°F.

In this typical cascade system (*Figure 10-7*), condenser B of system 1 is being cooled by evaporator C of system 2. This arrangement enables ultralow temperatures in evaporator A of system 1. The condenser of system 2 is shown at point D in the figure. Two thermostatic expansion valve (TEV) refrigerant controls are also indicated in the figure. Notice the use of oil separators to minimize the circulation of oil.

Figure 10-7 — Cascade refrigeration system.

3.4.2 ompound System

The compound system uses two or more compressors connected in series in the same refrigeration system. In this type of system the first stage compressor is the largest and for each succeeding stage the compressor gets smaller. This is because as the refrigerant passes through each compressor, it becomes a denser vapor. A two-stage compound system can attain a temperature of approximately –80°F. A three-stage system (*Figure 10-8*) can attain a temperature of –135°F efficiently. Compressor 1 pumps vapor into the intercooler and then into the intake of compressor 2. This operation is repeated between the second and third stages. In the third stage, the refrigerant vapor is further cooled and travels to the evaporator for specific cooling use.

Figure 10-8 — Compound refrigeration system (three-stage).

Test your Knowledge (Select the Correct Response)

2. What is the temperature range of the cylinders that store the liquid refrigerant in an expandable evaporator system?

   A. −5°F to −10°F
   B. −10°F to −20°F
   C. −20°F to −60°F
   D. −60°F to −80°F

3. **(True or False)** The compound refrigeration system allows two different refrigerants to be used, and can produce temperatures as low as −50°F.

   A. True
   B. False

4.1.1 MECHANICAL COMPOUND SELECTION

There are several mechanical components required in a refrigeration system. This section will discuss the four major components of a system and some equipment associated with the major components. These components include the following:

- Condensers
- Evaporators

- Compressors
- Refrigerant lines and piping
- Refrigerant capacity controls
- Receivers
- Accumulators

4.1.0 Condensers

There are several condensers to be considered when making a selection for installation. They are air-cooled, water-cooled, shell and tube, shell and coil, tube within a tube, and evaporative condensers.

Each type of condenser has its own unique application. Some determining factors include the size and the weight of the unit, weather conditions, location (city or rural), availability of electricity, and availability of water. For example, is single phase or three phase electricity available? Is electricity economical of prohibitive? Water in some locations may be scarce, expensive, or contain chemicals that make it unsuitable for use. Local zoning laws should also be checked to ensure there are no restrictions as to use of electricity, water, or location of the unit. If you installed a unit on a roof, the roof load strength is very important. In some locations, the noise factor of an operating unit is an important consideration.

With the rapid advances in technology, you should contact a manufacturer whenever possible to get the latest condenser design features available for a special-purpose installation.

4.2.0 Evaporators

There are almost as many different types of evaporators as there are applications. However, evaporators are divided into two general groups. The first group has evaporators that cool air that, in turn, cools the product. The second group has evaporators that cool a liquid such as brine solution that, in turn, cools the product. Normally, the proper evaporator comes with the unit (system) that you will be installing. However, there may be an occasion when you are designing a system. At this time, you will need to determine the requirements and select the proper evaporator from a manufacturer’s catalog or manual.

Figure 10-9 is a blower-type evaporator shown in a small space. The air enters the bottom of the evaporator, is cooled, and exits at the front of the unit. In *Figure 10-10*, view A, a forced circulation evaporator is shown partially installed; view B shows the unit with the fan removed.

Figure 10-9 — Blower-type evaporator.

Figure 10-10 — (A) Forced circulation evaporator partially installed; (B) fan unit removed.

A compact blower evaporator for use in low headroom fixtures is shown in *Figure 10-11*. A vertical, flat-type blower evaporator designed for mounting behind either a window or a door frame is shown in *Figure 10-12*.

Figure 10-11 — Compact blower evaporator.

Figure 10-12 — Vertical flat-type blower evaporator.

In the dual fan evaporator unit shown in *Figure 10-13*, the motor drives two propeller-type fans and the cool air exits at both ends of the evaporator. *Figure 10-14* shows a low-velocity blower evaporator. In this type of evaporator, the air enters at the two fan grills and exits on both sides. *Figure 10-15* shows a low-temperature blower evaporator. The low-temperature evaporator has two axial-flow fans and an electric defrost.

Figure 10-13 — Dual fan evaporator.

Figure 10-14 — Low-velocity blower evaporator.

Figure 10-15 — Low-temperature blower evaporator.

4.3.0 Compressors

With present technology, the newer air-conditioning and refrigeration systems use reciprocating, rotary, screw, centrifugal, swash plate, and scroll compressors. There are many designs and models available for all types of applications. A typical hermetic compressor is shown in *Figure 10-16*. For more in-depth information about compressors, you can refer to sources, such as *Modern Refrigeration and Air Conditioning* by Althouse/ Turnquist/Bracciano.

Figure 10-16 — Hermetic compressor.

4.4.0 Thermostats

The thermostat is a control that responds to changes in temperature and directly or indirectly controls the temperature. There are many different designs of thermostats. *Figure 10-17* shows a few of the common thermostats used in modem heating and cooling systems.

Thermostats are of three types: heating, cooling, and dual (combined heating and cooling thermostat in one).

The common sensing element of a thermostat is bimetal. A bimetal sensing element simply uses two different types of metal, brass and invar, which have different expansion rates. *Figure 10-18* depicts three common profiles of bimetals used in thermostats.

The bimetal element in *Figure 10-19* has a set of contacts on one end. The top contact is fixed. The two contacts open or close when the temperature changes around the bimetal.

Figure 10-17 — Thermostats.

When the contacts close, a path is created for current to flow. The snap action in the magnetic type makes the contacts close or open quickly. This eliminates any spark and extends the life of the contacts. *Figure 10-20* shows enclosed contacts that use a bimetal element for movement and contacts or mercury for making contact between two electrodes.

The manufacturing engineers determine what type and design of thermostat should be installed in a particular system. Knowing and understanding the advantages and disadvantages of different types of thermostats will help you identify the type of thermostat being used in a system and enable you to troubleshoot an inoperative system efficiently.

Figure 10-18 — Bimetal profiles.

Figure 10-19 — Bimetal element contacts.

Figure 10-20 — Enclosed contacts.

Electrical room thermostats are in three categories: line voltage, low voltage, and millivoltage. Line-voltage thermostats are usually 115 volts. When line-voltage thermostats are installed, there is no need for lowering voltage with a transformer. However, line-voltage thermostats are dangerous for the users and the cost is higher. Normally line-voltage thermostats are located only in industrial commercial applications.

Low-voltage thermostats (24 volts) are not dangerous to the user. They are also more cost efficient than line-voltage models. The disadvantage of low-voltage thermostats is the extra requirements of wiring and additional components; they are less rugged than line-voltage thermostats.

The millivoltage thermostat operates at 750, 500, or 250 millivolts. This thermostat uses its own power source for operation and is not affected by power interruptions. The system requires only a small amount of wiring compared to other systems. However, this system is limited for use only in heating applications. The temperature control is less precise than other systems, wire length and size are critical, and the system requires a separate device to power a 24-volt control, or you must use a millivoltage control.

4.4.1 Anticipators

One component that enhances the operation of a thermostat is an anticipator. The two types of anticipators are heating and cooling.

The heating anticipator produces false heat in a thermostat to prevent extreme temperature changes within a space. The false heat created by resistance increases the thermostat rate of response. Basically, the thermostat receives false heat which shuts down the heating source before the thermostat reaches the desired temperature. This action reduces overshooting and is economically efficient. The heating source shuts off and the blower continues to run using the heat transferred from the surface of the furnace and ductwork. When adjusting a heating anticipator, you must set the anticipator resistance to match the current rating of the primary control.

The cooling anticipator adds false heat to the thermostat bimetal element the same way as a heating anticipator. Unlike the heating anticipator, cooling anticipators are not adjustable; they are sized by the manufacturer of the thermostat. The cooling anticipator is placed in parallel with the cooling contacts. By studying *Figure 10-21*, you can see that the cooling anticipator is energized when the unit is in the OFF cycle (thermostat contacts open). The small amount of heat produced by the resistance heat closes the TC before the actual temperature in the space reaches the thermostat cut-in setting. This action allows the unit to start removing heat before the temperature in the space climbs above the desired temperature. When the cooling thermostat contacts close, the current flow through the anticipator is insignificant because the contacts of the thermostat offer less resistance to current flow than the anticipator resistance, so the anticipator is de-energized.

Figure 10-21 — Cooling anticipator.

4.5.0 Refrigerant Lines and Piping

Because of the progress made in this field, construction has become much simpler. Since pre-charged lines are in everyday use, the problems of installation are being eliminated. However, pay particular attention to neatness and cleanliness when you are installing support brackets (hangers) and insulation. *Figure 10-22* shows a schematic piping diagram of a typical commercial refrigeration system. This system has a roof-mounted air-cooled condenser and two motor compressors. Each motor compressor has a suction and liquid header and is connected to six refrigerant lines. A detailed view of an oil separator installation is shown in *Figure 10-23*.

Figure 10-22 — Schematic piping diagram for a commercial refrigeration system.

Figure 10-23 — Installation of an oil separator.

4.6.0 Refrigerant Capacity Controls

In a single-stage installation, one evaporator, one condensing unit, and any one of the five types of refrigerant controls will work. However, in a compound (multistage) installation (*Figure 10-8*) with one condenser, only two types of controls can be used. There are very few low-side float systems in actual operation, but you should be aware that there are some units that still use this control. Thermostatic expansion valves are the most commonly used, and on large capacity units, they usually operate a pilot valve that, in turn, operates a larger valve.

The biggest problem associated with capacity controls is using the wrong size. When ordering replacements and when making repairs, you should always ensure that the control markings are appropriate for the intended system. Also, ensure the replacement part being ordered is compatible with the type of refrigerant being used in the system.

4.6.1 Automatic Expansion Valve (AEV)

The AEV maintains a constant pressure in the evaporator (*Figure 10-24*). There are five pressures that affect the operation of the AEV. The pressures are P1 (atmospheric pressure), P2 (evaporator pressure), P3 (liquid line pressure), S1 (adjustable spring pressure), and S2 (fixed spring pressure). To adjust the valve, turn the adjusting screw until the desired pressure is obtained in the evaporator. Automatic expansion valves are installed on systems that have a relatively constant load. Primarily, the AEV is used on domestic refrigerators and small water coolers.

Figure 10-24 — Automatic expansion valve.

4.6.2 TEV Adjustment

The thermal expansion valve (TEV) is the most widely used expansion device. The TEV controls the flow of refrigerant to maintain a constant superheat in the tail coil of an evaporator. *Figure 10-25* shows the three pressures that affect the operation of this valve. They are P1 (bulb pressure), P2 (evaporator pressure), and P3 (spring pressure).

When the pressure of p1 is higher than the combined pressure of p2 and p3, the valve opens. This valve is equalized internally because the evaporator pressure is sensed through an internal port in the valve. *Figure 10-26* provides another view showing how a TEV is equalized externally.

When a TEV is used on a large evaporator or an evaporator with a pressure drop of 6 to 7 pounds across the evaporator, the valve will prematurely cause hunting (valve fluctuates toward opening and closing). In the case of valve hunting, install a TEV equipped with an external equalizer line. *Figure 10-27* shows the TEV installed with an external equalizer line. The external equalizer line compensates for a pressure drop from the inlet of the evaporator to the end of the tail coil and eliminates valve hunting. During installation of an equalizer line, ensure that it is located downstream from the sensing bulb. The bulb is filled with a volatile fluid that reacts to changes in temperature which in turn equalizes pressure within the expansion valve.

Figure 10-25 — Thermal Expansion Valve.

Figure 10-26 — Thermostatic expansion valve, externally equalized.

Figure 10-27 — Externally equalized TEV.

Air-conditioning refrigeration units come equipped with a metering device that the manufacturer has engineered for the system. You should *never* change the recommended type of metering device for a system without consulting the manufacturer.

Most TEVs are adjusted at a predetermined superheat setting and tested at the factory prior to being shipped. If you need a different superheat setting, the steps in *Table 10-1* may be useful, be sure to follow manufacturers recommendations.

Table 10-1 — Determining Superheat

STEP	ACTION
1.	Obtain the temperature of the suction line at the point where the TEV sensing bulb is attached. a. Take the temperature reading with a dial thermometer similar to the one shown in *Figure 10-28*, or use some other temperature measuring device that senses surface temperatures accurately.
2.	Obtain the suction pressure inside the piping at the location of the remote sensing bulb. a. If the valve is externally equalized, you can place a gauge in the external equalizer line. This is the most accurate method. b. The alternate method is to read the manifold pressure gauges at the compressor and add the estimated pressure drop through the suction line between the bulb and compressor. The sum of the two pressures provides approximate pressure at the location of the remote bulb.
3.	Convert the pressure you received in step 2 into saturated evaporator pressure. a. Use a pressure temperature chart. When using the chart ensure that you are looking at the proper refrigerant.
4.	Simply subtract the temperature in step 3 from the temperature in step 1. This will give you the superheat.

NOTE

When adjusting the expansion valve, turn the adjusting stem no more than one full turn and wait approximately 15-30 minutes for the system to balance out. Once the system is balanced, recheck the superheat setting by following the steps in *Table 10-1*.

4.7.0 Receivers and Accumulators

The receiver is a storage tank for liquid refrigerant. When a refrigeration system is equipped with a receiver, you can close the outlet valve (king valve) and pump refrigerant into the receiver. This enables you to store the refrigerant while you work on the unit. Additionally, when a unit is equipped with a receiver, the quantity of refrigerant in the system is less critical than a unit not equipped with a receiver. *Figure 10-29* shows the location of a

Figure 10-28 — Dial thermometer.

Figure 10-29 — Receiver location in a refrigeration cycle.

receiver installed in a system. This is a commercial system with an air-cooled condenser, a thermostatic expansion valve, and a V type reciprocating compressor.

The accumulator is located inside the refrigeration cabinet and acts as a safety device. As a safety device it prevents the flow of liquid refrigerant into the suction line and the compressor. This is because liquid refrigerant causes considerable knocking and damage to the compressor. *Figure 10-30* shows the location of an accumulator in a system.

Figure 10-30 — Accumulator location in a refrigeration system.

Test your Knowledg (Select the Correct Response)

4. What type of blower evaporator is designed for mounting behind windows and door frames?

   A. Low-temperature
   B. Vertical flat-type
   C. Low-velocity
   D. Compact

5. What electrical room thermostats are usually 115 volts, are dangerous to the user, and are more expensive?

   A. High-voltage
   B. Low-voltage
   C. Millivoltage
   D. Line-voltage

6. **(True or False)** The three pressures that affect the operation of the TEV are; bulb, evaporator, and spring.

   A. True
   B. False

5.1.1 SINGLE-PHASE HERMETIC MOTORS

As a UT supervisor/manager, it important that you have an understanding of the four types of single-phase motors used in hermetic assemblies. These types of motors include the following:

- Split-phase
- Capacitor-start, induction-run
- Capacitor-start, capacitor-run
- Permanent split-phase

5.1.0 Split-Phase

The split-phase motor is used generally on condensing units of 1/10-, 1/6-, and 1/4-horsepower capillary tube systems. It has a low starting torque and contains both a starting winding and a running winding. A disconnect device is required for the starting winding when the motor reaches sufficient speed to operate on the running winding. *Figure 10-31* is a schematic wiring diagram of a split-phase motor circuit.

Figure 10-31 — Schematic wiring diagram of a split-phase motor circuit.

5.2.0 Capacitor-Start, Induction-Run

This motor is similar to the split-phase type except that a starting capacitor is connected in series with the starting winding to provide higher starting torque. *Figure 10-32* is a schematic diagram illustrating this type of motor. A device is also required to disconnect the starting winding when the motor reaches rated speed. This motor is commonly used on commercial systems up to three-fourths horsepower.

