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Engine Cooling and Lubrication Systems

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Elie Tawil, P.E., LEED AP

CED CANADA
engineering.ca
CPD FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

www.cedengineering.ca

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Chapter 6

Cooling and Lubrication Systems

Topics

- 1.0.0 Engine Cooling Systems
- 2.0.0 Engine Lubricating Systems

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

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.

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*.

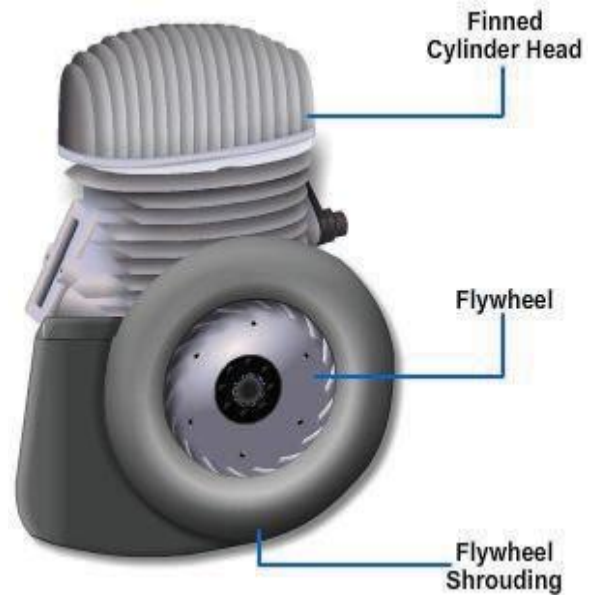


Figure 6-1 – Air-cooled Engine.

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:

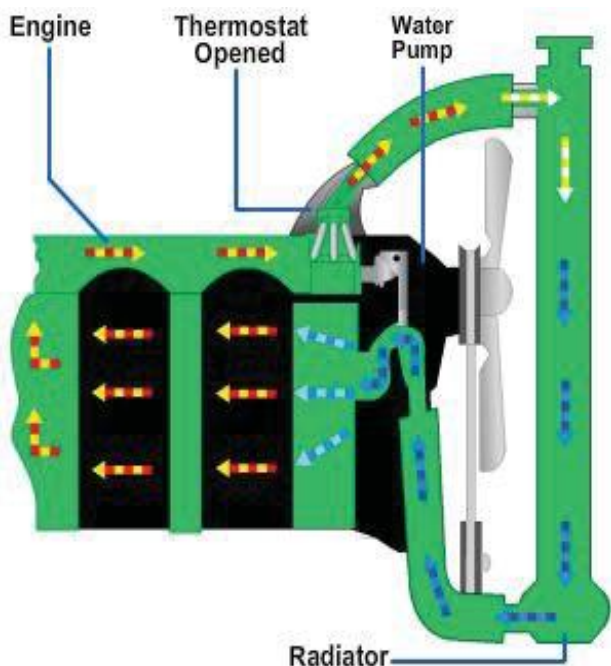


Figure 6-2 – Liquid-cooled System.

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

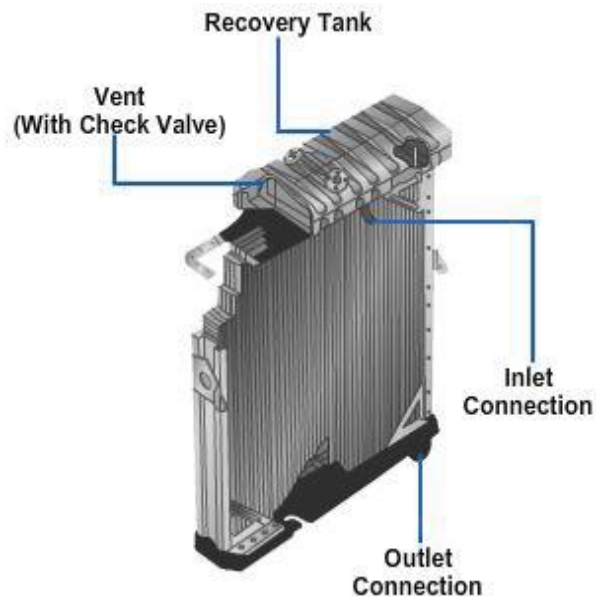


Figure 6-3 – Radiator.

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:

