Chapter 5

Diesel Fuel Systems

Topics

1.0.0 Diesel Fuel Systems

2.0.0 Methods of Injection

3.0.0 Superchargers and Turbochargers

4.0.0 Cold Starting Devices

5.0.0 Diesel Fuel System Maintenance

6.0.0 General Troubleshooting

To hear audio, click on the box.

Overview

Maintenance personnel form part of an important network of dedicated people who ensure that medium and heavy-duty trucks and construction equipment are maintained in safe and acceptable performance conditions. The diesel fuel injection system is a major component of a properly operating engine. An engine out of adjustment can cause excessive exhaust smoke, poor fuel economy, heavy carbon buildup within the combustion chambers, and short engine life. In this chapter you will learn the major components of the diesel fuel system and how they operate so you may better maintain or have the knowledge to repair a diesel engine.

Objectives

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

1. Understand the different types of diesel fuel systems, how the components function to provide fuel to the engine, and how to service diesel fuel systems.
2. Identify the properties of diesel fuel.
3. Understand the function and operation of governors and fuel system components.
4. Understand the principles and operation of the different diesel fuel systems.
5. Understand the operation of and the differences between superchargers and turbochargers.
6. Identify the different types of cold weather starting aids.
7. Understand the basic maintenance required for a diesel fuel system.
8. Understand general troubleshooting techniques used in the maintenance of a diesel fuel system.

Prerequisites

None

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

Automotive Chassis and Body	↑	
Brakes		
Construction Equipment Power Trains		C
Drive Lines, Differentials, Drive Axles, and Power Train Accessories		M
Automotive Clutches, Transmissions, and Transaxles		
Hydraulic and Pneumatic Systems		
Automotive Electrical Circuits and Wiring		B A
Basic Automotive Electricity		S
Cooling and Lubrication Systems		I
Diesel Fuel Systems		C
Gasoline Fuel Systems		
Construction of an Internal Combustion Engine		
Principles of an Internal Combustion Engine		
Technical Administration		

Features of this Manual

This manual has several features which make it easy 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 italicized instructions 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.

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1.0.0 DIESEL FUEL SYSTEMS

Like the gasoline engine, the diesel engine is an internal combustion engine using either a two- or four-stroke cycle. Burning or combustion of fuel within the engine cylinders is the source of the power. The main difference in a diesel engine is that the diesel fuel is mixed with compressed air in the cylinder as shown in *Figure 5-1*.

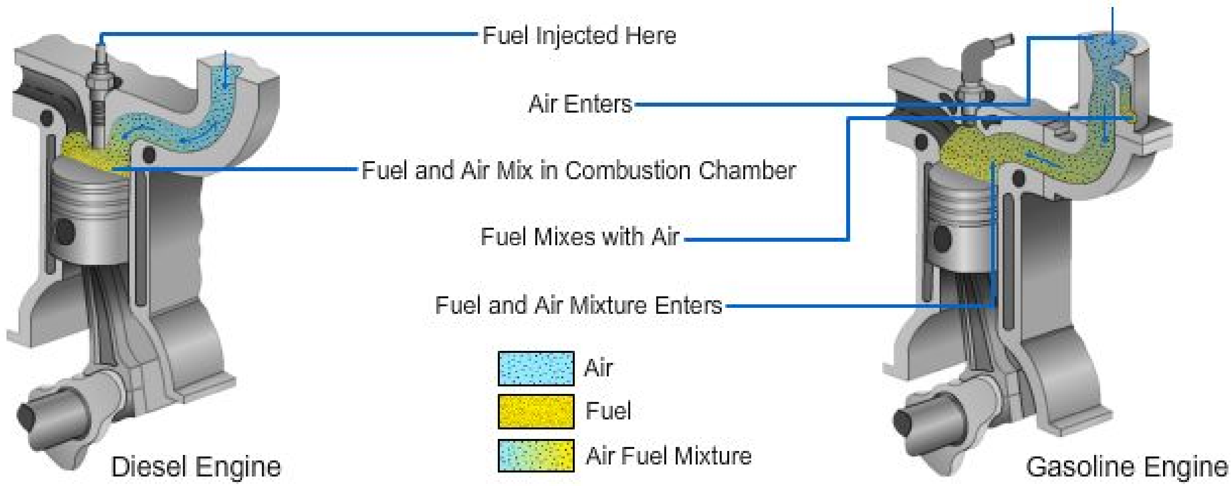

Figure 5-1 — Diesel and gasoline ingines intake strokes.

Compression ratios in the diesel engine range between 6:1 for a stationary engine and 24:1 for passenger vehicles. This high ratio causes increased compression pressures of 400 to 600 psi and cylinder temperatures reaching 800°F to 1200°F. At the proper time, the diesel fuel is injected into the cylinder by a fuel-injection system, which usually consists of a pump, fuel line, and injector or nozzle. When the fuel oil enters the cylinder, it will ignite because of the high temperatures. The diesel engine is known as a compression-ignition engine, while the gasoline engine is a spark-ignition engine.

The speed of a diesel engine is controlled by the amount of fuel injected into the cylinders. In a gasoline engine, the speed of the engine is controlled by the amount of air admitted into the carburetor or gasoline fuel injection systems.

Mechanically, the diesel engine is similar to the gasoline engine. The intake, compression, power, and exhaust strokes occur in the same order. The arrangement of the pistons, connecting rods, crankshaft, and engine valves is about the same. The diesel engine is also classified as in-line or v-type.

In comparison to the gasoline engine, the diesel engine produces more power per pound of fuel, is more reliable, has lower fuel consumption per horsepower per hour, and presents less of a fire hazard.

These advantages are partially offset by higher initial cost, heavier construction needed for its high compression pressures, and the difficulty in starting which results from these pressures.

1.1.0 Diesel Fuel

Diesel fuel is heavier than gasoline because it is obtained from the residue of the crude oil after the more volatile fuels have been removed. As with gasoline, the efficiency of diesel fuel varies with the type of engine in which it is used. By distillation, cracking, and blending of several oils, a suitable diesel fuel can be obtained for all engine operating conditions. Using a poor or improper grade of fuel can cause hard starting, incomplete combustion, a smoky exhaust, and engine knocks.

The high injection pressures needed in the diesel fuel system result from close tolerances in the pumps and injectors. These tolerances make it necessary for the diesel fuel to have sufficient lubrication qualities to prevent rapid wear or damage. It must also be clean, mix rapidly with the air, and burn smoothly to produce an even thrust on the piston during combustion.

1.1.1 Diesel Fuel Oil Grades

Diesel fuel is graded and designated by the American Society for Testing and Materials (ASTM), while its specific gravity and high and low heat values are listed by the American Petroleum Institute (API). Each individual oil refiner and supplier attempts to produce diesel fuels that comply as closely as possible with ASTM and API specifications. Because of different crude oil supplies, the diesel fuel may be on either the high or low end of the prescribed heat scale in ***BTU*** per pound or per gallon. Because of the deterioration of diesel fuel, only two grades of fuel are considered acceptable for use in high-speed heavy-duty vehicles. These are the No. 1D or No. 2D fuel oil classification. Grade No. 1D comprises the class of volatile fuel oils from kerosene to the intermediate distillates. Fuels within this classification are applicable for use in high-speed engines in service involving frequent and relatively wide variations in loads and speeds. In cold weather conditions, No. 1D fuel allows the engine to start easily. In summary, for heavy-duty high-speed diesel vehicles operating in continued cold-weather conditions, No. 1D fuel provides better operation than the heavier No. 2D.

Grade No. 2D includes the class of distillate oils of lower volatility. They are applicable for use in high-speed engines in service involving relatively high loads and speeds. This fuel is used more by truck fleets due to its greater heat value per gallon, particularly in warm to moderate climates. Even though No. 1D fuel has better properties for cold weather operations, many still use No. 2D in the winter, using fuel heater/water separators to provide suitable starting, as well as fuel additive conditioners, which are added directly into the fuel tank.

Selecting the correct diesel fuel is a must if the engine is to perform to its rated specifications.

Generally, seven factors must be considered in the selection of a fuel oil:

- Starting characteristics
- Fuel handling
- Wear on injection equipment
- Wear on pistons
- Wear on rings, valves, and cylinder liners
- Engine maintenance
- Fuel cost and availability

Other considerations in the selection of a fuel oil are as follows:

- Engine size and design
- Speed and load range
- Frequency of load and speed changes
- Atmospheric conditions

1.1.2 Cetane Number

Cetane number is a measure of the fuel oil's volatility; the higher the rating, the easier the engine will start and the smoother the combustion process will be within the ratings specified by the engine manufacturer. Current 1D and 2D diesel fuels have a cetane rating between 40 and 50.

Cetane rating differs from the octane rating used in gasoline in that the higher the number of gasoline on the octane scale, the greater the fuel resistance to self ignition, which is a desirable property in gasoline engines with a high compression ratio. Using a low octane fuel will cause premature ignition in high compression engines. However, the higher the cetane rating, the easier the fuel will ignite once injected into the diesel combustion chamber. If the cetane number is too low, you will have difficulty in starting. This can be accompanied by engine knock and puffs of white smoke during warm-up in cold weather.

High altitudes and low temperatures require the use of diesel fuel with an increased cetane number. Low temperature starting is enhanced by high cetane fuel oil in the proportion of 1.5°F lower starting temperature for each cetane number increase.

1.1.3 Volatility

Fuel volatility requirements depend on the same factors as cetane number. The more volatile fuels are best for engines where rapidly changing loads and speeds are encountered. Low volatile fuels tend to give better fuel economy where their characteristics are needed for complete combustion, and will produce less smoke, odor, deposits, crankcase dilution, and engine wear.

The volatility of a fuel is established by a distillation test where a given volume of fuel is placed into a container that is heated gradually. The readiness with which a liquid changes to a vapor is known as the volatility of the liquid. The 90 percent distillation temperature measures volatility of diesel fuel. This is the temperature at which 90 percent of a sample of the fuel has been distilled off. The lower the distillation temperature, the higher the volatility of the fuel. In small diesel engines higher fuel volatility is needed than in larger engines in order to obtain low fuel consumption, low exhaust temperature, and minimum exhaust smoke.

1.1.4 Viscosity

The viscosity is a measure of the resistance to flow of the fuel, and it will decrease as the fuel oil temperature increases. What this means is that a fluid with a high viscosity is heavier than a fluid with low viscosity. A high viscosity fuel may cause extreme pressures in the injection systems and will cause reduced atomization and vaporization of the fuel spray.

The viscosity of diesel fuel must be low enough for it to flow freely at its lowest operational temperature, yet high enough to provide lubrication to the moving parts of the finely machined injectors. The fuel must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. Viscosity also will determine the size of the fuel droplets, which in turn govern the atomization and penetration qualities of the fuel injector spray.

Recommended fuel oil viscosity for high-speed diesel engines is generally in the region of 39 SSU (Seconds Saybolt Universal), which is derived from using a Saybolt Viscosimeter to measure the time it takes for a quantity of fuel to flow through a restricted hole in a tube. A viscosity rating of 39 SSU provides good penetration into the combustion chamber, atomization of fuel, and suitable lubrication.

1.1.5 Sulfur Content

Sulfur has a definite effect on the wear of the internal components of the engine, such as the piston ring, pistons, valves, and cylinder liners. In addition, a high sulfur content fuel requires that the engine oil and filter be changed more often because the corrosive effects of hydrogen sulfide in the fuel and the sulfur dioxide or sulfur trioxide that is formed during the combustion process combine with water vapor to form acids. High additive lubricating oils are desired when high sulfur fuels are used. Refer to the engine manufacturer's specifications for the correct lube oil when using high sulfur fuel.

Sulfur content can be established only by chemical analysis of the fuel. Fuel sulfur content above 0.4% is considered as medium or high, and anything below 0.4% is low. No. 2D contains between 0.2 and 0.5% sulfur, whereas No. 1D contains less than 0.1%.

Sulfur content has a direct bearing on the life expectancy of the engine and its components. Active sulfur in diesel fuel will attack and corrode injection system components and contribute to combustion chamber and injection system deposits.

1.1.6 Cloud and Pour Point

Cloud point is the temperature at which wax crystals in the fuel (paraffin base) begin to settle out with the result that the fuel filter becomes clogged. This condition exists when cold temperatures are encountered and is the reason that a thermostatically controlled fuel heater is required on vehicles operating in cold weather environments. Failure to use a fuel heater will prevent fuel from flowing through the filter and the engine will not run. Cloud point generally occurs 9-14°F above the pour point.

Pour point of a fuel determines the lowest temperature at which the fuel can be pumped through the fuel system. The pour point is 5°F above the level at which oil becomes a solid or refuses to flow.

1.1.7 Cleanliness and Stability

Cleanliness is an important characteristic of diesel fuel. Fuel should not contain more than a trace of foreign substances; otherwise, fuel pump and injector difficulties will develop, leading to poor performance or seizure. Because it is heavier and more viscous, diesel fuel will hold dirt particles in suspension for a longer period than gasoline. Moisture in the fuel can also damage or cause seizure of injector parts when corrosion occurs.

Fuel stability is its capacity to resist chemical change caused by oxidation and heat. Good oxidation stability means that the fuel can be stored for extended periods of time without the formation of gum or sludge. Good thermal stability prevents the formation of carbon in hot parts such as fuel injectors or turbine nozzles. Carbon deposits disrupt the spray patterns and cause inefficient combustion.

1.2.0 Combustion Chamber Design

The fuel injected into the combustion chamber must be mixed thoroughly with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function at maximum efficiency and exhibit maximum drivability. A well designed engine uses a combustion chamber designed for the intended usage of the engine. The injectors used should complement the combustion chamber. The combustion chambers described in the following sections are the most common, and cover virtually all of the designs that are currently in use.

1.2.1 Direct Injection Combustion Chamber

Direct injection is the most common combustion chamber (*Figure 5-2, View A*) and is found in nearly all engines. The fuel is injected directly into an open combustion chamber formed by the piston and cylinder head. The main advantage of this type of injection is that it is simple and has high fuel efficiency.

In the direct combustion chamber, the fuel must atomize heat, vaporize, and mix with the combustion air in a very short period of time. The shape of the piston helps with this during the intake stroke. Direct injection systems operate at very high pressures of up to 30,000 psi.

1.2.2 Indirect Injection Combustion Chamber

Indirect injection chambers were previously used mostly in passenger cars and light truck applications because of lower exhaust emissions and quietness. In today's technology with electronic timing, direct injection systems are superior. Therefore, you will not see many indirect injections system on new engines; they are still on many older engines, however.

1.2.3 Pre-combustion Chamber

Precombustion chamber design involves a separate combustion chamber located in either the cylinder head or wall. As *Figure 5-2, View B* shows, this chamber takes up from 20% - 40% of the combustion chambers TDC volume and is connected to the chamber by one or more passages. As the compression stroke occurs, the air is forced up into the precombustion chamber. When fuel is injected into the precombustion chamber, it partially burns, building up pressure. This pressure forces the mixture back into the combustion chamber, and complete combustion occurs.

1.2.4 Swirl Combustion Chamber

Swirl chamber systems (*Figure 5-2, View C*) use the auxiliary combustion chamber that is ball-shaped and opens at an angle to the main combustion chamber. The swirl chamber contains 50% - 70% of the TDC cylinder volume and is connected at a right angle to the main combustion chamber. A strong vortex (mass of swirling air) is created during the compression stroke. The injector nozzle is positioned so the injected fuel penetrates the vortex and strikes the hot wall, and combustion begins. As combustion begins, the flow travels into the main combustion chamber for complete combustion.

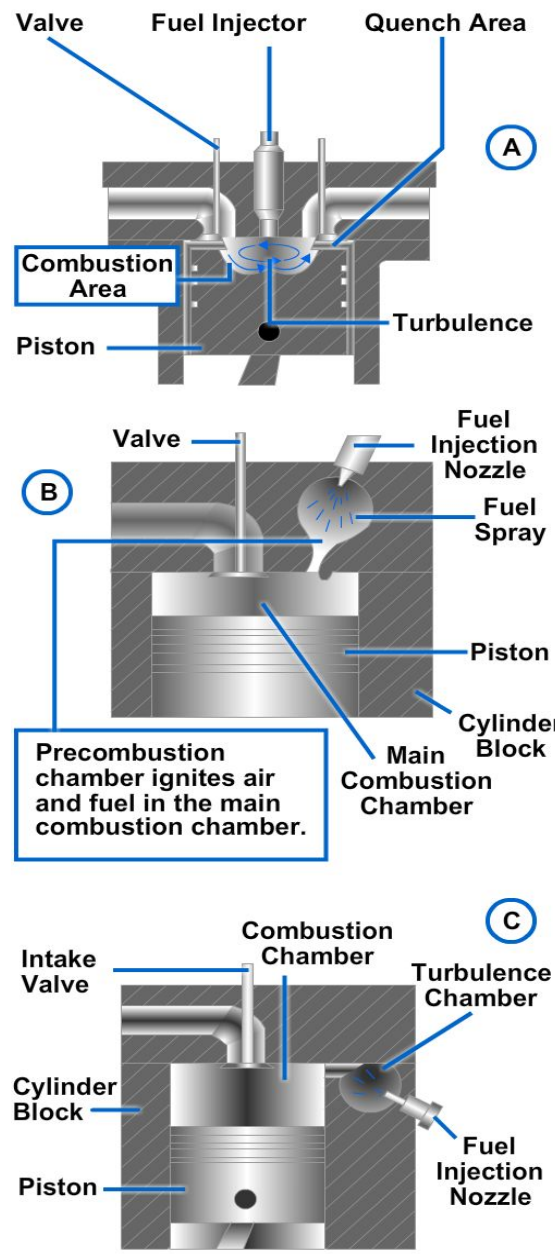

Figure 5-2 — Combustion chambers.

1.3.0 Engine Governors

1.3.1 Definition

A governor is a device that senses engine speed and load, and changes fuel delivery accordingly. All diesel engines use some sort of governor, whether it is mechanical, servo-mechanical, hydraulic, pneumatic or electronic. A governor is needed to regulate the amount of fuel delivered at idle to prevent it from stalling. It is also required so it can cut off the fuel supply when the engine reaches its maximum rated speed. Without a governor, a diesel engine could reach maximum RPM and destroy itself quickly. The governor is often included in the design of the fuel injection system. The main reason that a diesel requires a governor is that a diesel engine operates with excess air under all loads and speeds.

Even though it is not part of the fuel system, a governor is directly related to this system since it functions to regulate speed by the control of fuel or of the air-fuel mixture, depending on the type of engine. In diesel engines governors are connected in the linkage between the throttle and the fuel injectors. The governor acts through the fuel injection equipment to regulate the amount of fuel delivered to the cylinders. As a result, the governor holds engine speed reasonably constant during fluctuations in load.

To understand why different types of governors are needed for different kinds of job, you will need to know the meaning of several terms used in describing the action of the governor in regulating engine speed (*Table 5-1*).

Table 5-1 — Terms used to explain governor operation.

Term	Definition
Maximum no-load speed	The highest engine rpm obtainable when the throttle linkage is moved to its maximum position with no load applied to the engine.
Maximum full-load speed	Indicates the engine rpm at which a particular engine will produce its maximum designed horsepower setting as stated by the manufacturer.
Idle or low-idle speed	Indicates the normal speed at which the engine will rotate with the throttle linkage in the released or closed position.
Work capacity	Describes the amount of available work energy that can be produced to the output shaft of the governor.
Stability	Refers to the ability of the governor to maintain speed with either constant or varying loads without hunting.
Speed droop	Expresses the difference in the change in the governor rotating speed which causes the output shaft of the governor to move from its full-open throttle position to its full-closed position or vice versa.
Hunting	Is a repeated and sometimes rhythmic variation of speed due to over control by the governor. Also called speed drift.

Sensitivity	Is an expression of how quickly the governor responds to a change in speed.
Response time	Is normally the time taken in seconds for the fuel linkage to be moved from a no-load to a full-load position.
Isochronous	Indicates the zero-droop capability. In others words, the full-load and no-load speeds are the same
Overrun	Expresses the action of the governor when the engine exceeds its maximum governed speed.

1.3.2 Types of Governors

The type of governor used on a diesel engine is dependent upon the application required. The six basic types of governors are mechanical, pneumatic, servo, hydraulic, electric, and electronic. While electronically-controlled fuel governing systems are being used on nearly all late-model engines, there are millions of the other governor types still in service. The durability and rebuild capability of the diesel engines has ensured that mechanical and other types of governors have many more years of service to come.

The governors used on heavy-duty truck applications and construction equipment fall into one of two classifications:

- Limiting-speed governors, sometimes referred to as minimum/maximum models since they are intended to control the idle and maximum speed settings of the engine. Normally there is no governor control in the intermediate range, since it is regulated by the position of the throttle linkage.
- Variable-speed or all range governors that are designed to control the speed of the engine regardless of the throttle setting.

Other classifications of governors used on diesel engines are as follows:

- Constant-speed, intended to maintain the engine at a single speed from no load to full load.
- Load-limiting, to limit the load applied to the engine at any given speed. Prevents overloading the engine at whatever speed it may be running.
- Load-control, used for adjusting to the amount of load applied at the engine to suit the speed at which it is set to run.
- Pressure-regulating, used on an engine driving a pump to maintain a constant inlet or outlet pressure on the pump.

1.3.2.1 Mechanical Governors

In most governors installed on diesel engines used by the Navy, the centrifugal force of rotating weights (flyballs) and the tensions of a helical coil spring (or springs) are used in governor operation. On this basis, most of the governors used on diesel engines are generally called mechanical centrifugal flyweight governors.

In mechanical centrifugal flyweight governors (*Figure 5-3*), two forces oppose each other. One of these forces is tension spring (or springs) which may be varied either by an adjusting device or by movement of the manual throttle. The engine produces the other force. Weights attached to the governor drive shaft are rotated, and a centrifugal force is created when the engine drives the shaft. The centrifugal force varies with the speed of the engine.

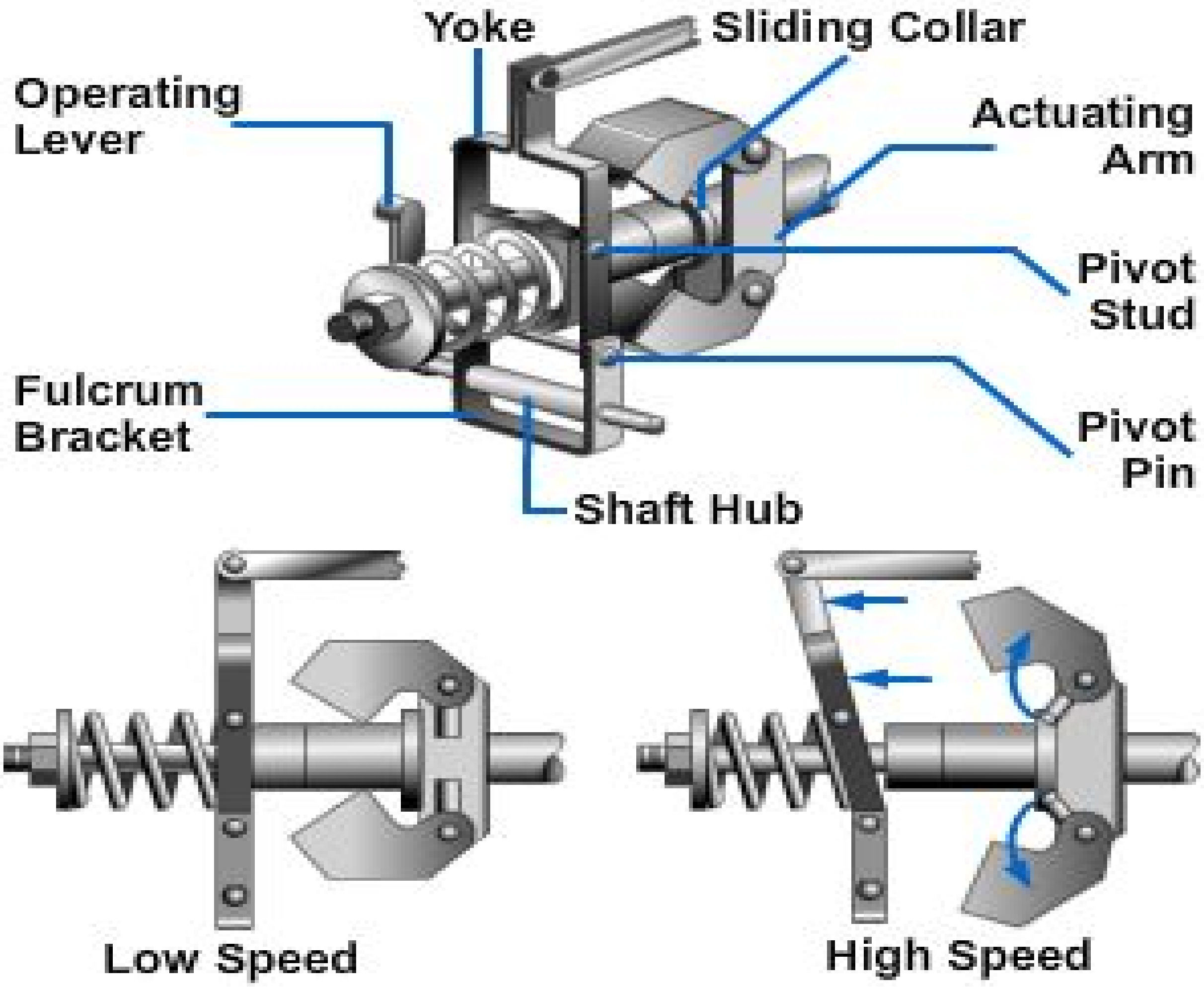

Figure 5-3 — Mechanical governor.

Transmitted to the fuel system through a connecting linkage, the tension of the spring (or springs) tends to increase the amount of fuel delivered to the cylinders. On the other hand, the centrifugal force of the rotating weights, through connecting linkage, tends to reduce the quantity of fuel injected. When the two opposing forces are equal, or balanced, the speed of the engine remains constant.

To show how the governor works when the load increases and decreases, let us assume you are driving a truck in hilly terrain. When the truck approaches a hill at a steady engine speed, the vehicle is moving from a set state of balance in the governor assembly (weights and springs are equal) with a fixed throttle setting to an unstable condition. As the vehicle starts to move up the hill at a fixed speed, the increased load demands result in a reduction in engine speed. This upsets the state of balance that had existed in the governor. The reduced rotational speed at the engine results in a reduction in speed, and, therefore, the centrifugal force of the governor weights. When the state of balance is upset, the high-speed governor spring is allowed to expand, giving up some of its stored energy, which moves the connecting fuel linkage to an increased delivery position. This additional fuel delivered to the combustion chambers results in an increase in horsepower, but not necessarily an increase in engine speed.

When the truck moves into a downhill situation, you are forced to back off the throttle to reduce the speed of the vehicle; otherwise, you have to apply the brakes or ***engine/transmission retarder***. You can also downshift the transmission to obtain additional braking power. However, when you do not reduce the throttle position or brake the vehicle mass in some way, an increase in road speed results. This is due to the reduction in engine load because of the additional reduction in vehicle resistance achieved through the mass weight of the vehicle and its load pushing the truck downhill. This action causes the governor weights to increase in speed, and they attempt to compress the high-speed spring, thereby reducing the fuel delivery to the engine. Engine over-speed can result if the road wheels of the vehicle are allowed to rotate fast enough that they, in effect, become the driving member.

The governor assembly would continue to reduce fuel supply to the engine due to increased speed of the engine. If over-speed does occur, the valves can end up floating (valve springs are unable to pull and keep the valves closed) and striking the piston crown. Therefore, it is necessary in a downhill run for you to ensure that the engine speed does not exceed maximum governed rpm by application of the vehicle, engine, or transmission forces.

Favorable as well as unfavorable characteristics are found in mechanical governors. The advantages are as follows:

- They are inexpensive.
- They are satisfactory when it is not necessary to maintain exactly the same speed, regardless of load.
- They are extremely simple with few parts.

The disadvantages are as follows:

- They have large deadbands, since the speed measuring device must also furnish the force to move the engine fuel control.
- Their power is relatively small unless they are excessively large.
- They have an unavoidable speed droop, and therefore cannot truly provide constant speed when this is needed.

1.3.2.2 Hydraulic Governors

Although hydraulic governors have more moving parts and are generally more expensive than mechanical governors, they are used in many applications because they are more sensitive, have greater power to move the fuel control mechanism of the engine, and can be timed for identical speed for all loads.

In hydraulic governors (*Figure 5-4*), the power which moves the engine throttle does NOT come from the speed-measuring device, but instead comes from a hydraulic

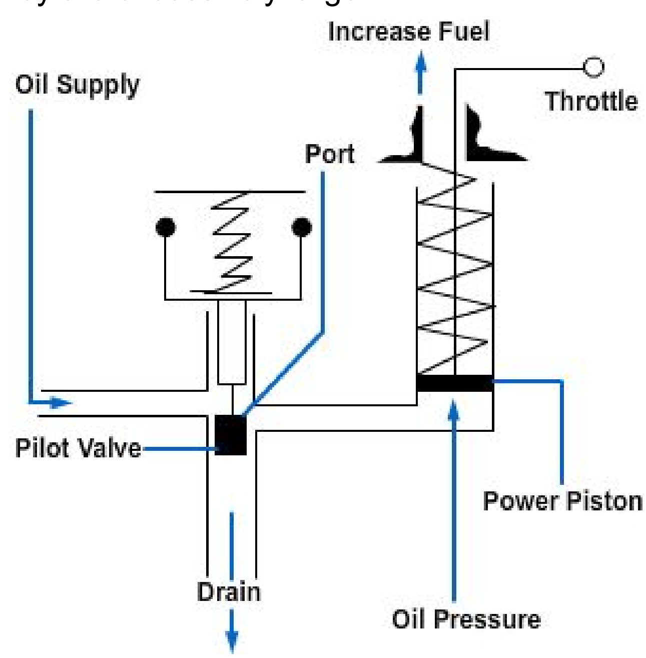

Figure 5-4 — Hydraulic governor.

power piston, or servomotor. This is a piston that is acted upon by fluid pressure, generally oil under the pressure of a pump. With appropriate piston size and oil pressure, the power of the governor at its output shaft (work capacity) can be made sufficient to operate the fuel-changing mechanism of the largest engines.

