CHAPTER 13

COOLING SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES

After studying Chapter 13, the reader will be able to:

1. Prepare for Engine Repair (A1) ASE certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair).
2. Describe how coolant flows through an engine.
3. Discuss the operation of the thermostat.
4. Explain the radiator pressure cap purpose and function.
5. Describe the various types of antifreezes and how to recycle and discard used coolant.
6. Discuss how to diagnose cooling system problems.

KEY TERMS

Back Flushing (p. 202)
Bar (p. 190)
Bleed Holes (p. 194)
Bypass (p. 182)
Centrifugal Pump (p. 192)
Coolant Recovery System (p. 191)
Cooling Fins (p. 188)
Core Tubes (p. 188)
DEX-COOL (p. 185)
Embittered Coolant (p. 186)
Ethylene Glycol-Based Antifreeze (p. 184)
Hybrid Organic Additive Technology (HOAT) (p. 186)
Impeller (p. 192)
Inorganic Additive Technology (IAT) (p. 185)
Organic Additive Technology (OAT) (p. 185)
Parallel Flow System (p. 194)
Reverse Cooling (p. 192)
Scroll (p. 193)
Series Flow System (p. 194)
Series-Parallel Flow System (p. 194)
Silicone Coupling (p. 196)
Steam Slits (p. 194)
Surge Tank (p. 190)
Thermostatic Spring (p. 197)

COOLING SYSTEM PURPOSE AND FUNCTION

Satisfactory cooling system operation depends on the design and operating conditions of the system. The design is based on heat output of the engine, radiator size, type of coolant, size of water pump (coolant pump), type of fan, thermostat, and system pressure. Unfortunately, the cooling system is usually neglected until there is a problem. Proper routine maintenance can prevent problems.

The cooling system must allow the engine to warm up to the required operating temperature as rapidly as possible and then maintain that temperature. It must be able to do this when the outside air temperature is as low as −30°F (−35°C) and as high as 110°F (45°C).

Peak combustion temperatures in the engine cycle run from 4,000° to 6,000°F (2,200° to 3,300°C). The combustion temperatures will *average* between 1,200° and 1,700°F (650° and 925°C). Continued temperatures as high as this would weaken engine parts, so heat must be removed from the engine. The cooling system keeps the head and cylinder walls at a temperature that is within the range for maximum efficiency. See Figure 13-1.

LOW-TEMPERATURE ENGINE PROBLEMS

Engine operating temperatures must be above a minimum temperature for proper engine operation. When the temperature is too low, there is not enough heat to properly vaporize

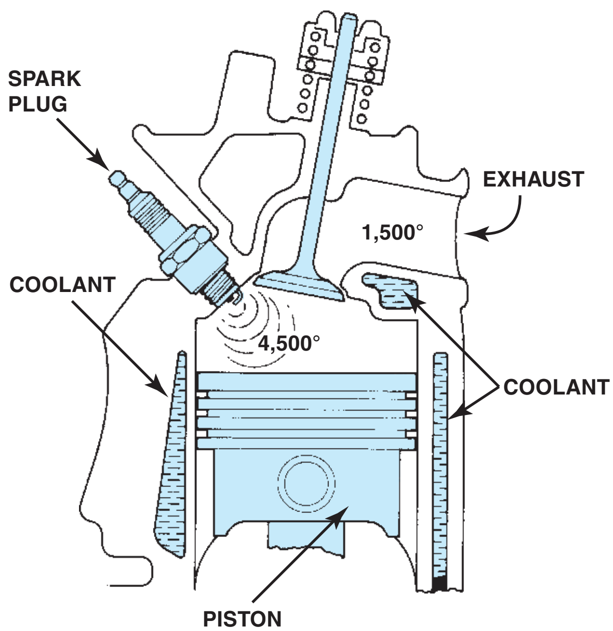


FIGURE 13-1 Typical combustion and exhaust temperatures.

TECH TIP

OVERHEATING CAN BE EXPENSIVE

A faulty cooling system seems to be a major cause of engine failure. Engine rebuilders often have nightmares about seeing their rebuilt engine placed back in service in a vehicle with a clogged radiator. Most engine technicians routinely replace the water pump and all hoses after an engine overhaul or repair. The radiator should also be checked for leaks and proper flow whenever the engine is repaired or replaced. Overheating is one of the most common causes of engine failure.