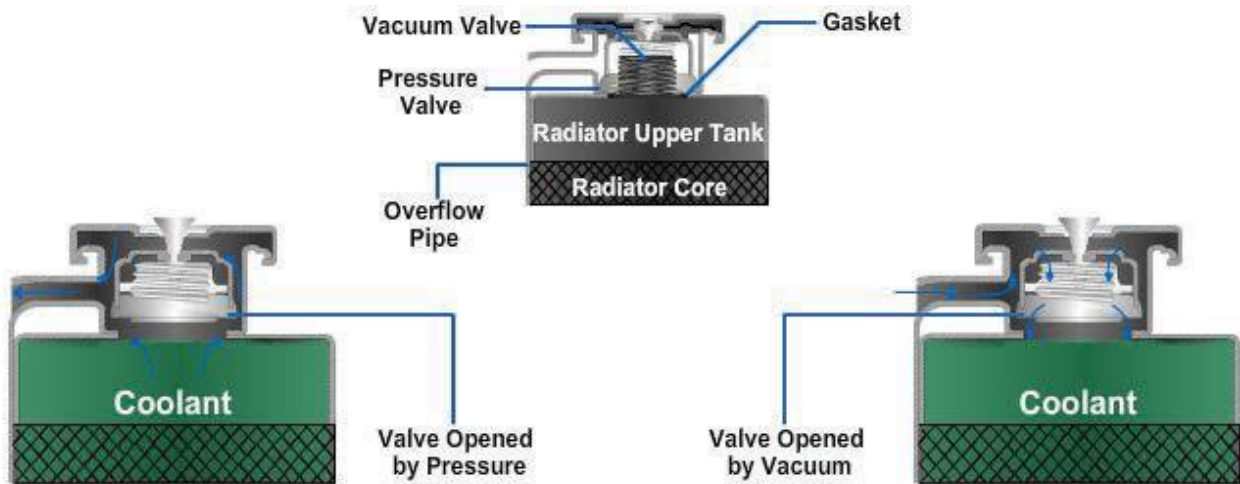


Figure 6-4 – Radiator Cap.

- 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 carefully. 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.

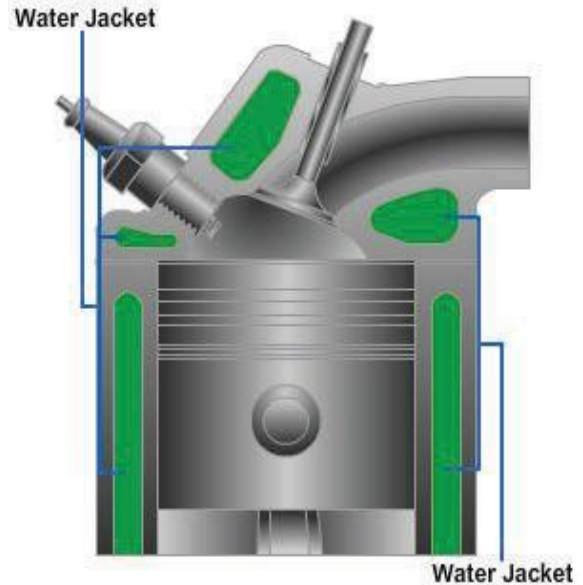


Figure 6-5 – Water jacket.

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

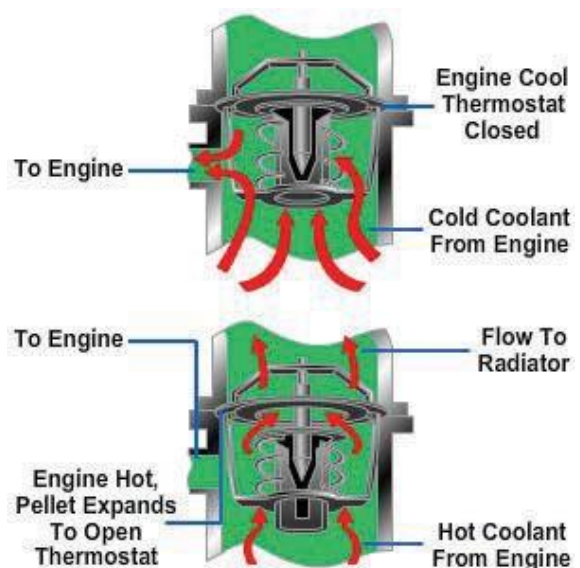


Figure 6-6 – Thermostat.

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.

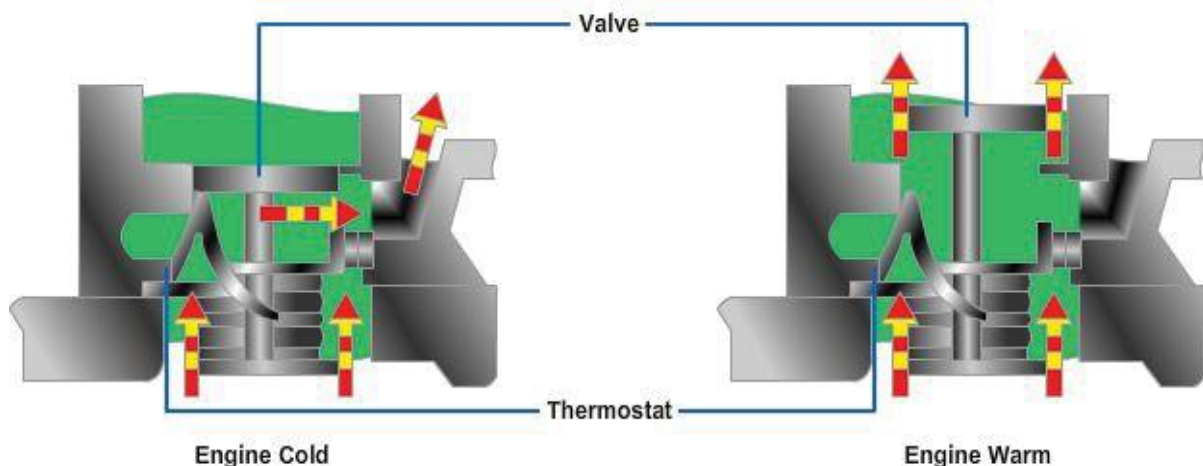


Figure 6-7 – Bypass Thermostat.