The speed-measuring device, through its speeder rod, is attached to a small cylindrical valve, called a pilot valve. The pilot valve slides up and down in a bushing which contains ports that control the oil flow to and from the servomotor. The force needed to slide the pilot valve is very little; a small ball head is able to control a large amount of power at the servomotor.

The basic principle of a hydraulic governor is very simple. When the governor is operating at control speed or state of balance, the pilot valve closes the port and there is no oil flow.

When the governor speed falls due to an increase in engine load, the flyweights move inward and the pilot valve moves down. This opens the port to the power piston and connects the oil supply of oil under pressure. This oil pressure acts on the power piston, forcing it upward to increase the fuel.

When the governor speed rises due to a decrease of engine load, the flyweights move out and the pilot valve moves up. This opens the port from the power piston to the drain into the sump. The spring above the power piston forces the power piston down, thus decreasing the speed.

Unfortunately, the simple hydraulic governor has a serious defect which prevents its practical use. It is inherently unstable, that is, it keeps moving continually, making unnecessary corrective actions. In other words it hunts. The cause of this hunting is the unavoidable time lag between the moment the governor acts and the moment the engine responds. The engine cannot come back to the speed called for by the governor.

Most hydraulic governors use a speed droop to obtain stability. Speed droop gives stability because the engine throttle can take only one position for any speed. Therefore, when a load change causes a speed change, the resulting governor action ceases at a particular point that gives the amount of fuel needed for a new load. In this way speed droop prevents unnecessary governor movement and overcorrection (hunting).

1.3.2.3 Electronic Governors

The recent introduction of an electronically controlled diesel fuel injection system on several heavy-duty high-speed truck engines has allowed the speed of the diesel engine to be controlled electronically rather than mechanically. The same type of balance condition in a mechanical governor occurs in an electronic governor. The major difference is that in the electronic governor, electric currents (amperes) and voltages (pressure) are used together instead of mechanical weight and spring forces. This is possible through the use of a magnetic pickup sensor (MPS), which is, in effect, a permanent magnet single-pole device. This magnetic pickup concept is being used on all existing electronic systems, and its operation can be considered common to all of them. MPSs are a vital communications link between the engine crankshaft speed and the onboard computer (ECM). The MPS is installed next to a drive shaft gear made of a material that reacts to a magnetic field. As each gear tooth passes the MPS, the gear interrupts the MPS’s magnetic field. This in turn produces an ***AC*** current signal, which corresponds to the rpm of the engine. This signal is sent to the ECM to establish the amount of fuel that should be injected into the combustion chambers of the engine. Electronic speed governing systems are set up to provide six basic governing modes:

- Idle speed control
- Maximum speed control
- Power takeoff speed control
- Vehicle speed cruise control
- Engine speed cruise control
- Road speed limiting

Each of the control modes above is described in more detail below.

- The idle speed control provides fixed speed control over the entire torque capability of the engine. Also, the idle speed set point is calculated as a function of the engine temperature to provide an optional cold idle speed, which is usually several hundred rpm higher than normal operating temperature.
- The engine maximum rpm setting can be programmed for different settings. This can improve fuel economy by eliminating engine over-speed in all gear ranges.
- The power takeoff speed control setting can operate at any speed between idle and maximum. The operator uses rotary control or a toggle switch in the cab to vary electronically the engine power to the ***PTO*** from idle to the preset rpm.
- Vehicle and engine cruise control includes set, resume, and coast features similar to that of a passenger car, as well as an accelerate mode to provide a fixed speed increase each time the control switch is activated.
- The road speed limiting function allows the organization assigned to determine what maximum vehicle road speed they desire independent of the maximum governed speed setting of the engine. Road speed governing provides the best method for ensuring ideal fuel economy.

The major advantage of the electronic governor over the mechanical governor lies in its ability to modify speed reference easily by various means to control such things as acceleration and deceleration, as well as load.

1.4.0 Diesel Fuel System Components

Before discussing the various types of fuel injection systems, let us spend some time looking at the basic components that are necessary to hold, supply, and filter the fuel before it passes to the actual injection system as shown in *Figure 5-5*. The basic

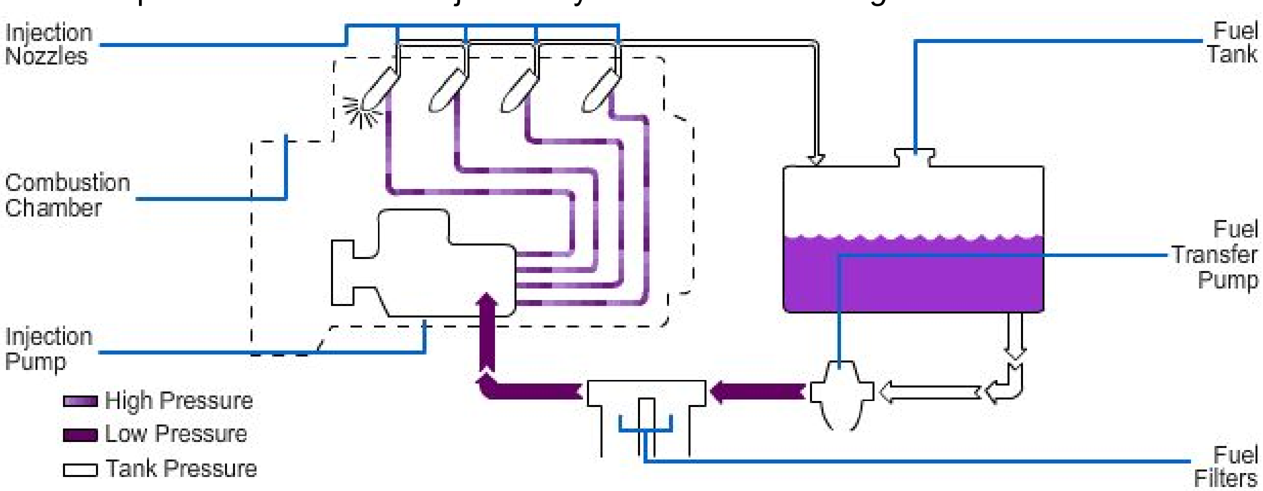

Figure 5-5— Diesel fuel injection system.

function of the fuel system is to provide a reservoir of diesel fuel, to provide sufficient circulation of clean filtered fuel for lubrication, cooling, and combustion purposes, and to allow warm fuel from the engine to re-circulate back to the tank(s). The specific layout and arrangement of the diesel fuel system will vary slightly between makes and models.

The basic fuel system consists of the fuel tank(s) and a fuel transfer pump (supply) that can be a separate engine-driven pump or can be mounted on or inside the injection pump. In addition, the system uses two fuel filters—a primary and secondary filter—to remove impurities from the fuel. In some systems you will have a fuel filter/water separator that contains an internal filter and water trap.

1.4.1 Tank and Cap

Fuel tanks used today can be constructed from aluminum or alloy steel. Baffles are welded into the tanks during construction. The baffle plates are designed with holes in them to prevent the fuel from sloshing while the vehicle is moving. The fuel inlet and return lines should be separated by a baffle in the tank and be at least twelve inches apart to prevent warm return fuel from being sucked right back up by the fuel inlet line. Both the inlet and return lines should be kept at least 1 inch above the bottom of the tank so sediment or water is not drawn into the inlet.

A well designed tank (*Figure 5-6*) will contain a drain plug in the base to allow for fuel tank drainage. This allows the fuel to be drained from the tank before removal for any service. Many tanks are equipped with a small low-mounted catchment basin so that any water in the tank can be quickly drained through a drain cock which is surrounded by a protective cage to prevent damage.

The diesel fuel tank is mounted directly on the chassis because of its weight (when filled) and to prevent movement of the tank when the equipment is operated over rough terrain. Its location depends on the type of equipment and the use of the equipment. On equipment used for ground clearing and earthwork, the tank is mounted where it has less chance of being damaged by foreign objects or striking the ground.

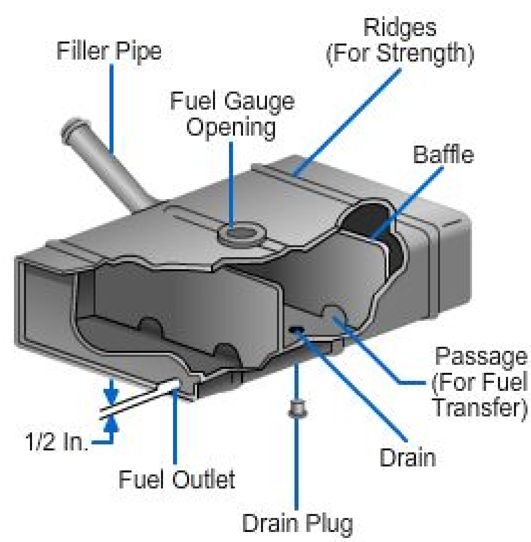

Figure 5-6 — Fuel tank construction.

The fuel tank filler cap is constructed with both a pressure relief valve and a vent valve. The vent valve is designed to seal when fuel enters it due to overfilling, vehicle operating angle, or a sudden jolt that would cause fuel slosh within the tank. Although some fuel will tend to seep from the vent cap, this leakage should not exceed 1 ounce per minute.

1.4.2 Supply Pump

Fuel injection pumps must be supplied with fuel under pressure because they have insufficient suction ability. All diesel injection systems require a supply pump to transfer fuel from the supply tank through the filters and lines to the injection pump. Supply pumps can be either external or internal to the injection pump. There are several types of supply pumps used on diesel engines.

The remaining task to be accomplished by the fuel system is to provide the proper quantity of fuel to the cylinders of the engine. This is done differently by each manufacturer and is referred to as fuel injection.

1.4.3 Fuel Filters

Diesel fuel filters (*Figure 5-7*) must be capable of trapping extremely small contaminants. The porosity of the filter material will determine the size of the impurities it can remove. Typical fuel injector nozzles are measured in microns. Therefore, it is necessary to filter very small impurities out of the fuel before it gets to the injector and plugs it. Diesel fuel filter elements fall into two categories of construction, depth filters and surface filters.

Figure 5-7 — Fuel filters.

Depth filters are made of woven cotton. The most popular material used for these filters is cotton thread that is blended with a springy supporting material. Depth element filters can be used either in a shell base bolt-on assembly or as a spin-on application. These filters are typically used as a primary filter and are located between the fuel tank and the transfer pump.

Surface filters are made of pleated paper that is made from cellulose fiber. The fiber is treated with a phenolic resin that acts as a binder. The physical properties of the paper--thickness, porosity, tinsel strength, basic weight, and micron rating--can be very closely controlled during the manufacturing process.

1.4.4 Water Separators

The purpose of a fuel filter is mainly to remove foreign particles as well as water. However, too much water in a fuel filter will render it incapable of protecting the system. So to ensure this does not happen, most diesel engine fuel systems are now equipped with fuel filter/water separators (*Figure 5-8*) for the main purpose of trapping and holding water that may be mixed in with the fuel. Generally, when a fuel filter/water separator is used on a diesel engine, it also serves as the primary filter. There are a number of manufacturers who produce fuel filter/water separators with their concept of operation being common and only design variations being the major difference. Their basic operation is as follows:

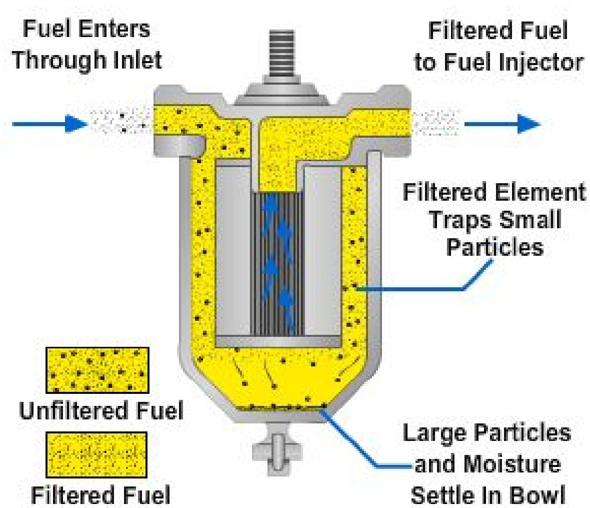

Figure 5-8 — Water seperators.

- The first stage of the fuel filter/water separator uses a pleated paper element to change water particles into large enough droplets that will fall by gravity to a water sump at the bottom of the filter.
- The second stage is made of silicone-treated nylon that acts as a safety device to prevent small particles of water that avoid the first stage from passing into the engine.

1.4.5 Injection Pump

A fuel injection pump is the pump that takes the fuel from the fuel manifold and pushes it under high pressure through the fuel lines to the fuel injectors. The fuel injection pump, or metering pump, boosts low and medium fuel pressures to the high pressures needed for injection.

1.4.6 Return Line

The fuel return line returns fuel to the tank and deposits it into the open space above the fuel. This allows the air bubbles to be vented. It should also be inserted to the tank at least 12 inches away from the fuel pickup point so that the returned fuel will not be picked up before the air is vented.

1.4.7 Gauges

There are three basic types of electric fuel gauges: the balancing coil, the thermostatic, and the electronic (digital) gauge system. Most gauge systems include a sending unit in the fuel tank and a fuel gauge on the instrument panel.

The balancing coil fuel gauge system has a sliding contact in the tank that moves back and forth as the position of the float changes. The resistance in the unit changes as the contact moves. When the tank is full, current flows through both coils, but the stronger field is around the full coil and the needle is pointed to the full mark. As the tank is emptied, the float moves down, the resistance decreases, and the flow of electricity moves easier through the tank unit and ground. Therefore, the magnetic pull of the full coil weakens, and the magnetic field around the empty coil increases. This pulls the needle to the empty mark.

The thermostatic fuel gauge system contains a pair of thermostat blades. Each blade has a heating coil connected in series through the ignition switch to the battery. As the tank blade heats up, the dash blade heats up as well, the movement corresponding with the tank blade. The dash blade movement goes through a linkage to the indicator, which moves to the appropriate position on the gauge dial.

The digital fuel gauge system consists of a fuel sensor which reads the amount of fuel in the tank and sends a signal to the gauge through a computer by an electrical pulse indicating how much fuel is in the tank.

Test your Knowledge (Select the Correct Response)

1. What grade of diesel fuel is used in warm and moderate climates?

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

2. Cloud point is the temperature at which ______ in the fuel begins to settle out, with the result that the fuel filter becomes clogged.

   A. cetane
   B. octane
   C. wax
   D. water

3. The fuel tank filler cap is constructed with both a pressure relief valve and a vent valve. The rate of leakage should not exceed how many ounces per minute?

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

2.0.0 METHODS of INJECTION

You have probably heard the statement, "The fuel injection system is the actual heart of the diesel engine." When you consider that indeed a diesel could not be developed until an adequate fuel injection system was designed and produced, this statement takes on a much broader and stronger meaning.

In this section you will learn about various methods of mechanical injections and metering control. There have been many important developments in pumps, nozzles, and unit injectors for diesel engines over the years, with the latest injection system today relying on electronic controls and sensors.

2.1.0 Fuel Injection Systems

Diesel fuel injection systems must accomplish five particular functions: meter, inject, time, atomize, and create pressure.

- Metering**--**Accurate metering or measuring of the fuel means that, for the same fuel control setting, the same quantity of fuel must be delivered to each cylinder for each power stroke of the engine. Only in this way can the engine operate at uniform speed with uniform power output. Smooth engine operation and an even distribution of the load between the cylinders depend upon the same volume of fuel being admitted to a particular cylinder each time it fires and upon equal volumes of fuel being delivered to all cylinders of the engine.
- Injection control--A fuel system must also control the rate of injection. The rate at which fuel is injected determines the rate of combustion. The rate of injection at the start should be low enough that excessive fuel does not accumulate in the cylinder during the initial ignition delay (before combustion begins). Injection should proceed at such a rate that the rise in combustion pressure is not too great, yet the rate of injection must be such that fuel is introduced as rapidly as possible to obtain complete combustion. An incorrect rate of injection affects engine operation in the same way as improper timing. When the rate of injection is too high, the results are similar to those caused by an injection that is too early; when the rate is too low, the results are similar to those caused by an injection that is too late.
- Timing--In addition to measuring the amount of fuel injected, the system must properly time injection to ensure efficient combustion so that maximum energy

can be obtained from the fuel. When the fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air at this point is not high enough. An excessive delay, on the other hand, gives rough and noisy operation of the engine. It also permits some fuel to be lost due to the wetting of the cylinder walls and piston head. This in turn results in poor fuel economy, high exhaust gas temperature, and smoke in the exhaust. When fuel is injected too late in the cycle, all the fuel will not be burned until the piston has traveled well past top center. When this happens, the engine does not develop enough power, the exhaust is smoky, and fuel consumption is high.

- Atomization of fuel--As used in connection with fuel injection, atomization means the breaking up of the fuel as it enters the cylinder into small particles which form a mist-like spray. Atomization of the fuel must meet the requirements of the type of combustion chamber in use. Some chambers require very fine atomization, while others function with dispersed atomization. Proper atomization makes it easier to start the burning process and ensures that each minute particle of fuel is surrounded by particles of oxygen that it can combine with.

  Atomization is generally obtained when liquid fuel, under high pressure, passes through the small opening (or openings) in the injector or nozzle. As the fuel enters the combustion space, high velocity is developed because the pressure in the cylinder is lower than the fuel pressure. The created friction, resulting from the fuel passing through the air at high velocity, causes the fuel to break up into small particles.

- Creating pressure--A fuel injection system must increase the pressure of the fuel to overcome compression pressure and to ensure proper dispersion of the fuel injected into the combustion space. Proper dispersion is essential if the fuel is to mix thoroughly with the air and burn efficiently. While pressure is a chief contributing factor, the dispersion of the fuel is influenced, in part, by atomization and penetration of the fuel. (Penetration is the distance through which the fuel particles are carried by the motion given them as they leave the injector or nozzle.)

  If the atomization process reduces the size of the fuel particles too much, they will lack penetration. Too little penetration results in the small particles of fuel igniting before they have been properly distributed or dispersed in the combustion space. Since penetration and atomization tend to oppose each other, a compromise in the degree of each is necessary in the design of the fuel injection equipment, particularly if uniform distribution of fuel within the combustion chamber is to be obtained.

Diesel engines are equipped with one of several distinct types of fuel injection systems: individual pump system; multiple-plunger, inline pump system; unit injector system; pressure-time injection system; distributor pump system; and common rail injection system.

2.1.1 Individual Pump System

The individual pump system is a small pump contained in its own housing, and supplies fuel to one cylinder. The individual plunger and pump barrel are driven off of the engine’s cam shaft. This system is found on large-bore, slow-speed industrial or marine diesel engines and on small air-cooled diesels; they are not used on high-speed diesels.

2.1.2 Multi-plunger, Inline Pump System

Multiple-plunger, inline pump systems (*Figure 5-9*) use individual pumps that are contained in a single injection pump housing. The number of plungers is equal to the number of cylinders on the engine, and they are operated on a pump camshaft. This system is used on many mobile applications and is very popular with several engine manufacturers.

The fuel is drawn in from the fuel tank by a pump, sent through filters, and delivered to the injection pump at a pressure of 10 to 35 psi. All pumps in the housing are subject to this fuel. The fuel at each pump is timed, metered, pressurized, and delivered through a high-pressure fuel line to each injector nozzle in firing order sequence.

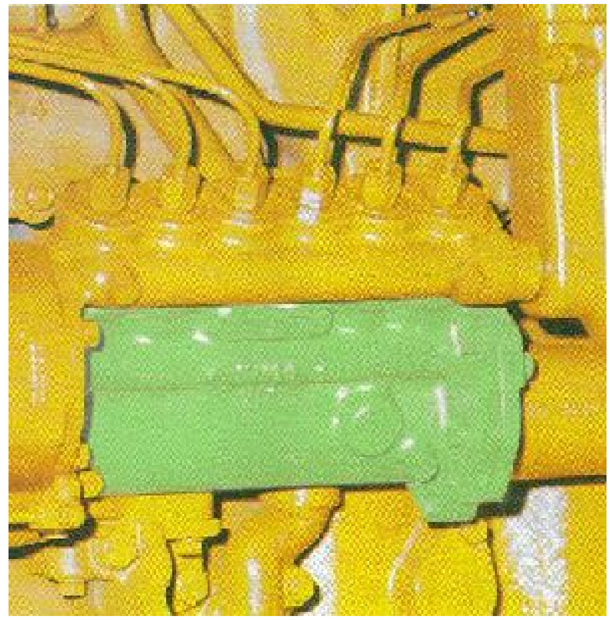

Figure 5-9 — Multiple plunger, inline pump system.

2.1.3 Unit Injector System

The unit injector systems utilize a system that allows timing, atomization, metering, and fuel pressure generation that takes place inside the injector body and services a particular cylinder. This system is compact and delivers a fuel pressure that is higher than any other system today.

Fuel is drawn from the tank by a transfer pump, filtered. and then delivered. The pressure is 50 – 70 psi before it enters the fuel inlet manifold located within the engine's cylinder head. All of the injectors are fed through a fuel inlet or jumper line. The fuel is pressurized, metered, and timed for proper injection to the combustion chamber by the injector. This system uses a camshaft-operated rocker arm assembly or a pushrod-actuated assembly to operate the injector plunger.

2.1.4 Pressure-time Injection System

The pressure-time injection system (PT system) got its name from two of the primary factors that affect the amount of fuel injected per combustion cycle. Pressure, or "P," refers to the pressure of the fuel at the inlet of the injector. Time, or "T," is the time available for the fuel to flow into the injector cup. The time is controlled by how fast the engine is rotating.

The PT system uses a camshaft-actuated plunger. This changes the rotary motion of the camshaft to a reciprocating motion of the injector. The movement opens and closes the injector metering orifice in the injector barrel. Fuel will flow only when the orifice is open; the metering time is inversely proportional to engine speed. The faster the engine is operating, the less time there is for fuel to enter. The orifice opening size is set according to careful calibration of the entire set of injection nozzles.

2.1.5 Distributor Injection Pump System

The distributor pump systems are used on small to medium-size diesel engines. These systems lack the capability to deliver high volume fuel flow to heavy-duty, large displacement, high-speed diesel engines like those used in trucks. These systems are sometimes called rotary pump systems. Their operating systems are similar to how an ignition distributor operates on a gasoline engine. The rotor is located inside the pump and distributes fuel at a high pressure to individual injectors at the proper firing order.

2.1.6 Common Rail Injection Pump System

The common rail injection is the newest high-pressure direct injection fuel delivery system. An advanced design fuel pump supplies fuel to a common rail that acts as a pressure accumulator. The common rail delivers fuel to the individual injectors via short high-pressure fuel lines. The system's electronic control unit precisely controls both the rail pressure and the timing and duration of the fuel injection. Injector nozzles are operated by rapid-fire solenoid valves or piezo-electric triggered actuators.

2.1.7 Electronically Controlled Fuel Injection System

With the exception of common rail injection systems, all of the systems described previously were designed to operate without the use of electronic controls. To meet modern performance, fuel efficiency, and emission standards, unit injectors, multiple-plunger, inline pumps, and distributor pump injection systems have all been adapted for use with various levels of electronic controls. Of these systems, electronically controlled and actuated unit injectors have become the prominent choice in heavy-duty engine design.

2.2.0 Caterpillar Fuel Systems

The Caterpillar diesel engine uses the pump and nozzle injection system. Each pump measures the amount of fuel to be injected into a particular cylinder, produces the pressure for injection of the fuel, and times the exact point of injection. The injection pump plunger is lifted by cam action and returned by spring action. The turning of the plungers in the barrels varies the metering of fuel. These plungers are turned by governor action through a rack that meshes with the gear segments on the bottom of the pump plungers. Each pump is interchangeable with other injection pumps mounted on the pump housing.

The sleeve metering and scroll-type pumps that are used by Caterpillar operate on the same fundamentals, a jerk pump system (where one small pump contained in its own housing supplied fuel to one cylinder). Individual "jerk" pumps that are contained in a single injection pump housing with the same number of pumping plungers as that of the engine cylinders are commonly referred to as inline multiple-plunger pumps.

2.2.1 Sleeve Metering Fuel System

The sleeve metering fuel system was designed to have the following seven advantages:

- It has fewer moving parts and fewer total parts.
- Its design is simple and compact.
- It can use a simple mechanical governor. No hydraulic assist is required.
- The injection pump housing is filled with fuel oil rather than crankcase oil for lubrication of all internal parts.
- The plunger, barrel, and sleeve design used in all Caterpillar sleeve metering units follows a common style.
- The transfer pump, governor, and injection pump are mounted in one unit.
- It uses a centrifugal timing advance for better fuel economy and easier starts.

The term "sleeve metering" comes from the method used to meter the amount of fuel sent to the cylinders. Rather than rotate the plungers to control the amount of fuel to be injected, like most pump and nozzle injection systems, the use of a sleeve system (*Figure 5-10*) is incorporated with the plunger. The sleeve blocks a spill port that is drilled into the plunger. The amount of plunger travel with its port blocked determines the amount of fuel to be injected. Basic operation is as follows:

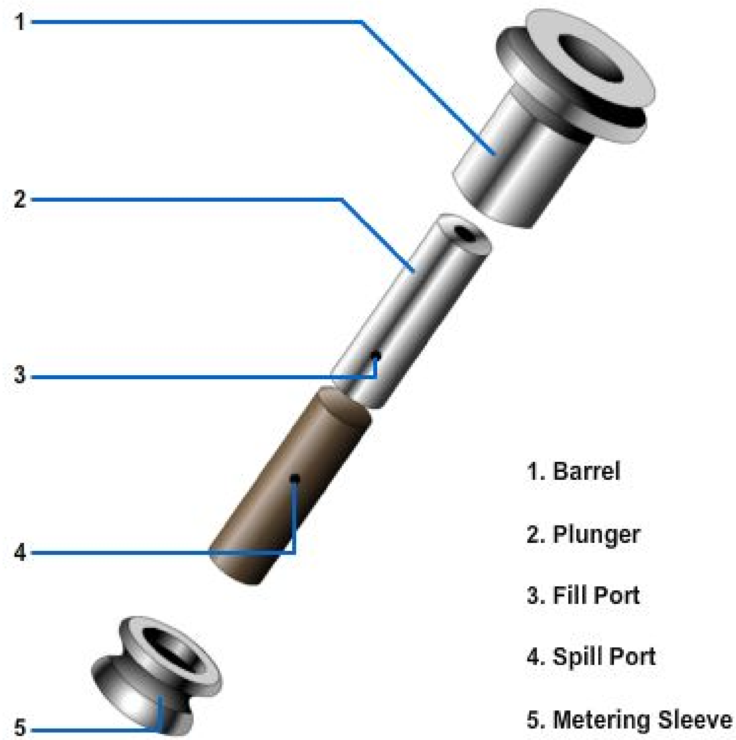

Figure 5-10 — Sleeve metering barrel and plunger assembly.

- Fuel is drawn from the fuel tank by the transfer pump through the fuel/water separator and the primary and secondary filters.
- Fuel from the transfer pump fills the injection pump housing at approximately 30 to 35 psi with the engine operating under full load. Any pressure in excess of this will be directed back to the inlet side of the transfer pump by the bypass valve. A constant-bleed valve is also used to allow a continuous return of fuel back to the tank at a rate of approximately 9 gallons per hour, so the temperature of the fuel stays cool for lubrication purposes, and to assist in maintaining housing pressure.
- Since the injection pump is constantly filled with diesel from the transfer pump under pressure, any time the fill port is uncovered, the internal drilling of the plunger will be primed by the incoming fuel caused by the downward moving plunger relative to pump camshaft rotation (*Figure 5-11*).
- At the correct moment, the rotation of the pump cam lobe begins to force the plunger upward until the fill port is closed as it passes into the barrel. At the same time, the sleeve closes the spill port. The pump, line, and fuel valves are subjected to a buildup in fuel pressure and injection will begin.
- Injection of the fuel will continue as long as both the fill port and spill port are completely covered by the barrel and sleeve.
- Injection ends the moment that the spill port starts to edge above the sleeve, releasing the pressure in the

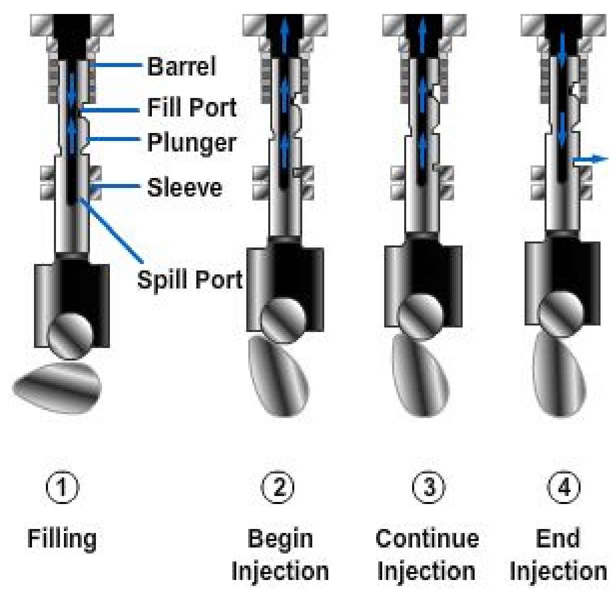

Figure 5-11 — Injection pump operating cycle.

plunger and letting fuel escape from the pump back into the housing. Also, at the end of the stroke, the check valve closes to prevent the fuel from flowing back from the injector fuel line.

To increase the amount of fuel injected, raise the sleeve through the control shaft and fork so that the sleeve is effectively positioned higher up on the plunger. This means that the spill port will be closed for a longer period of time as the cam lobe is raising the plunger. Increasing the effective stroke of the plunger (the time that both ports are closed) will increase the amount of fuel delivered.

2.2.2 Electronic Unit Injection

Electronic unit injection has proven to be the most adaptable fuel injection system available. Fuel enters the injector through two filters screens. Fuel not used for injection cools and lubricates the injector before exiting through the return port on its way back to the fuel tank.