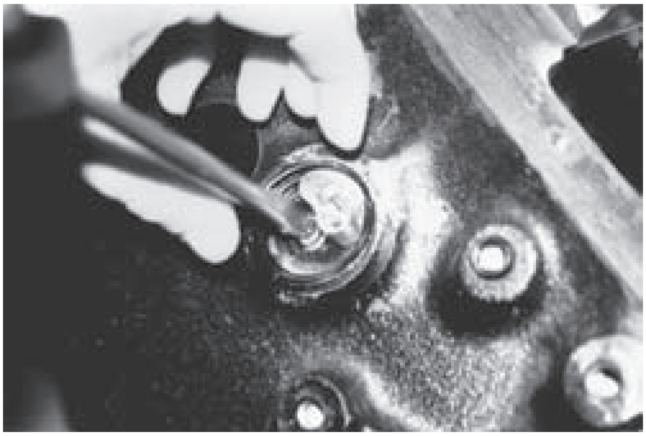
the fuel in the intake charge. As a result, extra fuel must be added to supply more volatile fuel to make a combustible mixture. The heavy, less volatile part of the gasoline does not vaporize, and so it remains as unburned liquid fuel. In addition, cool engine surfaces quench part of the combustion gases, leaving partially burned fuel as soot.

Gasoline combustion is a rapid oxidation process that releases heat as the hydrocarbon fuel chemically combines with oxygen from the air. *For each gallon of fuel used, moisture equal to a gallon of water is produced.* It is a part of this moisture that condenses and gets into the oil pan, along with unburned fuel and soot, and causes sludge formation. The condensed moisture combines with unburned hydrocarbons and additives to form carbonic acid, sulfuric acid, nitric acid, hydrobromic acid, and hydrochloric acid. These acids are responsible for engine wear by causing corrosion and rust within the engine. Rust occurs rapidly when the coolant temperature is below 130°F (55°C). Below 110°F (45°C), water from the combustion process will actually accumulate in the oil. High cylinder wall wear rates occur whenever the coolant temperature is below 150°F (65°C).

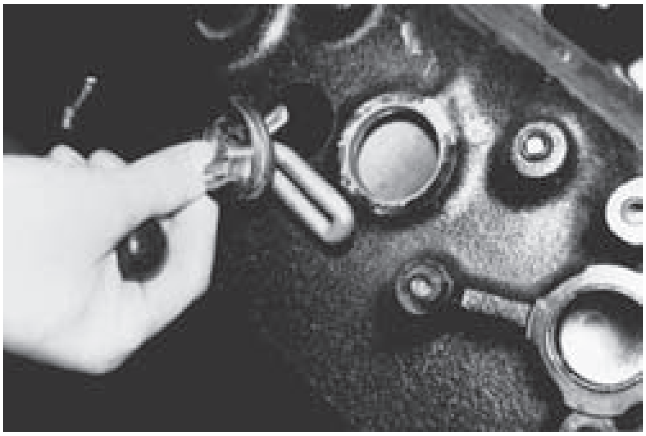
To reduce cold-engine problems and to help start engines in cold climates, most manufacturers offer block heaters as an option. These block heaters are plugged into household current (110 volts AC) and the heating element warms the coolant. See Figure 13-2.

HIGH-TEMPERATURE ENGINE PROBLEMS

Maximum temperature limits are required to protect the engine. High temperatures will oxidize the engine oil. This breaks the oil down, producing hard carbon and varnish. If high temperatures are allowed to continue, the carbon that is



(a)



(b)

FIGURE 13-2 (a) Loosening the screw that tightens the block heater element into the core plug opening in the side of the block. (b) Block heater element removed from block. The heater warms the coolant around the element, and the warm coolant rises, drawing cooler coolant up. As a result of this thermal circulation, all coolant surrounding the entire engine is warmed.

produced will plug piston rings. The varnish will cause the hydraulic valve lifter plungers to stick. High temperatures always thin the oil. Metal-to-metal contact within the engine will occur when the oil is too thin. This will cause high friction, loss of power, and rapid wear of the parts. Thinned oil will also get into the combustion chamber by going past the piston rings and through valve guides to cause excessive oil consumption.

The combustion process is very sensitive to temperature. High coolant temperatures raise the combustion temperatures to a point that may cause detonation and preignition to occur. These are common forms of abnormal combustion. If they are allowed to continue for any period of time, the engine will be damaged.

TECH TIP

ENGINE TEMPERATURE AND EXHAUST EMISSIONS

Many areas of the United States and Canada have exhaust emission testing. Hydrocarbon (HC) emissions are simply unburned gasoline. To help reduce HC emissions and be able to pass emission tests, be sure that the engine is at normal operating temperature. Vehicle manufacturers' definition of "normal operating temperature" includes the following:

1. Upper radiator hose is hot and pressurized.
2. Electric cooling fan(s) cycles twice.

Be sure that the engine is operating at normal operating temperature before testing for exhaust emissions. For best results, the vehicle should be driven about *20 miles* (32 kilometers) to be certain that the catalytic converter and engine oil, as well as the coolant, are at normal temperature. This is particularly important in cold weather. Most drivers believe that their vehicle will "warm up" if allowed to idle until heat starts flowing from the heater. The heat from the heater comes from the coolant. Most manufacturers recommend that idling be limited to a maximum of 5 minutes and that the vehicle should be warmed up by driving slowly after just a minute or two to allow the oil pressure to build.