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

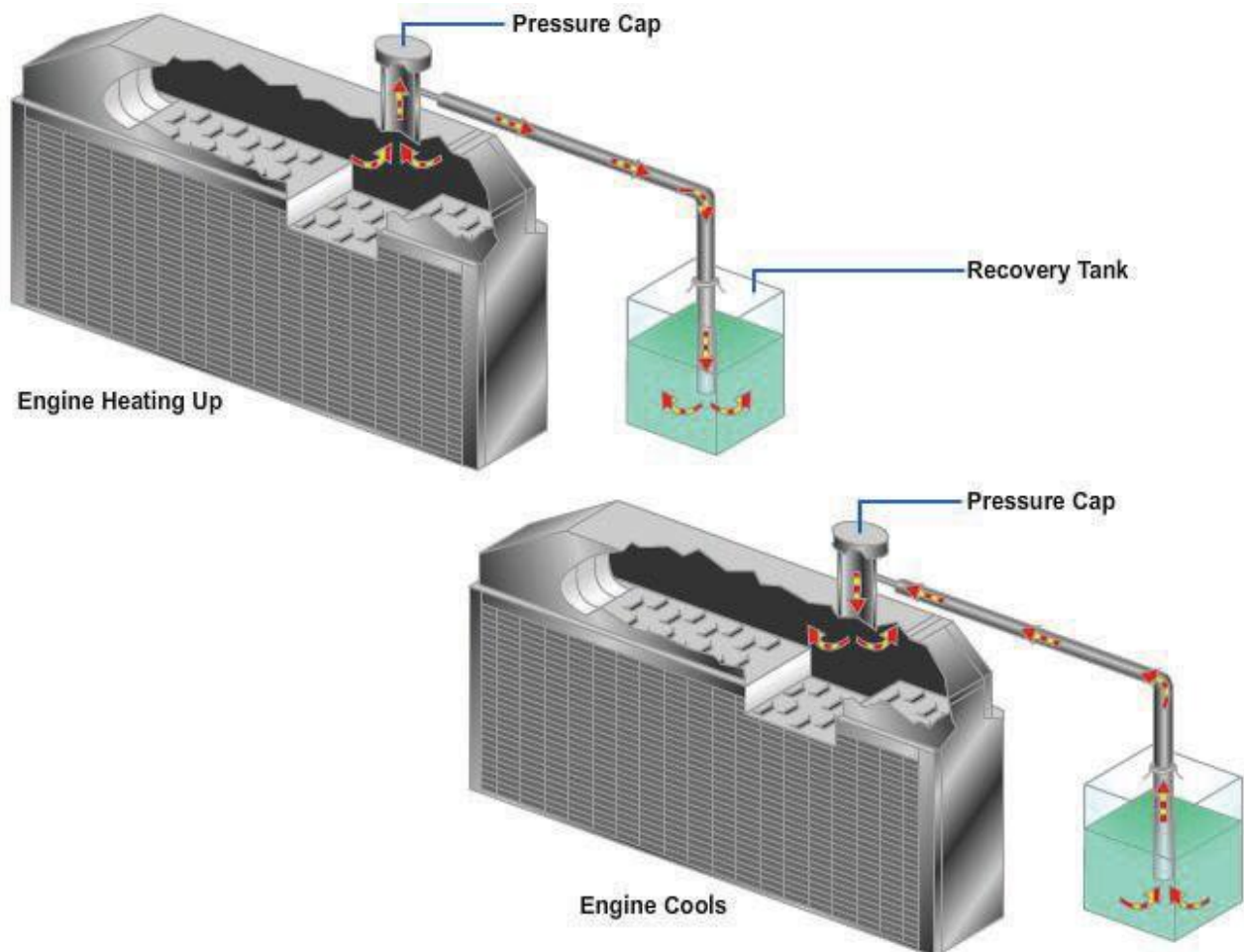


Figure 6-8 – Expansion recovery tank.

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.



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

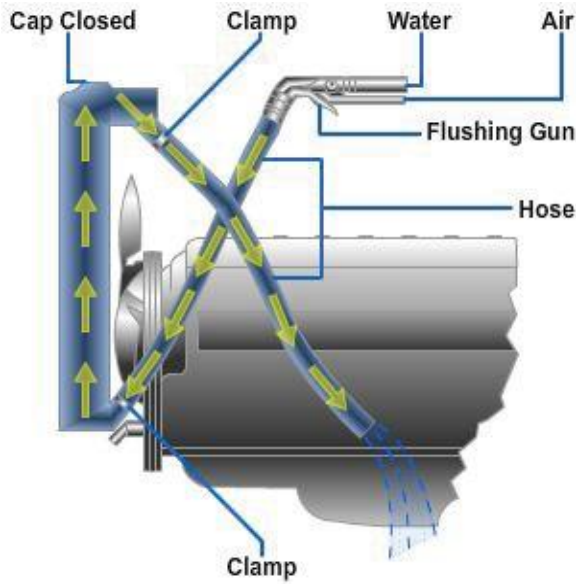


Figure 6-9– Reverseflushing of a radiator.