The electronic unit injection system uses mechanical action to create the pressures needed for injection. The fuel enters the injector through an inlet to the electronically controlled poppet valve. The valve is held open by spring pressure; the fuel simply flows into the opening. When the piston is approximately 60 degrees BTDC on its compression stroke, the camshaft pivots the rocker arm through its roller follower. When the solenoid is energized, the armature is pulled upward, closing the poppet valve. This forces the injector follower down against its external return spring. This action raises the trapped fuel to a pressure sufficient to lift the injector needle valve off its seat. The strength of the needle valve spring determines when the valve will open. Opening pressures of 2,800-3,200 psi are common. When the needle valve unseats, fuel flows through the opening in the injector; this increases the fuel pressure to approximately 20,000 psi.

2.3.0 Distributor-Type Fuel Systems

The distributor-type fuel system is found on small- to medium-sized diesel engines. Its operation is similar to an ignition distributor found on a gasoline engine. A rotating member within the pump, called a rotor, distributes fuel at high pressure to the individual injectors in engine firing order sequence.

There are several manufacturers of distributor-type fuel injection systems. The distributor-type fuel system that will be discussed is the DB2 Roosa Master diesel fuel-injection pump, manufactured by Stanadyne's Hartford Division.

2.3.1 Injection Pump

The Roosa Master fuel-injection pump is described as an opposed plunger, inlet metering, distributor-type pump. Simplicity, the prime advantage of this design, contributes to greater ease of service, low maintenance cost, and greater dependability. Before describing the injection pump components and operation, let us familiarize ourselves with the model numbering system.

The main components of the DB2 fuel-injection pump are the drive shaft, distributor rotor, transfer pump, pumping plungers, internal cam ring, hydraulic head, end plate, governor, and housing assembly with an integral advance mechanism. The rotating members that revolve on a common axis include the drive shaft, distributor rotor, and transfer pump.

The drive shaft is the driving member that rotates inside a pilot tube pressed into the housing. The rear of the shaft engages the front of the distributor rotor and turns the rotor shaft. Two lip-type seals prevent the entrance of engine oil into the pump and retain fuel used for pump lubrication.

The distributor rotor is the drive end of the rotor, containing two pumping plungers located in the pumping cylinder. Slots in the rear of the rotor provide a place for two spring-loaded transfer pump blades. In the rotor, the shoe, which provides a large bearing surface for the roller, is carried in guide slots. The rotor shaft rotates with a very close fit in the hydraulic head. A passage through the center of the rotor shaft connects the pumping cylinder with one charging port and one discharging port. The hydraulic head in which the rotor turns has a number of charging and discharging ports, based on the number of engine cylinders. An eight-cylinder engine will have eight charging and eight discharging ports. The governor weight retainer is supported on the forward end of the rotor.

The transfer pump is a positive displacement, vane-style unit, consisting of a stationary liner with spring-loaded blades that ride in slots at the end of the rotor shaft. The delivery capacity of the transfer pump is capable of exceeding both pressure and volume requirements of the engine, with both varying in proportion to engine speed. A pressure regulator valve in the pump end plate controls fuel pressure. A large percentage of the fuel from the pump is bypassed through the regulating valve to the inlet side of the pump. The quantity and pressure of the fuel bypassed increase as pump speed increases.

The operation of the model DB2 injection is similar to that of an ignition distributor. However, instead of the ignition rotor distributing high-voltage sparks to each cylinder in firing order, the DB2 pump distributes pressurized diesel fuel as two passages align during the rotation of the pump rotor, also in firing order. The basic fuel flow is as follows:

- Fuel is drawn from the fuel tank by a fuel lift pump (mechanical or electrical) through the primary and secondary filters before entering the transfer pump.
- As fuel enters the transfer pump, it passes through a cone-type filter and on into the hydraulic head assembly of the injection pump.
- Fuel under pressure is also directed against a pressure regulator assembly, where it is bypassed back to the suction side should the pressure exceed that of the regulator spring.
- Fuel under transfer pump pressure is also directed to and through a ball-check valve assembly and against an automatic advance piston.
- Pressurized fuel is also routed from the hydraulic head to a vent passage leading to the governor linkage area, allowing any air and a small quantity of fuel to return to the fuel tank through a return line which self-bleeds air from the system. Fuel that passes into the governor linkage compartment is sufficient to fill it and lubricate the internal parts.
- Fuel leaving the hydraulic head is directed to the metering valve, which is controlled by the operator throttle position and governor action. This valve controls the amount of fuel that will be allowed to flow on into the charging ring and ports.

- Rotation of the rotor by the drive shaft of the pump aligns the two inlet passages of the rotor with the charging ports in the charging ring, thereby allowing fuel to flow into the pumping chamber.
- The pumping chambers consist of a circular cam ring, two rollers, and two plungers. As the rotor continues to turn, the inlet passages of the rotor will move away from the charging ports, allowing fuel to be discharged, as the rotor registers with one of the hydraulic head outlets.
- With the discharge port open, both rollers come in contact with the cam ring lobes, which forces them toward each other. This causes the plungers to pressurize the fuel between them and send it on up to the injection nozzle and into the combustion chamber. The cam is relieved, allowing a slight outward movement of the roller before the discharge port is closed off. This action drops the pressure in the injection line enough to give sharp cutoff injection and to prevent nozzle dribbling.

The maximum amount of fuel that can be injected is limited by maximum outward travel of the plungers. The roller shoes, contacting an adjustable leaf spring, limit this maximum plunger travel. At the time the charging ports are in register, the rollers are between the cam lobes; therefore, their outward movement is unrestricted during the charging cycle except as limited by the leaf spring.

To prevent after-dribble and therefore un-burnt fuel at the exhaust, the end of injection must occur crisply and rapidly. To ensure that the nozzle valve does, in fact, return to its seat as rapidly as possible, the delivery valve, located in the drive passage of the rotor, acts to reduce injection line pressure. This occurs after fuel injection, and the pressure is reduced to a value lower than that of the injector nozzle closing pressure. The valve remains closed during charging and opens under high pressure, as the plungers are forced together. Two small grooves are located on either side of the charging port or the rotor near its flange end. These grooves carry fuel from the hydraulic head charging posts to the housing. This fuel flow lubricates the cam, the rollers, and the governor parts. The fuel flows through the entire pump housing, absorbs heat, and is allowed to return to the supply tank through a fuel return line connected to the pump housing cover, thereby providing for pump cooling.

In the DB2 fuel pump, automatic advance is accomplished in the pump by fuel pressure acting against a piston, which causes rotation of the cam ring, thereby aligning the fuel passages in the pump sooner. The rising fuel pressure from the transfer pump increases the flow to the power side of the advance piston. This flow from the transfer pump passes through a cut on the metering valve, through a passage in the hydraulic head, and then by the check valve in the drilled bottom head locking screw. The check valve provides a hydraulic lock, preventing the cam from retarding during injection. Fuel is directed by a passage in the advance housing and plug to the pressure side of the advance piston. The piston moves the cam counterclockwise (opposite to the direction of the pump rotation). The spring-loaded side of the piston balances the force of the power side of the piston and limits the maximum movement of the cam. Therefore, with increasing speed, the cam is advanced and, with decreasing speed, it is retarded.

We know that a small amount of fuel under pressure is vented into the governor linkage compartment. Flow into this area is controlled by a small vent wire that controls the volume of fuel returning to the fuel tank, thereby avoiding any undue fuel pressure loss. The vent passage is located behind the metering valve bore and leads to the governor compartment by a short vertical passage. The vent wire assembly is available in several sizes to control the amount of vented fuel being returned to the tank. The vent wire should **NOT** be tampered with, as it can be altered only by removing the governor cover. The correct wire size would be installed when the pump assembly is being flow-tested on a pump calibration stand.

2.3.2 Injection Pump Accessories

The DB2 injection pump can be used on a variety of applications; therefore, it is available with several options as required. The options are as follows:

- The flexible governor drive is a retaining ring that serves as a cushion between the governor weight retainer and the weight retainer hub. Any torsional vibrations that may be transmitted to the pump area are absorbed in the flexible ring, therefore reducing wear of pump parts and allowing more positive governor control.
- The electrical shutoff is available as either an energized to run (ETR) or energized to shut off (ETSO) model. In either case it will control the run and stop functions of the engine by positively stopping fuel flow to the pump plungers, thereby preventing fuel injection.
- The torque screw**,** used on DB2 pumps, allows a tailored maximum torque curve for a particular engine application. This feature is commonly referred to as torque backup, since the engine torque will generally increase toward the preselected and adjusted point as engine rpm decreases. The three factors that affect this torque are the metering valve opening area, the time allowed for fuel charging, and the transfer pump pressure curve.

Turning in the torque screw moves the fuel metering valve toward its closed position. The torque screw controls the amount of fuel delivered at full-load governor speed.

If additional load is applied to the engine while it is running at full-load governed speed, there will be a reduction in engine rpm. A greater quantity of fuel is allowed to pass into the pumping chamber because of the increased time that the charging ports are open. Fuel delivery will continue to increase until the rpm drops to the engine manufacturer's predetermined point of maximum torque.

CAUTION

Do NOT attempt to adjust the torque curve on the engine at any time. This adjustment can only be done during a dynamometer test where fuel flow can be checked along with the measured engine torque curve on a fuel pump test stand.

2.3.3 Governor

The DB2 fuel injection pump uses a mechanical type governor (*Figure 5-12*). As you learned earlier, the function of

Figure 5-12 — Fuel injection pump with governor assembly.

the governor is to control the engine speed under various load settings. As with any mechanical governor, it operates on the principle of spring pressure opposed by weight force, with the spring attempting to force the linkage to an increased fuel position at all times. The centrifugal force of the rotating flyweights attempts to pull the linkage to a decreased fuel position.

Rotation of the governor linkage varies the valve opening, thereby limiting and controlling the quantity of fuel that can be directed to the fuel plungers. The position of the throttle lever controlled by the operator's foot will vary the tension of the governor spring. This force, acting on the linkage, rotates the metering valve to an increased or decreased fuel position as required.

At any given throttle position the centrifugal force of the rotating flyweights will exert force back through the governor linkage which is equal to that of the spring, resulting in a state of balance. Outward movement of the weights acting through the governor thrust sleeve can turn the fuel-metering valve by means of the governor linkage arm and hook. The throttle and governor spring position will turn the metering valve in the opposite direction.

The governor is lubricated by fuel received from the fuel housing. Fuel pressure in the governor housing is maintained by a spring-loaded ball-check return fitting in the governor cover of the pump.

2.3.4 Nozzle

The injector nozzle used with the DB2 fuel-injection pump is opened outward by high fuel pressure and closed by spring tension. It has a unique feature in that it is screwed directly into the cylinder head. An outward opening valve creates a narrow spray that is evenly distributed into the precombustion chamber. Both engine compression and combustion pressure forces assist the nozzle spring in closing an outward opening valve. These factors allow the opening pressure settings of the nozzle to be lower than those of conventional injectors.

During injection, a degree of swirl is imparted to the fuel before it actually emerges around the head of the nozzle. This forms a closely controlled annular orifice with the nozzle valve seat, which produces a high velocity atomized fuel spray, forming a narrow cone suitable for efficient burning of the fuel in the precombustion chamber.

The nozzle has been designed as basically a throwaway item. After a period of service, the functional performance may not meet test specifications. Nozzle testing is comprised of the following checks:

- Nozzle opening pressure
- Leakage
- Chatter
- Spray pattern

Each test is done independently of the others (for example, when checking the opening pressure, do not check for leakage). If all the tests are satisfied, the nozzle can be reused. If any one of the tests is not satisfied, replace the nozzle. For testing procedures, consult the manufacturer’s service manual.

2.4.0 Cummins Diesel Fuel Systems

Over the years Cummins has produced a series of innovations, such as the first automotive diesel, in addition to being the first to use supercharging and then turbocharging. All cylinders are commonly served through a low-pressure fuel line. The camshaft control of the mechanical injector controls the timing of injection throughout the operating range. This design eliminates the timing-lag problems of high-pressure systems.

To meet Environmental Protection Agency (EPA) exhaust emissions standards, Cummins offers the Celect (electronically controlled injection) system. Since the Celect system did not start production until 1989, there are literally thousands of Cummins with pressure-time (PT) fuel systems.

2.4.1 Pressure-Time Fuel Systems

The pressure-time (PT) fuel system (*Figure 5-13*) is exclusive to Cummins diesel engines; it uses injectors that meter and inject the fuel with this metering based on a pressure-time principle. A gear-driven positive displacement low-pressure fuel pump supplies fuel pressure. The time for metering is determined by the interval that the metering orifice in the injector remains open. This interval is established and controlled by the engine speed, which determines the rate of camshaft rotation and consequently the injector plunger movement.

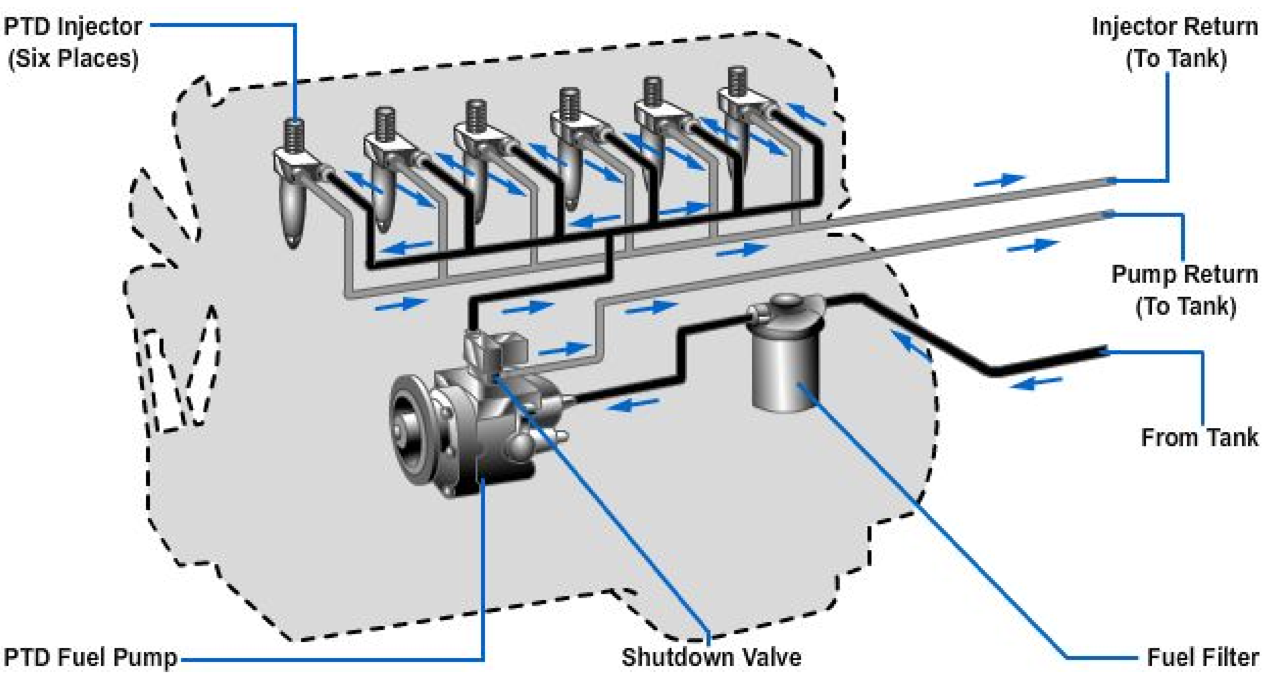

Figure 5-13 — Pressure-time fuel system.

Since Cummins engines are all four-cycle, the camshaft is driven from the crankshaft gear at one-half of engine speed. The fuel pump turns at engine speed. Because of this relationship, additional governing of fuel flow is necessary in the fuel pump.

A flyball-type mechanical governor controls fuel pressure and engine torque throughout the entire operating range. It also controls the idling speed of the engine and prevents engine over-speeding in the high-speed range. The throttle shaft is simply a shaft with a hole; therefore, the alignment of this hole with the fuel passages determines pressure at the injectors.

A single low-pressure fuel line from the fuel pump serves all injectors; therefore, the pressure and the amount of metered fuel to each cylinder are equal. The fuel-metering process in the PT fuel system has three main advantages:

- The injector accomplishes all metering and injection functions.
- The injector injects a finely atomized fuel spray into the combustion chamber at spray-in pressures exceeding 20,000 psi.
- A low-pressure common-rail system is used, with the pressure being developed in a gear-type pump. This eliminates the need for high-pressure fuel lines running from the fuel pump to each injector.

The fuel pump commonly used in the pressure-time system is the PTG-AFC pump (PT pump with a governor and an air-fuel control attachment) (*Figure 5-14*). The "P" in the name refers to the actual fuel pressure that is produced by the gear pump and maintained at the inlet to the injectors. The "T" refers to the fact that the actual "time" available for the fuel to flow into the injector assembly (cup) is determined by the engine speed as a function of the engine camshaft and injection train components.

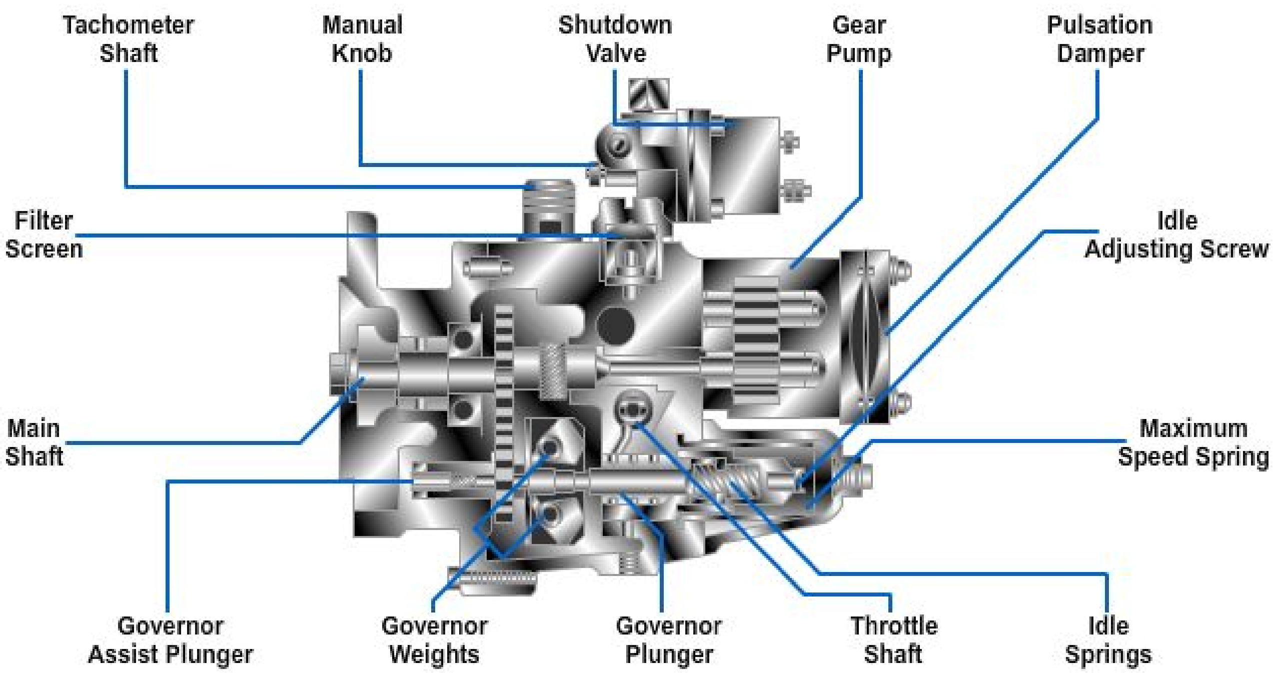

Figure 5-14 — Pressure-time gear pump.

The air-fuel control (AFC) is an acceleration exhaust smoke control device built internally into the pump body. The AFC unit is designed to restrict fuel flow in direct proportion to the air intake manifold pressure of the engine during acceleration, under load, and during lug-down conditions.

Within the pump assembly a fuel pump bypass button of varying sizes can be installed to control the maximum fuel delivery pressure of the gear-type pump before it opens and bypasses fuel back to the inlet side of the pump. In this way the horsepower setting of the engine can be altered fairly easily. The major functions of the PTG-AFC fuel pump assembly are as follows:

- To pull and transfer fuel from the tank and filter
- To develop sufficient fuel pressure to the fuel rail (common fuel passage) to all of the injectors

- To provide engine idle speed control (governing)
- To limit the maximum no-load and full-load speed of the engine (governing)
- To allow the operator to control the throttle position and therefore the power output of the engine
- To control exhaust smoke emissions to EPA specifications under all operating conditions
- To allow shutdown of the engine when desired

A major feature of the PT pump system is that there is no need to time the pump to the engine. The pump is designed simply to generate and supply a given flow rate at a specified pressure setting to the rail to all injectors. The injectors themselves are timed to ensure that the start of injection will occur at the right time for each cylinder.

The basic flow of fuel into and through the PT pump assembly will vary slightly depending on the actual model. A simplified fuel flow is as follows:

- As the operator cranks the engine, fuel is drawn from the fuel tank by the gear pump through the fuel supply line to the primary filter. This filter is normally a filter/water separator.
- The filtered fuel then flows through a small filter screen that is located within the PT pump assembly, and then flows down into the internal governor sleeve.
- The position of the governor plunger determines the fuel flow through various governor plunger ports.
- The position of the mechanically operated throttle determines the amount of fuel that can flow through the throttle shaft.
- Fuel from the throttle shaft is then directed to the AFC needle valve.
- The position of the AFC control plunger within the AFC barrel determines how much throttle fuel can flow into and through the AFC unit and on to the engine fuel rail, which feeds the fuel rail.

The AFC plunger position is determined by the amount of turbocharger boost pressure in the intake manifold, which is piped through the air passage from the intake manifold to the AFC unit. At engine start-up, the boost pressure is very low; therefore, flow is limited. Fuel under pressure flows through the electric solenoid valve, which is energized by power from the ignition switch. This fuel then flows through the fuel rail pressure line and into the injectors.

A percentage of the fuel from both the PT pump and the injectors is routed back to the fuel tank in order to carry away some of the heat that was picked up cooling and lubricating the internal components of the pump and the injectors.

A PT injector is provided at each engine cylinder to spray the fuel into the combustion chambers. PT injectors are of the unit type and are operated mechanically by a plunger return spring and a rocker arm mechanism operating off the camshaft. There are four phases of injector operation, as follows:

- Metering (*Figure 5-15, View A*)--The plunger is just beginning to move downward and the engine is on the beginning of the compression stroke. The fuel is trapped in the cup, the check ball stops the fuel flowing backwards, and fuel begins to be pressurized. The excess fuel flows around the lower annular ring, up the barrel, and is trapped there.
- Pre-injection (*Figure 5-15, View B*)--The plunger has moved most of the way down, the engine is almost at the end of the compression stroke, and the fuel is being pressurized by the plunger.
- Injection (*Figure 5-15, View C*)--The plunger is almost all the way down, the fuel is injected out of the eight orifices, and the engine is on the end of the compression stroke.
- Purging (*Figure 5-15, View D*)--The plunger is all the way down, injection is complete, and the fuel is flowing into the injector, around the lower annular groove, up a drilled passageway in the barrel, around the upper annular groove, and out through the fuel drain. The cylinder is on the power stroke. During the exhaust stroke, the plunger moves up and waits to begin the cycle all over.

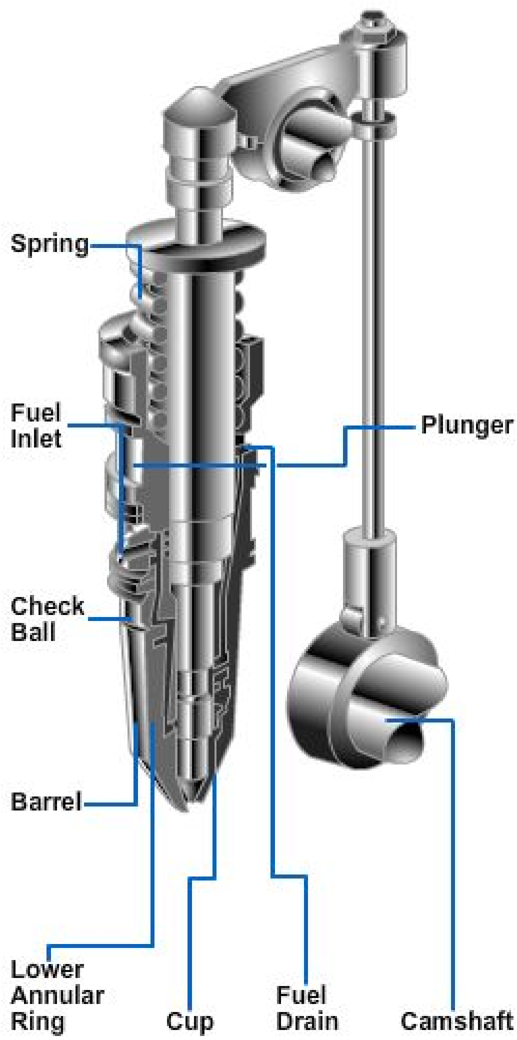

Figure 5-15 — Pressure-time injector operation.

Injector adjustments are extremely important on PT injectors because they perform the dual functions of metering and injecting. Check the manufacturer's manual for proper settings of injectors. On an engine where new or rebuilt injectors have been installed, initial adjustments can be made with the engine cold. Always readjust the injectors, using a torque wrench calibrated in inch-pounds after the engine has been warmed up. Engine oil temperature should read between 140°F and 160°F.

Anytime an injector is serviced, you must be certain that the correct orifices, plungers, and cups are used, as these can affect injection operation. You can also affect injection operation by any of the following actions:

- Improper timing
- Mixing plungers and barrels during teardown (Keep them together, since they are matched sets.)
- Incorrect injector adjustments after installation or during tune-up adjustment

- Installing an exchange set of injectors without taking time to check and correct other possible problems relating to injection operation (This is often overlooked).

Proper injector adjustment and maintenance will ensure a smooth running engine as long as the following factors are met:

- Adequate fuel delivery pressure from the fuel pump to the fuel manifold
- Selection of the proper sizes of balance and metering orifices
- The length of time that the metering orifice is uncovered by the upward moving injector plunger

⚠ CAUTION ⚠

For required adjustments and maintenance schedules, always consult the manufacturer's service manual.

2.4.2 Mechanical Electronic Unit Injector (MEUI)

The mechanical electronic unit injector is a common unit injector with an electronic solenoid that is controlled by the ECM. Mechanical pressure is created by the camshaft moving a roller and a pushrod, and a follower pressing on top of the injector unit. The rate and amount of fuel injected into the cylinder is controlled by the opening and closing of the solenoid that is controlled by the ECM.

2.4.3 Hydraulic Electronic Unit Injector (HEUI)

The hydraulic electronic unit injectors use high pressure engine oil to provide the force needed to complete injection. Many of the mechanical drive components found in standard mechanical or electronic unit injection systems, such as cam lobes, lifters, push rods, and rocker arms, are not used in this system.

A solenoid on each injector controls the amount of fuel delivered by the injector. A gear-driven axial pump raises the normal pressure to the levels required by the injectors. The ECM sends a signal to an injection pressure control valve to control pressure, and another signal to each injector solenoid to inject the fuel.

Pressure in the engine oil manifold is controlled by the ECM through the use of an injection pressure control valve. The injection pressure control valve, or dump valve, controls the injection pump outlet pressure by dumping excess oil back to the sump.

The ECM monitors pressure in the manifold through an injection pressure sensor. The ECM measures the pressure sensor signal to the desired injection pressure. Based on this measurement, the ECM changes the oil pressure in the high pressure manifold.

High pressure oil is routed from the pump to the high pressure manifold through a steel tube. From there it is routed to each injector through shorter jumper tubes.

Test your Knowledge (Select the Correct Response)

4. **(True or False)** Atomization occurs when the fuel enters the combustion chamber because the pressure in the cylinder is lower than the fuel pressure.

   A. True
   B. False

5. What manufacturer produced the first automotive diesel?

A. John-Deere
B. Caterpillar
C. International
D. Cummins

3.0.0 SUPERCHARGERS and TURBOCHARGERS

Supercharging and turbocharging are methods of increasing engine volumetric efficiency by forcing the air into the combustion chamber, rather than merely allowing the pistons to draw it naturally. Supercharging and turbocharging, in some cases, will push volumetric efficiencies over 100 percent.

3.1.0 Superchargers

A supercharger is an air pump that increases engine power by pushing a denser air charge into the combustion chamber. With more air and fuel, combustion produces more heat energy and pressure to push the piston down in the cylinder.

The term supercharger generally refers to a blower driven by a belt, chain, or gears. Superchargers are used on large diesel and racing engines.

The supercharger raises the air pressure in the engine intake manifold. When the intake valves open, more air-fuel mixture can flow into the cylinders. An intercooler is used between the supercharger outlet and the engine to cool the air and to increase power (cool charge of air carries more oxygen needed for combustion).

A supercharger will instantly produce increased pressure at low engine speed because it is mechanically linked to the engine crankshaft. This low-speed power and instant throttle response are desirable for passing and for entering interstate highways.

3.1.1 Centrifugal Supercharger

The centrifugal supercharger has an impeller equipped with curved vanes (*Figure 5-16*). As the engine drives the impeller, it draws air into its center and throws it off at its rim. The air then is pushed along the inside of the circular housing. The diameter of the housing gradually increases to the outlet where the air is pushed out.

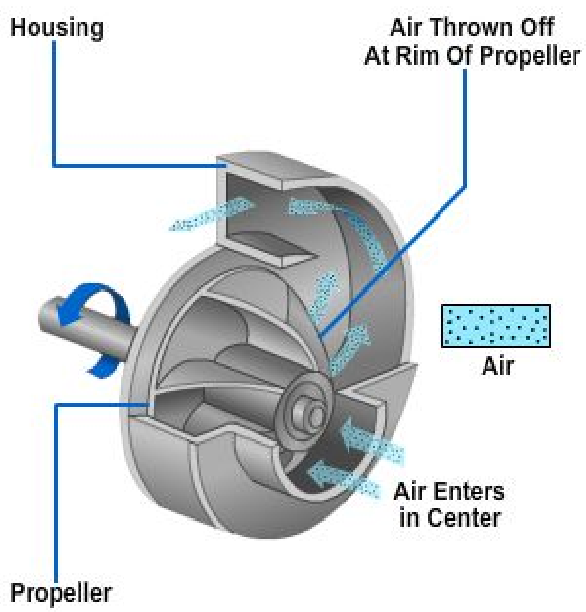

Figure 5-16 — Centrifugal supercharger.