Figure 10-32 — Schematic wiring diagram of a capacitor-start induction-run motor.

5.3.0 Capacitor-Start, Capacitor-Run

Two capacitors are used with the capacitor-start, capacitor-run motor: a starting capacitor and a running capacitor. The capacitors are in parallel with each other and in series with the starting winding. *Figure 10-33* is a schematic diagram illustrating this type of motor circuit. The two capacitors turn the motor power surges into two-phase power when the motor is started. At approximately two-thirds rated speed, the starting capacitor part of the circuit is disconnected by a start relay device. Only the running capacitor remains in the circuit. This type of motor has a high starting torque and is used with hermetic systems up to 5 horsepower.

Figure 10-33 — Schematic wiring diagram of a capacitor-start capacitor-run motor.

5.4.0 Permanent Split-Phase

The permanent split-phase motor has limited starting torque and is used basically with capillary tube air-conditioning equipment, such as window units. Capillary systems permit high-side and low-side pressure equalization when the compressor is not operating. A run capacitor is wired in series with the starting winding. Both the starting winding and the run capacitor remain in the circuit during operation. No start relay or start capacitor is needed. *Figure 10-34* is a schematic wiring diagram of the circuits used in this type of motor.

Figure 10-34 — Schematic wiring diagram of a permanent split-phase motor.

Test your Knowledge (Select the Correct Response)

7. What type of single-phase motor has limited starting torque and is usually used with window air conditioners?

   A. Capacitor-start, induction-run
   B. Permanent split-phase
   C. Split-phase
   D. Capacitor-start, capacitor-run

6.1.1 SPLIT-PHASE HERMETIC MOTOR WINDINGS and TERMINALS

Split-phase motors used in hermetic refrigeration and air-conditioning applications are designed to start under load. These split-phase and capacitor motors use two sets of spiral windings: a starting winding and a running winding. The two sets of windings differ in their impedance and in their positions in the stator slots.

The starting winding has high resistance and small reactance, whereas the running winding has low resistance and high reactance. Reactance is the opposition to the flow of alternating current by ***inductance*** and ***capacitance***.

The running winding has many turns of large wire and is placed in the bottom of the stator slots. The starting winding is wound of small, high resistance wire and is placed on top of the running winding.

Both windings are connected internally at one end to provide a common lead, and when starting, both are energized in parallel. The currents are out of phase with each other and their combined efforts produce a rotating field that starts the motor. *Figure 10-35* shows the starting and running windings of a two-pole motor in their 90-degree out-of-phase positions.

Figure 10-35 — Two-pole motor with starting and running windings.

Hermetic motors have three electrical terminals connected through an insulated seal to the motor windings inside the dome. (*Figure 10-36*).

Troubleshooting procedures require that these terminals be identified with respect to the winding connected to each. The terminals must be identified as the START TERMINAL, the RUN TERMINAL, and the COMMON TERMINAL. Some manufacturers mark the S-, R-, and C-terminals for start, run, and common, respectively; other manufacturers use different designations.

The terminals can always be identified by using a low-range ohmmeter following the procedure below:

- Disconnect all power to the terminals, discharge capacitor where necessary, remove the wires connected to the terminals, and mark the wires so they can be reconnected properly.
- Clean terminals to provide a good connection.
- Using the ohmmeter, find the two terminals across which the greatest resistance occurs. The remaining terminal is the C-terminal. The resistance between the S- and R-terminals is highest because both are being measured in a series circuit.
- Identify the S-terminal by placing one meter lead on the C-terminal and then checking the other two terminals to determine which one has the greatest

resistance. The S-terminal (starting winding) has windings with many turns of small wire, and therefore has the greatest resistance. The remaining terminal is the connection of the running winding.

- Always mark the terminals so they can be identified later.

Figure 10-36 — Identifying motor terminals using an ohmmeter.

Test your Knowledg (Select the Correct Response)

8. How many electrical terminals do hermetic motors have that are connected through an insulated seal to the motor windings inside the dome?

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

7.1.1 TROUBLESHOOTING ELECTRICAL SYSTEMS

Electrical troubleshooting techniques are used on refrigeration and air-conditioning equipment. Electrical troubleshooting is done by a process of elimination. You should begin by checking the most obvious trouble and gradually progress to the more remote possibilities.

As an Utilitiesman you cannot troubleshoot an electrical system for an air conditioner or refrigeration unit unless you understand the function of each component in a system.

When you can observe a unit operating and detect what is not functioning properly, you can identify the circuit or circuits that are having trouble.

At this point you must be able to test each of the components within a circuit that is not functioning properly. Of course to do all of this, you must also be able to do the following:

- Read and interpret electrical diagrams
- Understand loads
- Determine paths
- Perform electrical testing procedures

7.1.0 Circuits

The two basic types of circuits are load and control. A *load circuit* consists of a circuit that contains a load and all of the wiring that provides line voltage directly to the load, such as compressor motor, fan motor, solenoid valves, lights, or any device that consumes current (other than the movement of an electrical switch).

The *control circuit* contains controls that either open or close a path that operates a load device. Each load has a control circuit. Control circuits consist of thermostats, pressure switches, overload protectors, and all of the wiring in the control circuit.

7.2.0 Loads and Control Circuits

Air-conditioning and refrigeration units normally have two fan motors and a compressor. These components are considered load. A load is any device that consumes electrical energy. Most loads convert electrical energy into another type of energy to create some type of work. For example, electrical energy is converted to magnetism within a motor to make the motor run.

All loads have some type of control so they can be turned on, off, or regulated. These controls are located in a control circuit. The circuit is made up of controls and paths wiring. Controls and control circuits consume no electrical energy; they simply provide a path for electrical energy to flow, thus indirectly controlling the operation of various types of loads. *Figure 10-37* shows an electrical schematic wiring diagram of a heat pump. At first glance the diagram appears complex, but after studying the diagram briefly and looking at one circuit at a time, the diagram becomes easy to follow and understand. An example is as follows: Look at the first circuit in *Figure 10-37*. The circuit contains a control relay contact (CR), high-pressure switch (HP), liquid line pressure switch (LLP), compressor contactor (C), and an internal thermostat (IT). This is a complete circuit. The CR is simply a set of contacts and falls in the category of a path; the contacts are either open or closed. The HP and LLP are both pressure switches and are controls in this circuit; the pressure switches are either open or closed. The C is the compressor contactor. Actually this is a magnetic coil located within a contactor that simply closes all of the contacts in the diagram that are labeled C.

The IT is located inside the compressor and opens when there is a temperature rise. The only load in this circuit is the compressor contactor because it is a current consuming device. Now, look at the figure again and see if you can find the load in the second circuit. The load is the indoor fan motor (IFM) because it is a current consuming device. The indoor fan relay (IFR) contact only provides a path for the current to energize the IFM.

Figure 10-37 — Heat-pump schematic.

7.3.0 Testing Circuits

To troubleshoot an inoperative or improperly operating unit electrically, you must be able to use a process of elimination systematically and use a multimeter effectively. Remembering and understanding a few simple rules will enable you to use a multimeter to locate a faulty electrical component or control. The first circuit in *Figure 10-37* is used as an insert to illustrate the different meter readings you will encounter when troubleshooting an electrical system. Refer to the insert next to the applicable troubleshooting procedure.

7.3.1 Voltage Readings

To begin, set your multimeter to voltage; ensure the power is on and all wires are connected to the component being tested. The four important troubleshooting procedures that apply to reading voltage are as follows:

1. <u>Meter probes on a path</u>. Place one meter probe on the left side of the CR contact and the other probe on the left side of the HP switch (*Figure 10-38*). If you obtain a voltage reading, this indicates that either the path is open or the contacts are open.

Figure 10-38 — Voltage reading (path open).

2. <u>Meter probes on a path</u>. Place one meter probe on the left side of the CR contact and the other probe on the left side of the HP switch (*Figure 10-39*). If you obtain no voltage, the path is closed.

Figure 10-39 — Voltage reading (path closed).

3. Meter probes across a load. Place one meter probe on the right side of the LLP switch and the other probe on the left side of IT (*Figure 10-40*). If you obtain a voltage reading, the compressor contactor is energized and the compressor should be running. If the load is NOT operating, you should check for a grounded winding and for winding resistance.

Figure 10-40 —Voltage reading (compressor running).

4. Meter probes across a load. Place one meter probe on the right side of the LLP switch and the other probe on the left side of the IT (*Figure 10-41*). If there is not voltage reading, replace the load.

Figure 10-41 — Voltage reading (no reading replace load).

7.3.2 ontinuity Readings

To perform an ohmmeter continuity test, set your multimeter to resistance; disconnect the power and remove the wires from the component being tested. Perform a continuity test as follows:

1. Meter probes across a path. Place one meter probe on the left side of the CR contact and the other probe on the left side of the HP switch (*Figure 10-42*). If you obtain a reading, the path is open.

Figure 10-42 — Continuity reading (path open).

2. Meter probes across a path. Place on meter probe on the left side of the CR contact and the other probe on the left side of the HP switch. With the CR contact closed, you should obtain a zero reading, indicating the path is closed.

Figure 10-43 — Continuity reading (path closed).

3. Meter probes across a load. Place one meter probe on the right side of the LP and the other probe on the left side of the IT (Figure 10-44). You should obtain a reading. If you obtain no reading, replace the load.

To further increase your understanding of electrical troubleshooting, review the rules you have just read using a different method. The flow charts in Figures 10-45 and 10-46 provide you with a review of electrical troubleshooting with a digital multimeter. To use a multimeter effectively and troubleshoot air-conditioning and refrigeration units electrically, you must not only know the information provided here but also practice by testing circuits. Always remember to respect electricity. Whenever possible, perform your electrical troubleshooting with the power OFF using continuity checks.

Figure 10-44 — Continuity reading (no reading replace load).

NOTE

The flow charts in *Figures 10-45* and *10-46* do not cover every electrical troubleshooting procedure you will incur. The charts are presented to help you understand electrical troubleshooting.

Figure 10-45 — Electrical troubleshooting loads.

Figure 10-46 — Electrical troubleshooting testing controls and paths.

Test your Knowledge (Select the Correct Response)

9. What are the two basic types of circuits?

   A. Load and control
   B. Control and open
   C. Load and direct
   D. Closed and current

8.0.0 TESTING MOTOR WINDINGS

If, during the procedure for identifying motor terminals, the ohmmeter displays a blank readout during any test, there is probably a defective winding. A defective winding may be classified as *open* or *shorted*. The display will be zero if the winding is *grounded*.

8.1.0 Open Windings

Open windings can occur in the starting winding, the running winding, or both. An open winding is the result of a burned-out or grounded fault or simply a break somewhere in the lead or winding that prevents the current from completing the circuit. A motor with an open winding does not start. If only one winding is open, the motor hums, but if both windings are open, no sound is emitted nor current consumed. Open windings can be checked by an ohmmeter, a voltmeter, or a test light.

8.1.1 Ohmmeter Continuity Test Procedure

The procedure for making an ohmmeter continuity test is shown in *Figure 10-47* and outlined below.

- Turn the power OFF, discharge all capacitors, and remove the wires from the C-, S-, and R-terminals of the motor.
- With the ohmmeter set on the lowest scale, check the resistance from C to R, C to S, and R to S.
- Watch the digital readout in the meter as the check is made. Each reading should appear to be approximately 0 ohms, since winding resistance is usually less than 10 ohms. If, during the check, the resistance digital display remains blank (infinity), an open or break exists.

Figure 10-47 — Testing for an open winding using an ohmmeter.

8.1.2 Voltmeter Test Procedure

The procedure for carrying out a voltmeter test is as follows:

- Ensure the power is on and all wires are properly connected to motor terminals.
- With the voltmeter set on the proper scale, place the leads across the R- and C-terminals.
- Read the voltmeter. If the motor shows line voltage, the motor is energized and should be operating. The connections are similar to that shown in *Figure 10-47*.

8.1.3 Test Lamp Continuity Check Procedure

The procedure for conducting a test lamp continuity check is as follows:

- A simple test lamp consisting of a power circuit plug, two flexible insulated wires with clip leads, and a 25-watt socket with a bulb is used. *Figure 10-48* shows the test lamp procedure.
- Ensure the power is OFF, discharge all capacitors, and remove the motor terminal wires.
- Make a continuity test through both windings by attaching clips across the C-terminal then do the other terminals one at a time. Now plug the test lamp into a receptacle. If the bulb fails to light, there is an open winding.

Figure 10-48 — Testing for an open winding with a test lamp.

8.2.1 Shorted Windings

In an electric motor the winding turns lie side by side with only the insulating varnish separating one loop from another. When one loop of the copper wire contacts another, the winding is short. The pulling effect of the shorted portion of the winding is lost. This, in turn, places more load on the active winding, causing the motor to draw higher voltage and amperage with a concurrent increase in winding temperature. In this condition the motor fails to start, or it starts and continues to run causing the overload protector to open. The fuses may also blow. The result is likely to be a burnout where the insulating varnish deteriorates from excessive heat. Ultimately a ground or short occurs.

An ohmmeter can be used to check windings for shorts. For most applications a low-range meter with a scale graduated in tenths of ohms between 0 and 2 ohms is best. However, to check motors throughout the sizes normally encountered in hermetic motor-compressor units, a range of 0 to 25 ohms is necessary. The meter is used to measure resistance of the windings. The readings are compared with design resistances. A short is shown when measured resistance is less than design resistance. The ohmmeter connections are the same as those shown in *Figure 10-36*.

Often manufacturer's data is not available and the design resistances are not known. *Table 10-2* lists the approximate resistances for fractional horsepower single-phase motors. The following guidelines may also be helpful:

1. The starting winding of low-starting torque motors usually has a resistance of about seven to eight times that of the running winding.
2. The starting winding resistance of high- starting torque motors is usually three to four times that of the running winding.

Table 10-2 — Approximate Resistances for Fractional Horsepower Motor Windings

Horsepower (HP)	Running Winding	Starting Winding
1/8	4.7Ω	18Ω
1/6	2.7Ω	17Ω
1/5	2.3Ω	14Ω
1/4	1.7Ω	17Ω

8.3.0 Ground Windings

A ground is the result of an electrical conductor in contact, either directly or indirectly, with the motor frame or the metal shell of the unit. Either the starting winding, the running winding, or both can be affected. The ground is either one of low resistance or one of high resistance. A low-resistance ground is indicated when fuses blow repeatedly and the motor fails to start. A high-resistance ground is shown by an occasional blown fuse, but more often, by the opening of the overload protector.

Three methods of testing windings for grounds are the ohmmeter continuity test, the test lamp continuity check, and the resistance measurement with a megohmmeter (megger). The procedure to follow in making each of these tests is provided below.

8.3.1 Ohmmeter Continuity Test (Low-Resistance) Procedure

To perform an ohmmeter continuity test, complete the following steps:

1. Disconnect the power and remove the wires from the motor terminals.
2. Scrape off paint and clean a spot on the motor-compressor shell for testing.
3. With the ohmmeter set on its highest scale, test for continuity between the terminals and the shell. This procedure is shown in *Figure 10-49*. There is a ground if continuity exists between the terminals and the shell.

Figure 10-49 — Testing windings for ground.

8.3.2 Test Lamp Continuity Check (Low-Resistance) Procedures

Complete the following steps for conducting a test lamp continuity check:

1. Disconnect the power and remove the wires from the motor terminals.
2. Ensure the lamp is connected in the hot side of the line. Plug the test lamp into a receptacle.
3. Connect the hot-line probe to a motor winding terminal.
4. Touch the free probe to the cleaned spot on the shell. Ensure that a good connection is made. There is a grounded winding if the light illuminates.