COOLING SYSTEM DESIGN

Coolant flows through the engine, where it picks up heat. It then flows to the radiator, where the heat is given up to the outside air. The coolant continually recirculates through the cooling system, as illustrated in Figures 13-3 and 13-4. Its temperature rises as much as 15°F (8°C) as it goes through the engine; then it recools as it goes through the radiator. *The coolant flow rate may be as high as 1 gallon (4 liters) per minute for each horsepower the engine produces.*

Hot coolant comes out of the thermostat housing on the top of the engine. The engine coolant outlet is connected to the top of the radiator by the upper hose and clamps. The coolant in the radiator is cooled by air flowing through the radiator. As it cools, it moves from the top to the bottom of the radiator. Cool coolant leaves the lower radiator area through an outlet and lower hose, going into the inlet side of the water pump, where it is recirculated through the engine.

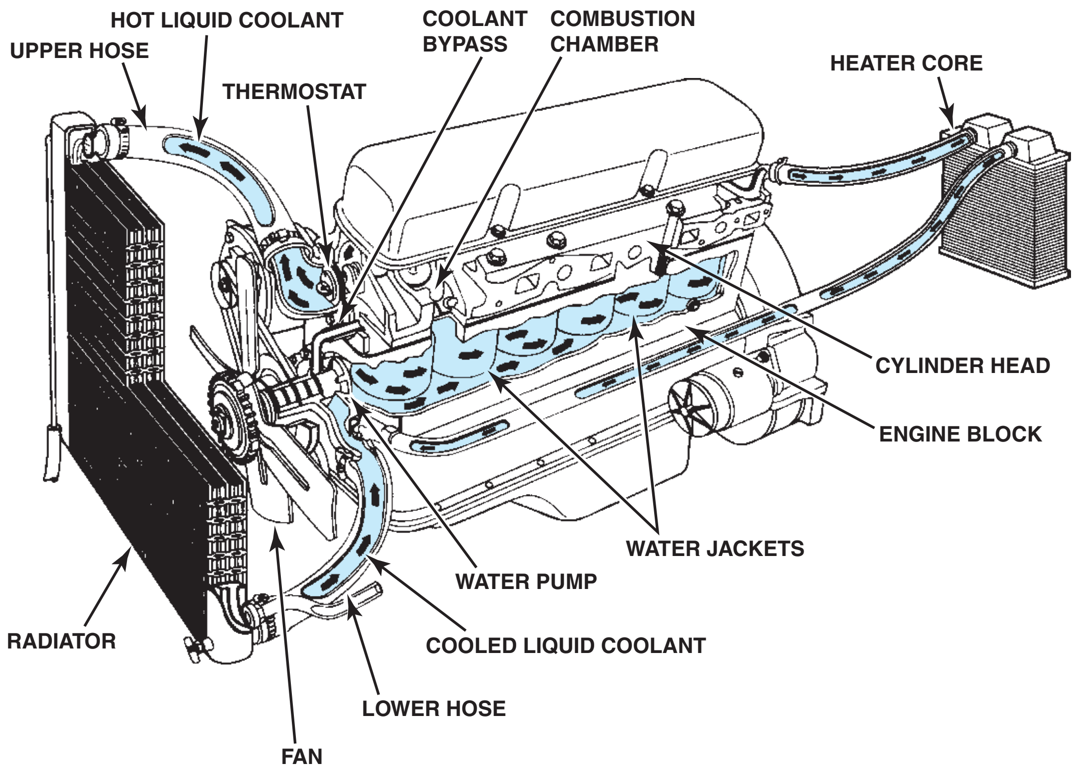


FIGURE 13-3 Coolant flow through a typical engine cooling system.