3.2.0 Turbochargers

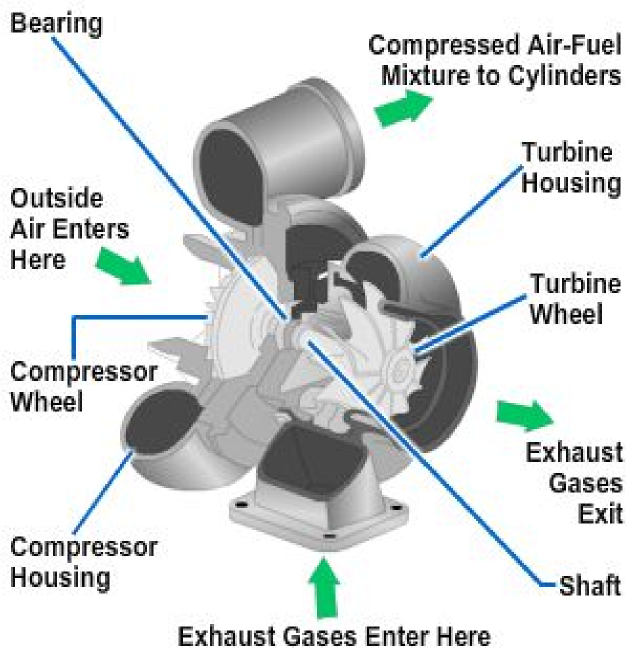

Figure 5-17 — Turbocharger.

A turbocharger is an exhaust-driven supercharger (fan or blower) that forces air into the engine under pressure (*Figure 5-17*). Turbochargers are frequently used on small gasoline and diesel engines to increase power output. By harnessing engine exhaust energy, a turbocharger can also improve engine efficiency (fuel economy and emissions levels).

A turbocharger is located on one side of the engine. An exhaust pipe connects the exhaust manifold to the turbine housing. The exhaust system header pipe connects to the outlet of the turbine housing.

Theoretically, the turbocharger should be located as close to the engine manifold as possible. Then a maximum amount of exhaust heat will enter the turbine housing. When the hot gases move past the spinning turbine wheel, they are still expanding and help rotate the turbine.

3.2.1 Components of a Turbocharger

The turbocharger consists of three major components: a radial inward flow turbine wheel and shaft, a centrifugal compressor wheel, and a center housing that supports the rotating assembly, bearings, seals, turbine housing, and compressor housing. The center housing also has connections for oil inlet and oil outlet fittings.

3.2.1.1 Turbine Wheel

The turbine wheel is located in the turbine housing and is mounted on one end of the turbine shaft. Exhaust gases enter the turbine housing and spin the turbine wheel.

3.2.1.2 Compressor Wheel

The compressor wheel is located on the turbine shaft on the opposite end of the turbine wheel. As the gases spin the turbine wheel, the turbine shaft spins the compressor wheel.

3.2.1.3 Turbine Housing

The turbine housing is made of a heat-resistant alloy casting that encloses the turbine wheel and provides a flanged exhaust gas inlet and an axially-located turbocharger exhaust gas outlet.

3.2.2 Operation

The basic operation of a turbocharger is as follows:

- When the engine is running, hot gases blow out the open exhaust valves and into the exhaust manifold. The exhaust manifold and connecting tubing route these gases into the turbine housing.

- As the gases pass through the turbine housing, they strike the fins or blades on the turbine wheel. When engine load is high enough, there is enough exhaust gas flow to spin the turbine wheel rapidly.
- Since the turbine wheel is connected to the impeller by the turbo shaft, the impeller rotates with the turbine. Impeller rotation pulls air into the compressor housing. Centrifugal force throws the spinning air outward. This causes air to flow out of the turbocharger and into the engine cylinder under pressure.

3.2.3 Advantages

The turbocharger offers a distinct advantage for a diesel engine operating at higher altitudes. The turbocharger automatically compensates for the loss of air density. An increase in altitude also increases the pressure drop across the turbine. Inlet turbine pressure remains the same, but outlet pressure decreases as the altitude increases. Turbine speed also increases as the pressure differential increases.

3.2.4 Lubrication

Turbocharger lubrication is required to protect the turbo shaft and bearings from damage. A turbocharger can operate at speeds up to 100,000 rpm. For this reason, the engine lubrication system forces oil into the turbo shaft bearings. Oil passages are provided in the turbo housing and bearings, and an oil supply line runs from the engine to the turbocharger. With the engine running, oil enters the turbocharger under pressure. A drain passage and drain line allow oil to return to the engine oil pan after passing through the turbo bearings.

Sealing rings (piston-type rings) are placed around the turbo shaft at each end of the turbo housing, preventing oil leakage into the compressor and turbine housings.

3.2.5 Controls

While there are many types of turbocharger controls, they fall into two groups: those that limit turbocharger speed and those that limit compressor outlet pressure, or boost. Controls that limit turbocharger speed keep the turbocharger from destroying itself. Those that limit boost keep the turbocharger from damaging the engine. Since the modern turbocharger can produce more pressure than the engine can use, most controls are designed to limit the amount of boost. One of the most common methods of limiting the boost is with a waste gate valve.

3.2.5.1 Waste Gate

A waste gate limits the maximum amount of boost pressure developed by the turbocharger. It is a butterfly or poppet-type valve that allows exhaust to bypass the turbine wheel.

Without a waste gate, the turbocharger could produce too much pressure in the combustion chambers. This could lead to detonation (spontaneous combustion) and engine damage.

A diaphragm assembly operates the waste gate. Intake manifold pressure acts on the diaphragm to control waste gate valve action. The valve controls the opening and closing of a passage around the turbine wheel.

Under partial load, the system routes all of the exhaust gases through the turbine housing. The waste gate is closed by the diaphragm spring. This assures that there is adequate boost to increase power.

Under a full load, boost may become high enough to overcome spring pressure. Manifold pressure compresses the spring and opens the waste gate. This permits some of the exhaust gases to flow through the waste gate passage and into the exhaust system. Less exhaust is left to spin the turbine. Boost pressure is limited to a preset value.

3.2.6 Aftercooler

The use of a turbocharger increases the temperature of the intake air. This increase in temperature is because the turbocharger compresses the air. To help counteract this increase in temperature, an intercooler or aftercooler is installed. There are two types of aftercoolers being used today: coolant aftercoolers and air-to-air aftercoolers.

In coolant aftercoolers, engine coolant flows through the aftercooler core tubes. As the hot compressed air from the turbocharger passes around the tubes, it is dropped to the temperature of the coolant.

In air-to-air aftercoolers, the air is a heat exchanger that cools the air entering the engine. It is a radiator-like device mounted at the pressure outlet of the turbocharger.

Outside air flows over and cools the fins and tubes of the intercooler. As the air flows through the intercooler, heat is removed. By cooling the air entering the engine, engine power is increased because the air is denser (contains more oxygen by volume). Cooling also reduces the tendency for engine detonation.

3.2.7 Turbo Lag

Turbo lag refers to a short delay before the turbocharger develops sufficient boost (pressure above atmospheric pressure).

As the accelerator pedal is pressed down for rapid acceleration, the engine may lack power for a few seconds. This is caused by the impeller and turbine wheels not spinning fast enough. It takes time for the exhaust gases to bring the turbocharger up to operating speed. To minimize turbo lag, the turbine and impeller wheels are made very light so they can accelerate up to rpm quickly.

Test your Knowledge (Select the Correct Response)

6. Which part does NOT drive a supercharger?

   A. Belt
   B. Exhaust
   C. Chain
   D. Gears

4.0.0 COLD STARTING DEVICES

Diesel fuel evaporates much slower than gasoline and requires more heat to cause combustion in the cylinder of the engine. For this reason, preheating devices and starting aids are used on diesel engines. These devices and starting aids either heat the air before it is drawn into the cylinder or allow combustion at a lower temperature than during normal engine operation.

4.1.0 Coolant Heaters

In cold weather, coolant heaters are used to keep the fuel flowing freely. There are three common types of heaters used on mobile diesel engines: immersion block heaters, circulating tank heaters, and fuel-fired heaters.

The immersion block heater is installed directly into the engine block in a location predetermined by the manufacturer. The warmed coolant circulates around the cylinders in the block by convection. The heater is powered by either 120 or 240 volts.

Circulating tank heaters are installed in a way that creates circulation. The coolant leaves through the bottom of the engine block and travels to the heater. The heated coolant rises and is transferred back to the top of the engine block. These types of heaters should be of a higher wattage than immersion block heaters because some of the heat is lost through the hoses and tank. Circulating heaters are available in 120 or 240 volts.

Fuel-fired heaters are used to heat the engine and cab unit via the coolant by burning diesel fuel. These units burn less fuel than the engine would if left idling. The unit operates like a kerosene-fired space heater. The flame warms the coolant that is flowed through the space.

4.2.0 Lubrication Oil Heaters

Most oil heaters are electric-powered immersion heaters that are installed in the oil sump through the drain plug or the dipstick opening. A thermostat can also be installed as part of the heating unit. This type of heater is designed to keep the oil pan warm; the heat radiates upward to warm the entire engine.

4.3.0 Glow Plugs

The purpose of a glow plug is to heat up the air that is drawn into the precombustion chamber to assist starting, especially in cold weather. Operating temperatures of 1500ºF can be reached in a matter of seconds. Glow plugs are common on precombustion chamber engines, but not on direct injection diesels because they use shaped piston crowns that produce a very effective turbulence to the air in the cylinder. Direct injection engines also have less immediate heat loss to the surrounding cylinder area than in a precombustion engine and generally have a higher injection spray-in pressure.

A glow plug is used for each cylinder located just below the injection nozzle and threaded into the cylinder head (*Figure 5-18*). The inner tip of the glow plug extends into the precombustion chamber. The glow plugs may be turned on using the ignition switch with the length of time being controlled from an electronic module. During colder weather, the system may have to be cycled more than once to start the engine.

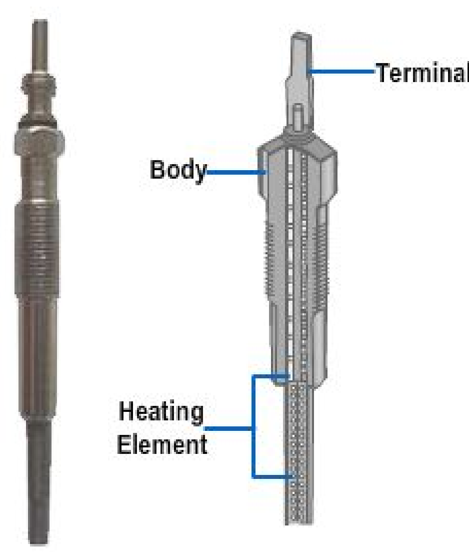

Figure 5-18 — Glow plugs.

Glow plugs are not complicated and are easy to test. Disconnect the wire going to the glow plug and use a multimeter to read the ohms resistance of the glow plug. Specifications for different glow plugs vary according to the manufacturer. Be sure and check the manufacturer's service manual for the correct ohms resistance value.

4.4.0 Automatic Ether Starting

WARNING

Starting fluids must never be used if the engine is equipped with either glow plugs or an electric intake heater.

Ether is a highly volatile fluid that is injected into the intake manifold as you crank the engine. It is found in an aerosol or capsule-type container. Since ether has a low ignition point, the heat generated in the combustion chamber is able to ignite it. Heat from this ignition then ignites the diesel fuel, and normal combustion takes place. Once the diesel engine starts, no more fluid is required. Use of spray cans of ether is discouraged. The only method of safely using ether is with a closed dispensing system.

Automatic ether systems are wired into the cranking circuit and dispense starting fluid when the cranking circuit is energized. Flow of the ether is controlled by a valve orifice or rapid cycling of the valve, resulting in continuous atomizer flow. An engine temperature switch prevents operation when the engine is warm.

The nozzle directs the flow of starting fluid into the airstream and determines the rate at which it is injected. The direction of the spray should be against the flow of incoming air to maximize mixing with the air.

Cold starting aids such as ether should be used only in extreme emergencies. Too much ether may detonate in the cylinder too far before top dead center (BDTC) on the compression stroke. This could cause serious damage, such as broken rings, ring lands, pistons, or even cracked cylinder heads. If you must use ether, the engine has to be turning over before you spray it into the intake manifold.

5.0.0 DIESEL FUEL SYSTEM MAINTENANCE

If all diesel engines had nearly identical fuel system trouble, diagnosis and maintenance procedures could follow a general pattern. But, with the exception of similar fuel tanks and basic piping system, diesel fuel systems differ considerably. Consequently, each engine manufacturer recommends different specific maintenance procedures. However, the tune-up and maintenance procedures described are representative of the job you will do. For all jobs, refer to the manufacturer's service manual for the fuel system you are servicing, even if you fully understand all procedures.

5.1.0 Dirt in Fuel System

Many diesel engine operating troubles result directly or indirectly from dirt in the fuel system. That is why proper fuel storage and handling are so important. One of the most important aspects of diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel pump and injector troubles will occur. Diesel fuel, because it is more viscous than gasoline, will hold dirt in suspension for longer periods. Therefore, every precaution should be taken to keep the fuel clean.

If the engine starts missing, running irregularly, rapping, or puffing black smoke from the exhaust manifold, look for trouble at the spray nozzle valves. In this event, it is almost a sure bet that dirt is responsible for improper fuel injection into the cylinder. A valve held open or scratched by particles of dirt so that it cannot seat properly will allow fuel to pass into the exhaust without being completely burned, causing black smoke. Too much fuel may cause a cylinder to miss entirely. If dirt prevents the proper amount of fuel from entering the cylinders by restricting spray nozzle holes, the engine may skip or stop entirely. In most cases, injector or valve troubles are easily identified.

Improper injection pump operation, however, is not easily recognized. It is more likely caused by excessive wear than by an accumulation of dirt or carbon, such as the spray nozzle is subjected to in the cylinder combustion chambers. If considerable abrasive dirt gets by the filters to increase (by wear) the small clearance between the injector pump plunger and barrel, fuel will leak by the plunger instead of being forced into the injector nozzle in the cylinder. This gradual decrease in fuel delivery at the spray nozzle may remain unnoticed for some time or until the operator complains of sluggish engine performance.

Although worn injector pumps will result in loss of engine power and hard starting, worn piston rings, cylinder liners, and valves (intake and exhaust) can be responsible for the same conditions. However, with worn cylinder parts or valves, poor compression, a smoky exhaust, and excessive blow-by will accompany the hard starting and loss of power from the crankcase breather.

5.2.0 Water in Fuel System

It requires only a little water in a fuel system to cause an engine to miss, and if present in large enough quantities, the engine will stop entirely. Many fuel filters are designed to clog completely when exposed to water, thereby stopping all fuel flow. Water that enters a tank with the fuel or that is formed by condensation in a partially empty tank or line usually settles to the lowest part of the fuel system. This water should be drained off daily.

5.3.0 Air in Fuel System

Air trapped in diesel fuel systems is one of the main reasons for a hard starting engine. Air can enter the fuel system at loose joints in the piping or through a spray nozzle that does not close properly. Letting the vehicle run out of fuel will also cause air to enter the system. Like water, air can interfere with the unbroken flow of fuel from the tank to the cylinder. A great deal of air in a system will prevent fuel pumps from picking up fuel and pushing it through the piping system. Air can be removed by bleeding the system as set forth in the procedures described in the manufacturer’s maintenance manual.

6.0.0 GENERAL TROUBLESHOOTING

When troubleshooting a diesel engine, keep in mind that problems associated with one make and type of engine (two-stroke versus four-stroke) may not occur exactly in the same way as in another. Specifically, particular features of one four-stroke-cycle engine may not appear on another due to the type of fuel system used and optional features on that engine. Follow the basic troubleshooting steps listed below before rolling up your sleeves and trying to pinpoint a problem area.

- Obtain as much information from the operator as possible concerning the complaint.
- Analyze the problem in detail first, beginning with the smallest and simplest things.
- Relate the problem symptoms to the basic engine systems and components.

- Consider any recent maintenance or repair job that might tie into the problem.
- Always double-check and think about the problem before disassembling anything.
- Solve the problem by checking the easiest and simplest things first.
- If possible, use the special tools and diagnostic equipment at your disposal to verify a complaint and pinpoint the general area.
- Determine the cause(s) of the problem and carry out the repair.
- Operate the engine and road test the vehicle to confirm that the problem is corrected.

6.1.0 Exhaust Smoke Color

One of the easiest methods to use when troubleshooting an engine for a performance complaint is to visually monitor the color of the smoke coming from the exhaust stack. There are four basic colors that may exit from the exhaust system at any time during engine operation—white, black, gray, or blue. The color of the smoke tips you off to just what and where the problem might lie.

6.1.1 White Smoke

White smoke is generally most noticeable at engine start-up, particularly during cold conditions. As the combustion and cylinder temperatures increase during the first few minutes of engine operation, the white smoke should start to disappear which indicates the engine is sound. However, if the white smoke takes longer than 3 to 5 minutes to fade away, a problem exists. The problems white smoke may indicate are as follows:

- Low cylinder compression from worn rings
- Scored piston or liner
- Valve seating problems
- Water leaking into the combustion chamber
- Faulty injectors
- Use of a low cetane diesel fuel

6.1.2 Black or Gray Smoke

Black or gray smoke generally is caused by the same conditions—the difference between the colors being one of opacity or denseness of smoke. Black or gray smoke should be checked with the engine at operating temperature of 160°F. Abnormal amounts of exhaust smoke emission is an indication that the engine is not operating correctly, resulting in a lack of power, as well as decreased fuel economy. Excessive black or gray exhaust smoke is caused by the following:

- Improper grade of diesel fuel
- Air starvation
- High exhaust back pressure
- Incorrect fuel injection timing
- Faulty nozzles or injectors

- Incorrect valve adjustment clearances
- Faulty injection pump
- Faulty automatic timing advance unit

6.1.3 Blue Smoke

Blue smoke is attributed to oil entering the combustion chamber and being burned or blown through the cylinder and burned in the exhaust manifold or turbocharger. Remember: always check the simplest things first, such as too much oil in the crankcase or a plugged crankcase ventilation breather. The more serious problems that can cause blue smoke are as follows:

- Worn valve guides
- Worn piston rings
- Worn cylinder walls
- Scored pistons or cylinder walls
- Broken ring
- Turbocharger seal leakage
- Glazed cylinder liner walls due to use of the wrong type of oil

6.2.0 Quick Injector Misfire Check

Listed below are several quick and acceptable checks that can be performed on a running engine to determine if one or more injectors are at fault on any type of engine.

On four-stroke-cycle engines with a high-pressure in-line pump or distributor system, such as Caterpillar and Roosa Master, you can loosen off one injector fuel line, one at a time, about one-half turn as you hold a rag around it while noting if there is any change in the operating sound of the engine. If the injector is firing properly, there should be a positive change to the sound and rpm of the engine when you loosen the line, since it prevents the delivery of fuel to the cylinder.

On an engine with the PT fuel system, a cylinder misfire can be checked by running the engine to a minimum of 160°F. Remove the rocker covers and install a rocker lever actuator over an injector rocker lever. Hold the injector plunger down while the engine is running at low idle. This will stop the fuel flow to that injector. If the engine speed decreases, the injector is good. If the engine rpm does not decrease, replace the injector.

On the two-stroke-cycle non-electronic Detroit diesel engines, remove the rocker cover; then, using a large screwdriver push and hold down the injector follower while the engine is idling. This action is like shorting out a spark plug on a gasoline engine, since it prevents fuel from being injected into the combustion chamber. If there is no change to the sound and speed of the engine, the injector is not firing. There should be a definite change to indicate that the injector was in fact firing.

6.3.0 Dead Cylinder Test

The dead cylinder Test is another name for the quick injector misfire check. It is performed in the same manner. If you experience a problem while performing this test, you have a “dead cylinder”.

Summary

In this lesson you have learned about the diesel fuel system and its components, different methods of injection, superchargers, turbochargers, and cold starting devices, and have been briefly introduced to some troubleshooting techniques. Because there are newer and better innovations every day, you should also refer to the manufacturer's guide for specific systems. Your knowledge of the diesel fuel system will enable you to evaluate certain engine problems with confidence that the fuel system can be diagnosed.

Review Questions (Select the Correct Response)

1. What factor makes it possible to ignite the air-fuel mixture of a diesel engine without the use of a spark plug as required in a gasoline engine?

   A. The ignition temperature of diesel fuel is low.
   B. The compression ratio of the diesel engine is low.
   C. The compression temperature of the diesel engine is high.
   D. The speed of the diesel engine's moving parts is high.

2. What action controls the speed of a diesel engine?

   A. Regulation of the amount of fuel delivered to the engine's cylinders
   B. Alteration of the compression pressure within the engine's cylinders
   C. Regulation of the volume of air entering the cylinders
   D. Limitation of the capacity of the fuel injection system

3. Which characteristic is one advantage of the diesel engine over the gasoline engine?

   A. Low production cost
   B. Suitability for vehicles transporting small loads
   C. Smoothness of operation
   D. High ratio of power output to fuel consumed

4. What agency is responsible for grading diesel fuel?

   A. Society of Automotive Engineers
   B. American Petroleum Institute
   C. American Society for Testing And Materials
   D. Society of Automotive Petroleum

5. What grade of diesel fuel is used in truck fleets because of its greater heat value?

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

6. Which factor must be considered when selecting a fuel oil?

   A. Engine size and design
   B. Fuel cost and availability
   C. Atmospheric conditions
   D. Speed and load range

7. The measure of the volatility of a diesel fuel is known as the _______ number.

A. cetane
B. octane
C. distillation
D. stability

8. If the cetane number of a diesel fuel is too low, which condition can result?

A. Pre-ignition
B. Difficulty in starting
C. Puffs of blue smoke during start-up
D. Detonation

9. Current diesel fuels have a cetane rating that ranges between _______.

A. 50 and 60
B. 40 and 50
C. 30 and 40
D. 20 and 30

10. Low volatile fuels tend to provide better fuel economy and produce _______.

A. more crankcase dilution
B. higher exhaust temperature
C. less exhaust smoke
D. less lubrication

11. Which property has a direct bearing on the life expectancy of the engine and its components?

A. Sulfur content
B. Viscosity
C. Volatility
D. Cleanliness and stability

12. Which combustion chamber design is the most common?

A. Swirl
B. Pre-combustion
C. Indirect
D. Direct

13. When precombustion chambers are used on a diesel engine, which factor causes the greatest amount of fuel atomization?

A. Rapid air movement within the cylinders
B. High fuel injection pressure
C. Dispersion of fuel from the multiorifice fuel injectors
D. Turbulence within the precombustion chamber

14. What component is designed to prevent an engine from over-speeding and allow the engine to meet changing load conditions?

A. Fuel pump
B. Carburetor
C. Throttle valve
D. Governor

15. At what location is the governor connected on a diesel engine?

A. Next to the fuel pump
B. Between the throttle and the fuel injector
C. Between the fuel pump and the fuel filter
D. Between the fuel filter and throttle

16. What type of governor prevents an engine from exceeding a specified maximum speed?

A. Limiting-speed
B. Constant-speed
C. Variable-speed
D. Load-control

17. What type of governor maintains any specified engine speed between idle and maximum speed?

A. Load-limiting
B. Load-control
C. Pressure-regulating
D. Variable-speed

18. What type of governor provides a regular or stable engine speed, regardless of load conditions?

A. Variable-speed
B. Constant-speed
C. Load-control
D. Pressure-regulating

19. What part of a spring-loaded mechanical governor does the manual throttle directly adjust?

A. Linkage between flyballs and injectors
B. Spring tension
C. Position of flyballs
D. Centrifugal-force generator

20. The tension of the spring in the mechanical flyweight governor has a tendency to _______.

A. stabilize the amount of fuel delivered to the cylinders
B. reduce the amount of fuel delivered to the cylinders
C. increase the amount of fuel delivered to the cylinders
D. increase and reduce the amount of fuel delivered to the cylinders

21. For engine speed to stabilize, what condition must exist within the governor?

A. Centrifugal force must overcome spring tension.
B. Spring tension must overcome centrifugal force.
C. Centrifugal force and spring tension must balance fuel supply pressure.
D. Centrifugal force and spring tension must be equalized.

22. Which characteristic is NOT an advantage of a mechanical governor?

A. Inexpensive to manufacture
B. Very simple, contains few parts
C. Large deadbands
D. Not required to maintain the same speed, regardless of load

23. The hydraulic governor is inherently unstable. To maintain stability, hydraulic governors employ _______.

A. speed droop
B. deadbands
C. sensitivity
D. isochronous

24. In an electronic governor, at what location is the magnetic pickup sensor installed?

A. Next to a drive shaft gear
B. Between the crankshaft and electronic control module
C. Between the flyweights and springs
D. Next to the idle speed control

25. Sediment or water is prevented from entering the fuel system because the inlet fuel line is how far from the bottom of the tank?

A. 2 inch
B. 1½ inch
C. 1 inches
D. ½ inches

26. Why is it necessary to have a supply pump to transfer fuel from the tank to the injection pump of a diesel engine?

A. Because the injection pump will not create sufficient suction
B. Because the fuel filters pass fuel only under pressure
C. Because the injection pump will deliver excessive fuel to the engine
D. Because use of the injection pump alone will cause the fuel system to become airbound

27. What are the five functions of a diesel fuel injection system?

A. Measure, introduce, time, atomize, and create force
B. Meter, inject, time, atomize, and create pressure
C. Measure, insert, time, atomize, and catalyze
D. Metered, introjection, timer, atomism, and catalyze

28. The rate at which fuel is injected also determines the rate of_____.

A. combustion
B. speed
C. timing
D. distribution

29. What type of injection system is used on Caterpillar diesel engines?

A. Unit injection
B. Pump and nozzle
C. Distributor
D. Pressure time

30. What action varies the metering of fuel in a Caterpillar injection system?

A. An increase and decrease in the nozzle orifices
B. Controlled cam and spring action
C. Turning of the plungers in the barrels
D. Turning of the rack and pinion

31. With the engine operating at full load, the transfer pump fills the injection pump housing with fuel at approximately _______ psi.

A. 10 to 15
B. 20 to 25
C. 30 to 35
D. 40 to 45

32. At approximately what rate, in gallons per hour, does the constant bleed valve return fuel back to the fuel tank?

A. 12
B. 9
C. 5
D. 2

33. What type of governor is used on the sleeve metering fuel system?

A. Mechanical
B. Hydraulic
C. Electronic
D. Hydromechanical

34. The sleeve metering fuel system uses what for lubrication?

A. Oil
B. Fuel
C. Greese
D. Not required

35. What type of seal is used to prevent engine oil from entering the DB2 fuel pump?

A. Two cone seals
B. Two lip seals
C. Two O rings
D. Two Quad-X rings

36. What positive displacement type of transfer pump is used in the DB2 fuel pump?

A. Vane
B. Rotary
C. Electric
D. Piston

37. What action limits the maximum amount of fuel that can be injected by the DB2 fuel pump?

A. Outward travel of the plungers
B. Roller shoes contacting the leaf spring
C. Opening of the charging ports
D. Movement of the cam lobes

38. In the PTG-AFC fuel pump, what determines the AFC plunger position?

A. Positive boost pressure in the exhaust manifold
B. Positive boost pressure in the intake manifold
C. Negative boost pressure in the intake manifold
D. Negative boost pressure in the exhaust manifold

39. After replacing the injectors in a Cummins PT fuel system, you should readjust them after the engine has been warmed up to within what temperature range?

A. Between 160° and 180°
B. Between 140° and 160°
C. Between 120° and 140°
D. Between 110° and 130°

40. When overhauling a set of PT fuel injectors, you must keep them together because they are ______ sets.

A. matched
B. paired
C. connected
D coupled

41. What drives a turbocharger?

A. Exhaust
B. Belt
C. Chain
D. Gear

42. What type of cold weather starting devices uses convection as a means to transfer heat?

A. Circulating tank heater
B. Immersion block heater
C. Manifold flame heater
D. Fuel-fired heater

43. Blue smoke coming from the exhaust indicates the existence of which condition?

A. High exhaust back pressure
B. Water leaking into the combustion chamber
C. Low cylinder compression from worn rings
D. Oil entering the combustion chamber

Trade Terms Introduced in this Chapter

BTU	The British thermal unit is a traditional unit of energy. It is approximately the amount of energy needed to heat one pound of water one degree Fahrenheit.
engine/transmission retarder	A device used to augment or replace some of the functions of primary friction-based braking systems.
AC	In alternating current (AC) the movement of electric charge periodically reverses direction.
PTO	A power take-off (PTO) is a splined driveshaft that is used to provide power to an attachment or a separate machine.

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.

Diesel Technology Seventh Edition, Andrew Norman and John “Drew” Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN-13: 978-1-59070-770-8)

Medium/Heavy Duty Truck Engines, Fuel & Computerized Management Systems 2nd Edition, Sean Bennett, The Thomson/Delmar Learning Company, INC.,2004. (ISBN-13:978-1-4018-1499-1)

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Chapter 6

Cooling and Lubrication Systems

Topics

1.0.0 Engine Cooling Systems

2.0.0 Engine Lubricating Systems

To hear audio, click on the box.

Overview

All internal combustion engines are equipped with cooling and lubricating systems that work in conjunction with each other to promote efficient engine operation and performance. The cooling and lubricating systems discussed in this chapter, along with their respective components and maintenance requirements, are representative of the types of systems you will be expected to maintain.

Because of the variety of engines used, there are differences in the applications of features of their cooling and lubricating systems. Keep in mind that maintenance procedures and operational characteristics vary from engine to engine; therefore, always refer to the manufacturer's service manuals for specific information.

Objectives

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

1. Understand the relationship of the cooling system to engine operation.
2. Identify design and functional features of individual cooling system components.
3. Identify maintenance procedures applicable to cooling systems.
4. Identify types of lubrication (oil) systems.
5. Understand operational characteristics and maintenance requirements of lubrication systems.