8.3.3 Megohmmeter (High-Resistance) Test Procedure

The megohmmeter consists of an indicating movement for which current is supplied by a small hand-driven generator. *Figure 10-50* illustrates a typical megger used by the Seabees. Two leads are supplied, one is marked Earth or Ground and the other is the free probe.

The procedure for making the megohmmeter (high-resistance) test is as follows:

- Disconnect power and remove the wires from the motor terminals.
- Place the megger probe marked Earth or Ground on the motor or compressor frame. Ensure there is a good metal-to-metal contact.
- Place the free probe on terminals C, S, and R in sequence. If any reading

Figure 10-50 — Typical megohmmeter (megger).

of low resistance is obtained, the motor is grounded.

NOTE

You should always refer to the manufacturer’s instructions when using a megger. It is also a good idea to request assistance from a Construction Electrician.

Test your Knowledge (Select the Correct Response)

10. Which method is used to test windings for grounds?

    A. Ohmmeter continuity test
    B. Test lamp continuity check
    C. Resistance measurement with a megohmmeter
    D. All of the above

11. **(True or False)** The first step in performing an ohmmeter continuity test is to disconnect the power and remove the wires from the motor terminals.

    A. True
    B. False

9.0.0 ELECTRICAL CIRCUIT COMPONENTS

Starting relays, overload protectors, and capacitors are electrical components that can cause trouble in hermetic motor compressor circuits. It is essential that the individual servicing refrigeration and air-conditioning units be able to identify these components and test them using the proper equipment and procedures.

9.1.1 Starting Relays

The three basic types of starting relays are as follows:

- Current relay (magnetic type)
- Voltage relay (magnetic type)
- Thermal relay (hot-wire type)

In the hermetic motor control circuit, a starting relay allows electricity to flow through the starting winding until the motor reaches two-thirds to three-fourths of its rated speed. At this time, about 3 to 4 seconds after starting, it disconnects the starting circuit.

9.1.1 Current Relay

A current relay is an electromagnet, similar to a solenoid valve that employs a weight and spring to hold the contacts open when the circuit is idle. In operation the instantaneous surge of starting current actuates the magnetic coil, causing the start winding contacts to close. This closure allows starting current to the winding; rated speed and the current decreases, causing the relay contact to open and disconnect the winding. Current relays are ideal for use with split-phase, induction-run motors. *Figure 10-5*1 is a schematic diagram of a current relay motor starting circuit.

Figure 10-51 — Schematic diagram of a current relay motor starting circuit.

9.1.2 Voltage Relay

A voltage relay looks much like a current relay; but differs in operation. It operates on increased voltage as the motor reaches rated speed, and unlike the current relay, the contacts remain closed during the off cycle. When the motor is first turned on, it draws heavy current and the voltage drop across the starting winding is low. As the motor picks up speed, there is less and less load; therefore, more and more voltage is induced into the winding. At about three-fourths rated speed the voltage is high enough to cause the relay coil to pull the contacts open and disconnect the winding. Voltage relays are used with capacitor-start motors. *Figure 10-52* is a schematic diagram of voltage relay motor starting circuit.

Figure 10-52 — Schematic diagram of a voltage relay motor starting circuit.

9.1.3 Thermal Relay

A thermal relay is commonly known as a hotwire relay. It is available in at least two different basic designs and is supplied by several manufacturers. All thermal relays operate on the theory that electrical energy can be turned into heat energy and that, when the temperature of a metal is increased, the metal expands. Thermal relays, like current and voltage relays, operate the starting winding circuit. In addition, the thermal relay controls the running winding circuit, if for any reason the circuit draws excessive current.

The device consists of a specially calibrated wire made from a material with high oxidation resistance and two sets of contacts, all of which are integrally attached to form the relay. *Figure 10-53* illustrates a typical thermal relay motor starting circuit. The contacts are controlled by the hot wire, either through the use of heat-absorbing bimetallic metal strips, or by its expansion of the hot wire, depending on the design of the relay.

Figure 10-53 — Typical thermal relay motor starting circuit.

9.2.0 Overload Protectors

Essentially, an overload protector is a heat sensitive device much like a circuit breaker. When current in the circuit increases above normal, the added current heats a bimetallic strip that bends and opens a pair of contacts. The opening of the contacts disconnects the motor-running circuit and the motor stops. This prevents damage to the compressor motor when troubles occur, such as a defective starting relay, an open starting capacitor, or high-head pressure. *Figure 10-54* shows a typical bimetallic disk-type overload protector. This overload protector is connected in the common line and mounted on the compressor motor shell.

9.3.1 Capacitors

In hermetic refrigeration and air-conditioning work, capacitors are identified in the following two groups:

- Start
- Run

These may be identified further as dry capacitors (start) that are used for intermittent operations and electrolytic capacitors (run) that are used for continuous operations.

9.4.0 Start Capacitors

Start capacitors are connected in series with starting windings. *Figure 10-55* shows the location of the start capacitor in a circuit. Because a start capacitor is placed in series with one of the two stator windings, the current will lead, as compared to the current going directly to the connected stator winding. This, in turn raises the attraction of one stator winding over the other, allowing the motor to begin turning. *Figure 10-56* shows that stator winding 2 is stronger than stator winding 1. This causes the motor to begin turning in the direction of the stronger winding. Once the initial starting of the motor is completed, the start capacitor is removed from the circuit.

Figure 10-54 — Bimetal disk-type overload.

Figure 10-55 — Start capacitor location in a circuit.

Figure 10-56 — Motor starting.

9.5.0 Run Capacitors

These types of capacitors are connected in the circuit between the line side of the starting and running windings. A run type capacitor (*Figure 10-57*) serves to provide a smoother and quieter operating motor.

Test your Knowledge

12. What type of starting relay is electromagnetic and is used with split-phase induction-run motors?

    A. Current
    B. Thermal
    C. Voltage
    D. Diaphragm

Figure 10-57 — Run capacitor.

10.0.0 EQUIPMENT and TEST PROCEDURES for ELECTRICAL CIRCUIT COMPONENTS

As a UT supervisor/manager you should have a thorough understanding of the equipment and procedures for testing circuit components. These components include starting relays, overload protectors, and capacitors.

10.1.0 Starting Relays

Starting relays can be tested two ways with an ohmmeter. The meter can be used to check across the relay coil, or it can be used to check across the relay contacts. This does not apply to thermal relays. *Figure 10-58* illustrates the procedures for these tests.

Figure 10-58 — Testing a starting relay with an ohmmeter.

When you check the relay contacts, you must know if the contacts are normally open or normally closed, refer to the schematic. Voltage relay contacts and thermal relay contacts are normally closed, whereas current relay contacts are normally open. The meter reading should indicate continuity through voltage and thermal relays since the contacts are normally closed. On the other hand, if the meter indicates continuity through the normally open contacts of a current relay, the contacts are probably fused together.

Another method of checking starting relays is by using a test line cord and fuse combination to isolate the relay. *Figure 10-59* illustrates the procedure used in making this test. Obtain a capacitor of the approximate size used with the compressor motor. Connect it from the hot side of the running winding to the hot side of the starting winding. Connect the test line to the motor terminals as illustrated in the figure and plug it in. If the compressor is good it should start running. After a short time, disconnect the capacitor. The compressor should continue to speed up and run normally. This procedure has accomplished manually what a properly functioning starting relay is supposed to accomplish. If the motor failed to start normally before the check, the relay is bad.

Figure 10-59 — Checking a starting relay with a test line.

Voltage and current relay coils can also be tested for resistance with an ohmmeter. When the coil is burned out, the meter indicates no resistance or an open coil. Commercial starting relay testers are available from several manufacturers.

10.2.0 Overload Protectors

Questionable Klixon external overload protectors (*Figure 10-60*) should be replaced with new ones. If the motor then operates properly, the old Klixon (protector) should be destroyed. Klixons can also be checked with an ohmmeter. Since the contacts are closed at ambient temperature, the meter should show continuity. When the meter shows an open, the Klixon should be replaced and destroyed.

Figure 10-60 — Klixon external overload protector.

Internal current temperature overloads can be tested by making continuity checks. Continuity checks must be made across terminals C and S, C and R, and S and R. When both C and S and C and R are open and continuity is indicated across S and R, the protector is open. When the temperature is normal and the continuity test indicates the overload contacts are open, the motor compressor assembly must be replaced. When the operating temperature is normal, the internal current temperature overload contacts should be closed.

10.3.0 Capacitor Test

The best test for a questionable motor capacitor is to try a new one of the correct size. If the motor operates properly, the old capacitor is defective and should be destroyed. Capacitors can also be tested with ohmmeter. First the power must be turned OFF and the capacitor disconnected and discharged with a 2 watt 20,000 ohm resister. Set the meter on the 0 to 10,000 ohm scale and touch the meter probes to the capacitor terminals.

If the digital display indicates 0 or low resistance and then climbs towards high resistance, the capacitor is good. If the display indicates 0 or low resistance and stays there, the capacitor is shorted. If the display stays blank, the capacitor is open. *Figure 10-61* shows these procedures.

Figure 10-61 — Testing capacitors with an ohmmeter.

Test your Knowledge (Select the Correct Response)

13. When a starting relay fails, which of the following devices can be used to start the compressor motor by bypassing the relay manually?

    A. A test lamp and scale
    B. An ohmmeter and four lead wires
    C. A test line cord, fuse, and capacitor
    D. A jumper placed across terminals C and R and a test lamp

11.1.1 HERMETIC ELECTRICAL SCHEMATIC WIRING DIAGRAMS

It is important for you to understand how and why air-conditioning and refrigeration units work like they do. Schematic wiring diagrams provide the type of detail you need to meet this requirement. All wiring circuits are built around the following four requirements:

- A source of electrons
- A place for them to flow
- A path for them to follow
- A load to make use of and control the flow

The schematic wiring diagram puts the symbol and line representation on paper in a manner that allows instant identification of all four requirements.

In the schematic wiring diagram, the source of electrons is a line drawn on one side of the diagram and it is usually designated as L1. Any and all points on this line have a surplus of electrons. On the opposite side, a line is drawn representing a shortage of electrons and it is usually designated as L2. There is a potential for electron flow between the two wires represented by L1 and L2. If a load is inserted between L1 and L2 the current flows and the load functions.

Figure 10-62 is a typical schematic diagram for a hermetic electrical system. *Figure 10-63* is a wiring detail for a typical room air-conditioner.

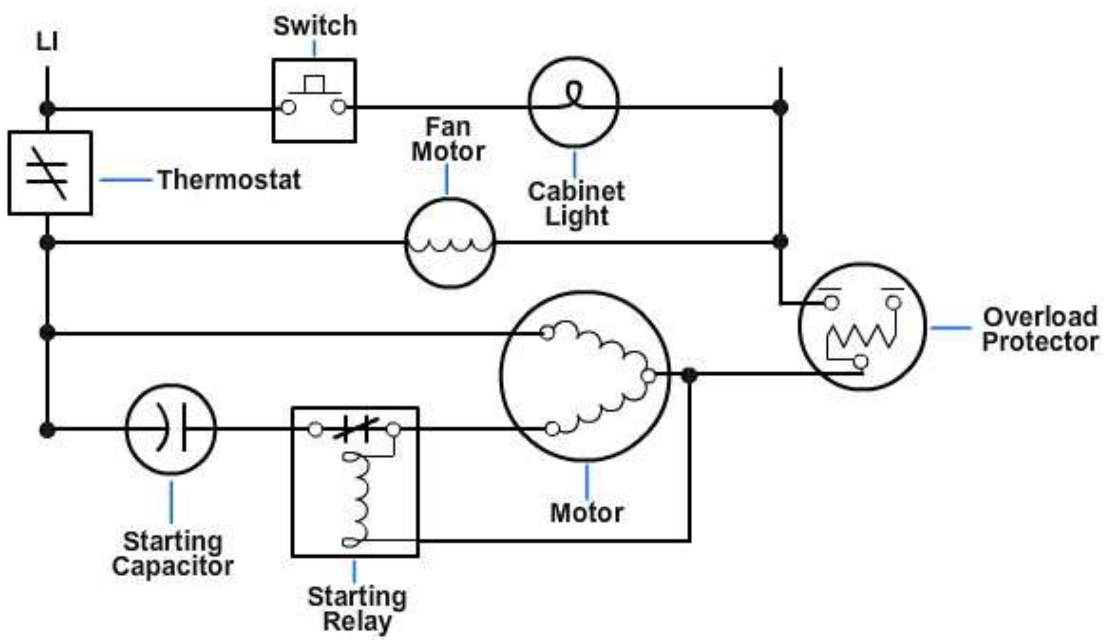


Figure 10-62 — Typical hermetic system schematic wiring diagram.

Figure 10-63 — Wiring detail for a typical room air-conditioner.

Summary

In this chapter you were provided with technical information required for selecting and installing air-conditioning and refrigeration equipment. Also discussed were the individual components required in air-conditioning and refrigeration systems, along with the fundamental electrical knowledge needed to install, maintain, and repair the equipment for those systems.

Review Questions (Select the Correct Response)

1. What type of air-conditioning system should be used when the areas to be air-conditioned are in close proximity to each other?

   A. Chilled water only
   B. Hat and chilled water
   C. Forced air
   D. Natural draft

2. What type of manifold gauges are needed when working on an ammonia-absorption refrigeration system?

   A. Brass
   B. Cooper
   C. Bronze
   D. Steel

3. What type of evaporator system is used to preserve the freshness of fruits, vegetables, meats, and fish?

   A. Spray
   B. Thermoelectric
   C. Eutectic
   D. Evaporator

4. What type of refrigeration system has no moving parts?

   A. Evaporator
   B. Thermoelectric
   C. Spray
   D. Eutectic

5. What maximum temperature can be maintained in a cascade refrigeration system?

   A. −50°F
   B. −100°F
   C. −150°F
   D. −250°F

6. What maximum temperature can be attained in a three-stage compound refrigeration system?

   A. −100°F
   B. −135°F
   C. −150°F
   D. −250°F

7. When mounting a condenser on a roof, what consideration is considered the most important?

A. Noise level
B. Availability of water
C. Availability of electricity
D. Roof load strength

8. What types of metal are used in a bimetal thermostat?

A. Tin and antimony
B. Cooper and steel
C. Brass and invar
D. Tin and steel

9. What type of thermostat uses 24 volts?

A. Line-voltage
B. Low-voltage
C. Millivoltage
D. High-voltage

10. What is the most commonly used metering device?

A. AEX
B. Capillary tube
C. TEV
D. Low-side float

11. Which of the following types of motors should be used for 5-horsepower, high-starting torque requirement?

A. Split-phase
B. Capacitor-start, capacitor-run
C. Permanent split-phase
D. Capacitor-start, induction run

12. Which of the following components is considered a load?

A. Thermostat
B. High-pressure switch
C. Set of contacts
D. Compressor contactor

13. Which of the following conditions exists in the case of a shorted-winding?

A. A wire is burned in half
B. The winding has a high resistance
C. A loop of cooper wire is in contact with another wire
D. A wire is touching the hermetic shell

14. Which of the following devices can be used to test a hermetic motor for grounds?

    A. Ohmmeter
    B. Test lamp
    C. Megger
    D. All of the above

15. Which of the following starting relays is capable of de-energizing the running winding circuit when the circuit draws excessive current?

    A. Hot wire
    B. Voltage
    C. Current
    D. None of the above

16. **(True or False)** When checking relay contacts, voltage and thermal relay contacts are normally open.

    A. True
    B. False

17. When testing a capacitor with an ohmmeter, what general reading on the meter indicates the capacitor is good?

    A. High resistance
    B. Low resistance then climbs to high resistance
    C. Medium resistance
    D. Low resistance

Trade Terms Introduced In This Chapter

Psychometrics	The measurement of the heat and water vapor properties of air. Commonly used psychrometric variables are temperature, relative humidity, dew-point temperature, and wet-bulb temperature.
inductance	The property of an electrical circuit measuring the induced electric voltage compared to the rate of change of the electric current in the circuit.
capacitance	A measure of the ability of a configuration of materials to store electric charge.