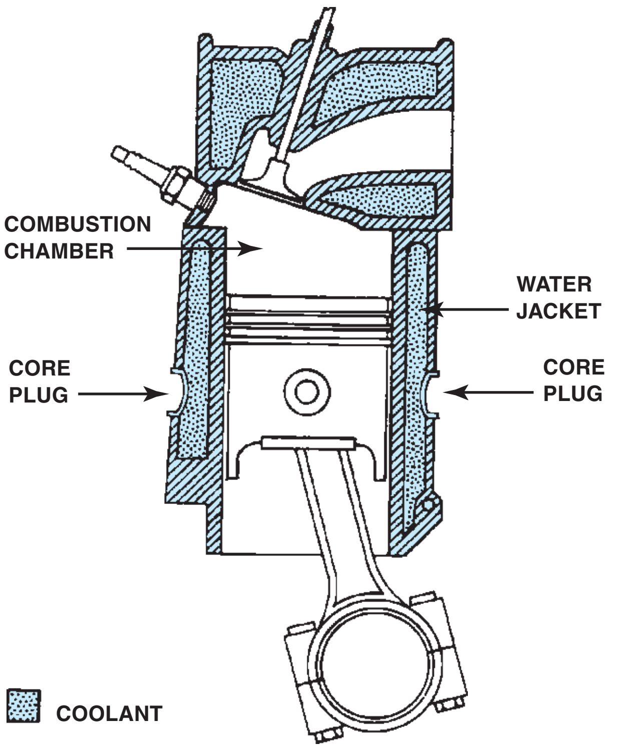


FIGURE 13-4 Coolant circulates through the water jackets in the engine block and cylinder head.

NOTE: **Some newer engine designs such as Chrysler's 4.7 L V-8 and General Motors' 4.8, 5.3, 5.7, and 6.0 L V-8s place the thermostat on the inlet side of the water pump. As the cooled coolant hits the thermostat, the thermostat closes until the coolant temperature again causes it to open. Placing the thermostat in the inlet side of the water pump therefore reduces thermal cycling by reducing the rapid temperature changes that could cause stress in the engine, especially if aluminum heads are used with a cast-iron block.**

Much of the cooling capacity of the cooling system is based on the functioning of the radiator. Radiators are designed for the maximum rate of heat transfer using minimum space. Cooling airflow through the radiator is aided by a belt- or electric motor-driven cooling fan.

THERMOSTAT TEMPERATURE CONTROL

There is a normal operating temperature range between low-temperature and high-temperature extremes. The thermostat controls the minimum normal temperature. The thermostat is a temperature-controlled valve placed at the engine coolant outlet. An encapsulated, wax-based, plastic-pellet heat sensor is located on the engine side of the thermostatic valve. As the engine warms, heat swells the heat sensor. See Figure 13-5.

A mechanical link, connected to the heat sensor, opens the thermostat valve. As the thermostat begins to open, it allows some coolant to flow to the radiator, where it is cooled. The remaining part of the coolant continues to flow through the bypass, thereby bypassing the thermostat and flowing back through the engine. See Figure 13-6.

The rated temperature of the thermostat indicates the temperature at which the thermostat starts to open. The thermostat is fully open at about 20°F higher than its opening temperature. See the following examples.

Thermostat Temperature Rating	*Starts to Open*	*Fully Open*
180°F (82°C)	180°F (82°C)	200°F (93°C)
195°F (91°C)	195°F (91°C)	215°F (107°C)

If the radiator, water pump, and coolant passages are functioning correctly, the engine should always be operating within the opening and fully open temperature range of the thermostat. See Figure 13-7.

NOTE: A **bypass** around the closed thermostat allows a small part of the coolant to circulate within the engine during warm-up. It is a small passage that leads from the engine side of the thermostat to the inlet side of the water pump. It allows some coolant to bypass the thermostat even when the thermostat is open. The bypass may be cast or drilled into the engine and pump parts. See Figures 13-8 and 13-9.

The bypass aids in uniform engine warm-up. Its operation eliminates hot spots and prevents the building of excessive coolant pressure in the engine when the thermostat is closed.

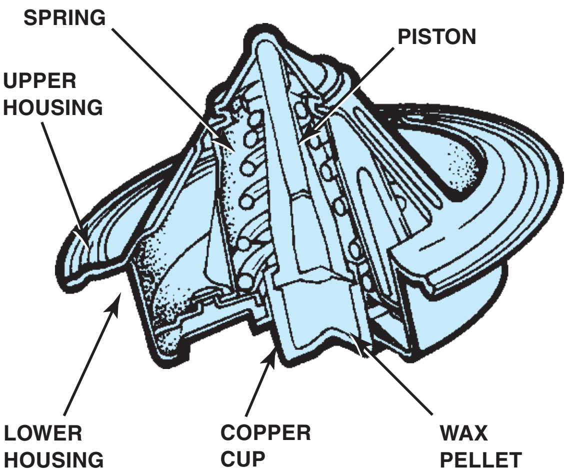


FIGURE 13-5 A cross-section of a typical wax-actuated thermostat showing the position of the wax pellet and spring.