Prerequisites

None

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

Automotive Chassis and Body	↑	
Brakes		
Construction Equipment Power Trains		C
Drive Lines, Differentials, Drive Axles, and Power Train Accessories		M
Automotive Clutches, Transmissions, and Transaxles		
Hydraulic and Pneumatic Systems		
Automotive Electrical Circuits and Wiring		B A
Basic Automotive Electricity		S
Cooling and Lubrication Systems		I
Diesel Fuel Systems		C
Gasoline Fuel Systems		
Construction of an Internal Combustion Engine		
Principles of an Internal Combustion Engine		
Technical Administration		

Features of this Manual

This manual has several features which make it easy 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 italicized instructions 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 ENGINE COOLING SYSTEMS

An internal combustion engine produces power by burning fuel within the cylinders; therefore, it is often referred to as a "heat engine." However, only about 25% of the heat is converted to useful power. What happens to the remaining 75 percent? Thirty to thirty five percent of the heat produced in the combustion chambers by the burning fuel is dissipated by the cooling system along with the lubrication and fuel systems. Forty to forty-five percent of the heat produced passes out with the exhaust gases. If this heat were not removed quickly, overheating and extensive damage would result. Valves would burn and warp, lubricating oil would break down, pistons and bearings would overheat and ***seize***, and the engine would soon stop.

The necessity for cooling may be emphasized by considering the total heat developed by an ordinary six cylinder engine. It is estimated that such an engine operating at ordinary speeds generates enough heat to warm a six-room house in freezing weather. Also, peak combustion temperatures in a gasoline engine may reach as high as 4500°F, while that of a diesel engine may approach 6000°F. The valves, pistons, cylinder walls, and cylinder head, all of which must be provided some means of cooling to avoid excessive temperatures, absorb some of this heat. Even though heated gases may reach high temperatures, the cylinder wall temperatures must not be allowed to rise above 400°F to 500°F. Temperatures above this result in serious damage, as already indicated. However, for the best thermal efficiency, it is desirable to operate the engine at temperatures closely approximating the limits imposed by the lubricating oil properties.

The cooling system has four primary functions:

- Remove excess heat from the engine.
- Maintain a constant engine operating temperature.
- Increase the temperature of a cold engine as quickly as possible.
- Provide a means for heater operation (warming the passenger compartment).

Air is continually present in large enough quantities to cool a running engine; therefore, vehicle engines are designed to dissipate their heat into the air through which a vehicle passes. This action is accomplished either by direct air-cooling or indirectly by liquid cooling. In this chapter we will be concerned with both types, and the discussion will include a description of the various components of the systems and an explanation of their operation.

1.1.0 Air-Cooled Systems

The simplest type of cooling is the air-cooled, or direct, method in which the heat is drawn off by moving air in direct contact with the engine. Several fundamental principles of cooling are embodied in this type of engine cooling. The rate of the cooling is dependent upon the following:

- Area exposed to the cooling medium
- Heat conductivity of the metal used and the volume of the metal or its size in cross section
- Amount of air flowing over the heated surfaces
- Difference in temperature between the exposed metal surfaces and the cooling air

Some heat, of course, must be retained for efficient operation. This is done by use of thermostatic controls and mechanical linkage, which open and close shutters to control the volume of cooling air. You will find that air-cooled engines generally operate at a higher temperature than liquid-cooled engines whose operating temperature is largely limited by the boiling point of the coolant used. Consequently, greater clearances must be provided between the moving parts of air-cooled engines to allow for increased expansion. Also, lubricating oil of a higher viscosity is generally required.

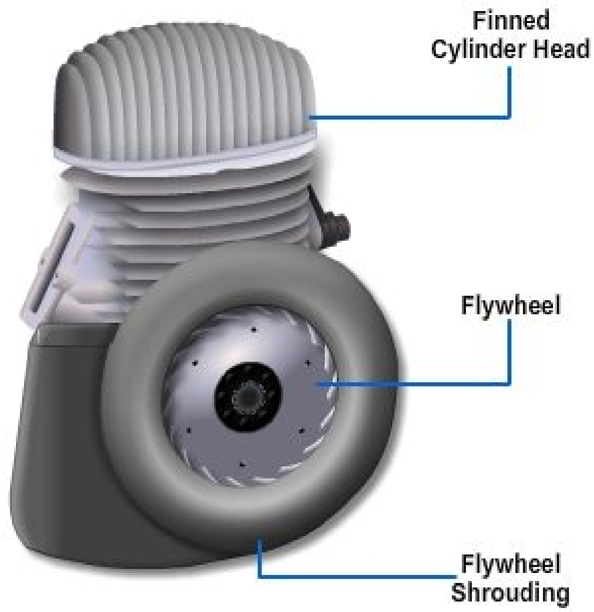

Figure 6-1 — Air-cooled Engine.

In air-cooled engines the cylinders are mounted independently to the crankcase so an adequate volume of air can circulate directly around each cylinder, absorbing heat and maintaining cylinder head temperatures within allowable limits for satisfactory operation. In all cases, the cooling action is based on the simple principle that the surrounding air is cooler than the engine. The main components of an air-cooled system are the fan, shroud, baffles, and fins. A typical air-cooled engine is shown in *Figure 6-1.*

1.1.1 Fan and Shroud

All ***stationary*** air-cooled engines must have a fan or blowers of some type to circulate a large volume of cooling air over and around the cylinders. The fan for the air-cooled engine shown in *Figure 6-1* is built into the flywheel. Notice that the shrouding, or cowling, when assembled will form a compartment around the engine so the cooling air is properly directed for effective cooling. Air-cooled engines, such as those used on motorcycles and outboard engines, do not require the use of fans or shrouds because their movement through the air results in sufficient airflow over the engine for adequate cooling.

1.1.2 Baffles and Fins

In addition to the fan and shroud, some engines use baffles or deflectors to direct the cooling air from the fan to those parts of the engine not in the direct path of the airflow. Baffles are usually made of light metal and are semicircular, with one edge in the air stream to direct the air to the back of the cylinders.

Most air-cooled engines use thin fins that are raised projections on the cylinder barrel and head. The fins provide more cooling area or surface, and aid in directing airflow. Heat, resulting from combustion, passes by conduction from the cylinder walls and cylinder head to the fins and is carried away by the passing air.

1.1.3 Maintaining the Air-Cooled System

You may think that because the air-cooled system is so simple it requires no maintenance. Many mechanics think this way and many air-cooled engine failures occur as a result. Maintenance of an air-cooled system consists primarily of keeping cooling components clean. Clean components permit rapid transfer of heat and ensure that nothing prevents the continuous flow and circulation of air. To accomplish this, keep fans, shrouds, baffles, and fins free of dirt, bugs, grease, and other foreign matter. The engine may look clean from the outside, but what is under the shroud? An accumulation of dirt and debris here can cause real problems; therefore, keep this area between the engine and shroud clean.

Paint can cause a problem. Sometimes a mechanic will reduce the efficiency of the cooling system by the careless use of paint. The engine may look good, but most paints act as an insulator and hold in heat. In addition to keeping the cooling components clean, you must inspect them each time the engine is serviced. Replace or repair any broken or bent parts. Check the fins for cracks or breaks. When cracks extend into the combustion chamber area, the cylinder barrel must be replaced.

Now that we have studied the simplest method of cooling, let us look at the most common, but also the most complex system.

1.2.0 Liquid-Cooled System

Nearly all multi cylinder engines used in automotive, construction, and material-handling equipment use a liquid-cooled system. Any liquid used in this type of system is called a coolant.

A simple liquid-cooled system consists of a radiator, coolant pump, piping, fan, thermostat, and a system of water jackets and passages in the cylinder head and block through which the coolant circulates (*Figure 6-2*). Some vehicles are equipped with a coolant distribution tube inside the cooling passages that directs additional coolant to the points where temperatures are highest. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The operation of a liquid cooled system is as follows:

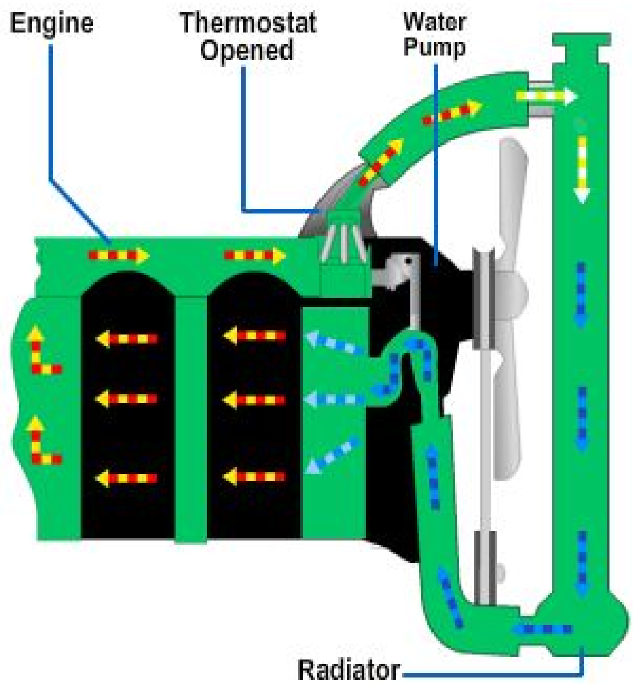

Figure 6-2 — Liquid-cooled System.

- The pump draws the coolant from the bottom of the radiator, forcing the coolant through the water jackets and passages, and ejects it into the upper radiator tank.
- The coolant then passes through a set of tubes to the bottom of the radiator from which the cooling cycle begins.
- The radiator is situated in front of a fan that is driven either by the water pump or an electric motor. The fan ensures airflow through the radiator at times when there is no vehicle motion.
- The downward flow of coolant through the radiator creates what is known as a thermo siphon action. This simply means that as the coolant is heated in the jackets of the engine, it expands. As it expands, it becomes less dense and therefore lighter. This causes it to flow out of the top outlet of the engine and into the top tank of the radiator.

- As the coolant is cooled in the radiator, it again becomes more dense and heavier. This causes the coolant to settle to the bottom tank of the radiator.
- The heating in the engine and the cooling in the radiator therefore create a natural circulation that aids the water pump.

The amount of engine heat that must be removed by the cooling system is much greater than is generally realized. To handle this heat load, it may be necessary for the cooling system in some engines to circulate 4,000 to 10,000 gallons of coolant per hour. The water passages, the size of the pump and radiator, and other details are so designed as to maintain the working parts of the engine at the most efficient temperature within the limitation imposed by the coolant.

1.2.1 Radiator

In the cooling system, the radiator is a heat exchanger that removes the heat from the coolant passing through it. The radiator holds a large volume of coolant in close contact with a large volume of air so heat will transfer from the coolant to the air. The components of a radiator are as follows:

- Core—the center section of the radiator made up of tubes and cooling fins.
- Tanks—the metal or plastic ends that fit over core tube ends to provide storage for coolant and fittings for the hoses.
- Filler neck—the opening for adding coolant. It also holds the radiator cap and overflow tube.

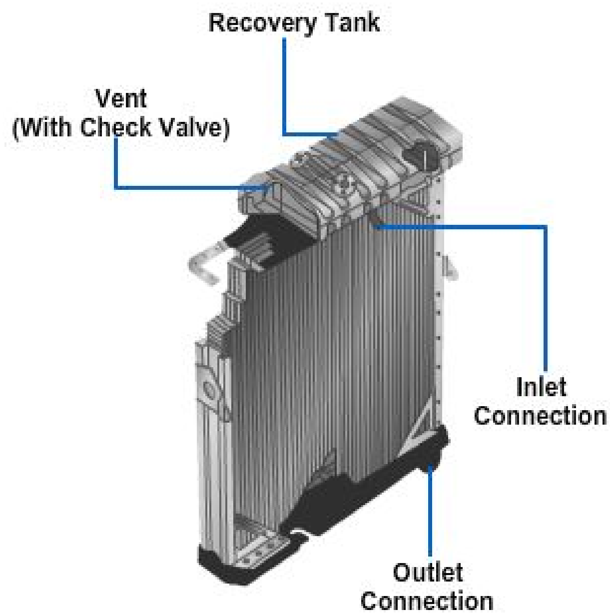

Figure 6-3 — Radiator.

- Oil cooler—the inner tank for cooling automatic transmission or transaxle fluid.
- Petcock—the fitting on the bottom of the tank for draining coolant.

A tube-and-fin radiator consists of a series of tubes extending from top to bottom or from side to side (*Figure 6-3*). The tubes run from the inlet tank to the outlet tank. Fins are placed around the outside of the tubes to improve heat transfer. Air passes between the fins. As the air passes by, it absorbs heat from the coolant. In a typical radiator, there are five fins per inch. Radiators used in vehicles that have air conditioning have seven fins per inch. This design provides the additional cooling surface required to handle the added heat load imposed by the air conditioner.

Radiators are classified according to the direction that the coolant flows through them. The two types of radiators are the downflow and crossflow.

- The older, downflow radiator has the coolant tanks on the top and bottom, and the core tubes run vertically. Hot coolant from the engine enters the top tank. The coolant flows downward through the core tubes. After cooling, coolant flows out the bottom tank and back into the engine.
- The crossflow radiator is a design that has the tanks on the sides of the core and is the modern type of radiator. The core tubes are arranged for horizontal coolant

flow. The tank with the radiator cap is normally the outer tank. A crossflow radiator can be shorter, allowing for a lower vehicle hood.

The operation of a radiator is as follows:

- Tanks on each end of the radiator direct coolant flow into the radiator tubes in the core or an outlet that will lead back to the engine.
- The core is made up of numerous rows of small horizontal tubes that connect the left side tank with the right side tank. Sandwiched between the rows of tubes are thin sheet metal fins. As the coolant passes through the tubes to the lower tank, the fins conduct the heat away from it and dissipate this heat into the atmosphere. The dissipation of the heat from the fins is aided by directing a constant air flow between the tube and over the fins.
- The overflow tube provides an opening from the radiator for escape of coolant if the pressure in the system exceeds the regulated maximum. This will prevent rupture of cooling system components.

A transmission oil cooler is often placed in the radiator on vehicles with automatic transmissions. It is a small tank enclosed in one of the main radiator tanks. Since the transmission fluid is hotter than engine coolant, heat is removed from the fluid as it passes through the radiator and cooler.

In downflow radiators, the transmission oil cooler is located in the lower tank. In a crossflow radiator, it is located in the tank having the radiator cap. Both tanks are coolant outlet tanks.

Line fittings from the cooler extend through the radiator tank to the outside. Metal lines from the automatic transmission connect to these fittings. The transmission oil pump forces the fluid through the lines and cooler.

1.2.2 Radiator Hoses

Radiator hoses carry coolant between the engine and the radiator. Being flexible, hoses can withstand the vibration and rocking of the engine without breaking.

The upper radiator hose normally connects to the thermostat housing on the intake manifold or cylinder head. The other end of the hose fits on the radiator. The lower hose connects the water pump inlet and the radiator.

A molded hose is manufactured into a special shape with bends to clear the parts, especially the cooling fan. It must be purchased to fit the exact year and make of the vehicle.

A flexible hose has an accordion shape and can be bent to different angles. The pleated construction allows the hose to bend without collapsing and blocking coolant flow. It is also known as a universal type radiator hose.

A hose spring is used in the lower radiator hose to prevent its collapse. The lower hose is exposed to suction from the water pump. The spring assures that the inner lining of the hose does NOT tear away, close up, and stop circulation.

1.2.3 Radiator Pressure Cap

The radiator pressure cap is used on nearly all of the modern engines (*Figure 6-4*). The radiator cap locks onto the radiator tank filler neck, rubber or metal seals make the cap-to-neck joint airtight. The functions of the pressure cap are as follows:

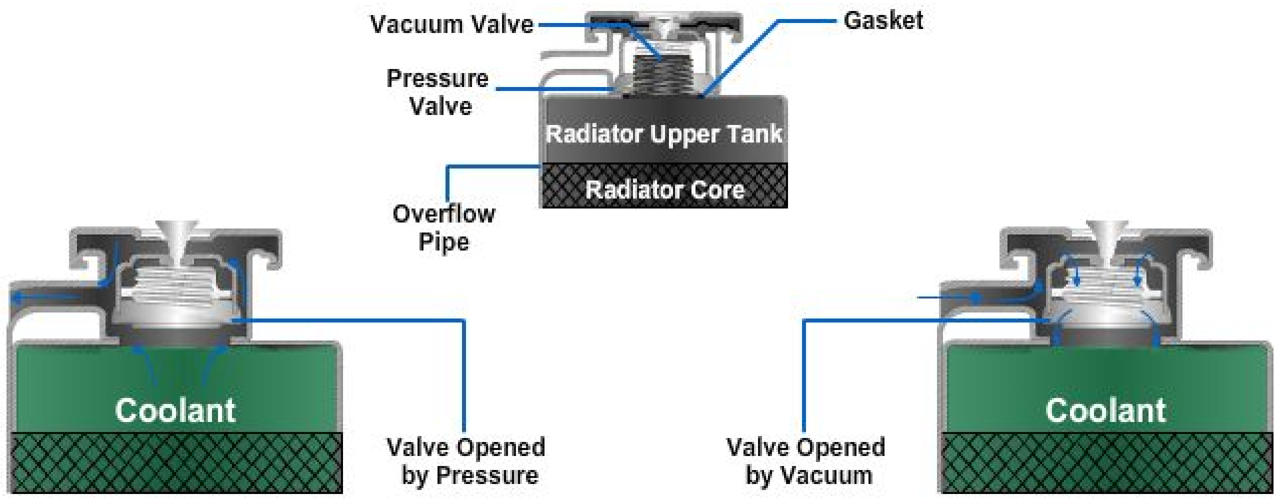

Figure 6-4 — Radiator Cap.

- Seals the top of the radiator tiller neck to prevent leakage.
- Pressurizes the system to raise the boiling point of the coolant.
- Relieves excess pressure to protect against system damage.
- In a closed system, it allows coolant flow into and from the coolant reservoir.

The radiator cap pressure valve consists of a spring-loaded disc that contacts the filler neck. The spring pushes the valve into the neck to form a seal. Under pressure, the boiling point of water increases. Normally, water boils at 212°F. However, for every pound of pressure increase, the boiling point goes up 3°F.

Typical radiator cap pressure is 12 to 16 psi. This raises the boiling point of the engine coolant to about 248°F. Many surfaces inside the water jackets can be above 212°F.

If the engine overheats and the pressure exceeds the cap rating, the pressure valve opens. Excess pressure forces coolant out of the overflow tube and into the reservoir or onto the ground. This prevents high pressure from rupturing the radiator, gaskets, seals, or hoses.

The radiator cap vacuum valve opens to allow reverse flow back into the radiator when the coolant temperature drops after engine operation. It is a smaller valve located in the center, bottom of the cap.

The cooling and contraction of the coolant and air in the system could decrease coolant volume and pressure. Outside atmospheric pressure could then crush inward on the hoses and radiator. Without a cap vacuum or vent valve, the radiator hose and radiator could collapse.

CAUTION

Always remove the radiator cap slowly and carfully. Removing the radiator cap from a hot pressurized system can cause serious burns from escaping steam and coolant.

1.2.4 Fan and Shroud

The cooling system fan pulls a large volume of air through the radiator core that cools the hot water circulating through the radiator. A fan belt or an electric motor drives the fan. A fan driven by a fan belt is known as an engine-powered fan and is bolted to the water pump hub and pulley. Sometimes a spacer fits between the fan and pulley to move the fan closer to the radiator. Besides removing heat from the coolant in the radiator, the flow of air created by the fan causes some direct cooling of the engine itself.

Fan blades are spaced at intervals around the fan hub to aid in controlling vibration and noise. They are often curled at the tip to increase their ability to move air. Except for differences in location around the hub, most blades have the same pitch and angularity.

Bent fan blades are very common and result in noise, vibration, and excess wear on the water pump shaft. You should inspect the fan blades, pulleys, pump shaft end play, and drive belt at every preventive maintenance inspection.

A variable pitch (flex) fan has thin, flexible blades that alter airflow with engine speed. These fan blades are made to change pitch as the speed of the fan increases so that the fan will not create excessive noise or draw excessive engine power at highway speeds. At low speeds, the fan blades remain curved and pull air through the radiator. At higher speeds, the blades flex until they are almost straight. This reduces fan action and saves engine power.

The fluid coupling fan clutch is designed to slip at high speeds, performing the same function as a flexible fan. The clutch is filled with silicone-based oil. Fan speed is controlled by the torque-carrying capacity of the oil. The more oil in the coupling, the greater the fan speed; the less oil in the coupling, the slower the fan speed.

The thermostatic fan clutch has a temperature-sensitive, bimetallic spring that controls fan action. The spring controls oil flow in the fan clutch. When cold, the spring causes the clutch to slip, speeding engine warm-up. After reaching operating temperature, the spring locks the clutch, providing forced air circulation.

An electric engine fan uses an electric motor and a thermostatic switch to provide cooling action. An electric fan is used on front-wheel drive vehicles having transverse mounted engines. The water pump is normally located away from the radiator.

The fan motor is a small, direct current (DC) motor. It mounts on a bracket secured to the radiator. A metal or plastic fan blade mounts on the end of the motor shaft.

A fan switch or temperature-sensing switch controls fan motor operation. When the engine is cold, the switch is open, keeping the fan from spinning and speeding engine warm-up. When coolant temperature reaches approximately 210°F, the switch closes to operate the fan and provide cooling.

An electric engine fan saves energy and increases cooling system efficiency. It functions only when needed. By speeding engine warm-up, it reduces emissions and fuel consumption. In cold weather, the electric fan may shut off at highway speeds. There may be enough cool air rushing through the grille of the vehicle to provide adequate cooling. On some models a timed relay may be incorporated that allows the fan to run for a short time after engine shutdown. This, in conjunction with thermosiphon action, helps to prevent boil over after engine shutdown.

The radiator shroud ensures that the fan pulls air through the radiator. It fastens to the rear of the radiator and surrounds the area around the fan. When the fan is spinning, the shroud keeps air from circulating between the back of the radiator and the front of the fan. As a result, a large volume of air flows through the radiator core.

1.2.5 Water Jacket

The water passages in the cylinder block and cylinder head form the engine water jacket as shown in *Figure 6-5*. In the cylinder block, the water jacket completely surrounds all cylinders along their full length. Within the jacket, narrow passages are provided between the cylinders for coolant circulation around them. In addition, water passages are provided around the valve seats and other hot parts of the cylinder block. In the cylinder head, the water jacket covers the combustion chambers at the top of the cylinders and contains passages around the valve seats when the valves are located in the head.

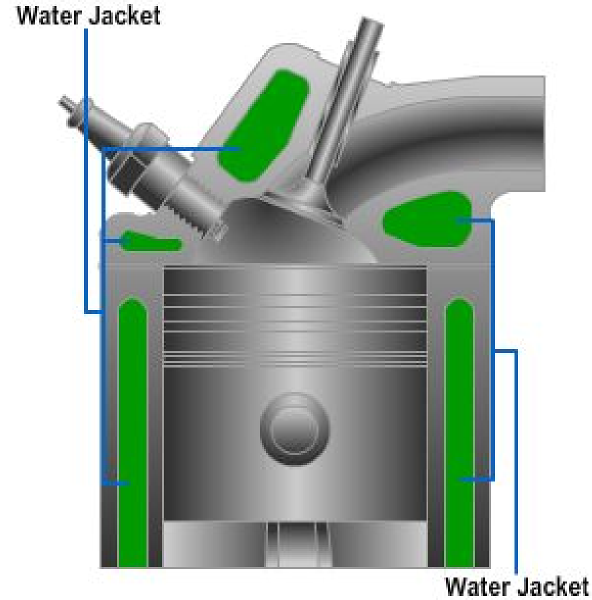

Figure 6-5 — Water jacket.

The passages of the water jacket are designed to control circulation of coolant and provide proper cooling throughout the engine. The pump forces coolant directly from the radiator tank connection into the forward portion of the cylinder block. This type of circulation would, obviously, cool the number one cylinder first, causing the rear cylinder to accept coolant progressively heated by the cylinders ahead. To prevent this condition, the L-head block is equipped with a coolant distribution tube that extends from front to rear of the block, having holes adjacent to (and directed at) the hottest parts of each cylinder. I-head engines are equipped with ferrule type coolant directors that direct a jet of coolant toward the exhaust valve seats.

1.2.6 Thermostats

Automatic control of the temperature of the engine is necessary for efficient engine performance and economical operation. If the engine is allowed to operate at a low temperature, sludge buildup and excessive fuel consumption will occur. On the other hand, overheating the engine or operating it above normal temperature will result in burnt valves and faulty lubrication. The latter causes early engine failure.

The thermostat senses engine temperature and controls coolant flow through the radiator. It allows coolant to circulate freely only within the block until the desired temperature is reached. This action shortens the warm-up period. The thermostat normally fits under the thermostat housing between the engine and the end of the upper radiator hose. The pellet-type thermostat that is used in modern pressurized cooling systems incorporates the piston and spring principle (*Figure 6-6*). The thermostat consists of a valve that is operated by a piston or a steel pin that fits into a small case containing a copper-impregnated wax pellet. A spring

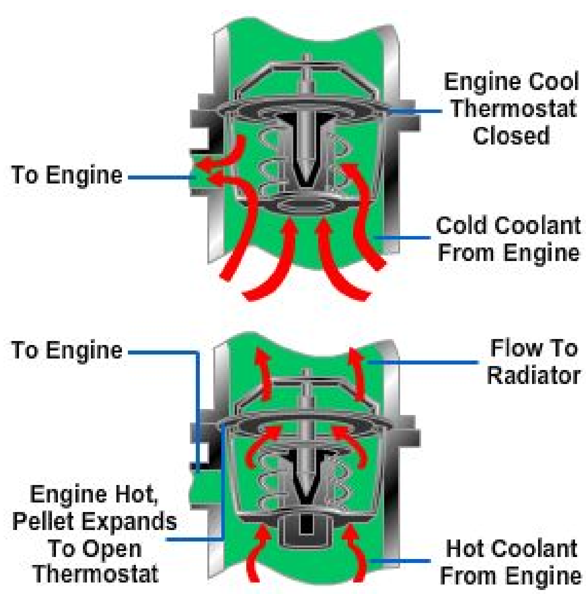

Figure 6-6 — Thermostat.

holds the piston and valve in a normally closed position. When the thermostat is heated, the pellet expands and pushes the valve open. As the pellet and thermostat cool, spring tension overcomes pellet expansion and the valve closes.

Thermostats are designed to open at specific temperatures. This is known as thermostat rating. Normal ratings are between 180°F and 195°F for automotive applications and between 170°F and 203°F for heavy-duty applications. Thermostats will begin to open at their rated temperature and are fully open about 20°F higher. For example, a thermostat with a rating of 195°F starts to open at that temperature and is fully open at about 215°F.

Most engines have a small coolant bypass passage that permits some coolant to circulate within the cylinder block and head when the engine is cold and the thermostat is closed. This provides equal warming of the cylinders and prevents hot spots. When the engine warms up, the bypass must close or become restricted. Otherwise, the coolant would continue to circulate within the engine and too little would return to the radiator for cooling.

The bypass passage may be an internal passage or an external bypass hose. The bypass hose connects the cylinder block or head to the water pump. There are two internal bypass systems that can be used on an engine.

- One internal bypass system uses a small, spring-loaded valve located in the back of the water pump. The valve is forced open by coolant pressure from the pump when the thermostat is closed. As the thermostat opens, the coolant pressure drops within the engine and the bypass valve closes.
- Another bypass system has a blocking-bypass thermostat (*Figure 6-7*). This thermostat operates as previously described, but it also has a secondary, or bypass, valve. When the thermostat valve is closed, the circulation to the radiator is shut off. However, when the bypass valve is open, coolant is allowed to circulate through the bypass. As the thermostat valve opens, coolant flows into the radiator and the bypass valve closes.

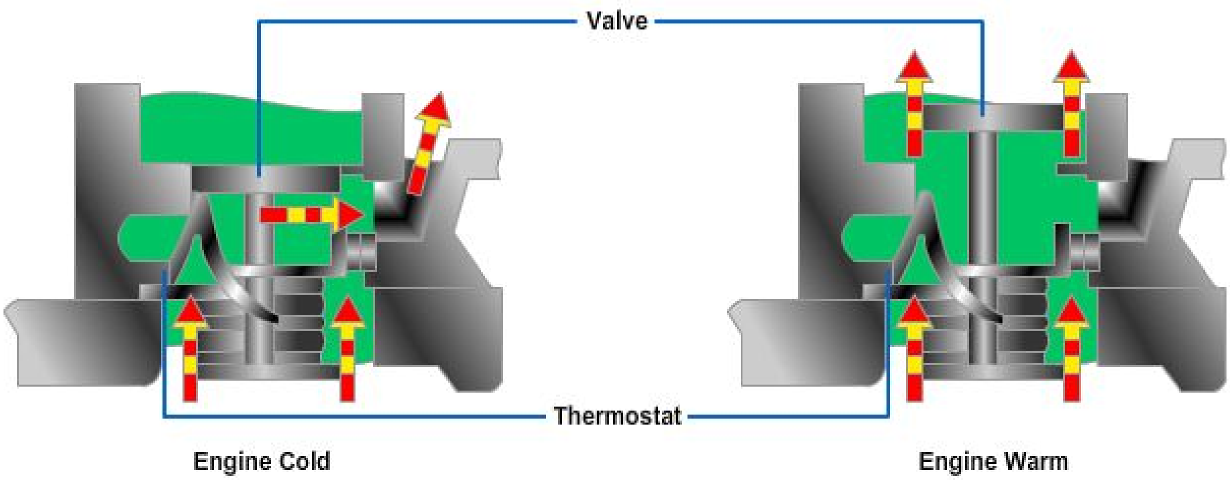

Figure 6-7 — Bypass Thermostat.

Some stationary engines and large trucks are equipped with shutters that supplement the action of the thermostat in providing a faster warm-up and in maintaining proper operating temperatures. When the engine coolant is below a predetermined temperature, the shutters, located in front of the radiator, remain closed and restrict the flow of air through the radiator. Then as the coolant reaches proper temperature, the shutters start to open. Two methods are used to control the shutter opening. A stationary engine uses a shutterstat (long thermostatic valve) connected to the engine cooling system with hoses or pipes that allow the coolant to circulate through the valve. The temperature of the coolant, when it reaches a predetermined temperature, causes the valve to expand, extending a rod which through linkage forces the shutters open. Trucks equipped with an air brake use a smaller thermostatic valve that actuates an air valve. This air valve allows pressure from the air tank to enter the air cylinder attached to the shutter-operating mechanism, forcing the shutters open.