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.

Heating, Ventilating, Air-Conditioning, and Dehumidifying Systems, NAVFAC DM 3.3

Modern Refrigeration and Air Conditioning, by Althouse/Turnquist/Bracciano

Navy Safety and Occupational Health (SOH) Program Manual, OPNAVINST 5100.23 (series), Naval Safety Center, Norfolk, Va.

American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Handbook of Fundamentals.

Occupational Safety and Health Standards (Part 1910), Occupational Safety & Health Administration (OSHA).

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*.

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-6 — Trapezoid.

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-7 — Parallelogram.

Square is a rectangle having its adjoining sides equal. Refer to *Figure A-9*.

Figure A-8 — Rectangle.

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

Ohm's Law- Alternating Current

Figure A-13 — Direct 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

$PF = -\frac{\text{actual power}}{\text{apparent power}} = \frac{\text{watts}}{\text{volts x amperes}} = \frac{kW}{kVA} = \frac{R}{Z}$

$PF = \frac{P}{E \times I}$

$= kVA \times PF$

lanced

Power: Three-Phase Balanced Wye or Delta Circuits

P = 1.732 x E x I x PF VA = 1.732 x E x I

$E = \frac{P}{PF\ x\ 1.73\ x\ I} = \frac{0.577\ x\ P}{PF\ x\ I}$

$I = \frac{P}{PF\ x\ 1.73\ x\ E} = \frac{0.577\ x\ P}{PF\ x\ E}$

$PF = \frac{P}{PF\ x\ 1.73\ x\ E} = \frac{0.577\ x\ P}{I\ x\ E}$

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

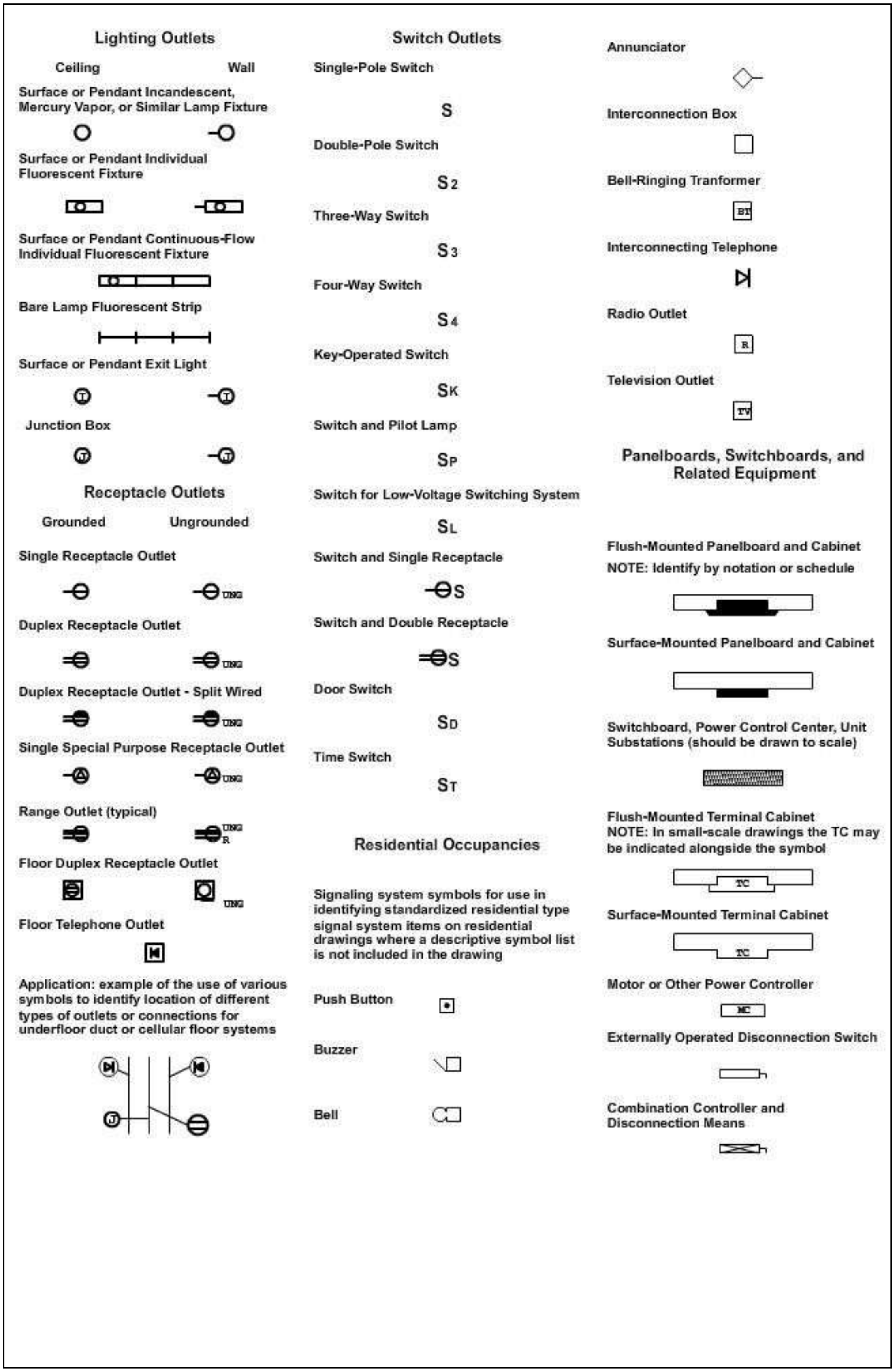
Crowd or Extend

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

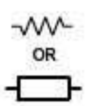
3-phase, wye or star, ungrounded

3-phase, wye, grounded neutral

Graphic Symbols for Fundamental Items

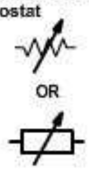
Resistor

General



See Note

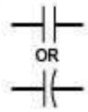
Application: adjustable or continuously adjustable (variable) resistor rheostat



See Note

NOTE: Always add identification within , or adjacent to, the rectangle.

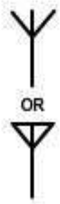
Capacitor



Antenna

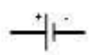
General

Types or functions may be indicated by words or abbreviations adjacent to the symbol.

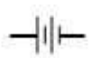


Battery

The long line is always positive, but polarity may be indicated in addition. Example:

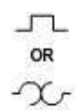


Multicell



Thermal Element

Actuating device, self-heating or with external heater. (Not operated primarily by ambient temperature.)



Graphic Symbols for Transmission Path

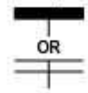
Transmission Path
Conductor
Cable
Wiring

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.

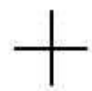


Conductive path or conductor; wire

Two conductors or conductive paths

Crossing of paths or conductors not connected

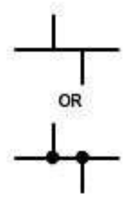
The crossing is not necessarily at a 90° angle.



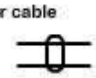
Junction of paths or conductors
Junction (if desired)

Junction of paths, conductors, or cable. If desired, indicate path type, or size.

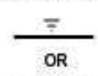
Junction of paths, conductors, or wires



2-conductor cable

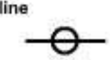


Cable underground; underground line



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).

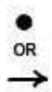
Chassis or frame connection, equivalent chassis connection (of printed-wiring boards)

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.

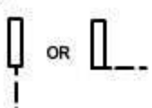
Graphic Symbols for Contacts, Switches, Contacts, and Relays

Electrical Contact

Fixed contact for jack, key, relay, switch, etc.



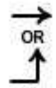
‡ Sleeve



‡ 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.



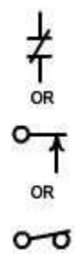
Locking

Nonlocking

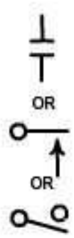
Basic Contact Assemblies

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.

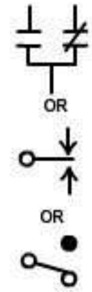
Closed contact (break)



Open contact (make)

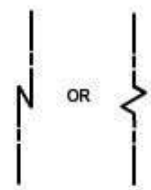


Transfer



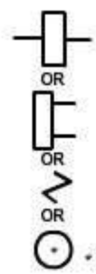
Make-before-break

Magnetic Blowout Coil



Operating Coil

Relay Coil

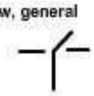


Switch

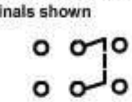
Fundamental symbols for contacts, mechanical connections, etc, may be used for switch symbols.

Single-throw, general

Double-throw, general



2-pole double-throw switch with terminals shown

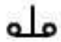


NOTE: The asterisk is not part of the symbol. Always replace the asterisk by a device designation.

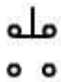
Push button, Momentary or Spring-Return

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)

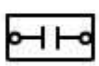
Any number of transmission paths may be shown.

OR

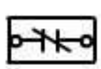
Limit Switch
Sensitive Switch

NOTE: Identity by LS or other suitable note.

Track-type, circuit-closing contact



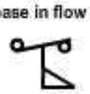
Track-type, circuit-opening contact



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

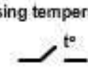
Temperature-Actuated Switch

Closes on rising temperature

Opens on rising temperature

Thermostat

Closes on rising temperature



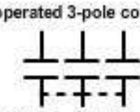
* See Note

Contactor

See also CIRCUIT BREAKER

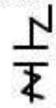
Fundamental symbols for contacts, coils, mechanical connections, etc, are the basis of contactor symbols and should be used to represent contactors on complete diagrams. Complete diagrams of contactors consist of combinations of fundamental symbols for control coils, mechanical connections, etc, in such configurations as to represent the actual device. Mechanical interlocking should be indicated by notes.

Manually operated 3-pole contactor

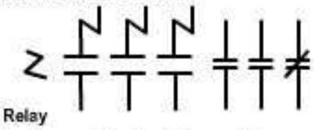


NOTE: The t° symbol shall be shown or be replaced by data giving the nominal or specific operating temperature of the device.

Electrically operated 1-pole contactor with series blowout coil



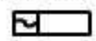
Electrically operated 3-pole contactor with series blowout coils; 2 open and 1 closed auxiliary contacts (shown smaller than the main contacts)



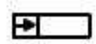
Relay

Fundamental symbols for contacts, mechanical connections, coils, etc, are the basis of relays on complete diagrams.

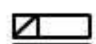
The following letter combinations or symbol elements may be used with relay symbols. The requisite number of these letters or symbol elements may be used to show what special features a relay possesses.



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 (re-manent)
NB No bias
NR Nonreactive



P Magnetically polarized using biasing spring, or having magnet bias
SA Slow-operate and slow-release



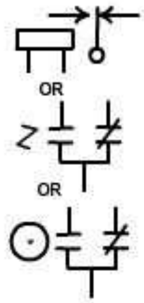
SO Slow-operate

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 alson be shown.

Basic

Relay with transfer contacts



Graphic Symbols for Terminals and Connectors

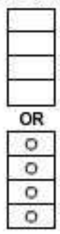
Terminals

Circuit terminal

Terminal board or terminal strip, with 4 terminals shown; group of 4 terminals

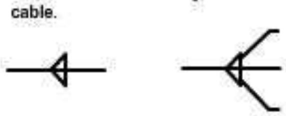
Number and arrangement as convenient.

NOTE: Internal lines and terminals may be omitted if terminal identifications are shown within the symbol.



Cable Termination

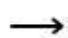
Line shown on left of symbol indicates cable.



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 

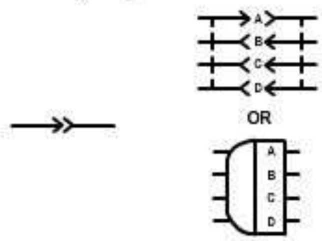
Receptacle or jack (usually stationary)

NOTE: The asterick is not part of the symbol. If desired, indicate the type of contacts: male (⟶) or female (—<).

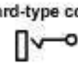
Plug (usually movable) OR

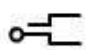
Separable connectors (engaged)

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

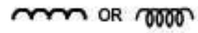
Magnetic core of inductor or transformer

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

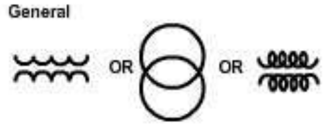
If necessary to show a magnetic core.

Tapped 

Adjustable inductor

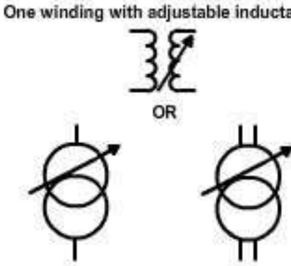
Transformer

General

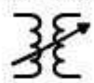


Shielded transformer with magnetic core shown

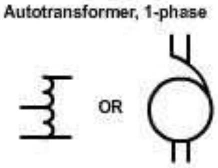
One winding with adjustable inductance



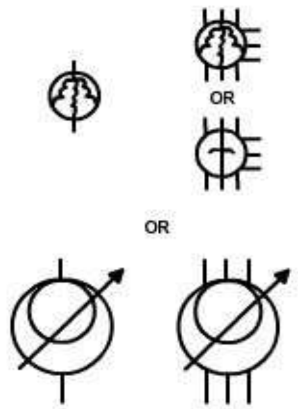
Adjustable mutual inductor; constant-current transformer



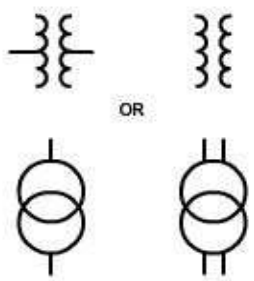
Autotransformer, 1-phase



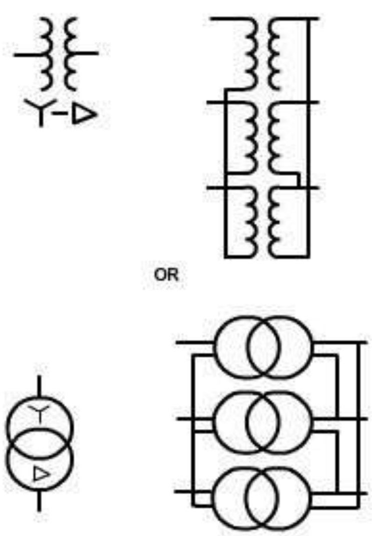
3-phase induction voltage regulator



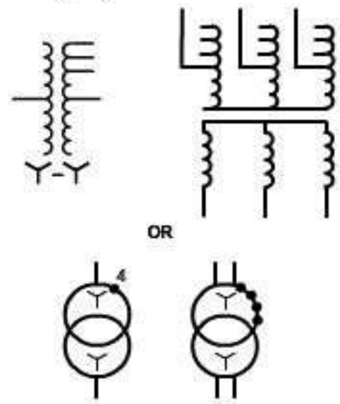
1-phase, 2-winding transformer



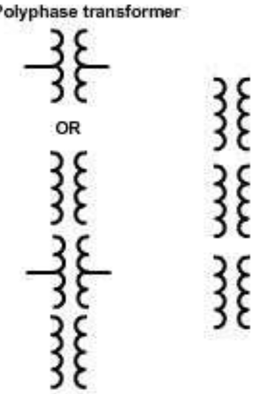
3-phase bank of 1-phase, 2-winding transformers with wye-delta connections



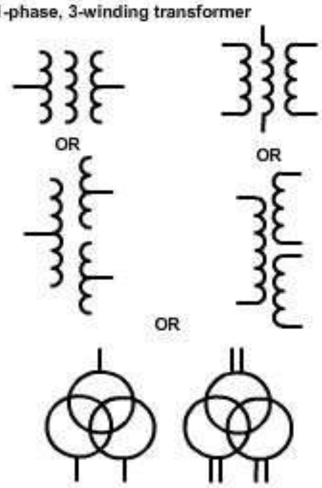
These phases transformer with 4 taps with wye-wye connections



Polyphase transformer

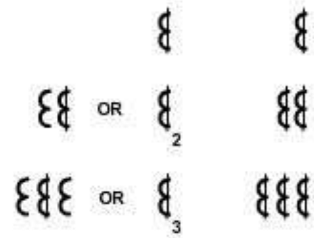


1-phase, 3-winding transformer

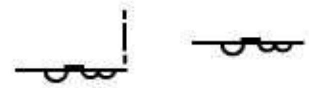


Current transformer(s)

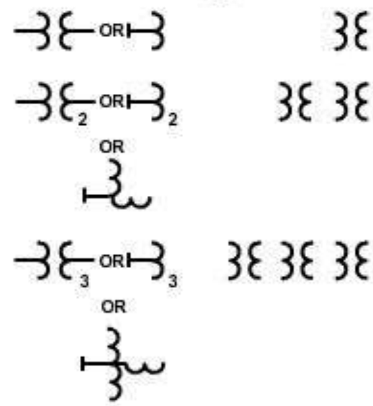
Avoid conflict with symbol for loaded line if used on the same diagram.