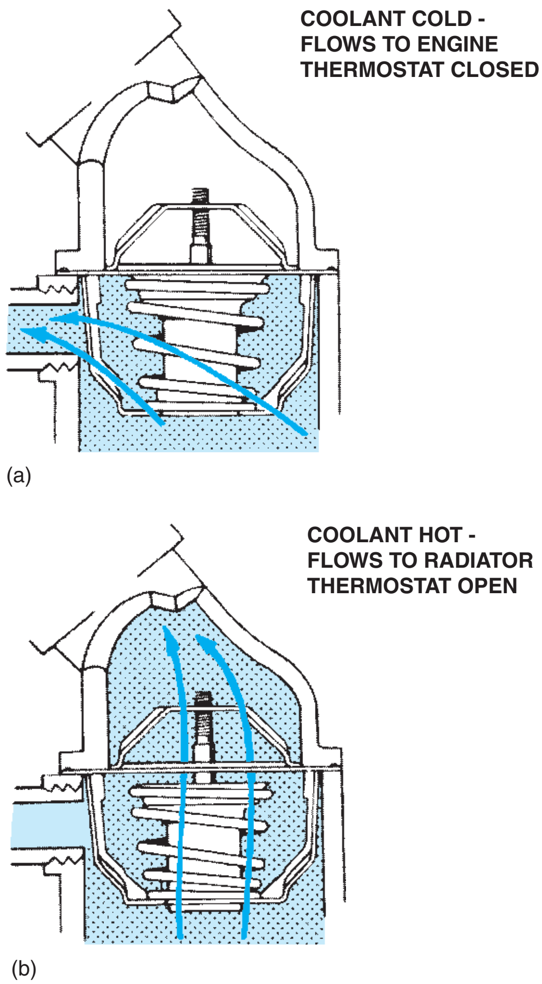


FIGURE 13-6 (a) When the engine is cold, the coolant flows through the bypass. (b) When the thermostat opens, the coolant can flow to the radiator.

FIGURE 13-7 A thermostat stuck in the open position caused the engine to operate too cold. The vehicle failed an exhaust emission test because of this defect.

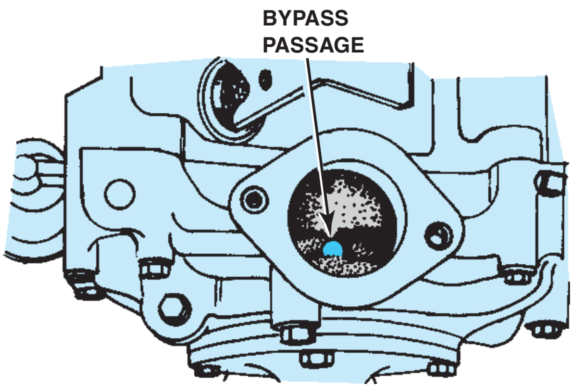


FIGURE 13-8 This internal bypass passage in the thermostat housing directs cold coolant to the water pump.

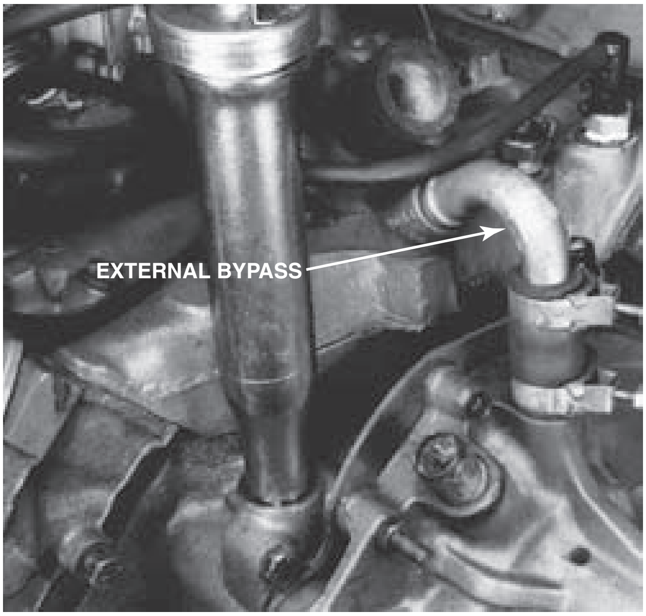


FIGURE 13-9 One type of cooling system external bypass.

TESTING THE THERMOSTAT

There are three basic methods that can be used to check the operation of the thermostat.