1.2.7 Expansion (Recovery) Tank

Many cooling systems have a separate coolant reservoir or expansion tank, also called the recovery tank. It is partly filled with coolant and is connected to the overflow tube from the radiator filler neck. The coolant in the engine expands as the engine heats up. Instead of dripping out of the overflow tube onto the ground and being lost out of the system completely, the coolant flows into the expansion tank.

When the engine cools, a vacuum is created in the cooling system. The vacuum ***siphons*** some of the coolant back into the radiator from the expansion tank. In effect, a cooling system with an expansion tank is a closed cooling system (*Figure 6-8*). Coolant can flow back and forth between the radiator and the expansion tank. This occurs as the coolant expands and contracts from the heating and cooling. Under normal conditions, no coolant is lost. Coolant is added in this system through the expansion tank that is marked for proper coolant level. NEVER remove the cap located on the radiator unless you are positive the system is cold. If there is any pressure in the radiator, it will spray

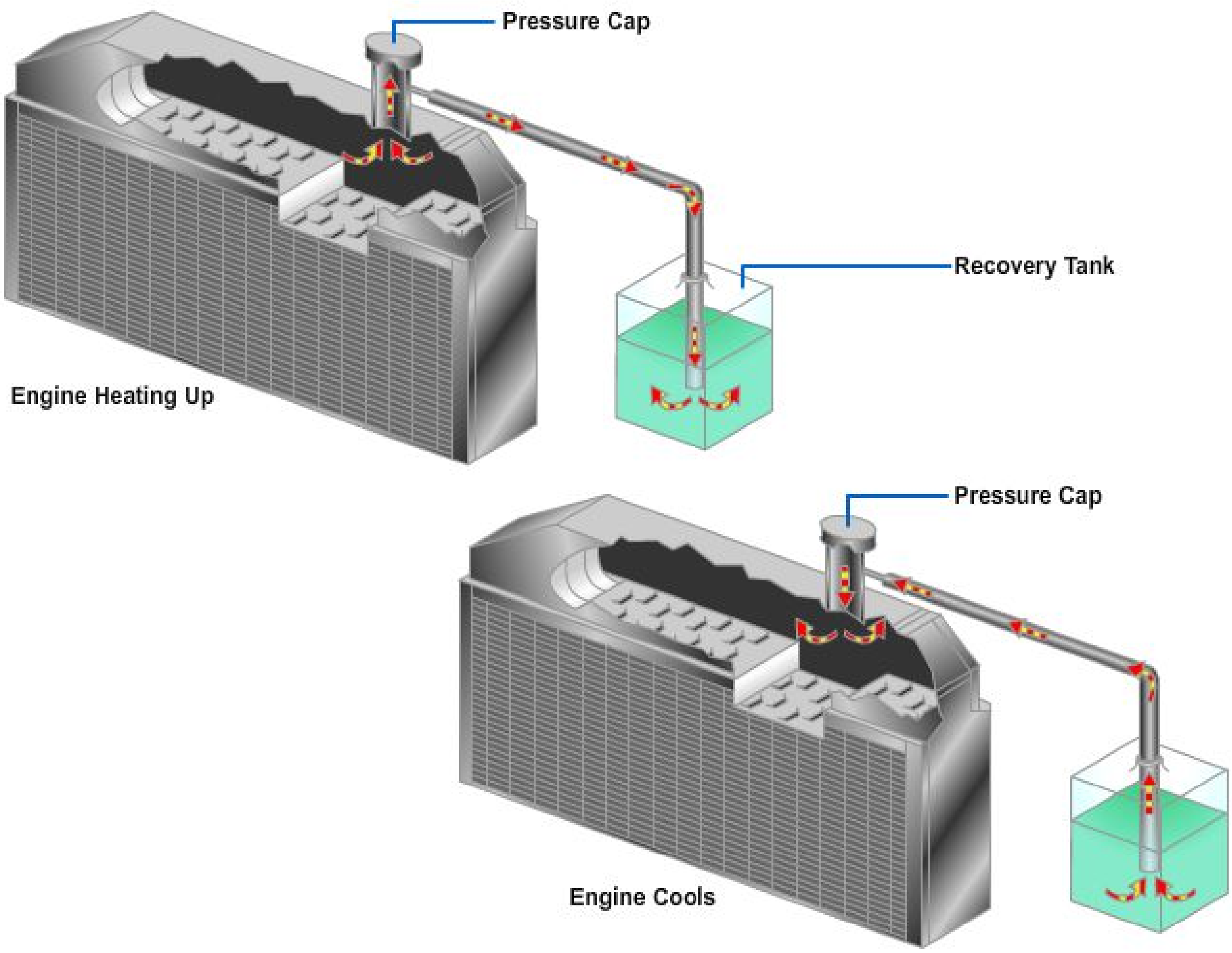

Figure 6-8 — Expansion recovery tank.

you with hot steam and coolant. Use extreme caution whenever you work around a closed cooling system.

An advantage to the use of an expansion tank is that it eliminates almost all air bubbles from the cooling system. Coolant without bubbles absorbs heat better. Although the coolant level in the expansion tank goes up and down, the radiator and cooling system are kept full. This results in maximum cooling efficiency.

1.2.8 Temperature Gauge and Warning Light

The operator should be warned if the temperature of the coolant in the cooling system goes too high. For this reason, a temperature gauge or warning light is installed in the instrument panel of the vehicle. An abnormal heat rise is a warning of abnormal conditions in the engine. The warning lights alert the operator to stop the vehicle before serious engine damage can occur. Temperature gauges are of two general types—the balancing-coil (magnetic) type and the bimetal thermostat (thermal) type.

The balancing-coil consists of two coils and an armature to which a pointer is attached. An engine-sending unit that changes resistance with temperature is placed in the engine so that the end of the unit is in the coolant. When the engine is cold, only a small amount of current is allowed to flow through the right coil; the left coil has more magnetism than the right coil. The pointer, attached to the armature, moves left indicating that the engine is cold. As the engine warms up, the sending unit passes more current. More current flows through the right coil, creating a stronger magnetic field. Therefore, the pointer moves to the right to indicate a higher coolant temperature.

The bimetal-thermostat is similar to the balancing-coil type except for the use of a bimetal thermostat in the gauge. This thermostat is linked to the pointer. As the sending unit warms up and passes more current, the thermostat heats up and bends. This causes the pointer to swing to the right to indicate that the engine coolant temperature is rising.

A temperature warning light informs the operator when the vehicle is overheating. When the engine coolant becomes too hot, a sending unit in the engine block closes, completing the circuit and the dash indicating light comes ON. The indicating light warns of an overheating condition about 5°F to 10°F below coolant boiling point.

In some construction equipment a "prove-out" circuit is incorporated in the system. When the ignition switch is turned from OFF to RUN, the light comes on, proving that the system is operating. If the light does not come on, either the bulb is burned out or the sending unit or connecting wire is defective. The light will go out normally after the engine starts.

1.2.9 Coolants and Antifreeze

Since water is easily obtained, cheap, and able to transfer heat readily, it has served as a basic coolant for many years. Some properties of water, such as its boiling point, freezing point, and natural corrosive action on metals, limit its usefulness as a coolant. To counteract this, use antifreeze.

Antifreeze, usually ethylene glycol, is mixed with water to produce the engine coolant. Antifreeze has several functions:

- Prevents winter freeze up, which can cause serious damage to the engine and cooling system.
- Prevents rust and corrosion by providing a protective film on the metal surfaces.

- Lubricates the water pump, which increases the service life of the pump and seals.
- Cools the engine; prevents overheating in hot weather.

For ideal cooling and winter protection, a 50/50 mixture of antifreeze and water is recommended. It will provide protection from ice formation to about –35°F. Higher ratios of antifreeze produce even lower freezing temperatures; for example, a 60/40 mixture will protect the cooling system to about –62°F. However, this much protection is not normally needed.

A mixture of antifreeze and water also raises the boiling point of water. A 50/50 mixture has about an 11°F higher boiling point over just plain water. A mixture of up to a 70/30 can be used in severe climates.

WARNING

Ethylene glycol is a toxic material. Avoid prolonged skin contact or accidental ingestion. Wear protective gloves and goggles while handling antifreeze and coolants.

1.3.0 Servicing the Liquid-Cooled System

A cooling system is extremely important to the performance and service life of the engine. Major engine damage could occur in a matter of minutes without proper cooling because combustion heat collects in metal engine parts. This heat can melt pistons, crack or warp the cylinder head or block, and cause valves to burn or the head gasket to "blow." To prevent these costly problems, keep the cooling system in good condition.

As a mechanic, you must be able to locate and correct cooling system problems quickly and accurately. It is equally important that you know how to service a cooling system.

1.3.1 Flushing the System

The original additives in antifreeze fight rust and corrosion breakdown but are ineffective after 1 to 2 years. This is because of the continual exposure to the heat in the cooling system. After the additives break down, rust rapidly begins to form. Therefore, rust-colored antifreeze is an indication that the cooling system service is required.

The cooling system should be cleaned periodically to remove rust, scale, grease, oil, and any acids formed by exhaust-gas leakage into the coolant.

Flushing (cleaning) of a cooling system should be done based on the manufacturer’s recommendations or when rust and other contaminants are found in the system. Flushing involves running water or a cleaning chemical through the cooling system to wash out contaminants. Rust is very harmful to the cooling system because it causes premature water pump wear and can collect and clog the radiator or heater core tubes. There are three methods of flushing - fast flushing, reverse flushing, and chemical flushing.

Fast flushing is a common method of cleaning a cooling system because the thermostat does not have to be removed from the engine. A water hose is connected to a heater hose fitting. The radiator cap is removed and the petcock is opened. When the water hose is ON and water flows through the system, loose rust and scale are removed.

Reverse flushing of a radiator requires a special flushing gun device that is connected to the radiator outlet tank by a piece of hose (*Figure 6-9*). Another hose is attached to the inlet tank so the water and debris can be directed to the floor drains. Compressed air under low pressure is used to force water through the radiator core backwards. The air

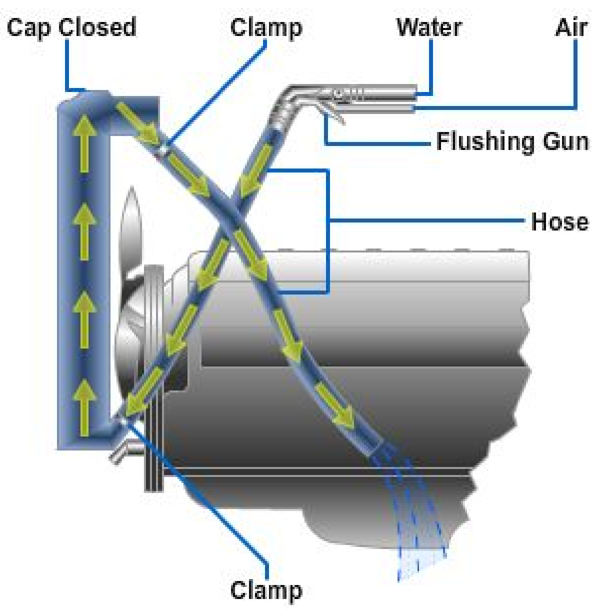

Figure 6-9 — Reverse flushing of a radiator.

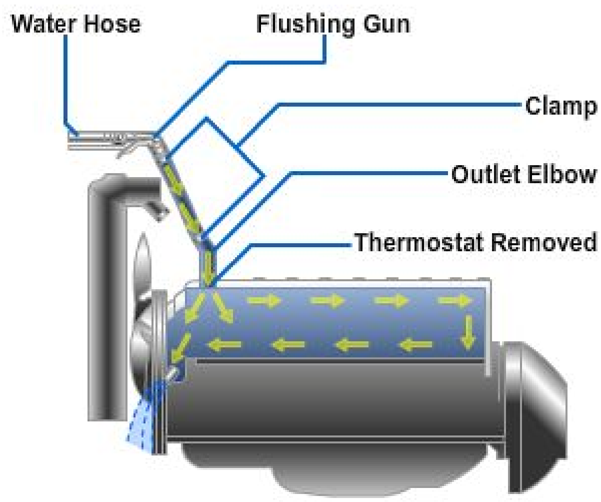

Figure 6-10 — Reverse flushing of a water jacket.

pressure is used intermittently to loosen scale and sediment. Excessive air pressure should be avoided to prevent damage to the radiator; therefore, it should not be used on radiators with plastic tanks. Starting and stopping the water flow produces a fluctuation in pressure and tends to loosen all foreign matter clinging to the passages in the radiator core.

Reverse flushing can also be used on the engine block and head (*Figure 6-10*). First, remove the thermostat and disconnect the upper radiator hose. Then disconnect the lower radiator hose at the water pump. Insert the flushing equipment in the upper radiator hose. Reverse flush the system by sending water and air through the water jackets and coolant passages. Following the flushing, replace the thermostat and hoses so the system can be refilled.

When reverse flushing equipment is not available, you can still reverse flush the system with a garden hose. This is often effective following the use of a chemical cleaner.

Chemical flushing is needed when a scale buildup in the system is causing engine overheating. Add the chemical cleaner to the coolant. Run the engine at fast idle for about 20 minutes. Wait for the engine to cool. Then drain out the coolant and cleaner solution. Using a garden hose, flush out the loosened rust and scale. Continue to flush until the water runs clear.

CAUTION

Always follow manufacturer's instructions when using a cooling system cleaning agent. Wear protective gloves and goggles when handling cleaning agents. Chemicals may cause eye and skin burns.

1.3.2 Antifreeze Service

Antifreeze should be checked and changed at regular intervals. After prolonged use, antifreeze will break down and become very corrosive. It can lose its rust preventative properties and the cooling system can fill rapidly with rust.

A visual inspection of the antifreeze will help determine its condition. Rub your fingers inside the radiator filler neck. Check for rust, oil (internal engine leak), scale, or transmission fluid (leaking oil cooler).

Also check to find out how long the antifreeze has been in service. If contaminated or too old, replace the antifreeze. If badly rusted, you may need to flush the system. Antifreeze should be changed when contaminated or when 2 years old. Check the service manual for exact change schedules.

Antifreeze strength is a measurement of the concentration of antifreeze compared to water. It determines the freeze-up protection of the solution. There are two devices used to check antifreeze strength—the antifreeze hydrometer and the refractometer.

- The antifreeze hydrometer is used to measure the freezing point of the cooling system. A squeeze and release bulb draws coolant into the tester, and a needle floats to show the freeze protection point.
- With the refractometer, you draw coolant into the tester. Then you place a few drops of coolant on the measuring window (surface). Aim the tester at a light and view through the tester sight. The scale in the refractometer indicates the freeze protection point.

Minimum antifreeze strength should be several degrees lower than the lowest possible temperature for the climate of the area. For example, if the lowest normal temperature for the area is 10°F, the antifreeze should test to -20°F. A 50/50 mixture of antifreeze and water is commonly used to provide protection for most weather conditions.

⚠ CAUTION ⚠

Vehicles using an aluminum cooling system and engine parts can be corroded by some types of antifreeze. Use only antifreeze designed for aluminum components. Check the vehicle's service manual or antifreeze label for details.

1.4.0 Cooling System Tests

It is often necessary to check the cooling system for cooling system problems, which can be grouped into three general categories:

- Coolant leaks—crack or rupture, allowing pressure cap action to push coolant out of the system.
- Overheating—engine operating temperature too high, warning light on, temperature gauge shows hot, or coolant and steam are blowing out the overflow.
- Overcooling—engine fails to reach full operating temperature, engine performance poor or sluggish.

To diagnose and repair cooling system problems, perform several tests. These tests include the cooling system pressure test, combustion leak test, thermostat test, engine fan test, and fan belt test.

1.4.1 Cooling System Pressure Test

A cooling system pressure test is used to locate leaks quickly. Low air pressure is forced into the system, causing coolant to pour or drip from any leak in the system.

A pressure tester is a hand-operated air pump used to pressurize the system for leak detection. Install the pressure tester on the radiator filler neck. Then pump the tester until the pressure gauge reads radiator cap pressure.

WARNING

Do not pump too much pressure into the cooling system or damage may result.

With pressure in the system, inspect all parts for coolant leakage. Check at all fittings, at gaskets, under the water pump, around the radiator, and at engine freeze (core) plugs. Once the leak is located, tighten, repair, or replace parts as needed.

A pressure test can also be applied to the radiator cap. The radiator pressure test measures cap-opening pressure and checks the condition of the sealing washer. The cap is installed on the cooling system pressure tester.

Pump the tester to pressurize the cap. Watch the pressure gauge. The cap should release pressure at its rated pressure (pressure stamped on cap). It should also hold that pressure for at least 1 minute. If not, install a new cap.

1.4.2 Combustion Leak Test

A combustion leak test is designed to check for the presence of combustion gases in the engine coolant. It should be performed when signs (overheating, bubbles in the coolant, or a rise in coolant level upon starting) point to a blown head gasket, cracked block, or cracked cylinder head.

A block tester, often called a combustion leak tester, is placed in the radiator filler neck. The engine is started and the test bulb is squeezed and then released. This will pull air from the radiator through the test fluid.

The fluid in the block tester is normally blue. The chemicals in the exhaust gases cause a reaction in the test fluid, changing its color. A combustion leak will turn the fluid yellow. If the fluid remains blue, there is no combustion leak.

Combustion leakage into the cooling system is very damaging. Exhaust gases mix with the coolant and form corrosive acids. The acids can cause holes in the radiator and corrode other components.

An exhaust gas analyzer will also detect combustion pressure leakage into the coolant. Place the analyzer probe over the filler neck and accelerate the engine. The probe will pick up any hydrocarbons (HC) leaking from the system, which indicates combustion leakage.

1.4.3 Thermostat Test

To check thermostat action, watch the coolant through the radiator neck. When the engine is cold, coolant should not flow through the radiator. When the engine warms, the thermostat should open. Coolant should begin to circulate through the radiator. If this action does not occur, the thermostat may be defective.

There are several ways to test a thermostat. The most common is to suspend the thermostat in a container of water together with a high-temperature thermometer. Then by heating the container on a stove or hot plate, you can determine the temperature at which the thermostat begins to open, as well as when it is full open. If the thermostat fails to respond at specified temperatures, it should be discarded. Specifications vary on different thermostats. For example, for a thermostat with an opening temperature of

180°F to 185°F, the full-open temperature is 200°F to 202°F. If the test is satisfactory, the thermostat can be reinstalled.

You can also use a digital thermometer to check the operating temperature of an engine and thermostat. Simply touch the tester probe on the engine next to the thermostat housing and note its reading. If the thermostat does not open at the correct temperature, it is defective and should be replaced.

The use of a temperature stick is another way to test a thermostat quickly. The temperature stick is a pencil-like device that contains a wax material containing certain chemicals that melt at a given temperature. Using two sticks (one for opening temperature and the other for full-open temperature), rub the sticks on the thermostat housing. As the coolant warms to operating temperature, the wax-like marks will melt. If the marks do not melt, the thermostat is defective and needs to be replaced.

1.4.4 Engine Fan Test

A faulty engine fan can cause overheating, overcooling, vibration, and water pump wear or damage. Testing the fan ensures that it is operating properly.

To test a thermostatic fan clutch, start the engine. The fan should slip when cold; as the engine warms up, the clutch should engage. Air should begin to flow through the radiator and over the engine. You will be able to hear and feel the air when the fan clutch locks up.

If the fan clutch is locked all the time (cold or hot), it is defective and must be replaced. Excessive play or oil leakage also indicates fan clutch failure.

When testing an electric cooling fan, observe whether the fan turns ON when the engine is warm. Make sure the fan motor is spinning at normal speed and forcing enough air through the radiator.

If the fan does not function, check the fuse, electrical connections, and supply voltage to the motor. If the fan motor fails to operate with voltage applied, replace it.

If the engine is warm and no voltage is supplied to the fan motor, check the action of the fan switch. Use either a voltmeter or test light. The switch should have almost zero resistance (pass current and voltage) when the engine is warm. Resistance should be infinite (stop current and voltage) when the engine is cold.

If these tests do not locate the trouble with the electric cooling fan, refer to the manufacturer’s service manual for instructions. There may be a defective relay, connection, or other problem.

1.5.0 Service and Repair of Cooling System Components

The individual components of the cooling system which require servicing and repair include the water pump, thermostat, hoses, fan and fan belt, and the radiator and pressure cap. Proper service of the components ensures an efficient cooling system and extends the life of the vehicle.

1.5.1 Water Pump

A water pump (*Figure 6-11*) is required in order to maintain proper operating temperature within an engine. A bad water pump may leak coolant, fail to circulate coolant, or produce a grinding sound. Rust in the cooling system or lack of antifreeze is the most common causes for pump failure. These conditions can accelerate seal, shaft, and bearing wear. An over-tightened fan belt will also cause water pump failure.

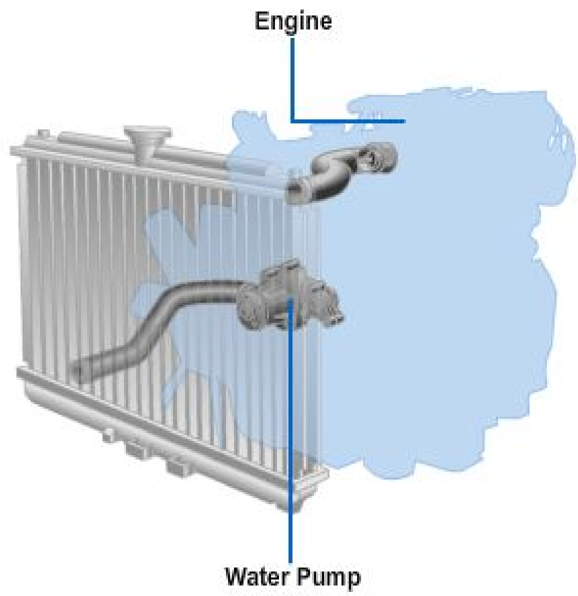

Figure 6-11 — Water pump.

To check for a worn water pump seal, pressure test the system and watch for coolant leakage. Coolant will leak out of the small drain hole at the bottom of the pump or at the end of the pump shaft.

Worn water pump bearings are checked by wiggling the fan or pump pulley up and down. If the pump shaft is loose in its housing, the pump bearings are badly worn. A ***stethoscope*** can also be used to listen for worn, noisy water pump bearings.

Water pump action can be checked with a warm engine. Squeeze the top radiator hose while someone starts the engine. You should feel a pressure surge (hose swelling) if the pump is working. If not, pump shaft or impeller problems are indicated. You can also watch for coolant circulation in the radiator with the engine at operating temperature.

Whether a defective pump is replaced or rebuilt depends on parts supply and cost. A water pump rebuild involves disassembly, cleaning, part inspection, worn part replacement, and reassembly. Few mechanics rebuild water pumps because rebuilding takes too much time and is not cost effective.

The removal and installation of the water pump varies with different vehicles. Therefore, consult the applicable shop manual for the step-by-step procedures.

When you replace a pump, install a new gasket. Make sure the mating surfaces are clean and smooth. The application of a gasket sealer to both sides of the gasket is recommended. Then, after refilling the cooling system, check the pump for leaks, noise, and proper operation.

1.5.2 Thermostat

There are no repairs or adjustments to be made on the thermostat. The unit must be replaced when it fails to operate properly. A stuck thermostat can cause either engine overheating or overcooling.

If a thermostat is stuck closed, coolant will not circulate through the radiator. As a result, overheating could make the coolant boil.

When a thermostat is stuck open, too much coolant may circulate through the radiator and the engine may not reach proper operating temperature. The engine may run poorly for extended periods in cold weather. Engine efficiency (power, fuel mileage, and drivability) will be reduced.

The procedure for thermostat replacement is as follows:

- To remove the thermostat, drain the coolant and remove the upper radiator hose from the engine.
- Remove the retaining cap screws holding the thermostat housing to the engine. Tap the housing free with a rubber hammer. Lift off the housing and thermostat.
- Scrape all of the old gasket material off the thermostat housing and sealing surface of the engine.
- Make sure that the housing is not warped. Place it on a flat surface and check the gaps between the housing and the surface. If warped, file the surface flat. This action will prevent coolant leakage.
- Make sure the temperature rating is correct. Then place the thermostat into the engine. Normally, the pointed end on the thermostat should face the radiator hose. The pellet chamber should face the inside of the engine.
- Position the new gasket with approved sealer. Start the cap screws by hand. Then torque them to the manufacturer's specifications in an alternating pattern. DO NOT over tighten the housing bolts, or warpage and/or breakage may result. Most housings are made of soft aluminum or "pot metal."

1.5.3 Hoses

Old radiator hoses and heater hoses are frequent causes of cooling system problems. Hoses (*Figure 6-12*) should be checked periodically for leakage and general condition. The leakage may often be corrected by tightening or replacing hose clamps. After a few years of use, hoses deteriorate. They may become soft and mushy, or hard and brittle. Deteriorated hoses should be replaced to prevent future troubles. Cooling system pressure can rupture the hoses and result in coolant loss.

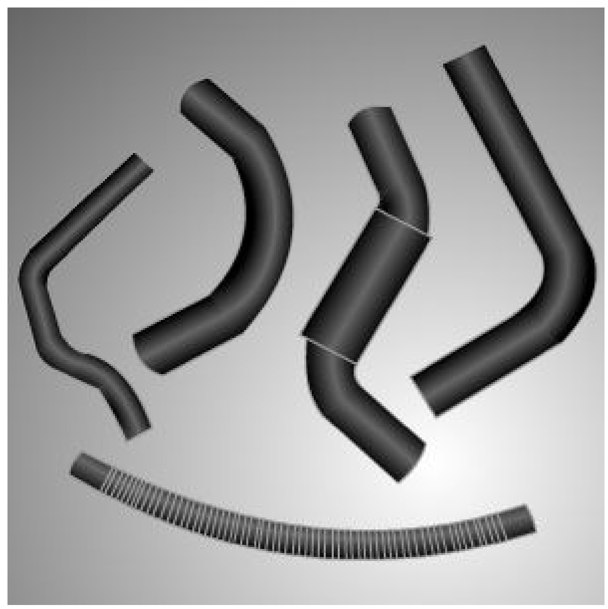

Figure 6-12 — Radiator and heater hoses.

Inspect the radiator and heater hoses for cracks, bulges, cuts, or any other sign of deterioration. Squeeze the hoses to check whether they are hardened, softened, or faulty. Flex or bend heater hoses and watch for signs of surface cracks. If any problem is detected, replace the affected hose. However, where spiral spring stiffeners are used to control the tendency to collapse, such tests will not work and the hose must be removed for inspection.

1.5.4 Fan and Belt

One of the easiest and quickest checks to the cooling system is inspecting the fan and fan belt (*Figure 6-13*). Check the fan for bent blades, cracks, and other problems. A bent or distorted fan or one with a loose blade should be replaced. Where the fan is just loose on its mounting, tightening is in order.

Fan belts, or drive belts, should be checked for wear and tension. Most wear occurs on the underside of the belt. To check a V-belt, twist the belt with your fingers. Check for small cracks, grease, glazing, and tears or splits. Small cracks will enlarge as the belt is flexed. Grease rots the rubber and makes the side slick so that the belt slips easily. A high-pitched squeal results from slippage. Large tears or splits in a belt allow it to be tossed from the pulley. On vehicles with a set of two belts, replace both if one is worn and requires replacement.

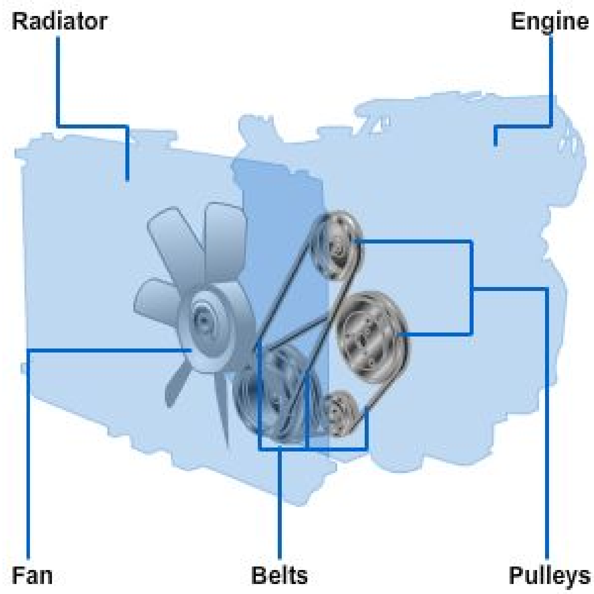

Figure 6-13 — Fan and belt.

Use a belt tension gauge to check and adjust the fan belt tension. When you do not have a gauge or if space does not allow use of a gauge, you can make a quick check of belt tension. Press down on the free span of the belt, a point midway between the alternator or generator pulley and the fan pulley. Measure the amount of deflection. When free span is less than 12 inches between pulleys, belt deflection should be 1/8 to 1/4 inch. When free span is longer than 12 inches, belt deflection should be 1/4 to 1/2 inch.

A slipping belt can cause overheating and a rundown battery. These troubles result because a slipping belt cannot drive the water pump and alternator fast enough for normal operation. Sometimes a belt will slip and make noise even after it is adjusted to the proper tension. Several types of belt dressing are available which can be applied to both sides of the belt to prevent this problem. Belt dressing helps to eliminate noise and increase belt friction.

Check the fan belt every time a vehicle comes in for preventive maintenance (PM) to make sure it is in good condition. Replace a fan belt that has become frayed or has separated plies.

You can usually replace a defective belt by loosening the alternator or generator mounting bolts. With the mounting bolts loose, push the alternator or generator closer to the engine. This action provides enough slack in the belt so it can be removed and a new one installed. After installing a new belt, adjust it to the proper tension and tighten the mounting bolts.