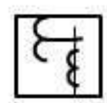
Bushing-type current transformer



Potential transformer(s)



Outdoor metering device



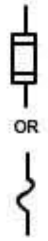
SHOW ACTUAL CONNECTION INSIDE BORDER

Graphic Symbols for Circuit Protectors

Fuse (one-time thermal current-over-load device)

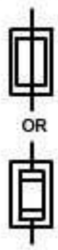
General

OR



Isolating fuse-switch: high-voltage primary fuse cutout, dry

High-voltage primary fuse cutout, oil



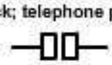
Current Limiter (for power cable)

The arrowheads in this case are filled.

Lightning Arrester
Arrester (electric surge, etc)
Gap

General

Carbon block; telephone protector block



Horn gap

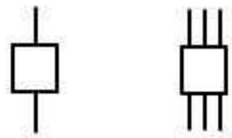
Circuit Breaker

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

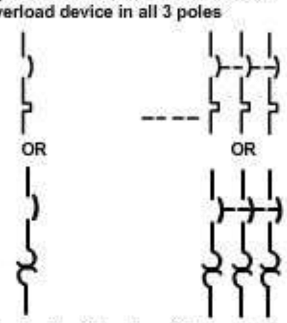
Network protector

Circuit breaker, other than covered by the above symbol

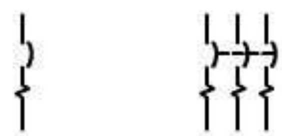
The symbol in the right column is for a 3-pole breaker.



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

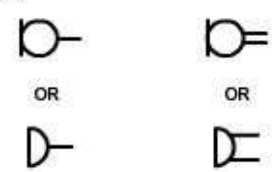
Buzzer

Loudspeaker
Horn, Electrical
Sirem

General

Microphone
Telephone Transmitter

General



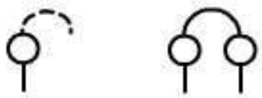
Handset
Operator's Set

General

Telephone Receiver
Earphone

General

Headset, double

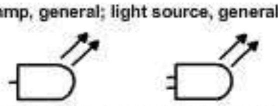


Headset, single

Graphic Symbols for Lamps and Visual-Signaling Devices

Lamp

Lamp, general; light source, general



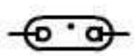
NOTE: This symbol may be used to represent one or more lamps with or without operating auxiliaries.

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.

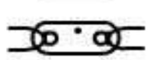
A	Amber
B	Blue
C	Clear
G	Green
O	Orange
OP	Opelescent
P	Purple
R	Red
W	White
Y	Yellow
ARC	Arc
EL	Electroluminescent
FL	Fluorescent
HG	Mercury vapor
IN	Incandescent
IR	Infrared
NA	Sodium vapor
NE	Neon
UV	Ultraviolet
XE	Xenon
LED	Light-emitting diode

Fluorescent lamp

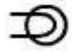
2-terminal



4-terminal

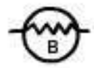


Incandescent lamp (incandescent-filament illuminating lamp



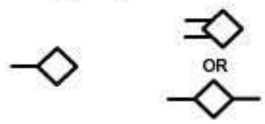
Ballest lamp; ballast tube

The primary characteristic of the element within the circle is designed to vary non-linearity with the temperature of the element.



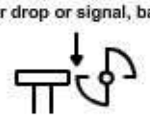
Visual-Signaling Device

Annunciator (general)

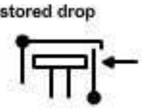


Annunciator drop or signal, shutter or grid type

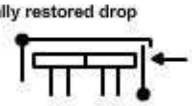
Annunciator drop or signal, ball type



Manually restored drop



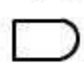
Electrically restored drop



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.



OR

OR

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

Graphic Symbols for Rotating Machinery

Rotating Machine

Basic

Generator (general)

Avoid conflict with symbols for galvanometer if used on the same diagram.

OR

Generator, direct-current

Generator, alternating-current

Motor (general)

OR

Motor, direct-current

Motor, alternating-current

Winding Connection Symbols

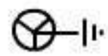
Motor and generator winding connection symbols may be shown in the basic circle using the following representations.

1-phase

2-phase

3-phase wye (ungrounded)

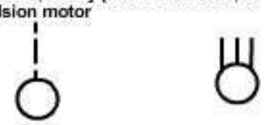
3-phase wye (grounded)



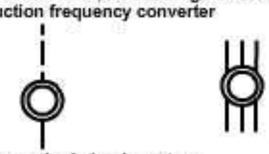
3-phase delta

Alternating-Current Machines

Squirrel-cage induction motor or generator, split-phase induction motor or generator, rotary phase converter, or repulsion motor



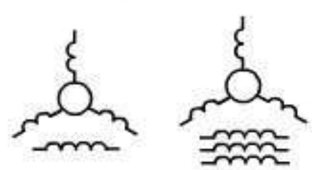
Wound-rotor induction motor, synchronous induction motor, induction generator, or induction frequency converter



1-phase shaded-pole motor

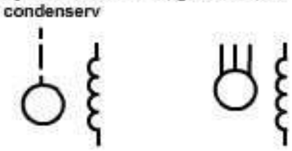
1-phase repulsion-start induction motor

3-phase regulating machine



Alternating-Current Machines with Direct-Current Field Excitation

Synchronous motor, generator, or condenserv



Graphic Symbols for Mechanical Functions

Mechanical Connection
Mechanical Interlock

Mechanical connection

The top symbol consists of shor dashees.

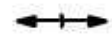
NOTE: The short parallel lines should be used only where there is insufficient space for the short dashes in series

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.

OR

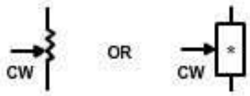
Rotation, both directions

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.

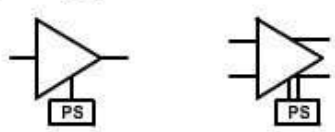
The symbol represents any method of amplification (electron tube, solid-state device, magnetic device, etc).

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

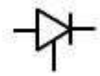


General

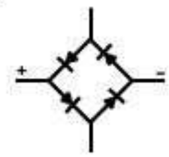
NOTE: Triangle points in direction of forward (easy) current as indicated by a direct-current ammeter, unless otherwise noted adjacent to the symbol. Electron flow is in the opposite direction.

NOTE: This symbol represents any method of rectification (electron tube, solid-state device, electrochemical device, etc).

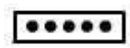
Controlled



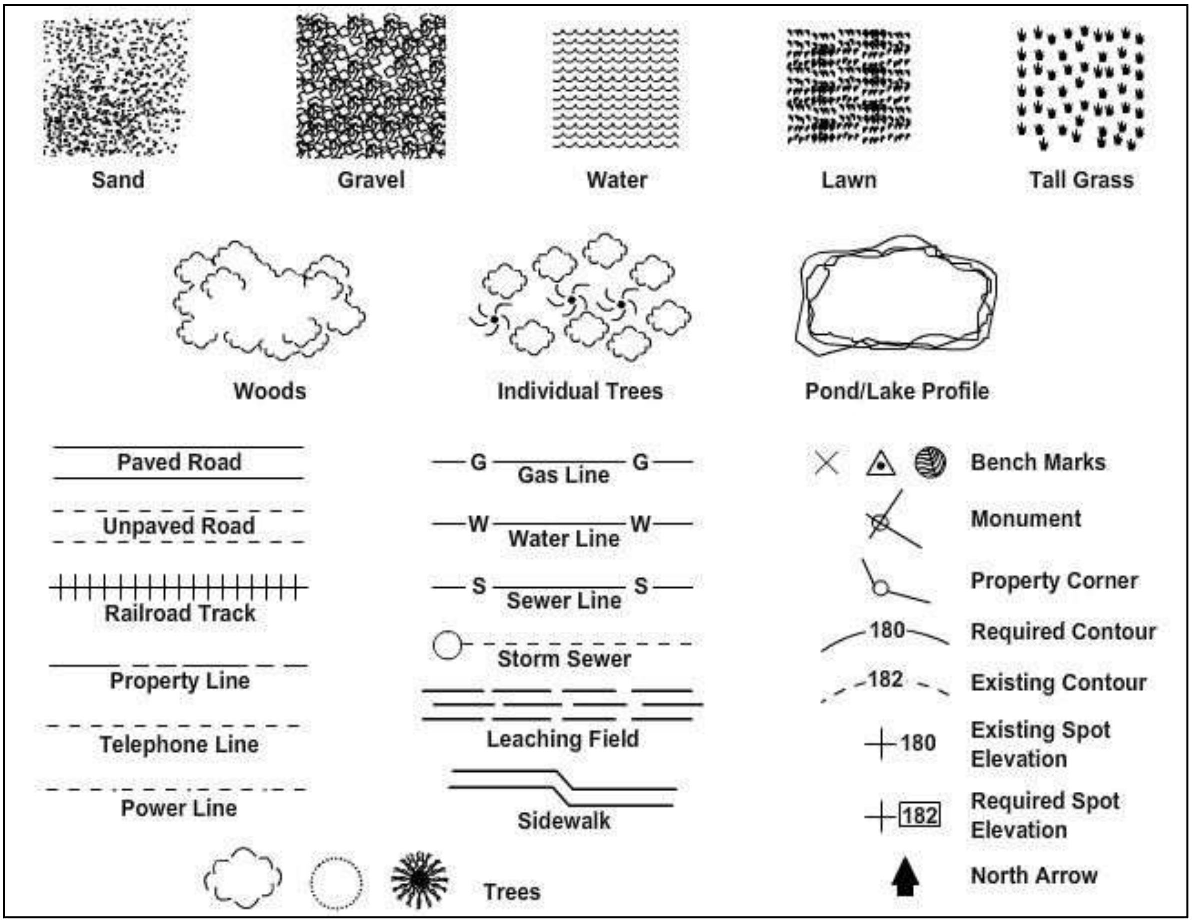
Bridge-type rectifier



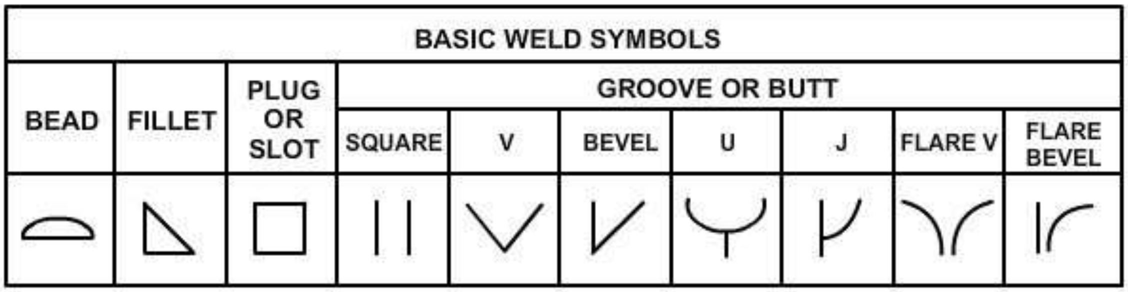
On connection or wiring diagrams, rectifier may be shown with terminals and plarity marking. Heavy line may be used to indicate nameplate or positive-polarity end.