1. **Hot water method.** If the thermostat is removed from the vehicle and is closed, insert a 0.015-inch (0.4-millimeter) feeler gauge in the opening so that the thermostat will hang on the feeler gauge. The thermostat should then be suspended by the feeler gauge in a bath along with a thermometer. See Figure 13-10. The bath should be heated until the thermostat opens enough to release and fall from the feeler gauge. The temperature of the bath when the thermostat falls is the opening temperature of the thermostat. If it is within 5°F (4°C) of the temperature stamped on the thermostat, the thermostat is satisfactory for use. If the temperature difference is greater, the thermostat should be replaced.
2. **Infrared pyrometer method.** An infrared pyrometer can be used to measure the temperature of the coolant near the thermostat. The area on the engine side of the thermostat should be at the highest temperature that

TECH TIP

DO NOT TAKE OUT THE THERMOSTAT!

Some vehicle owners and technicians remove the thermostat in the cooling system to "cure" an overheating problem. In some cases, removing the thermostat can *cause* overheating—not stop overheating. This is true for three reasons:

1. Without a thermostat the coolant can flow more quickly through the radiator. The thermostat adds some restriction to the coolant flow, and therefore keeps the coolant in the radiator longer. The presence of the thermostat thus ensures a greater reduction in the coolant temperature before it returns to the engine.
2. Heat transfer is greater with a greater difference between the coolant temperature and air temperature. Therefore, when coolant flow rate is increased (no thermostat), the temperature difference is reduced.
3. Without the restriction of the thermostat, much of the coolant flow often bypasses the radiator entirely and returns directly to the engine.

If overheating is a problem, removing the thermostat will usually not solve the problem. Remember, the thermostat controls the temperature of the engine coolant by opening at a certain temperature and closing when the temperature falls below the minimum rated temperature of the thermostat. If overheating occurs, two basic problems could be the cause:

1. The engine is producing too much heat for the cooling system to handle. For example, if the engine is running too lean or if the ignition timing is either excessively advanced or excessively retarded, overheating of the engine can result.
2. The cooling system has a malfunction or defect that prevents it from getting rid of its heat.

FIGURE 13-10 Setup used to check the opening temperature of a thermostat.

exists in the engine. A properly operating cooling system should cause the pyrometer to read as follows:

a. As the engine warms, the temperature reaches near thermostat opening temperature.
b. As the thermostat opens, the temperature drops just as the thermostat opens, sending coolant to the radiator.
c. As the thermostat cycles, the temperature should range between the opening temperature of the thermostat and 20°F (11°C) above the opening temperature.

NOTE: If the temperature rises higher than 20°F (11°C) above the opening temperature of the thermostat, inspect the cooling system for a restriction or low coolant flow. A clogged radiator could also cause the excessive temperature rise.

3. **Scan tool method.** A scan tool can be used on many vehicles to read the actual temperature of the coolant as detected by the engine coolant temperature (ECT) sensor. Although the sensor or the wiring to and from the sensor may be defective, at least the scan tool can indicate what the computer "thinks" the engine coolant temperature is.

THERMOSTAT REPLACEMENT

An overheating engine may result from a faulty thermostat. An engine that does not get warm enough always indicates a faulty thermostat.

FIGURE 13-11 Some thermostats are an integral part of the housing. This thermostat and radiator hose housing is serviced as an assembly. Some thermostats simply snap into the engine radiator fill tube underneath the pressure cap.

To replace the thermostat, coolant will have to be drained from the radiator drain petcock to lower the coolant level below the thermostat. It is not necessary to completely drain the system. The upper hose should be removed from the thermostat housing neck; then the housing must be removed to expose the thermostat. See Figure 13-11.

The gasket flanges of the engine and thermostat housing should be cleaned, and the gasket surface of the housing must be flat. The thermostat should be placed in the engine with the sensing pellet *toward* the engine. Make sure that the thermostat position is correct, and install the thermostat housing with a new gasket.

CAUTION: Failure to set the thermostat into the recessed groove will cause the housing to become tilted when tightened. If this happens and the housing bolts are tightened, the housing will usually crack, creating a leak.

The upper hose should then be installed and the system refilled. Install the proper size of radiator hose clamp.

ANTIFREEZE/COOLANT

Coolant is a mixture of antifreeze and water. Water is able to absorb more heat per gallon than any other liquid coolant. Under standard conditions, water boils at 212°F (100°C) and freezes at 32°F (0°C). *When water freezes, it increases in volume about 9%.* The expansion of the freezing water can easily crack engine blocks, cylinder heads, and radiators. All manufacturers recommend the use of **ethylene glycol-based antifreeze** mixtures for protection against this problem.

A curve depicting the freezing point as compared with the percentage of antifreeze mixture is shown in Figure 13-12.

It should be noted that the freezing point increases as the antifreeze concentration is increased above 60%. The normal mixture is 50% antifreeze and 50% water. Ethylene glycol antifreezes contain anticorrosion additives, rust inhibitors, and water pump lubricants.