1.5.5 Radiator and Pressure Cap

When overheating problems occur and the system is not leaking, check the radiator and pressure cap. They are common sources of overheating. The pressure cap could have bad seals, allowing pressure loss. The radiator could be clogged and preventing adequate air flow or coolant flow.

Straighten bent fins and check the radiator core for any obstructions tending to restrict the airflow. You can clean radiator air passages by blowing them out with an air hose in the direction opposite to the ordinary flow of air. You can also use water to soften obstructions before applying the air blast. In any event, the cleaning gets rid of dirt, bugs, leaves, straw, and other debris which otherwise would clog the radiator and reduce its cooling efficiency. Sometimes screens are used in front of the radiator core to reduce this type of clogging.

You can check the radiator for internal clogging by removing the hose connections and draining the coolant. Use a garden hose to introduce a stream of water into the top of the radiator. If the flow is sluggish, the radiator is partially clogged. Another way to check for this condition is to feel the radiator with your hand. The radiator should be warm at the bottom and hot at the top, with the temperature uniformly increasing from bottom to top. Any clogged sections will feel cool.

⚠ CAUTION ⚠

Be sure that the engine is off to avoid injury from the fan.

When the use of cleaning compounds and reverse flushing fail to relieve a clogged core, you must remove the radiator for mechanical cleaning. This requires the removal of the radiator tanks and rodding out the accumulated rust and scale from the water passages of the core.

You should also check the radiator pressure cap for condition and proper operation. If it is dirty, you can clean the cap with soap and water, and then rinse it. The seating surface of the vacuum and pressure valves should be smooth and undamaged. The valves should operate freely when pressed against their spring pressure and should seal properly when closed.

During the vehicle's preventive maintenance (PM) inspection, you should check the radiator for leaks, particularly where the tanks are soldered to the core, since vibration and pulsation from pressure can cause fatigue of soldered joints or seams. Neglect of small leaks may result in complete radiator failure, excessive leakage, rust clogging, and overheating. Thus it is extremely important to keep the radiator mounting properly adjusted and tight at all times and to detect and correct even the smallest leaks.

A leak usually reveals its presence by scale marks or watermarks below the leak on the outside of the core. Permanent antifreeze does not leak through spaces where water cannot pass. The antifreeze leak is more noticeable, since it does not evaporate as quickly as water.

Stop-leak compounds can be effective to stop small leaks, at least temporarily. Stop-leak compounds harden upon contact with the air, thus sealing off any small openings. The main problem is that they give the mechanic a sense of false security. For example, stop leak may prevent seepage at a hose connection through the inner lining, but finally the hose will rot and burst, losing coolant and overheating the engine.

Stop-leak compounds can lead to radiator clogging if water tubes already contain deposits that act as a strainer. If coolant level gets too low, some stop-leak ingredients may harden in the upper radiator and block it.

Before using stop leak, check your service manual. The compound must be compatible with the antifreeze and the inhibitors and be installed correctly and in the right quantity.

When large leaks or considerable damage is present, removal of the radiator for extensive repair or replacement is usually required.

Test your Knowledge (Select the Correct Response)

1. When replacing antifreeze, what is the recommended mixture?

   A. 70/30
   B. 60/40
   C. 50/50
   D. 40/60

2. Where is the automatic transmission oil cooler located?

A. In front of the radiator
B. In the radiator
C. In line with the radiator
D. In the transmission

2.0.0 ENGINE LUBRICATING SYSTEMS

All internal combustion engines are equipped with an internal lubricating system (*Figure 6-14*). Without lubrication, an engine quickly overheats and its working parts seize due to excessive friction. All moving parts must be adequately lubricated to assure maximum wear and long engine life.

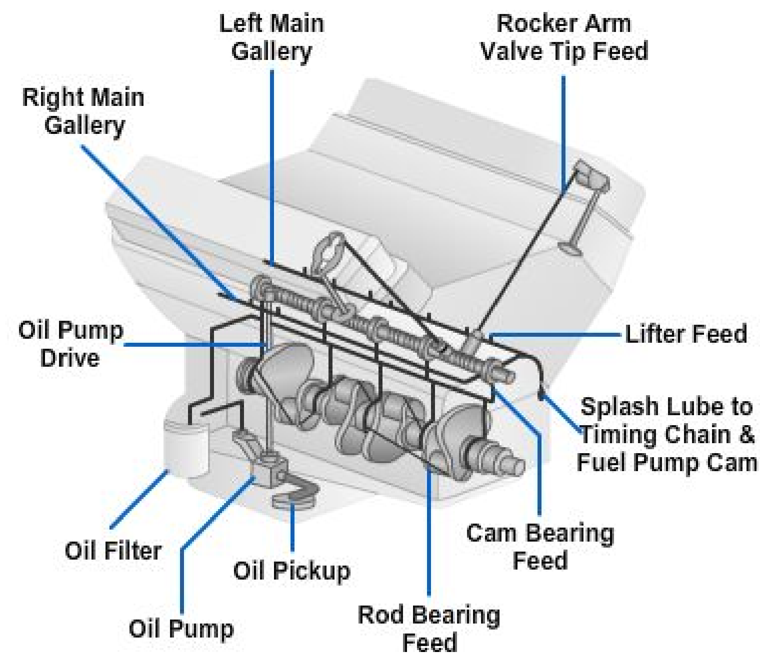

Figure 6-14 — Engine lubrication system.

2.1.0 Purposes of Lubrication

The functions of an engine lubrication system are as follows:

- Reduces friction and wear between moving parts (*Figure 6-15*).
- Helps transfer heat and cool engine parts.
- Cleans the inside of the engine by removing contaminants (metal, dirt, plastic, rubber, and other particles).
- Absorbs shocks between moving parts to quiet engine operation and increase engine life.

The properties of engine oil and the design of modern engines allow the lubrication system to accomplish these functions.

Figure 6-15 — How oil lubricates.

2.2.0 Engine Oil

Engine oil, also called motor oil, is used to produce a lubricating film on the moving parts in an engine. The military specification for this type of oil prescribes that the oil should be petroleum or a synthetic petroleum product, or a combination thereof.

This oil is intended for lubrication of internal-combustion engines other than aircraft engines or for general-purpose lubrication.

2.2.1 Oil Viscosity and Measurements

Oil viscosity, also called oil weight, is the thickness or fluidity (flow ability) of the oil. High viscosity oil is very thick and resists flow. A low viscosity oil is very thin and flows easily.

Oils are graded according to their viscosity by a series of Society of Automotive Engineers (SAE) numbers. The viscosity of the oil increases progressively with the SAE number. An SAE 4 oil would be very light (low viscosity) and SAE 90 oil would be very heavy (high viscosity). The viscosity of the oil used in internal-combustion engines ranges from SAE 5 (arctic use) to SAE 60 (desert use). It should be noted that the SAE number of the oil has nothing to do with the quality of the oil.

The viscosity number of the oil is determined by heating the oil to a predetermined temperature and allowing it to flow through a precisely sized orifice while measuring the rate of flow. The faster an oil flows, the lower the viscosity. The testing device is called a viscosimeter. The viscosity of the oil is printed on top of the oil can. Oil viscosity is written SAE 10, SAE 20, SAE 30, and so on. The letter W will follow any oil that meets SAE low-temperature requirements. An example would be SAE 10W.

Multi-viscosity oil or multi-weight oil has the operating characteristics of a thin, light oil when cold and a thicker, heavy oil when hot. A multi-weight oil is numbered SAE 10W-30, 10W-40, 20W-50, and so on. For example, a 10W-30 oil will flow easily (like 10W oil) when starting a cold engine. It will then act as a thicker oil (like 30 weight) when the engine warms to operating temperature. This will make the engine start more easily in cold weather. It will also provide adequate film strength (thickness) when the engine is at full operating temperature.

Normally, you should use the oil viscosity recommended by the manufacturer. However, in a very cold, high mileage, worn engine, higher viscosity may be beneficial. Thicker oil will tend to seal the rings and provide better bearing protection. It may also help cut engine oil consumption and smoking.

2.2.2 Oil Service Rating

The oil service rating is a set of letters printed on the oil can to denote how well the oil will perform under operating conditions. The American Petroleum Institute (API) sets this performance standard.

The API system for rating oil classifies oil according to its performance characteristics. The higher rated oils contain additives that provide maximum protection against rust, wear, oil oxidation, and thickening at high temperatures. Oils designed for gasoline engines fall under the “S” categories as shown in *Table 6-1*.

Table 6-1 — System rating of oils designed for gasoline engines.

Category	Status	Service
SA	Obsolete	Adequate for utility engines subjected to light loads, moderate speeds, and clean conditions. Straight mineral oil. Contains no additives. For older engines, use only when specifically recommended by the manufacturer.
SB	Obsolete	Adequate for automotive use under favorable conditions (light loads, low speeds, and moderate temperatures) with relatively short oil change intervals. Generally offers only minimal protection to the engine against bearing scuffing, corrosion, and oil oxidation. Use only when specifically recommended by the manufacturer.
SC	Obsolete	For 1964 through 1967 automotive gasoline engines.
SD	Obsolete	For 1968 through 1970 automotive gasoline engines. Offers additional protection over SC oils that are necessary with the introduction of emission controls.
SE	Obsolete	For 1972 through 1979 automotive gasoline engines. Stricter emission requirements created the need for this detergent oil.
SF	Obsolete	For 1980 through 1988 automotive gasoline engines. The SF oil is designed to meet the demands of small, high-revving engines.
SG	Obsolete	For 1989 through 1993 automotive gasoline engines.
SH	Obsolete	For 1994 through 1996 automotive gasoline engines.
SJ	Current	For 1997 through 2001 automotive gasoline engines.
SL	Current	For 2001 through 2003 automotive gasoline engines.
SM	Current	For 2004 through present automotive gasoline engines. Designed to provide a superior resistance to oxidation and provide better engine wear.

Oils designed for diesel engines fall under the “C” category as shown in *Table 6-2*.

Table 6-2 — System rating of oils designed for diesel engines.

CA	Obsolete	For naturally aspirated diesel engines operated on low sulfur fuel, mainly used in the 1940s and 1950s.
CB	Obsolete	For naturally aspirated diesel engines operated on high sulfur fuel used in the 1950s.
CC	Obsolete	For lightly supercharged diesel engines, introduced in 1961.
CD	Obsolete	For moderately supercharged diesel engines, introduced in 1955.
CD-II	Obsolete	For two-stroke cycle diesel engines. Meets requirements of API Service category CD.
CE	Obsolete	For moderately supercharged diesel engines, introduced in 1983. Typical for high load and high speed, also meets requirements of API Service category CD.
CF	Current	For indirect-injection diesel engines that use a broad range of diesel fuel, may be used when category CD is recommended.
CF-2	Current	For severe duty two-stroke cycle diesel engines, may be used when category CD-II is recommended.
CF-4	Obsolete	For high-speed four-stroke cycle naturally aspirated and turbocharged diesel engines, may be used when category CD and CE are recommended.
CG-4	Obsolete	For severe duty, high-speed four-stroke cycle with less than 0.5% weight sulfur, may be used when category CD, CE and CF-4 are recommended.
CH-4	Current	For high-speed four-stroke cycle with less than 0.5% weight sulfur to meet 1988 emissions, may be used when category CD, CE, CF-4 and CG-4 are recommended.
CI-4	Current	For high-speed four-stroke cycle with less than 0.5% weight sulfur to meet 2004 emissions where EGR is used, may be used when category CD, CE, CF-4, CG-4 and CH-4 are recommended. Some CI-4 oils qualify for the PLUS designation by providing a higher level protection soot-related viscosity break down.
CJ-4	Current	For high-speed four-stroke cycle with less than 0.05% weight sulfur to meet 2007, may be used when category CD, CE, CF-4, CG-4 and CH-4 are recommended. CJ-4 oils exceed the performance criteria of CI-4, CI-4 PLUS, CF-4, CH-4, and CG-4.

The operator's manual provides the service rating recommended for a specific vehicle. You can use a better service rating than recommended, but NEVER a lower service rating. A high service rating (SM, for example) can withstand higher temperatures and loads while still maintaining a lubricating film. It will have more oil additives to prevent oil oxidation, engine deposits, breakdown, foaming, and other problems.

2.3.0 Lubricating (Oil) System Components

You must remember that the lubricating system is actually an integral part of the engine and the operation of one depends upon the operation of the other. Thus the lubricating system, in actual practice, cannot be considered as a separate and independent system; it is part of the engine. The lubricating system basically consists of the following:

- Oil pump—forces oil throughout the system.
- Oil pickup and strainers—carries oil to the pump and removes large particles.
- Pressure relief valve—limits maximum oil pressure.
- Oil filter—strains out impurities in the oil.
- Oil cooler—provides cooling for the oil system.
- Oil pan—reservoir or storage area for engine oil.
- Oil level gauge—checks the amount of oil in the oil pan.
- Oil galleries—oil passages through the engine.
- Oil pressure indicator—warns the operator of low oil pressure.
- Oil pressure gauge—registers actual oil pressure in the engine.
- Oil temperature regulator—controls engine oil temperature on diesel engines.

2.3.1 Oil Pump

The oil pump is the heart of the lubricating system; it forces oil out of the oil pan, through the oil filter and galleries, and to the engine bearings. Normally, a gear on the engine camshaft drives the oil pump; however, a cogged belt or a direct connection with the end of the camshaft or crankshaft drives the pump in some cases.

There are two basic types of oil pumps—rotary and gear.

The rotary pump has an inner rotor with lobes that match similar shaped depressions in the outer rotor (*Figure 6-16*). The inner rotor is off center from the outer rotor.

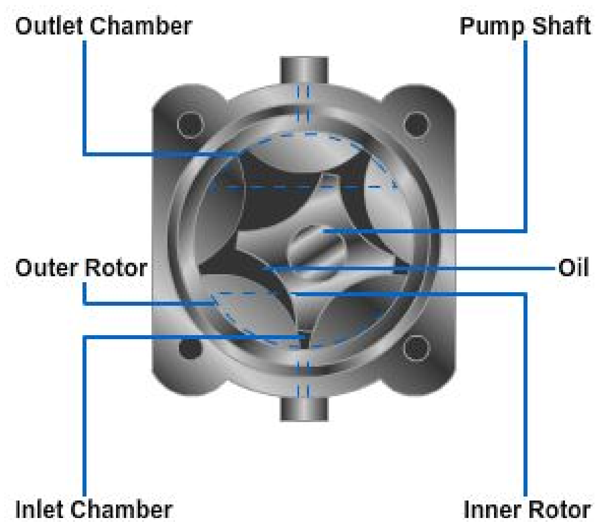

Figure 6-16 — Rotary oil pump.

As the oil pump shaft turns, the inner rotor causes the outer rotor to spin. The eccentric action of the two rotors forms pockets that change size. A large pocket is formed on the inlet side of the pump. As the rotors turn, the oil-filled pocket becomes smaller as it nears the outlet of the pump. This action squeezes the oil and makes it spurt out under pressure. As the pump spins, this action is repeated over and over to produce a relatively smooth flow of oil.

The gear pump consists of two pump gears mounted within a close-fitting housing (*Figure 6-17*). A shaft, usually turned by the distributor, crankshaft, or accessory shaft, rotates one of the pump gears. The gear turns the other pump gear that is supported on a short shaft inside the pump housing.

Oil on the inlet side of the pump is caught in the gear teeth and carried around the outer wall inside the pump housing. When oil reaches the outlet side of the pump, the gear teeth mesh and seal. Oil caught in each gear tooth is forced into the pocket at the pump outlet and pressure is formed. Oil squirts out of the pump and to the engine bearings.

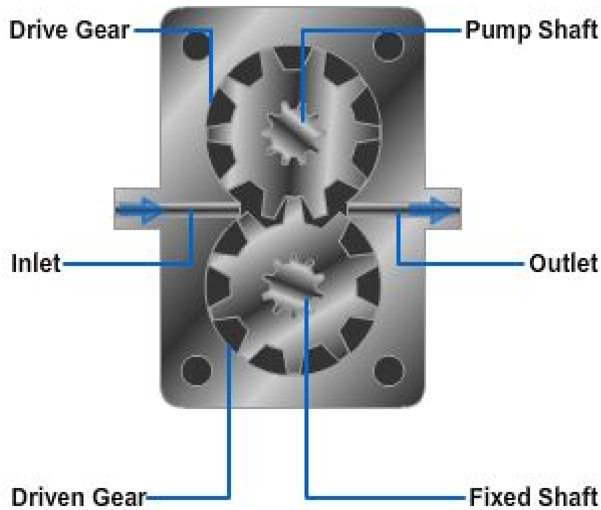

Figure 6-17 — Rotary oil pump.

As a safety factor to assure sufficient oil delivery under extreme operating conditions, the oil pump (gear or rotary) is designed to supply a greater amount of oil than is normally required for adequate lubrication. This requires that an oil pressure relief valve be incorporated in the pump to limit maximum oil pressure.

2.3.2 Oil Pickup and Strainer

The oil pickup is a tube that extends from the oil pump to the bottom of the oil pan. One end of the pickup tube bolts or screws into the oil pump or to the engine block. The other end holds the strainer.

The strainer has a mesh screen suitable for straining large particles from the oil and yet passes a sufficient quantity of oil to the inlet side of the oil pump. The strainer is located so all oil entering the pump from the oil pan must flow through it. Some assemblies also incorporate a safety valve that opens in the event the strainers become clogged, thus bypassing oil to the pump. Strainer assemblies may be either the floating or the fixed type.

The floating strainer has a sealed air chamber, is hinged to the oil pump inlet, and floats just below the top of the oil. As the oil level changes, the floating intake will rise or fall accordingly. This action allows all oil taken into the pump to come from the surface. This design prevents the pump from drawing oil from the bottom of the oil pan where dirt, water, and sludge are likely to collect. The strainer screen is held to the float by a holding clip. The up-and-down movement of the float is limited by stops.

The fixed strainer is simply an inverted funnel-like device placed about 1/2 inch to 1 inch from the bottom of the oil pan (*Figure 6-18*). This device prevents any sludge or dirt that has accumulated from entering and circulating through the system. The assembly is attached solidly to the oil pump in a fixed position.

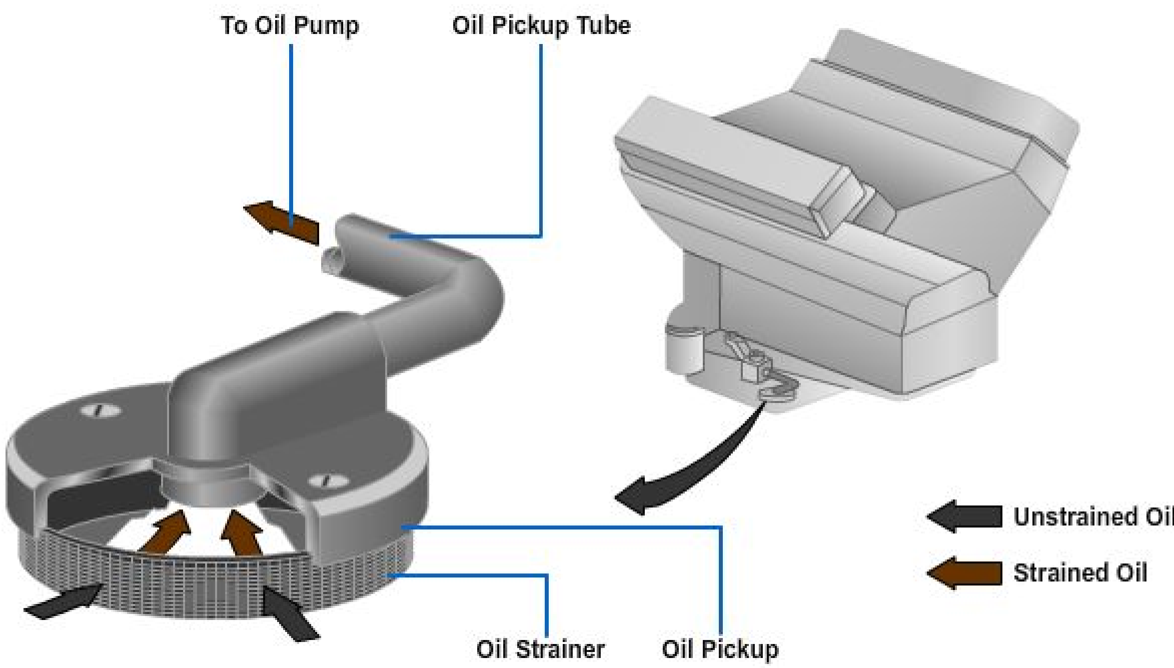

Figure 6-18 — Oil pick up and strainer.

2.3.3 Pressure Relief Valve

The pressure relief valve is a spring-loaded bypass valve in the oil pump, engine block, or oil filter housing. The valve consists of a small piston, spring, and cylinder. Under normal pressure conditions, the spring holds the relief valve closed. All the oil from the oil pump flows into the oil galleries and to the bearings.

However, under abnormally high oil pressure conditions (cold, thick oil, for example), the pressure relief valve opens. Oil pressure pushes the small piston back in its cylinder by overcoming spring tension. This allows some oil to bypass the main oil galleries and pour back into the oil pan. Most of the oil still flows to the bearings and a preset pressure is maintained. Some pressure relief valves are adjustable. By turning a bolt or screw or by changing spring shim thickness, you can alter the pressure setting.

2.3.4 Oil Filter

The oil filter removes most of the impurities that have been picked up by the oil as it circulates through the engine. Designed to be replaced readily, the filter is mounted in an accessible location outside the engine. There are two basic filter element configurations—the cartridge type and spin-on type.

The cartridge-type element fits into a permanent metal container (*Figure 6-19*). Oil is pumped under pressure into the container where it passes from the outside of the filter element to the center. From here, the oil exits the container. The element is changed easily by removing the cover from the container.

The spin-on filter is completely self-contained, consisting of an integral metal container and filter element (*Figure 6-19*). Oil is pumped into the container on the outside of the filter element. The oil then passes through the filter medium to the center of the element where it exits the container. This type of filter is screwed onto its base and is removed by spinning it off.

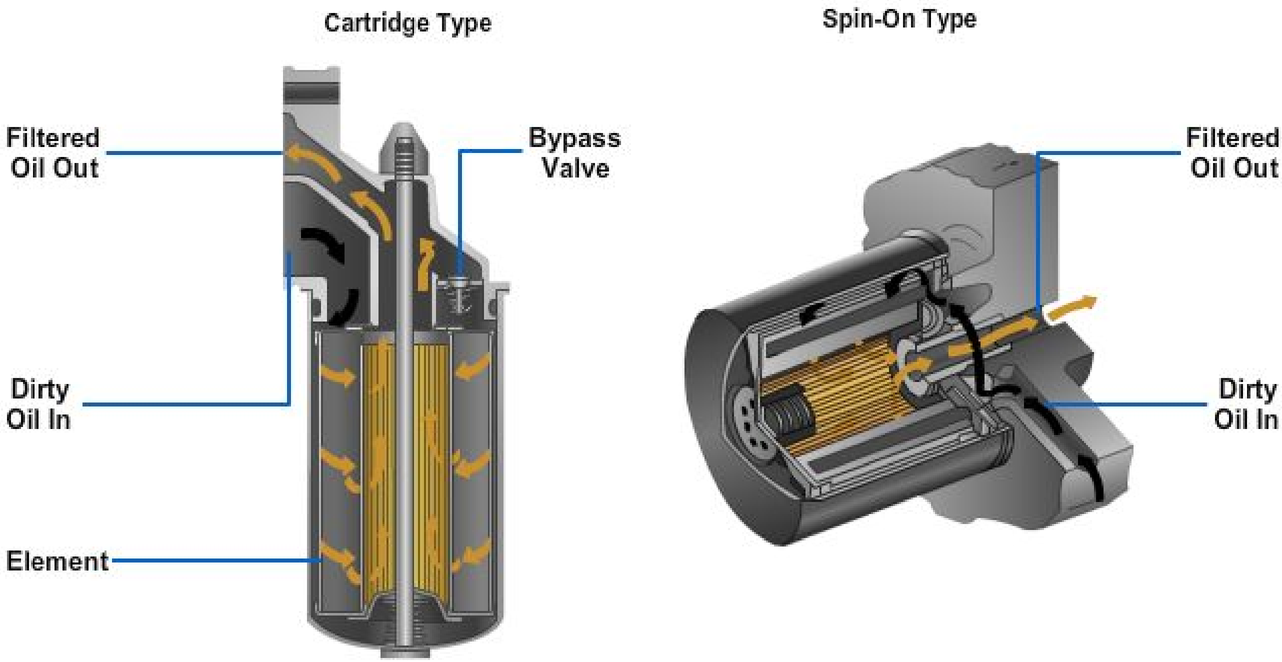

Figure 6-19 — Oil filters.

The elements themselves may be either metallic or nonmetallic. Cotton waste and resin-treated paper are the most popular filter mediums. They are held in place by sandwiching them between two perforated metal sheets. Some heavy-duty applications use layers of metal that are thinly spaced apart. Foreign matter is strained out as the oil passes between the metal layers.

There are two filter configurations: the full-flow system and the bypass system. The operations of both systems are as follows:

- The full-flow system is the most common (*Figure 6-20*). All oil in a full-flow system is circulated through the filter before it reaches the engine. When a full-flow system is used, it is necessary to incorporate a bypass valve in the oil filter to allow the oil to circulate through the system without passing through the element in the event that it becomes clogged. This prevents the oil supply to the engine from being cut off.
- The bypass system diverts only a small quantity of oil each time it is circulated and returns it directly to the oil pan after it is filtered. This

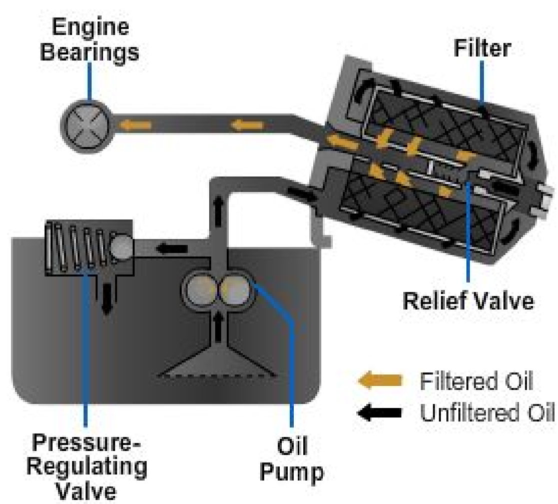

Figure 6-20 — Full flow oil system.

type of system does not filter the oil before it is sent to the engine. The oil from the main oil gallery enters the filter and flows through the filter element. It then passes into the collector in the center of the filter. The filtered oil then flows out a restricted outlet, preventing the loss of pressure. The oil then returns directly to the oil pan.

2.3.5 Oil Cooler

Some engines require an additional oil cooler (*Figure 6-21*) to help lower and control the operating temperature of the engine oil. It consists of a radiator-like device, called a heat exchanger, connected to the lubrication system by the use of an oil cooler adapter. Oil is pumped through the cooler before it flows back into the engine.

The heat exchanger looks like a small radiator that is fitted onto the vehicle in front of the radiator. Air flows across the fins of the heat exchanger, cooling the oil before it goes back into the engine.

The oil cooler adapter is a device that fits between the filter and the oil filter housing. It provides hose connections for the oil lines leading to and from the heat exchanger.

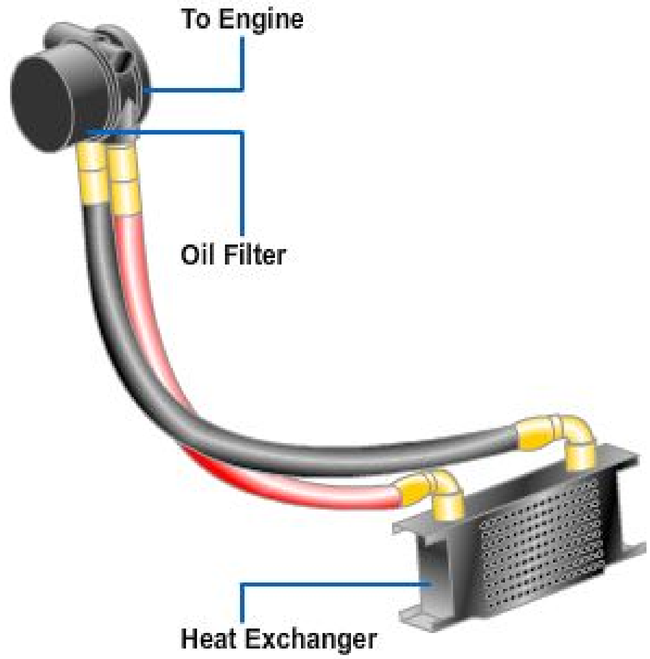

Figure 6-21 — Oil cooler.

2.3.6 Oil Pan

The oil pan is normally made of thin sheet metal or aluminum, and bolts to the bottom of the engine block. It holds a supply of oil for the lubrication system. The oil pan is fitted with a screw-in drain plug for oil changes. Baffles may be used to keep the oil from splashing around in the pan.

The sump is the lowest area in the oil pan where oil collects. As oil drains from the engine, it fills the sump. Then the oil pump can pull oil out of the pan for recirculation.

2.3.7 Oil Level Gauge

The oil level gauge, also known as a dipstick, is usually of the bayonet type (*Figure 6-22*). It consists of a long rod or blade that extends into the oil pan. It is marked to show the level of oil within the oil pan. Readings are taken by pulling the rod out from its normal place in the crankcase, wiping it clean, replacing it, and again removing and noting the height of the oil on the lower or marked end. This should be done with the engine stopped unless the manufacturer recommends otherwise. It is important that the oil level not drop below the low mark or rise above the full mark.

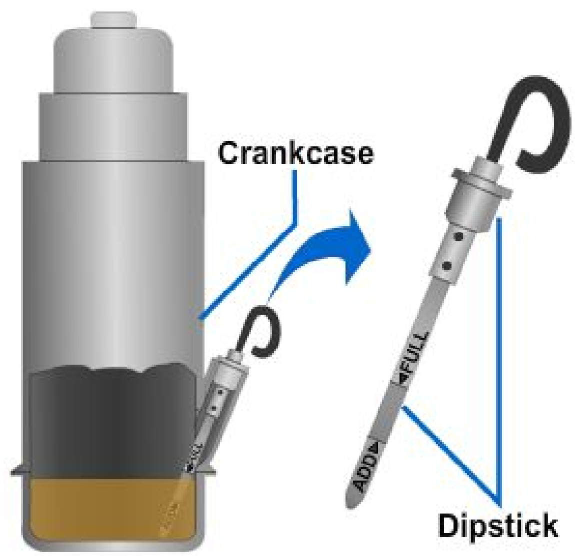

Figure 6-22— Dipstick.