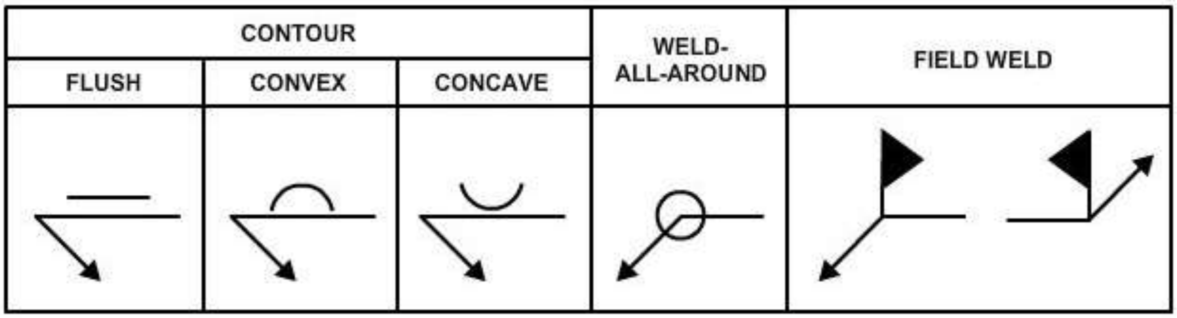


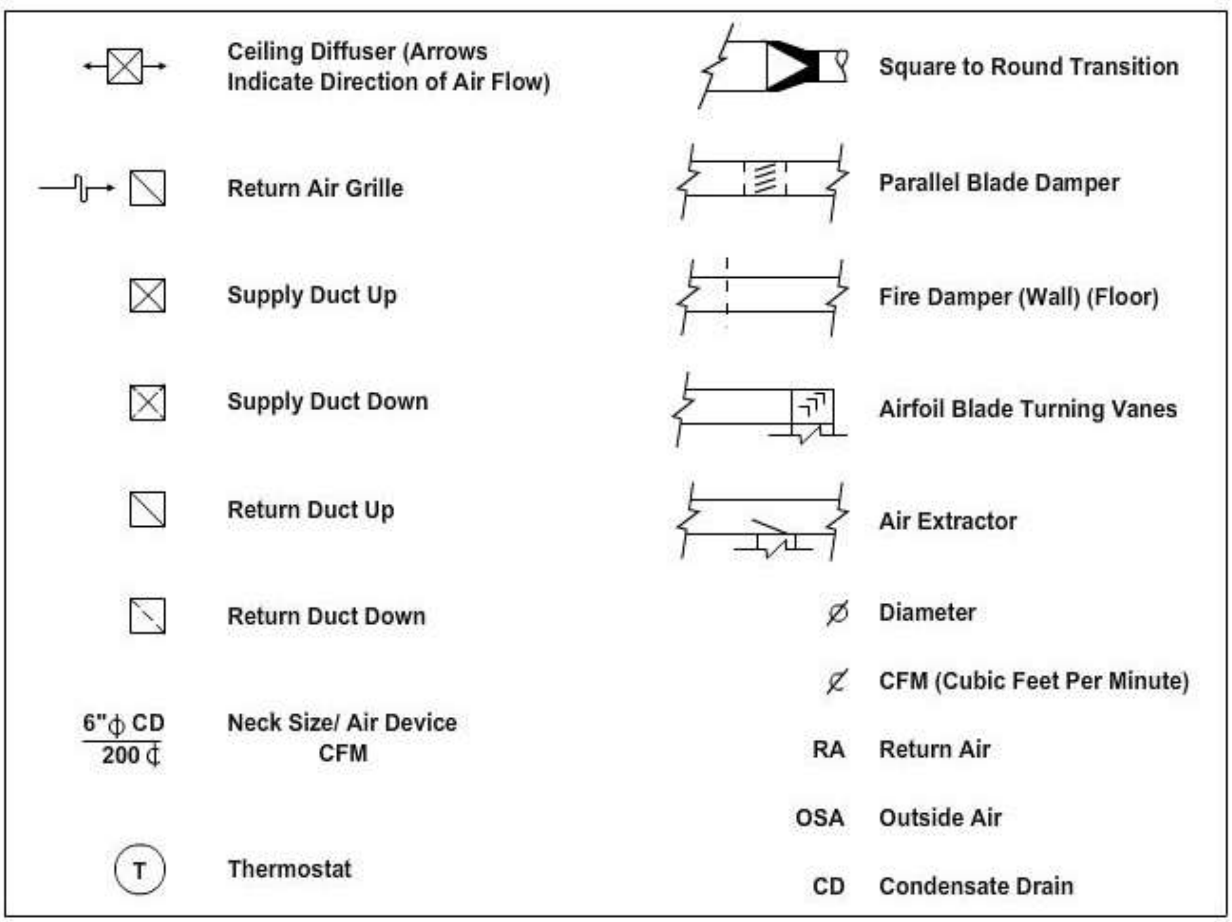
For connection or wiring diagram

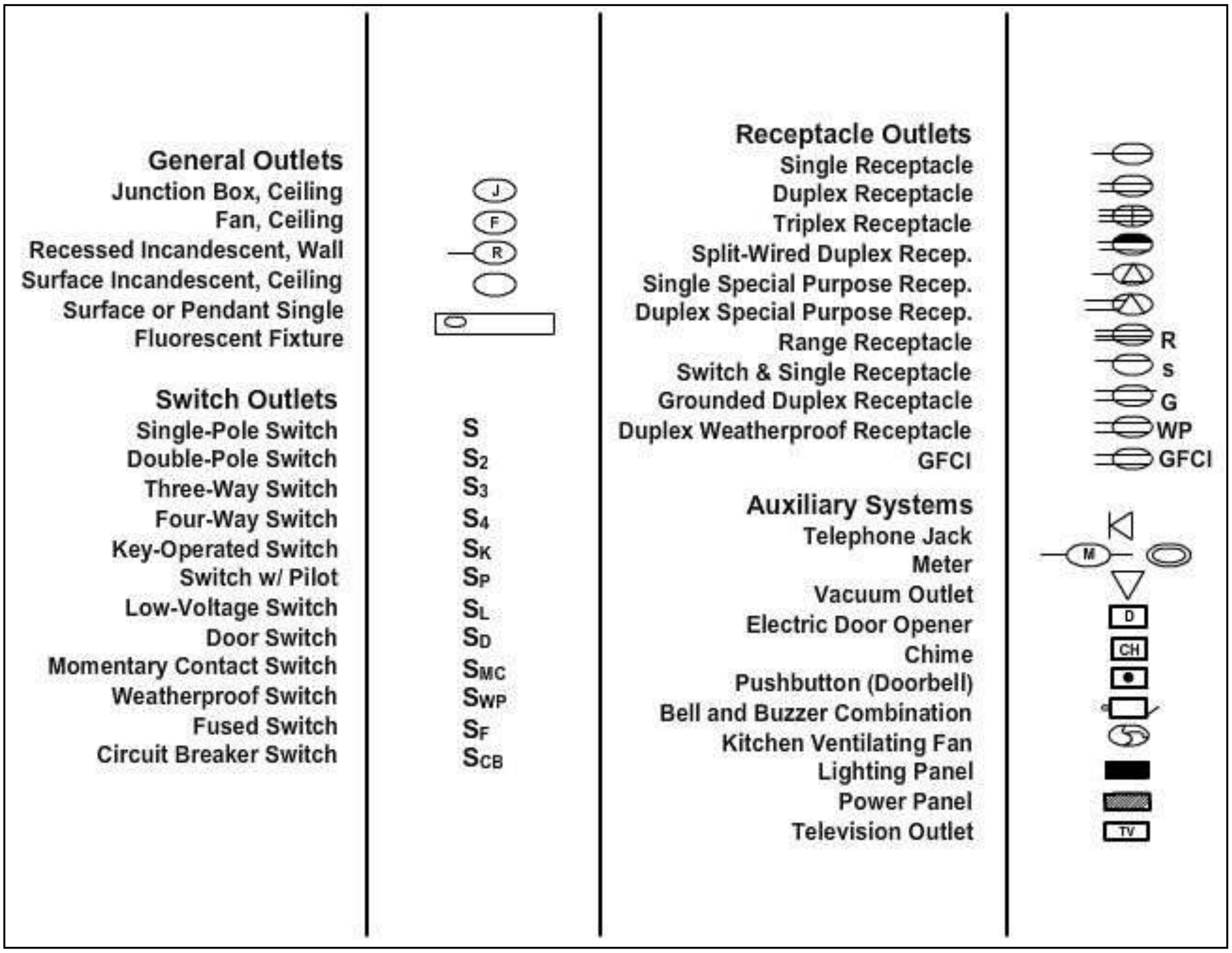


Description	Example	Symbol	Illustrated Use
W- Shape (Wide Flange)		W	W24 x 78
Bearing Pile		BP	BP14 x 73
S-Shape (American STD I-Beam)		S	S15 x 42.9
C-Shape (American STD Channel)		C	C9 x 13.4
M-Shape (Misc Shapes Other Than W, BP, S, & C)		M	M5 x 34.3 M5 x 17 M7 x 5.5
MC-Shape (Channels Other Than American 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

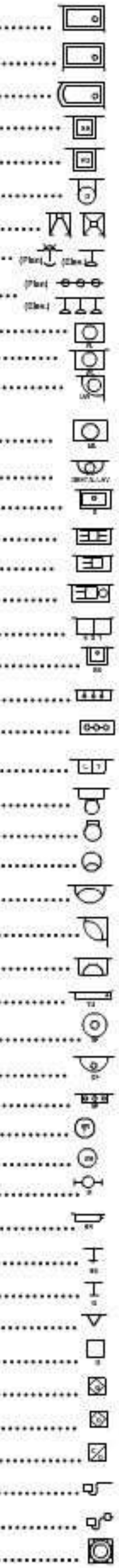

CONTOUR
FLUSH
CONVEX
CONCAVE
WELD-ALL-AROUND
FIELD WELD


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
Diameter
CFM (Cubic Feet Per Minute)
RA
Return Air
OSA
Outside Air
CD
Condensate Drain

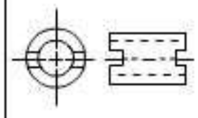
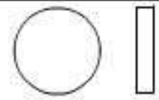
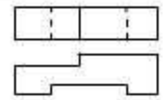
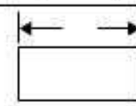
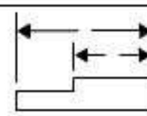
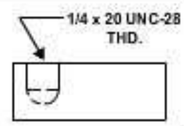
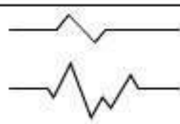
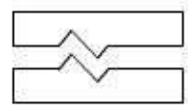
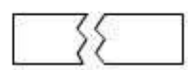
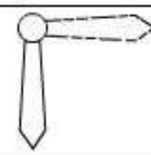
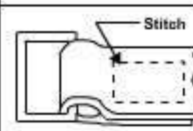
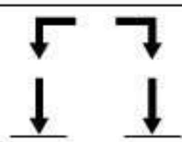
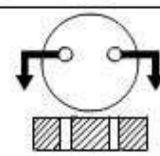
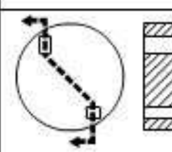

General Outlets
Junction Box, Ceiling
Fan, Ceiling
Recessed Incandescent, Wall
Surface Incandescent, Ceiling
Surface or Pendant Single Fluorescent Fixture
J
F
R
Switch Outlets
Single-Pole Switch
Double-Pole Switch
Three-Way Switch
Four-Way Switch
Key-Operated Switch
Switch w/ Pilot
Low-Voltage Switch
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



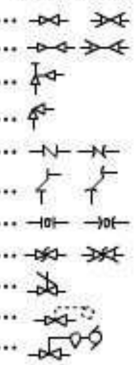
LINE STANDARDS

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

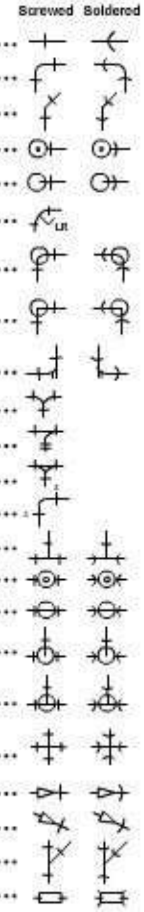
- Gate Valve
- Globe Valve
- Angle Glove Valve
- Angle Gate Valve
- Check Valve
- Angle Check Valve
- Stop Cock
- Safety Valve
- Quick Opening Valve
- Float Opening Valve
- Motor Operated Gate Valve