At the maximum level of protection, an ethylene glycol concentration of 60% will absorb about 85% as much heat as will water. Ethylene glycol-based antifreeze also has a higher boiling point than water. See Figure 13-13.

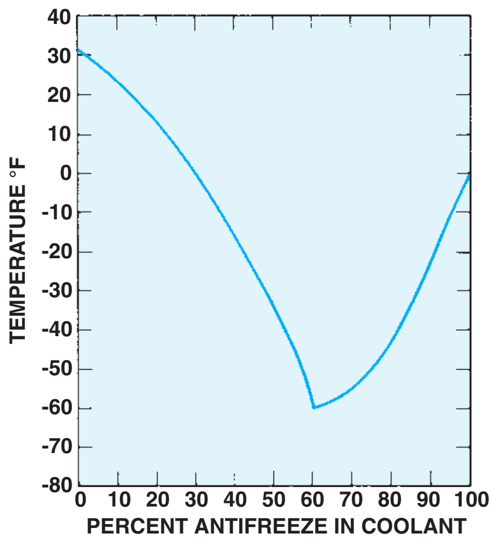


FIGURE 13-12 Graph showing the relationship of the freezing point of the coolant to the percentage of antifreeze used in the coolant.

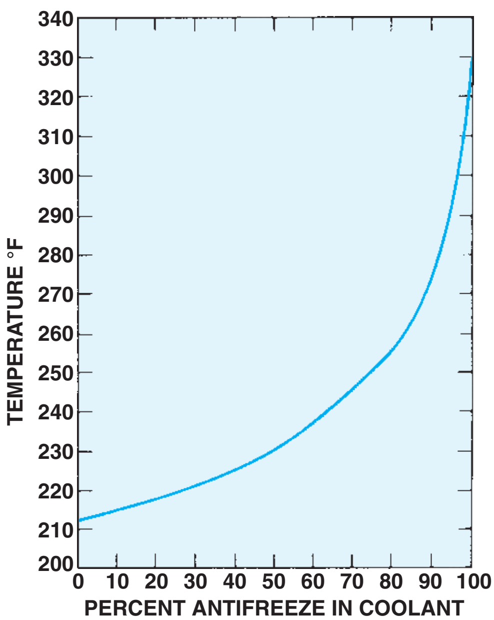


FIGURE 13-13 Graph showing how the boiling point of the coolant increases as the percentage of antifreeze in the coolant increases.

If the coolant boils, it vaporizes and does not act as a cooling agent because it is not in liquid form and in contact with the cooling surfaces.

All coolants have rust and corrosion inhibitors to help protect the metals in the engine and cooling systems. Most conventional green antifreeze contains inorganic salts such as sodium silicate and phosphates.

TYPES OF COOLANT

Antifreeze coolant contains about 93% ethylene glycol plus water and additives. There are three basic types of coolant available today, which are grouped according to the additives used for rust and corrosion protection.

Inorganic Additive Technology (IAT)

Inorganic additive technology (IAT) is conventional coolant that has been used for over 50 years. The additives used to protect against rust and corrosion include phosphates and silicates. Silicates have been found to be the cause of erosive wear to water pump impellers. The color of IAT coolant is usually green. Phosphates in these coolants can cause deposits to form if used with water that is hard (contains minerals).

Organic Additive Technology (OAT)

Organic additive technology (OAT) antifreeze coolant contains ethylene glycol, but does not contain silicates or phosphates. This type of coolant is usually orange in color and was first developed by Havoline (called **DEX-COOL**) and used in General Motors vehicles starting in 1996. See Figure 13-14.

FIGURE 13-14 DEX-COOL coolant uses organic acid technology and is both silicate and phosphate free.

Hybrid Organic Additive Technology (HOAT)

A newer variation of this technology is called **hybrid organic additive technology (HOAT)** and is similar to the OAT- type antifreeze as it uses organic acid salts (carboxylates) additives that are not abrasive to water pumps, yet provide the correct pH. The pH of the coolant is usually above 11. A pH of 7 is neutral, with lower numbers indicating an acidic solution and higher numbers indicating a caustic solution. If the pH is too high, the coolant can cause scaling and reduce the heat transfer ability of the coolant. If the pH is too low, the resulting acidic solution could cause corrosion of the engine components exposed to the coolant. HOAT coolants can be green, orange, yellow, gold, pink, red, or blue.

Some samples of HOAT coolants include:

- VW/Audi pink—contains some silicates and an organic acid and is phosphate free
- Mercedes yellow—low amounts of silicate and no phosphate
- Ford yellow—low silicate, no phosphate, and dyed yellow for identification

REAL WORLD FIX

IF 50% IS GOOD, 100% MUST BE BETTER

A vehicle owner said that the cooling system of his vehicle would never freeze or rust. He said that he used 100% antifreeze (ethylene glycol) instead of a 50/50 mixture with water.