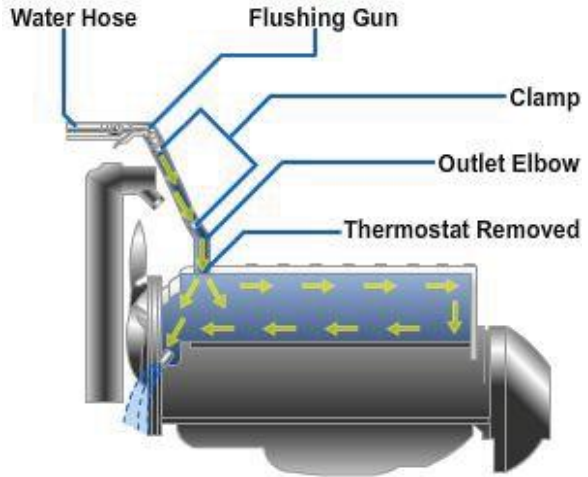


Figure 6-10– Reverseflushing of a water jacket.

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.



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.



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.



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.

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:

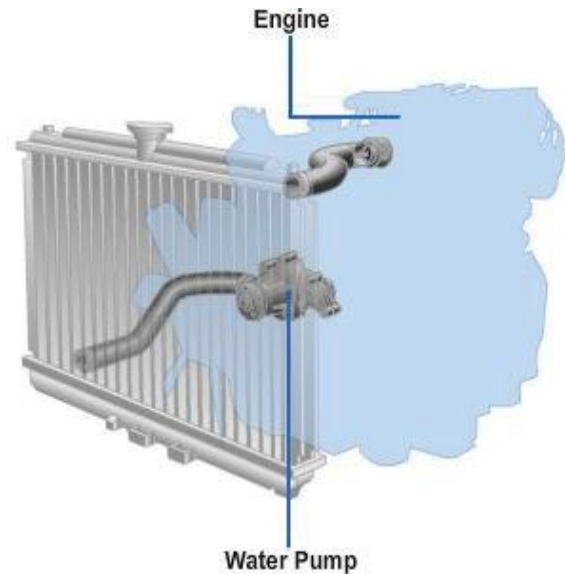


Figure 6-11 – Water pump.

- 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.

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.



Figure 6-12— Radiator and heater hoses.

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.

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.

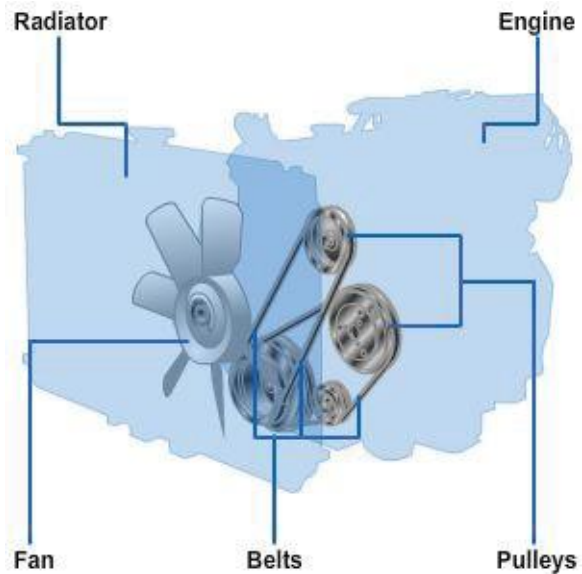


Figure 6-13 – Fan and belt.

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.



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.

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.

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.