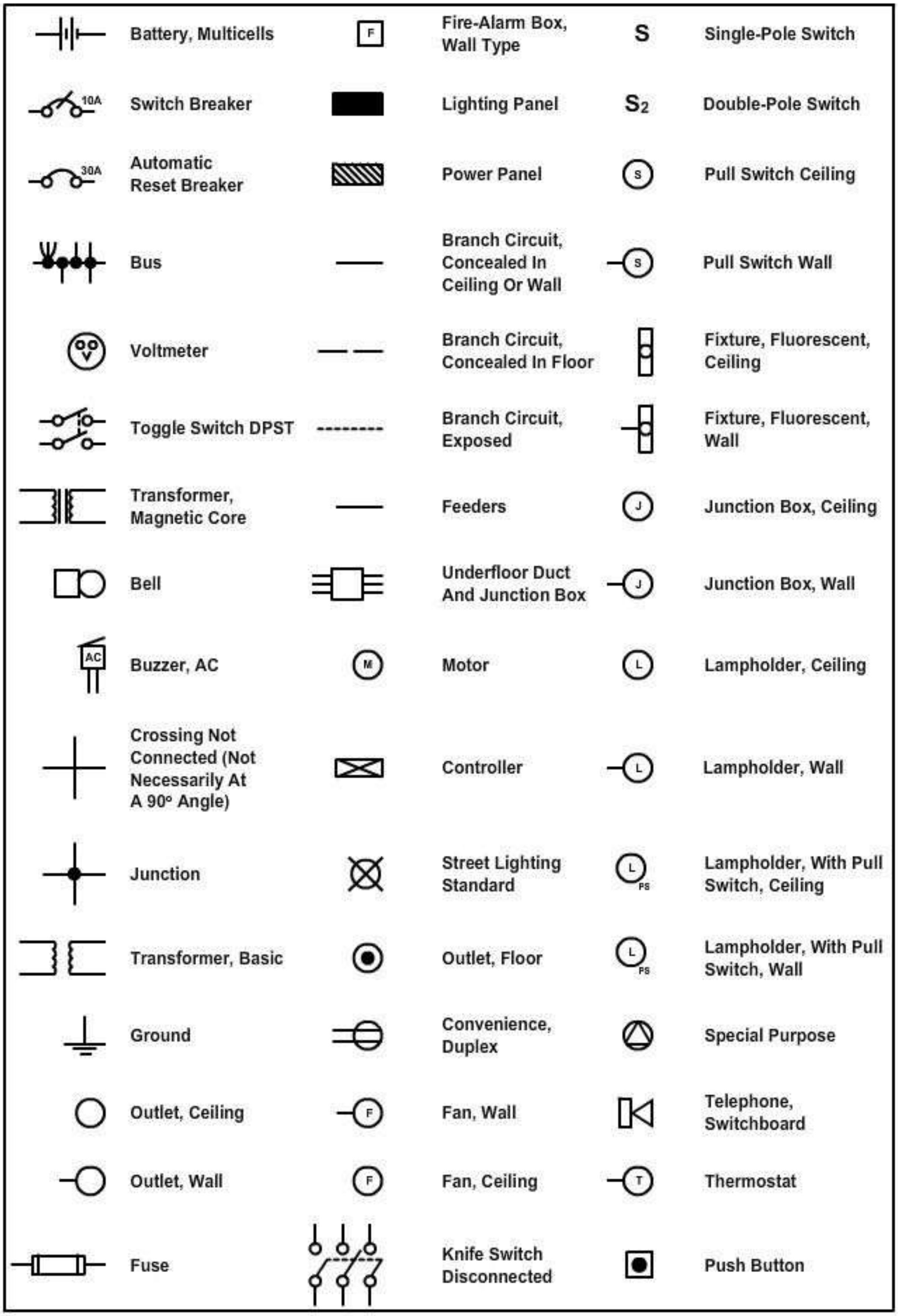


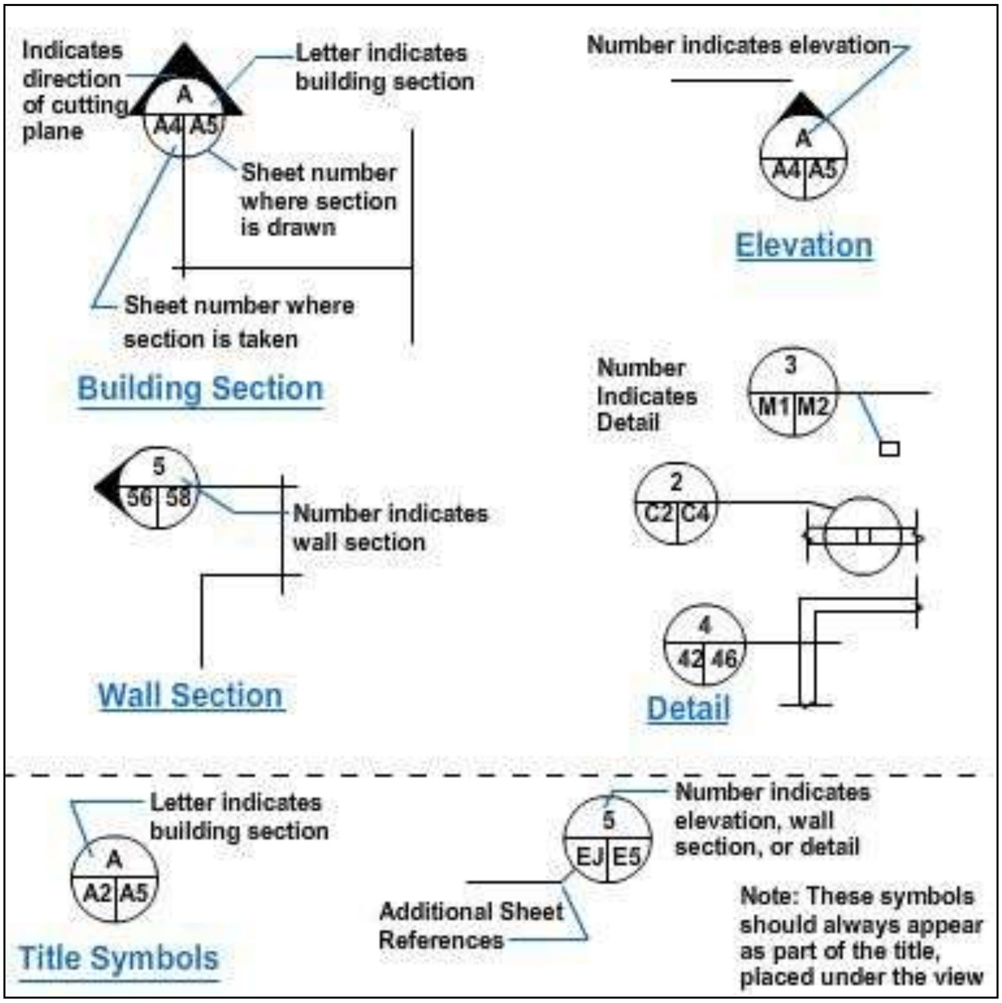
Pipe Fittings

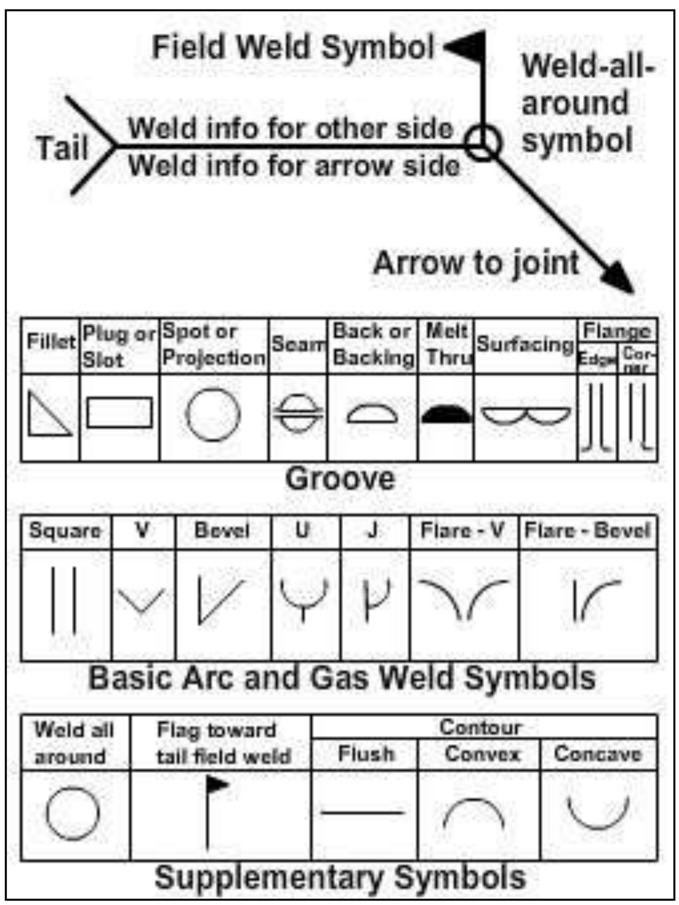
Screwed Soldered

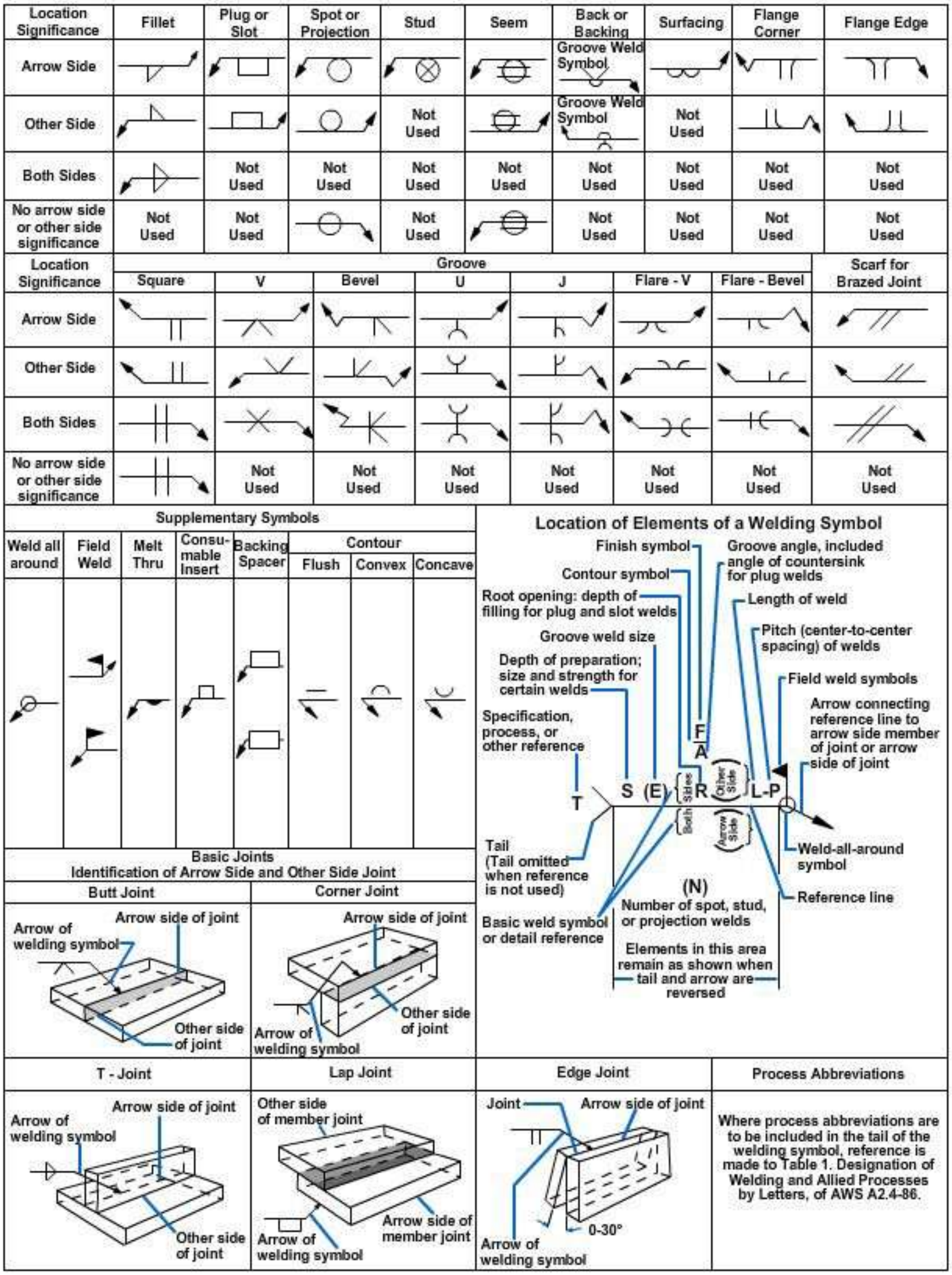
- Joint
- Elbow - 90
- Elbow - 45
- Elbow - Turned Up
- Elbow - Turned Down
- Elbow Long Radius
- Side Outlet Elbow- Outlet Down
- Side outlet Elbow - Outlet Up
- Base Elbow
- Double Branch Elbow
- Single Sweep Tee
- Double Sweep Tee
- Reducing Elbow
- Tee
- Tee - Outlet UP
- Tee - Outlet Down
- Side Outlet Tee - Outlet Up
- Side Outlet Tee - Outlet Down
- Cross
- Reducer
- Eccentric Reducer
- Lateral
- Expansion Joint Flanged



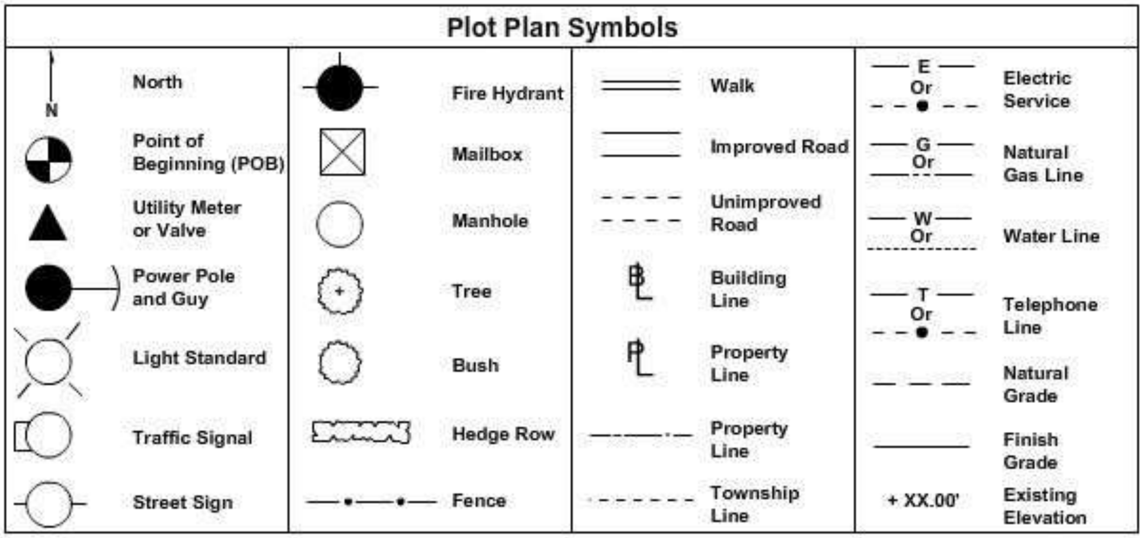

Battery, Multicells
F
Fire-Alarm Box, Wall Type
S
Single-Pole Switch
10A
Switch Breaker
Lighting Panel
S2
Double-Pole Switch
30A
Automatic Reset Breaker
Power Panel
Pull Switch Ceiling
Bus
Branch Circuit, Concealed In Ceiling Or Wall
Pull Switch Wall
Voltmeter
Branch Circuit, Concealed In Floor
Fixture, 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

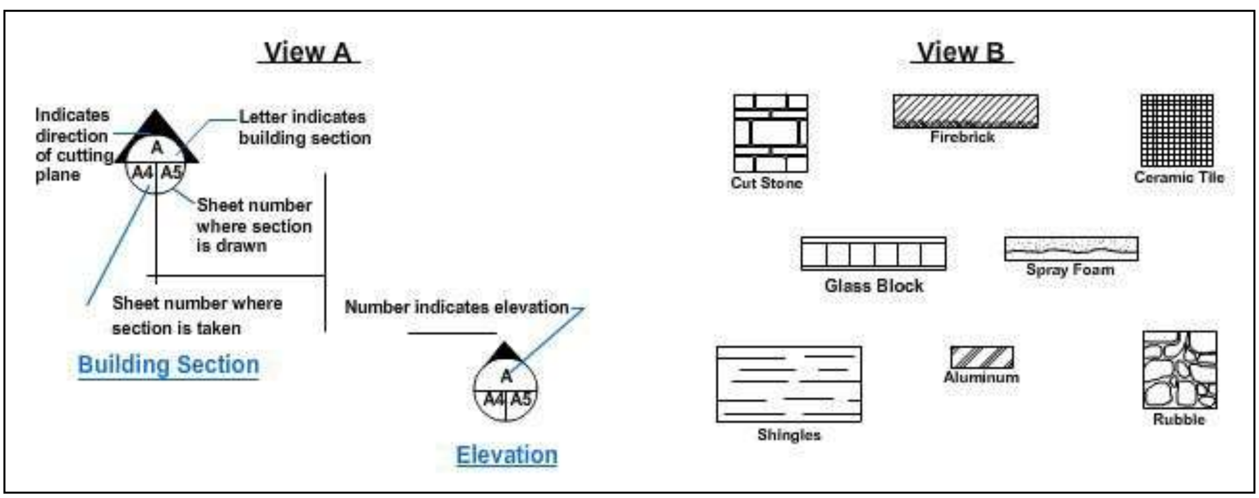

Indicates direction of cutting plane
A
A4 A5
Letter indicates building section
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
A
A4 A5
Elevation
5
56 58
Number indicates wall section
Wall Section
Number Indicates Detail
3
M1 M2
2
C2 C4
4
42 46
Detail
Letter indicates building section
A
A2 A5
Title Symbols
5
EJ E5
Number indicates elevation, wall section, or detail
Additional Sheet References
Note: These symbols should always appear as part of the title, placed under the view

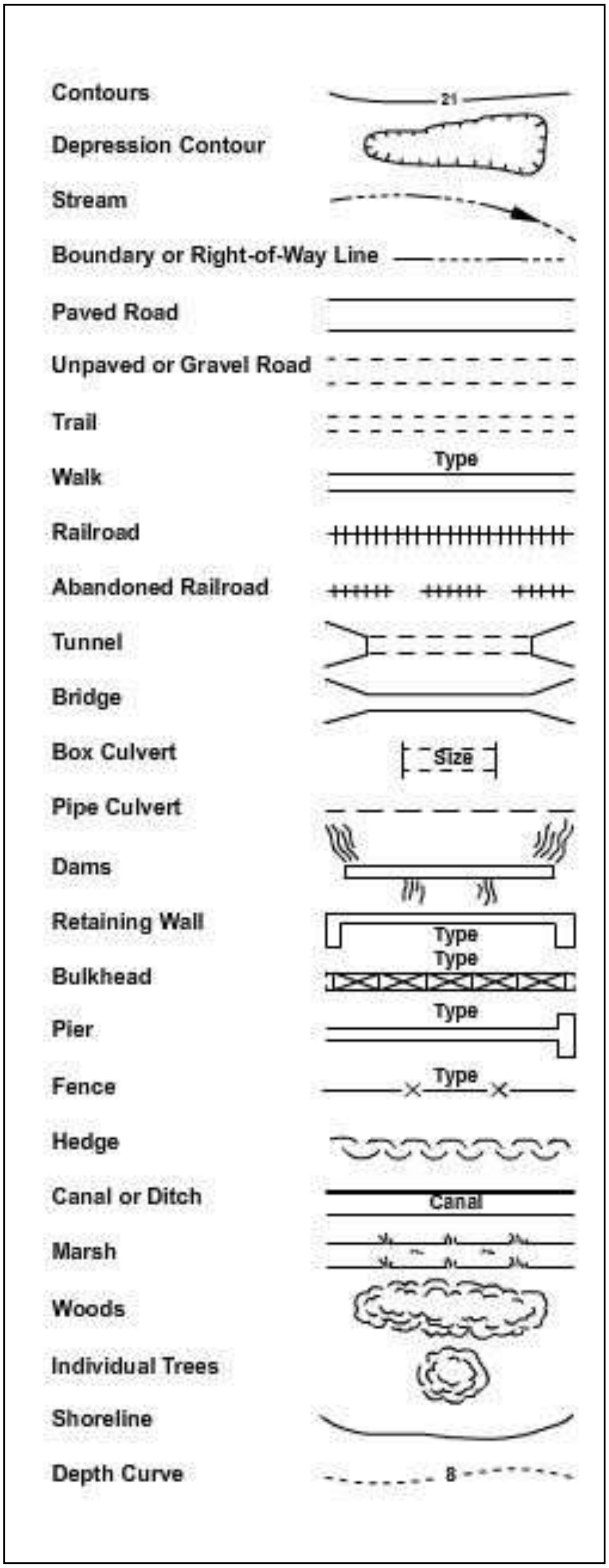

Field Weld Symbol
Weld-all-around symbol
Tail
Weld info for other side
Weld info for arrow side
Arrow to joint
Fillet
Plug or Slot
Spot or Projection
Seam
Back or Backing
Melt Thru
Surfacing
Flange
Edge
Corner
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Basic Arc and Gas Weld Symbols
Weld all around
Flag toward tail field weld
Contour
Flush
Convex
Concave
Supplementary Symbols