2.3.8 Oil Galleries

Oil galleries are small passages through the cylinder block and head for lubricating oil. They are cast or machined passages that allow oil to flow to the engine bearings and other moving parts.

The main oil galleries are large passages through the center of the block. They feed oil to the crankshaft bearings, camshaft bearings, and lifters. The main oil galleries also feed oil to smaller passages running up to the cylinder heads.

2.3.9 Oil Pressure Warning Light

The oil pressure warning light is used in place of a gauge on many vehicles. The warning light, although not as accurate, is valuable because of its high visibility in the event of a low oil pressure condition. Because the engine can fail or be damaged in less than a minute of operation without oil pressure, the warning light is used as a backup for a gauge to attract instant attention to a malfunction.

The warning light receives battery power through the ignition switch. The circuit to ground is completed through the oil pressure-sending unit that screws into the engine and is exposed to one of the oil galleries. The sending unit consists of a pressure-sensitive diaphragm that operates a set of contact points. The contact points are calibrated to turn on the warning light anytime oil pressure drops below approximately 15 psi in most vehicles.

2.3.10 Oil Pressure Gauge

The oil pressure gauge is mounted on the instrument panel of a vehicle. Marked off on a dial in pounds per square inch (psi), the gauge indicates how regularly and evenly the oil is being delivered to all vital parts of the engine and warns of any stoppages in this delivery. Pressure gauges may be electrical or mechanical.

In the mechanical type, the gauge on the instrument panel is connected to an oil line tapped into an oil gallery leading from the pump. The pressure of the oil in the system acts on a diaphragm within the gauge, causing the needle to register on the dial.

In the electrical type, oil pressure operates a rheostat connected to the engine that signals electrically to the pressure gauge indicating oil pressure within the system.

2.3.11 Oil Temperature Regulator

The oil temperature regulator must be used in diesel engine lubricating systems. It prevents oil temperature from rising too high in hot weather, and assists in raising the temperature during cold starts in winter weather. It provides a more positive means of controlling oil temperature than does cooling by radiation of heat from the oil pan wells.

The regulator uses engine coolant in the cooling system to regulate the temperature of the oil and is made up of a core and housing. The core, through which the oil circulates, is of cellular or bellows construction and is built to expose as much oil as possible to the coolant that circulates through the housing. The regulator is attached to the engine so that the oil will flow through the regulator after passing through the pump. As the oil passes through the regulator, it is either cooled or heated, depending on the temperature of the coolant, and then is circulated through the engine.

2.4.0 Types of Lubricating (Oil) Systems

Now that you are familiar with the lubricating system components, you are ready to study the different systems that circulate oil through the engine. The systems used to circulate oil are known as splash, combination splash force feed, force feed, full force feed, and dry sump.

2.4.1 Splash

The splash system is no longer used in automotive engines. It is widely used in small four-cycle engines for lawn mowers, outboard marine operation, and so on.

In the splash lubricating system, oil is splashed up from the oil pan or oil trays in the lower part of the crankcase (*Figure 6-23*). The oil is thrown upward as droplets or fine mist and provides adequate lubrication to valve mechanisms, piston pins, cylinder walls, and piston rings.

In the engine, dippers on the connecting-rod bearing caps enter the oil pan with each crankshaft revolution to produce the oil splash. A passage is drilled in each connecting rod from the dipper to the bearing to ensure lubrication.

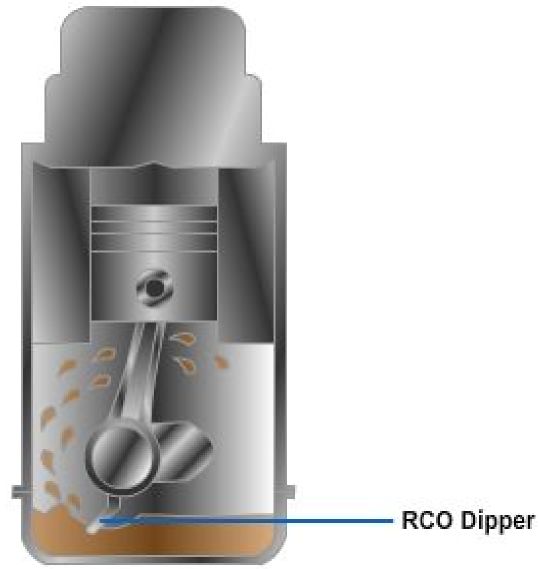

Figure 6-23— Splash type oil system.

This system is too uncertain for automotive applications. One reason is that the level of oil in the crankcase will greatly vary the amount of lubrication received by the engine. A high level results in excess lubrication and oil consumption, and a slightly low level results in inadequate lubrication and failure of the engine.

2.4.2 Force Fed

A somewhat more complete pressurization of lubrication is achieved in the force feed lubrication system (*Figure 6-24*). Oil is forced by the oil pump from the crankcase to the main bearings and the camshaft bearings. Unlike the combination system, the connecting-rod bearings are also fed oil under pressure from the pump.

Oil passages are drilled in the crankshaft to lead oil to the connecting-rod bearings. The passages deliver oil from the main bearing journals to the rod bearing journals. In some

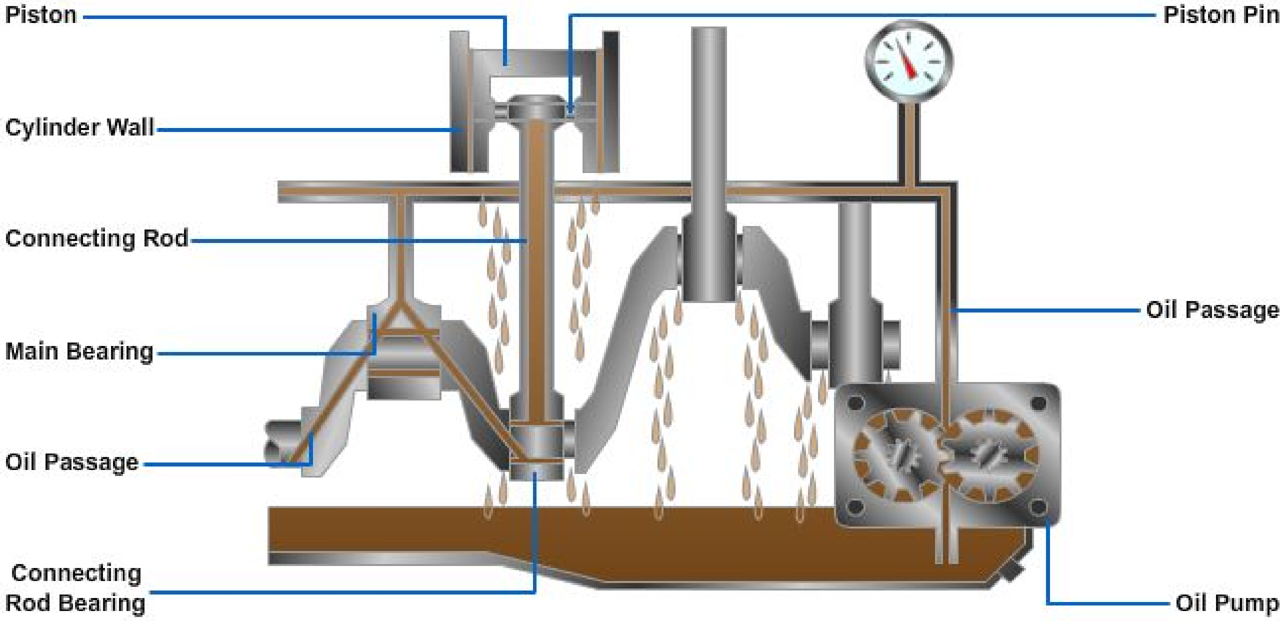

Figure 6-24 — Force fed oil system.

engines, these opening are holes that line up once for every crankshaft revolution. In other engines, there are annular grooves in the main bearings through which oil can feed constantly into the hole in the crankshaft.

The pressurized oil that lubricates the connecting rod bearings goes on to lubricate the pistons and walls by squirting out through strategically drilled holes. This lubrication system is used in virtually all engines that are equipped with semi-floating piston pins.

2.4.3 Combination Splash and Force Fed

In a combination splash and force feed, oil is delivered to some parts by means of splashing and to other parts through oil passages under pressure from the oil pump (*Figure 6-25*).

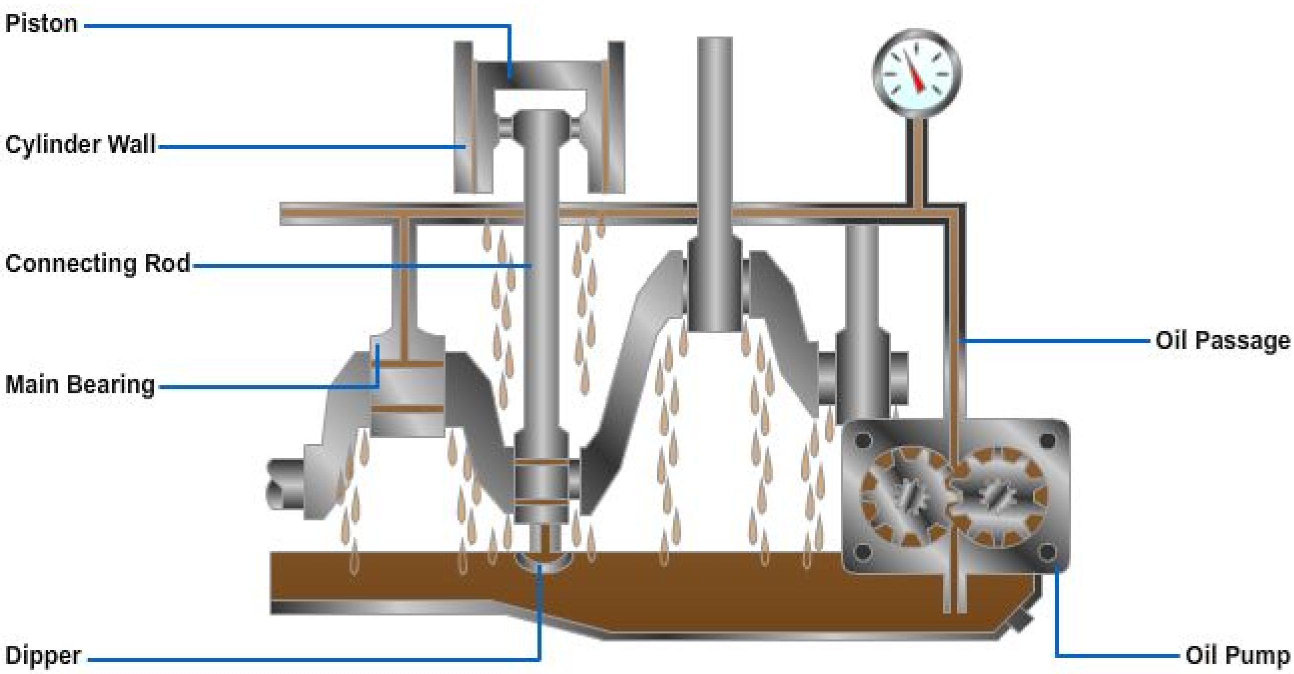

Figure 6-25 — Combination splash and force fed oil system.

The oil from the pump enters the oil galleries. From the oil galleries, it flows to the main bearings and camshaft bearings. The main bearings have oil-feed holes or grooves that feed oil into drilled passages in the crankshaft. The oil flows through these passages to the connecting rod bearings. From there, on some engines, it flows through holes drilled in the connecting rods to the piston-pin bearings.

Cylinder walls are lubricated by splashing oil thrown off from the connecting-rod bearings. Some engines use small troughs under each connecting rod that are kept full by small nozzles which deliver oil under pressure from the oil pump. These oil nozzles deliver an increasingly heavy stream as speed increases. At very high speeds these oil streams are powerful enough to strike the dippers directly. This causes a much heavier splash so that adequate lubrication of the pistons and the connecting-rod bearings is provided at higher speeds.

If a combination system is used on an overhead valve engine, the upper valve train is lubricated by pressure from the pump.

2.4.4 Full Force Fed

In a full force feed lubrication system, the main bearings, rod bearings, camshaft bearings, and the complete valve mechanism are lubricated by oil under pressure. In addition, the full force feed lubrication system provides lubrication under pressure to the pistons and the piston pins. This is accomplished by holes drilled the length of the connecting rod, creating an oil passage from the connecting rod bearing to the piston pin bearing. This passage not only feeds the piston pin bearings but also provides lubrication for the pistons and cylinder walls. This system is used in virtually all engines that are equipped with full-floating piston pins.

2.4.5 Dry Sump

The dry sump lubrication system uses two oil pumps and a separate oil reservoir. No oil is stored in the oil pan itself. The main pump pulls oil from the reservoir and pushes it into the engine bearings and other high-friction points. The second pump, called the scavenge pump, pulls oil out of the pan and sends it to the oil reservoir.

These types of systems are found on exotic high-performance cars. Because there is no oil in the oil pan, engine horsepower and dependability are increased.

2.5.0 Lubricating System Problem Diagnosis

To troubleshoot an engine lubricating system, begin by gathering information on the problem. Ask the operator questions. Analyze the symptoms using your understanding of system operation. You should arrive at a logical deduction about the cause of the problem.

The four problems that most often occur in the lubrication system are as follows:

- High oil consumption (oil must be added frequently)
- Low oil pressure (gauge reads low, indicator light glows, or there are abnormal engine noises)
- High oil pressure (gauge reads high, oil filter swells)
- Indicator or gauge problems (inaccurate operation or readings)

When diagnosing these troubles, make a visual inspection of the engine for obvious problems. Check for oil leakage, a disconnected sending unit wire, low oil level, damaged oil pan, or other troubles that relate to the symptoms.

2.5.1 High Oil Consumption

If the operator must add oil frequently to the engine, this is a symptom of high oil consumption. External oil leakage out of the engine or internal leakage of oil into the combustion chambers causes high oil consumption. A description of each of these problems is as follows:

- External oil leakage—detected as darkened oil wet areas on or around the engine. Oil may also be found in small puddles under the vehicle. Leaking gaskets or seals are usually the source of external engine oil leakage.
- Internal oil leakage—shows up as blue smoke exiting the exhaust system of the vehicle. For example, if the engine piston rings and cylinders are badly worn, oil can enter the combustion chambers and will be burned during combustion.

NOTE

Do not confuse black smoke (excess fuel in the cylinder) and white smoke (water leakage into the engine cylinder) with blue smoke caused by engine oil.

2.5.2 Low Oil Pressure

Low oil pressure is indicated when the oil indicator light glows, the oil gauge reads low, or the engine lifters or bearings rattle. The most common causes of low oil pressure are as follows:

- Low oil level (oil not high enough in pan to cover oil pickup)
- Worn connecting rod or main bearings (pump cannot provide enough oil volume)
- Thin or diluted oil (low viscosity or fuel in the oil)
- Weak or broken pressure relief valve spring (valve opens too easily)
- Cracked or loose pump pickup tube (air is being pulled into the oil pump)
- Worn oil pump (excess clearance between rotors or gears and housing)

- Clogged oil pickup screen (reduced amount of oil entering pump)

A low oil level is a common cause of low oil pressure. Always check the oil level first when troubleshooting a low oil pressure problem.

2.5.3 High Oil Pressure

High oil pressure is seldom a problem. When it occurs, the oil pressure gauge will read high. The most frequent causes of high oil pressure are as follows:

- Pressure relief valve stuck open (not opening at specified pressure)
- High relief valve spring tension (strong spring or spring has been improperly shimmed)
- High oil viscosity (excessively thick oil or use of oil additive that increases viscosity)
- Restricted oil gallery (defective block casting or debris in oil passage)

2.5.4 Indicator or Gauge Problems

A bad oil pressure indicator or gauge may scare the operator into believing there are major problems. The indicator light may stay on or flicker, pointing to a low oil pressure problem. The gauge may read low or high, also indicating a lubrication system problem.

Inspect the indicator or gauge circuit for problems. The wire going to the sending unit may have fallen off. The sending unit wire may also be shorted to ground (light stays on or gauge always reads high).

To check the action of the indicator or gauge, remove the wire from the sending unit. Touch it on a metal part of the engine. This should make the indicator light glow or the oil pressure gauge read maximum. If it does, the sending unit may be defective. If it does not, then the circuit, indicator, or gauge may be faulty.

NOTE

Always check the service manual before testing an indicator or gauge circuit. Some manufacturers recommend a special gauge tester. This is especially important with some computer-controlled systems.

2.6.0 Lubricating System Maintenance

There are certain lubricating system service jobs that are more or less done automatically when an engine is repaired. For example, the oil pan is removed and cleaned during such engine overhaul jobs as replacing bearing or rings. When the crankshaft is removed, it is usual procedure to clean out the oil passages in the crankshaft. Also, the oil passages in the cylinder block should be cleaned out as part of the overhaul.

As a Construction Mechanic, you will be required to maintain the lubrication system. This maintenance normally consists of changing the oil and filter(s). Occasionally you will be required to perform such maintenance tasks as replacing lines and fittings, servicing or replacing the oil pump and relief valve, and flushing the system. The following discussion provides information that will aid you in carrying out these duties.

2.6.1 Oil and Filter Change

It is extremely important that the oil and filter(s) (*Figure 6-26*) of the engine are serviced regularly. Lack of oil and filter maintenance will greatly shorten engine service life.

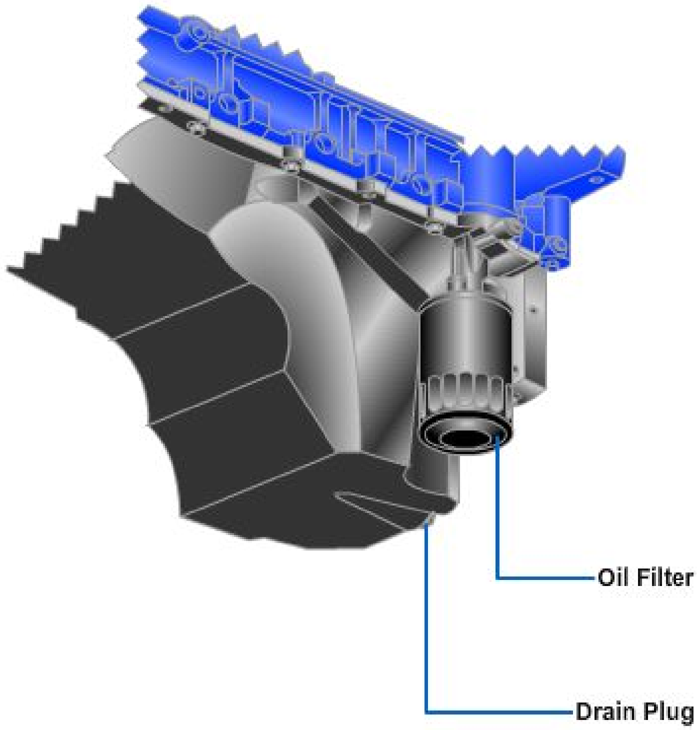

Figure 6-26 — Oil and filter change.

Manufacturers give a maximum number of miles or hours a vehicle can be operated between oil changes. Newer automotive vehicles can be operated 5,000 miles between changes. Older automotive vehicles should have their oil changed about every 3,000 miles. Most construction equipment averages between 200 and 250 hours of operation between oil changes. However, depending on the climate and working conditions, the miles and hours between oil changes can be greatly reduced. Refer to the service manual for exact intervals.

To change the engine oil, warm the engine to full operating temperature, this will help suspend debris in the oil and make the oil drain more thoroughly. Unscrew the drain plug and allow the oil to flow into a catchment pan. Be careful of hot oil; it can cause painful burns.

Usually the filter elements are replaced at the same time the oil is changed. The most common filters are the spin-on filter or replaceable element type oil filter.

- Spin-on, throwaway oil filters—replaced as a complete unit. Unscrew the filter from the base by hand or a filter wrench and throw the filter away. When replacing, wipe the base clean with a cloth and place a small amount of oil or grease on the gasket to ensure a good seal. Screw on a new filter, tightening at least a half a turn after the gasket contacts the base. Do not use a filter wrench because the filter canister could distort and leak.
- Replaceable element oil filter—removed from the filter housing and replaced. Place a pan underneath the filter to catch oil from the filter. Remove the fastening bolt and lift off the cover or filter housing. Remove the gasket from the cover or housing and throw it away. Take out the old element and throw it away. Clean the inside of the filter housing and cover it. Install a new element and insert a new cover or housing gasket (ensure the gasket is completely seated in the recess). Replace the cover or housing and fasten it to the center bolt securely.

After the oil has been completely drained and the drain plug replaced, fill the crankcase to the full mark on the dipstick with the proper grade and weight of oil. Start and idle the engine. Check the oil pressure immediately. Inspect the filter or filter housing for leaks. Stop the engine and check the crankcase oil level and add to the full mark.

Summary

This chapter not only described engine cooling and lubricating systems, it also explained the harsh effects that can occur if they are not routinely cared for. By simply inspecting and replenishing coolant and oil levels, and inspecting a radiator, an operator can prevent major engine problems and extend the life of a piece of equipment.

Review Questions (Select the Correct Response)

1. What percentage of engine heat is dissipated through the cooling, lubricating, and fuel systems?

   A. Between 10% to 15%
   B. Between 20% to 25%
   C. Between 30% to 35%
   D. Between 40% to 45%

2. Why are cylinders on an air-cooled engine mounted independently?

   A. To reduce engine weight
   B. To expose more surface area to the cooling air
   C. To eliminate the need for cooling system maintenance
   D. To provide easy access to the crankcase

3. When inspecting an air-cooled engine, you notice a crack in one of the cooling fins extending into the combustion area. What action is required?

   A. Replace the engine.
   B. Replace the cylinder barrel.
   C. Weld the cooling fin.
   D. Nothing, this will not affect the cooling.

4. What action is created during the downward flow of the coolant through the radiator?

   A. Thermosiphon
   B. Thermoexpansion
   C. Thermoflow
   D. Thermocooling

5. How do radiator fins contribute to cooling system efficiency?

   A. They hold the tubes in a position that allows maximum contact with the air flow.
   B. They increase heat dissipation by enlarging the surface area exposed to the air flow.
   C. They increase heat dissipation by enlarging the surface area exposed to the coolant.
   D. They direct the flow of air to the hottest areas of the radiator.

6. The radiator of an air-conditioned vehicle has how many fins per inch?

   A. Five
   B. Six
   C. Seven
   D. Eight

7. The lower radiator hose connects the radiator to the _______.

A. thermostat housing
B. engine block water passages
C. cylinder head water passages
D. water pump inlet

8. What is the purpose of the hose spring used in the lower radiator hose?

A. To prevent the hose from collapsing
B. To protect the system against damage
C. To allow the hose to be shaped to clear moving parts
D. To allow the hose to withstand engine vibration

9. Which is NOT a function of the radiator pressure cap?

A. Seals the top of the radiator filler neck to prevent leakage.
B. Pressurizes the system to raise the boiling point of the coolant.
C. In an open system, allows coolant to flow into and from the coolant reservoir.
D. Relieves excess pressure to protect the system against damage.

10. A radiator is equipped with a 12-pound pressure cap. What effect does this cap have on the boiling point of the coolant?

A. Raises it by 36°
B. Lowers it by 26°
C. Raises it by 16°
D. Lowers it by 6°

11. What part of the water pump provides a mounting place for the fan and belt?

A. Hub
B. Housing
C. Shaft
D. Impeller

12. A bent fan blade will NOT cause which condition?

A. Worn fan belt
B. Vibration
C. Excessive wear of the water pump shaft
D. Noise

13. When an electric fan is used, the fan switch closes to operate the fan when coolant temperature reaches approximately what temperature?

A. 170°F
B. 190'F
C. 210°F
D. 230°F

14. A coolant distribution tube is used in cooling systems of an L-head engine in order to _______.

A. disperse hot coolant that enters the top tank of the radiator
B. distribute the coolant equally between the cylinder block and the cylinder head
C. direct the coolant to the cylinder head only
D. direct the coolant to the hottest parts of the cylinders

15. A ferrule type coolant director is used in the cooling system of I-head engines to direct a jet of coolant towards the exhaust _______.

A. valve guides
B. valve seats
C. ports
D. manifold heat valve

16. What type of thermostat is used in a modem pressurized cooling system?

A. Pellet
B. Bypass
C. Bellows
D. Butterfly

17. A thermostat rated at 190°F will fully open at what temperature?

A. 190°F
B. 200°F
C. 210°F
D. 220°F

18. Why do some stationary engines and large trucks have shutters placed in front of the radiators?

A. To restrict the flow of air through the radiator
B. To prevent foreign matter from damaging the radiator core
C. To eliminate the need for a cooling fan
D. To provide slower warm-up and operating temperatures

19. Radiator shutters used on large trucks are opened by what type of pressure?

A. Water
B. Spring
C. Hydraulic
D. Air

20. A temperature warning light warns of an overheating condition about _______ coolant boiling point.

A. 5° to 10° below
B. 5° to 10° above
C. 10° to 15° below
D. 10° to 15° above

21. A coolant mixture containing 60% antifreeze provides adequate protection against freezing to what maximum temperature?

A. -20°F
B. -34°F
C. -50°F
D. -62°F

22. What is the most common method of flushing?

A. Reverse
B. Fast
C. Chemical
D. Fast-reverse

23. When a pressure tester is being used to test a radiator cap, what is the minimum length of time, in minutes, that the pressure should be held to indicate that the cap is operational?

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

24. When a combustion leak is detected in the cooling system, the fluid in the block test will change color from blue to _______.

A. green
B. orange
C. yellow
D. purple

25. Correct fan belt tension can be determined by measuring the _______.

A. distance between the belt pulleys
B. width of the belt
C. deflection of the belt between pulleys
D. distance between pulleys and then subtracting the width of the belt

26. Which is NOT a function of the engine lubrication system?

A. Reduces friction between moving parts.
B. Transfers heat.
C. Cleans the inside of the engine by removing contaminants.
D. Assures maximum wear on moving parts.

27. Oil service ratings are determined by what agency?

A. Society of Automotive Engineers
B. Society of Petroleum Engineers
C. American Petroleum Institute
D. American Automotive Institute

28. Which is an operating principle of the rotary oil pump?

A. The inner rotor is centrally located in the outer rotor.
B. The inner rotor causes the outer rotor to spin.
C. The outer rotor causes the inner rotor to spin.
D. A small pocket is formed on the inlet side of the pump.

29. Which action is an operating principle of a gear type oil pump?

A. Both gears are independently driven by shafts.
B. Both gears turn in the same direction.
C. Pumping action forces oil to pass between the gear teeth.
D. The pump is driven by the crankshaft or distributor.

30. In an engine lubrication system, where is the oil strainer located?

A. In the oil return line to the crankcase
B. At the inlet of the oil pump pickup tube
C. In the discharge line from the oil pump
D. At the inlet side of the oil galleries

31. Why are dirt, water, and sludge unable to pass through an oil strainer with the oil?

A. All oil is collected from the surface of the oil in the oil pan.
B. The mesh of the screen allows only the lubricating oil to pass.
C. The strainers are located above the bottom of the oil pan.
D. The strainers are designed to allow oil pumps to pick up oil based on their viscosity.

32. Which factor is an advantage of using a full flow oil filter in a lubricating system?

    A. All oil is circulated through the filter before it reaches the engine.
    B. The filter does not need to be changed as often as other filters.
    C. The filter never permits any unfiltered oil to reach the moving parts of the engine.
    D. The filter diverts a small amount of oil and returns it to the oil pan.

33. The sending unit for an oil pressure warning light is calibrated to come on when oil pressure drops below what psi level?

    A. 10
    B. 15
    C. 20
    D. 25

34. In a mechanical type oil pressure gauge, the oil line is tapped at what location?

    A. Base of the oil filter
    B. Oil gallery leading from the oil pump
    C. Oil gallery leading from the side of the engine
    D. Oil filter housing unit

35. An operator reports that a vehicle is using a lot of oil; however, there is no sign of external leakage. What color smoke is a sign of internal oil leakage?

    A. Gray
    B. Black
    C. White
    D. Blue

36. Which condition is NOT a cause of low oil pressure?

    A. Worn main bearings
    B. Worn oil pump
    C. Restricted oil gallery
    D. Weak or broken pressure relief valve spring

37. Which condition is indicated by a high oil pressure reading?

    A. Worn engine bearings
    B. Overheated engine
    C. Blocked oil passage
    D. Cracked oil pickup tube

38. In changing engine oil, when should you drain the oil from the vehicle?

    A. When the engine is warm
    B. While the engine is cold
    C. Anytime
    D. Whenever the vehicle is deadlined

39. When replacing a spin-on filter, you should turn the filter how far after contact is made with the base?

A. One-fourth turn
B. One-third turn
C. One-half turn
D. Full turn

Trade Terms Introduced in this Chapter

Seize	To top motion, to fuse with another part due to high pressure or temperature.
Stationary	The framework does not move, it is fixed in a particular location.
Siphons	Continuous tubes that allows liquid to drain from a reservoir through an intermediate point that is higher, or lower, than the reservoir, the flow being driven only by the difference in hydrostatic pressure without any need for pumping.
Stethoscope	Used to listen to internal sounds made by machines, such as diagnosing a malfunctioning automobile engine by listening to the sounds of its internal parts.

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.

Modern Automotive Technology Seventh Edition, James E. Duffy, The Goodheart-Willcox Company, Inc., 2009. (ISBN 978-1-59070-956-6)

Automotive Technology, A systems Approach Fourth Edition, Jack Erjavec, The Thomson-Delmar Learning Company, Inc., 2005. (ISBN 1-4018-4831-1)

Diesel Technology Seventh Edition, Andrew Norman and John “Drew” Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN-13: 978-1-59070-770-8)

American Petroleum Institute, www.api.org

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