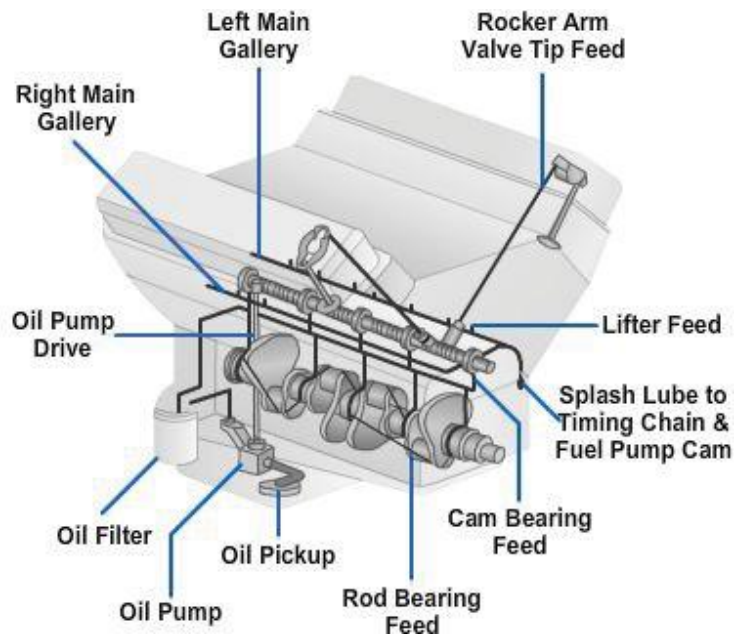
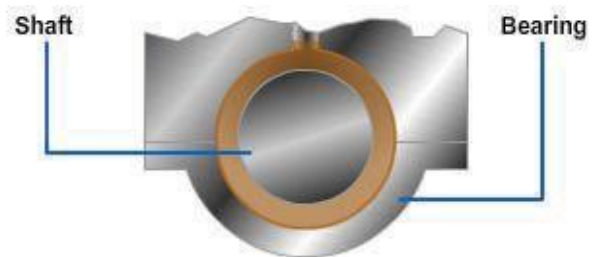


Figure 6-14 – Engine lubrication system.



**Oil Entering Bearing.
Shaft Rotating.**

Figure 6-15 – How oil lubricates.

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.

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.

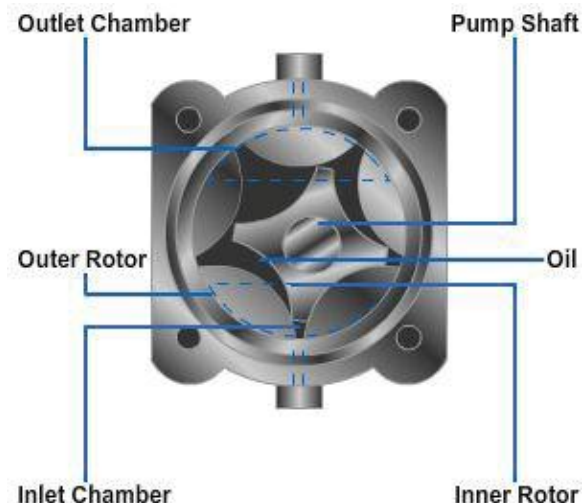


Figure 6-16 – Rotary oil pump.

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.

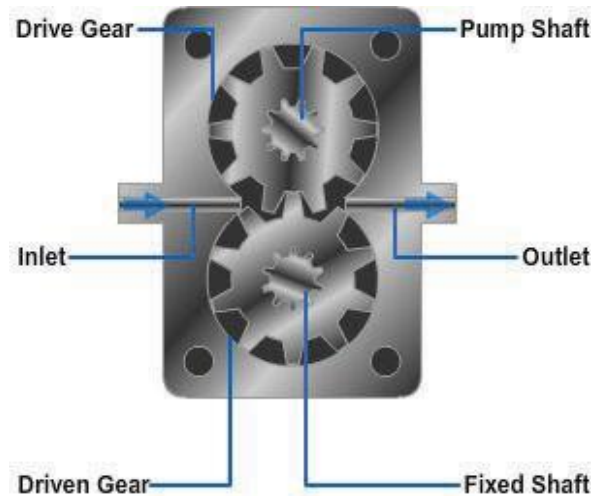


Figure 6-17 – Rotary oil pump.

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.