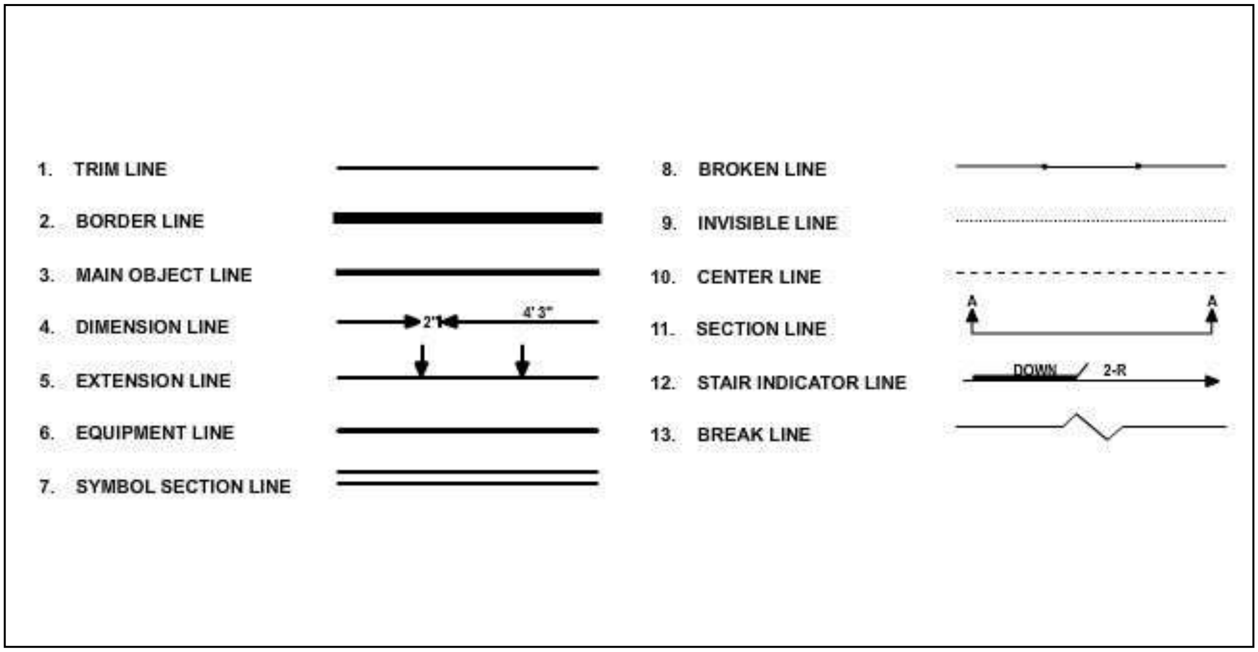

Location Significance
Fillet
Plug or Slot
Spot or Projection
Stud
Seem
Back or Backing
Surfacing
Flange Corner
Flange Edge
Arrow Side
Groove Weld Symbol
Other Side
Groove Weld Symbol
Not Used
Both Sides
No arrow side or other side significance
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Scarf for Brazed Joint
Supplementary Symbols
Weld all around
Field Weld
Melt Thru
Consumable 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
T
S (E)
R
L-P
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
Corner Joint
Arrow of welding symbol
Arrow side of joint
Other side of joint
T - Joint
Lap Joint
Other side of member joint
Arrow side of member joint
Edge Joint
Joint
0-30°
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.

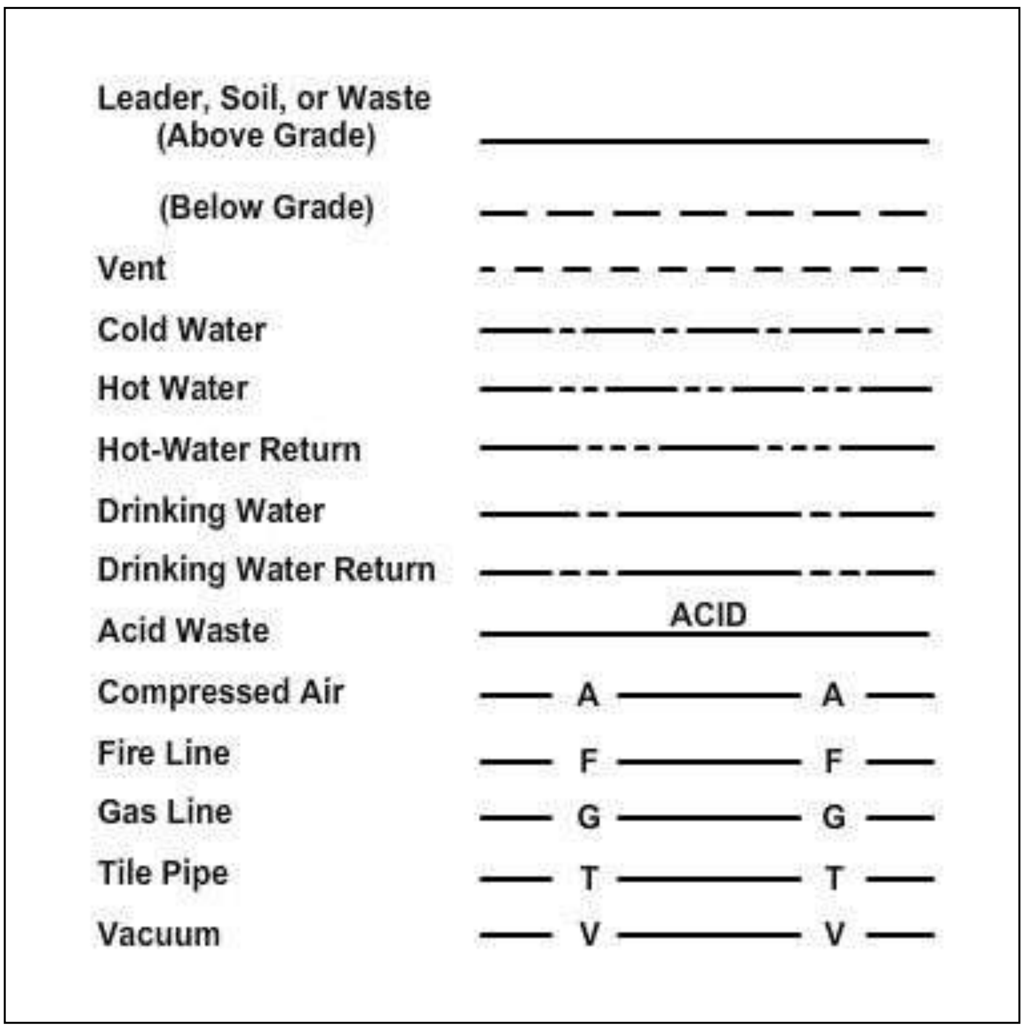
Architectural Symbols			
Material	**Elevation**	**Plan**	**Section**
Earth			
Brick	With note indicating type of brick (common, face, ets.)	Common or Face Firebrick	Same as Plan Views
Concrete		Lightweight Structural	Same as Plan Views
Concrete Block		Or	Or
Stone	Cut Stone Rubble	Cut Stone Rubble Cast 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.

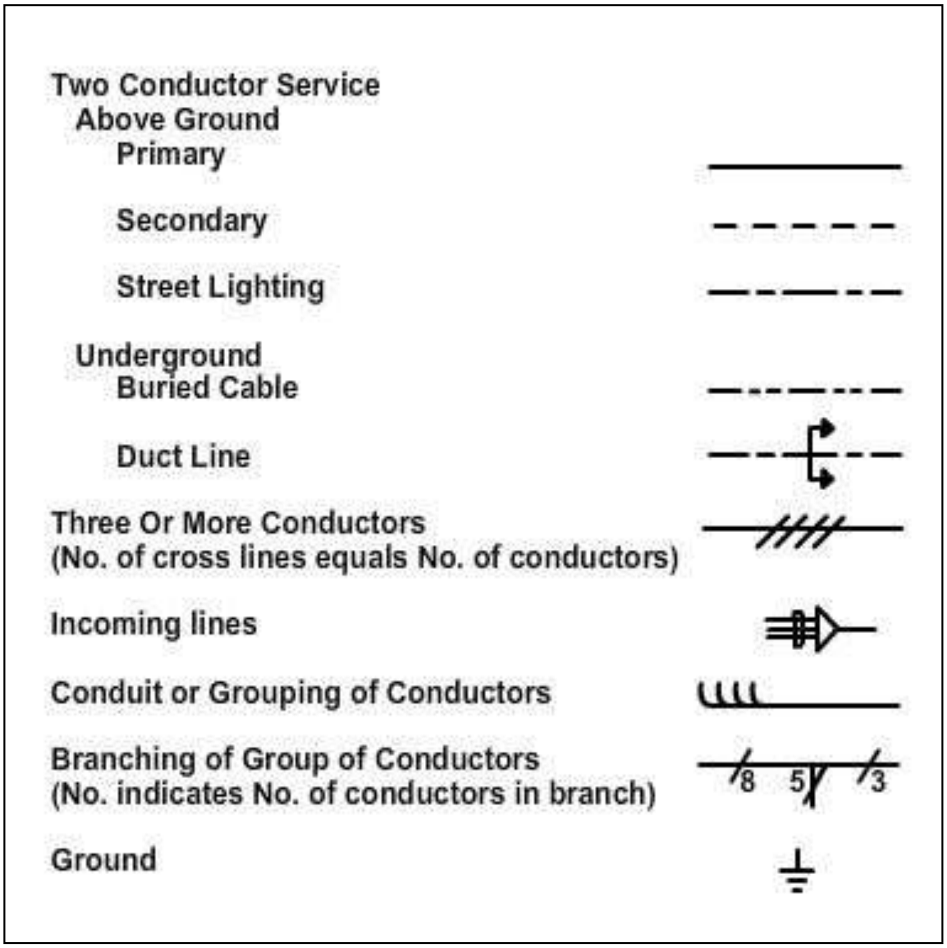

Plot Plan Symbols
North
N
Point of Beginning (POB)
Utility Meter or Valve
Power Pole and Guy
Light Standard
Traffic Signal
Street Sign
Fire Hydrant
Mailbox
Manhole
Tree
Bush
Hedge Row
Fence
Walk
Improved Road
Unimproved Road
Building Line
Property Line
Property Line
Township Line
E Or
Electric Service
G Or
Natural Gas Line
W Or
Water Line
T Or
Telephone Line
Natural Grade
Finish Grade
+ XX.00'
Existing Elevation

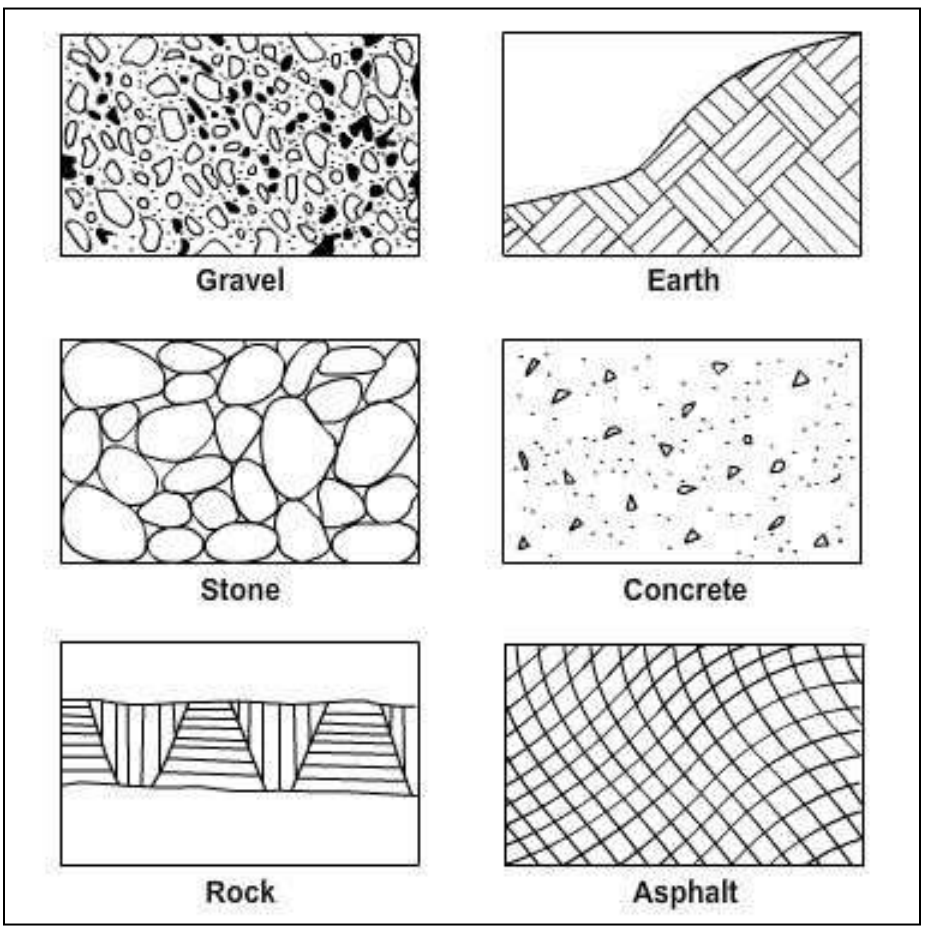

View A
Indicates direction of cutting plane
Letter indicates building section
A
A4 A5
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
A
A4 A5
Elevation
View B
Cut Stone
Firebrick
Ceramic Tile
Glass Block
Spray Foam
Shingles
Aluminum
Rubble

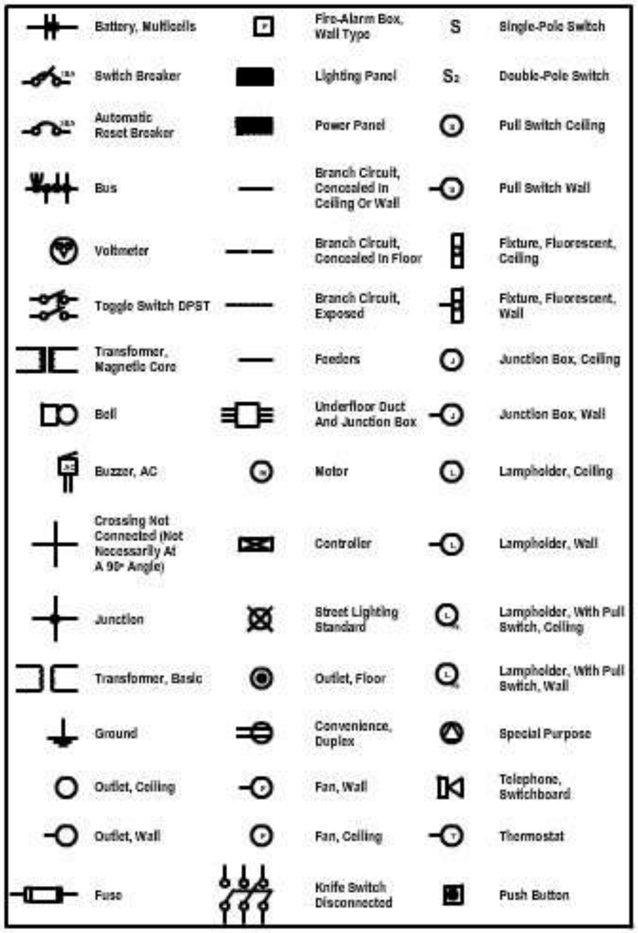

Contours
21
Depression Contour
Stream
Boundary or Right-of-Way Line
Paved Road
Unpaved or Gravel Road
Trail
Type
Walk
Railroad
Abandoned Railroad
Tunnel
Bridge
Box Culvert
Size
Pipe Culvert
Dams
Retaining Wall
Type
Type
Bulkhead
Type
Pier
Fence
Type
Hedge
Canal or Ditch
Canal
Marsh
Woods
Individual Trees
Shoreline
Depth Curve
8


1. TRIM LINE
2. BORDER LINE
3. MAIN OBJECT LINE
4. DIMENSION LINE
2'1
4' 3"
5. EXTENSION LINE
6. EQUIPMENT LINE
7. SYMBOL SECTION LINE
8. BROKEN LINE
9. INVISIBLE LINE
10. CENTER LINE
11. SECTION LINE
A
A
12. STAIR INDICATOR LINE
DOWN
2-R
13. BREAK LINE


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
Fire-Alarm Box, Wall Type
Single-Pole Switch
Switch Breaker
Lighting Panel
Double-Pole Switch
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
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