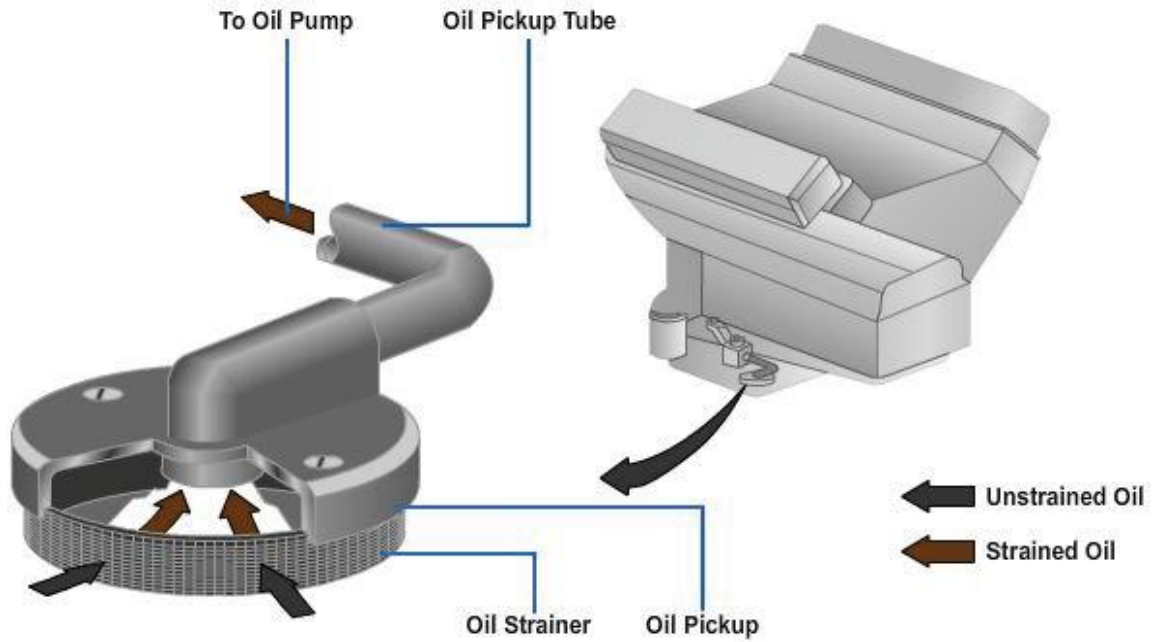


Figure 6-18 – Oil pick up and strainer.

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.

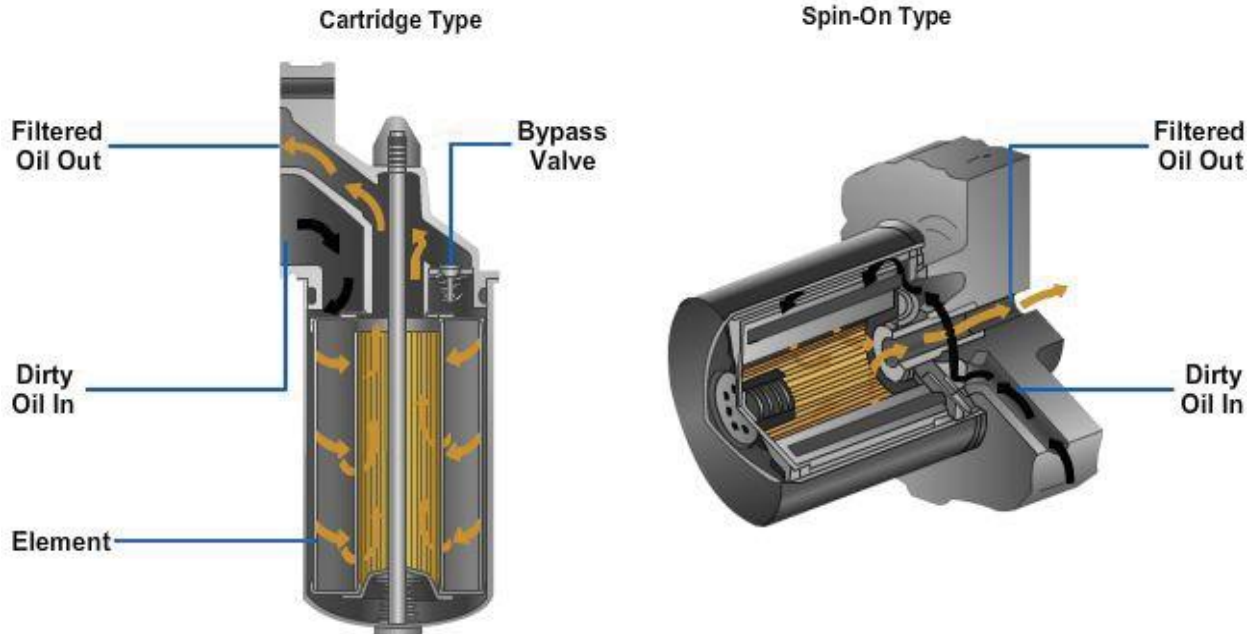


Figure 6-19 – Oil filters.

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

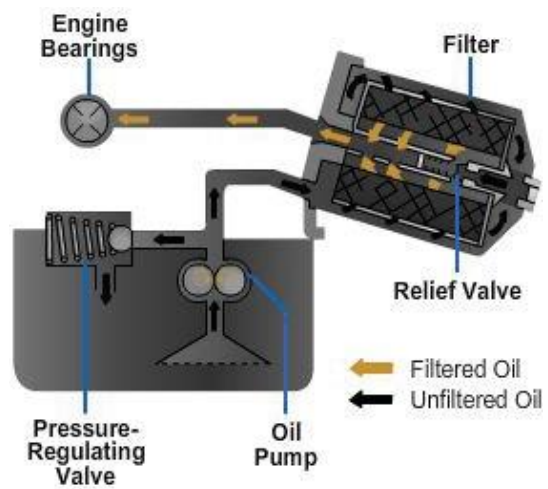


Figure 6-20 – Full flow oil system.

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.

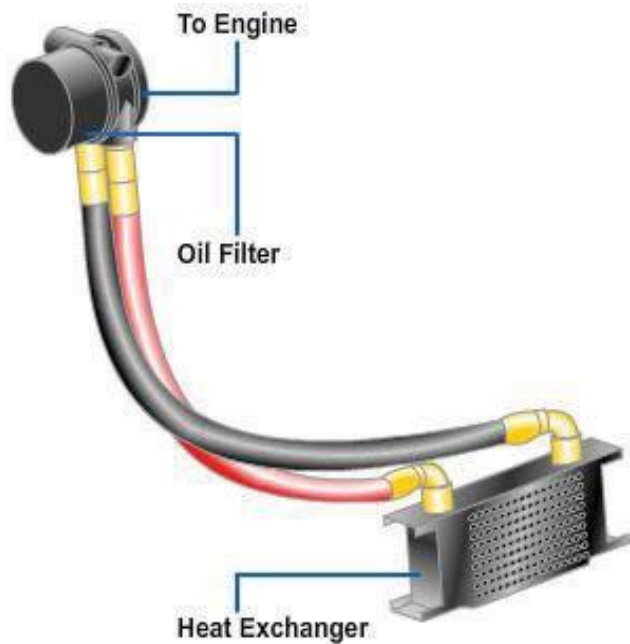


Figure 6-21 – Oil cooler.

2.3.6 Oil Pan

The oil pan is normally made of thin sheet metal of 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.

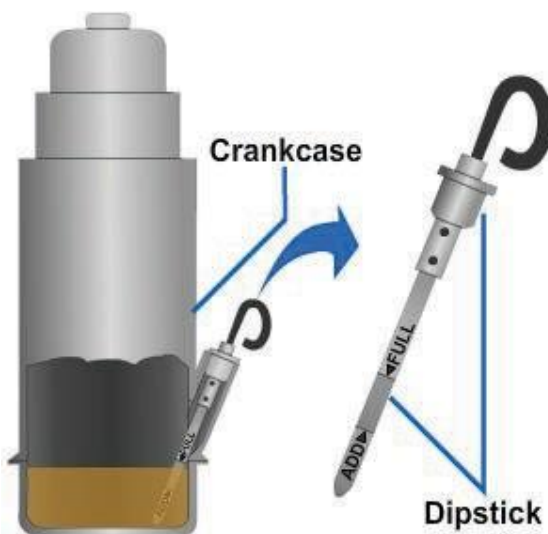


Figure 6-22- Dipstick.

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.

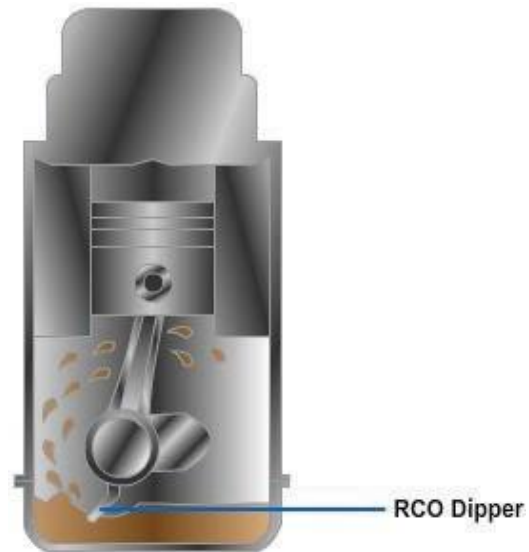


Figure 6-23- Splash type oil system.

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

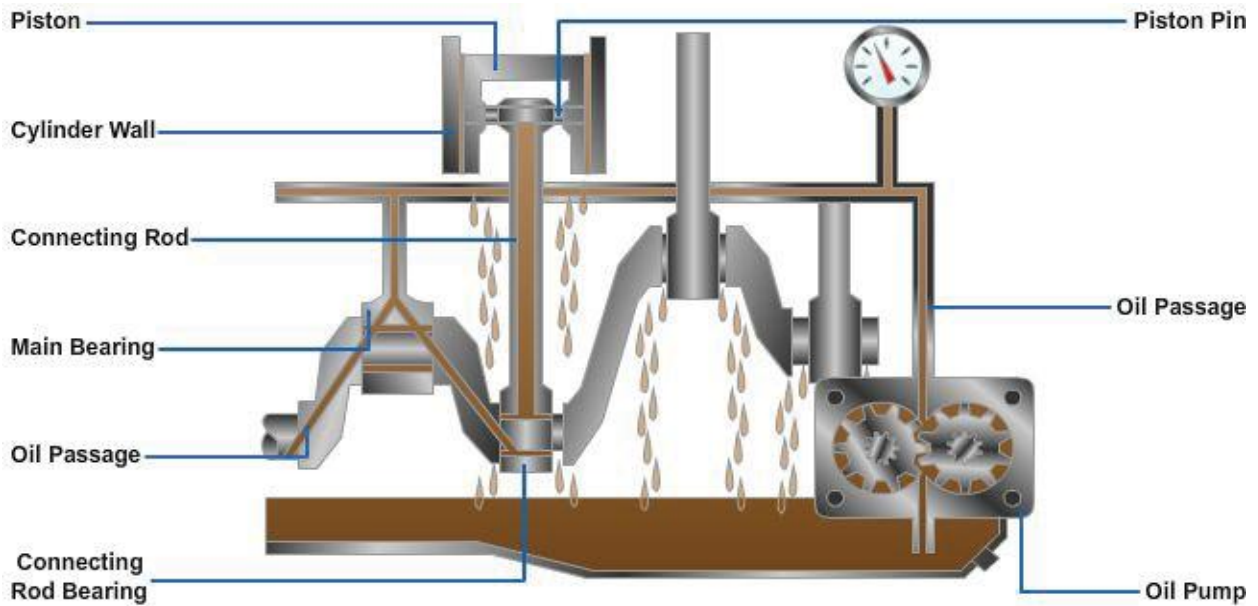


Figure 6-24 – Force fed oil system.

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*).

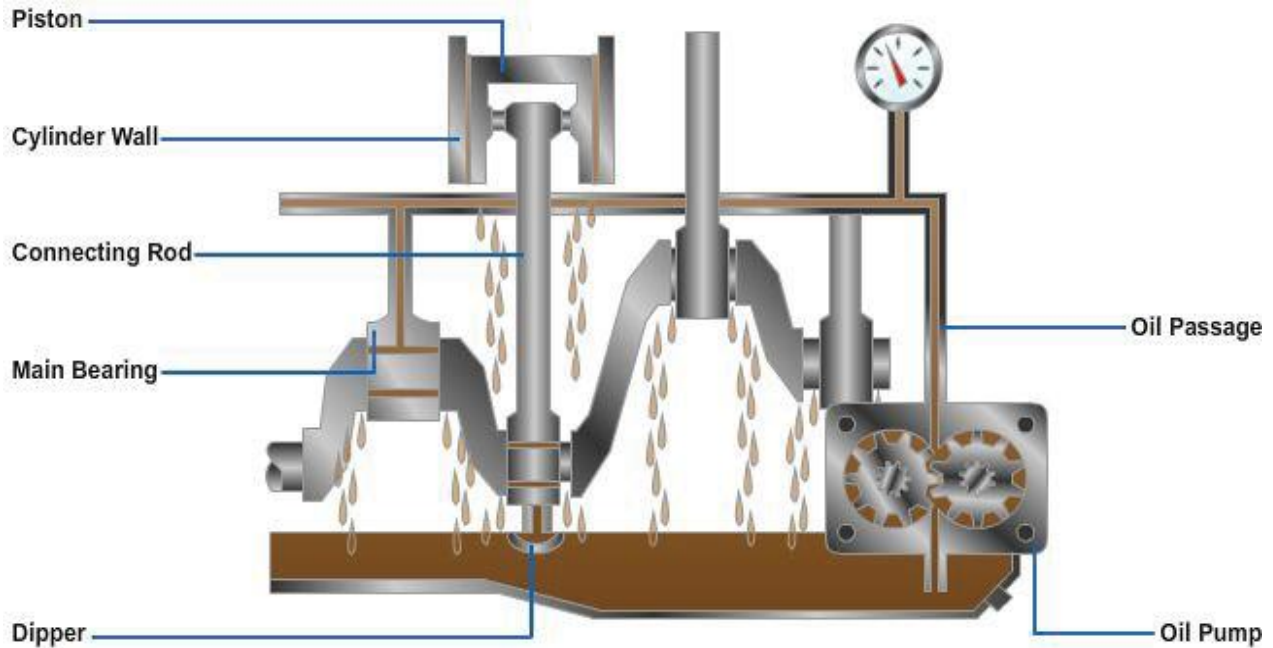


Figure 6-25 – Combination splash and force fed oil system.

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.

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

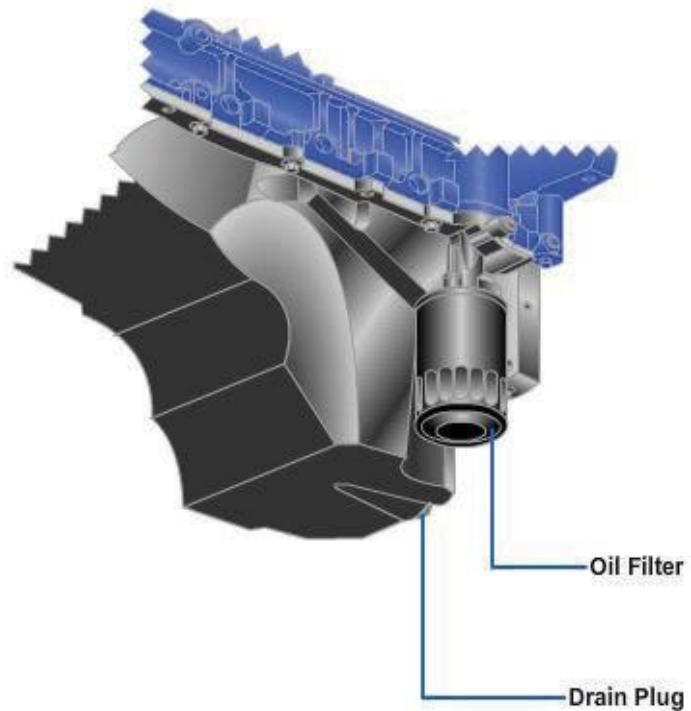


Figure 6-26 – Oil and filter change.

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.

Trade Terms Introduced in this Chapter

Seize

To stop 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 allow 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