However, after the temperature dropped to −20°F (−29°C), the radiator froze and cracked. (Pure antifreeze freezes at about 0°F [−18°C].) After thawing, the radiator had to be repaired. The owner was lucky that the engine block did not also crack.

For best freeze protection with good heat transfer, use a 50/50 mixture of antifreeze and water. A 50/50 mixture of antifreeze and water is the best compromise between temperature protection and the heat transfer that is necessary for cooling system operation. Do not exceed 70% antifreeze (30% water). As the percentage of antifreeze increases, the boiling temperature increases, and freezing protection increases (up to 70% antifreeze), but the heat transfer performance of the mixture decreases.

FREQUENTLY ASKED QUESTION

WHAT IS "PET FRIENDLY" ANTIFREEZE?

Conventional ethylene glycol antifreeze, regardless of the additives used, is attractive to pets and animals because it is sweet. Ethylene glycol is fatal to any animal if swallowed and therefore, any spill should be cleaned up quickly. Another type of antifreeze coolant, called propylene glycol, is less attractive to pets and animals because it is less sweet, but is still harmful if swallowed. This type of coolant should not be mixed with ethylene glycol coolant.

NOTE: Some IAT coolant has been made bitter to deter animals and is called **embittered coolant.**

CAUTION: Some vehicle manufacturers do not recommend the use of propylene glycol coolant. Check the recommendation in the owner's manual or service information before using it in a vehicle.

- Honda blue—a special coolant that contains just one organic acid
- European blue—low silicates and no phosphates (*Glysantin* is the trade name associated with this coolant.)
- Asian red—contains no silicates but has some phosphate

ANTIFREEZE CAN FREEZE

An antifreeze and water mixture is an example wherein the freezing point differs from the freezing point of either pure antifreeze or pure water.

	Freezing Point
Pure water	32°F (0°C)
Pure antifreeze*	0°F (−18°C)
50/50 mixture	−34°F (−37°C)
70% antifreeze/30% water	−84°F (−64°C)

*Pure antifreeze is usually 95% ethylene glycol, 2% to 3% water, and 2% to 3% additives.

Depending on the exact percentage of water used, antifreeze, as sold in containers, freezes between −8°F and +8°F (−13°C and −22°C). Therefore, it is easiest just to remember that most antifreeze freezes at about 0°F (−18°C).

TECH TIP

IGNORE THE WIND-CHILL FACTOR

The wind-chill factor is a temperature that combines the actual temperature and the wind speed to determine the overall heat loss effect on exposed skin. Because it is the heat loss factor for exposed skin, the wind-chill temperature is *not* to be considered when determining antifreeze protection levels.

Although moving air does make it feel colder, the actual temperature is not changed by the wind and the engine coolant will not be affected by the wind-chill. Not convinced? Try this. Place a thermometer in a room and wait until a stable reading is obtained. Now turn on a fan and have the air blow across the thermometer. The temperature will not change.

The boiling point of antifreeze and water is also a factor of mixture concentrations.

	Boiling Point at Sea Level	*Boiling Point with 15 PSI Pressure Cap*
Pure water	212°F (100°C)	257°F (125°C)
50/50 mixture	218°F (103°C)	265°F (130°C)
70/30 mixture	225°F (107°C)	276°F (136°C)

HYDROMETER TESTING

Coolant can be checked using a coolant hydrometer. The hydrometer measures the density of the coolant. The higher the density, the more concentration of antifreeze in the water. Most coolant hydrometers read the freezing point and boiling point of the coolant. See Figure 13-15.

If the engine is overheating and the hydrometer reading is near −50°F (−60°C), suspect that pure 100% antifreeze is present. For best results, the coolant should have a freezing point lower than −20°F (−29°C) and a boiling point above 234°F (112°C).

RECYCLING COOLANT

Coolant (antifreeze and water) should be recycled. Used coolant may contain heavy metals, such as lead, aluminum, and iron, which are absorbed by the coolant during its use in the engine.

FIGURE 13-15 Checking the freezing and boiling protection levels of the coolant using a hydrometer.

Recycle machines filter out these metals and dirt and reinstall the depleted additives. The recycled coolant, restored to be like new, can be reinstalled into the vehicle.

CAUTION: Most vehicle manufacturers warn that antifreeze coolant should not be reused unless it is recycled and the additives restored.

DISPOSING OF USED COOLANT

Used coolant drained from vehicles can usually be disposed of by combining it with used engine oil. The equipment used for recycling the used engine oil can easily separate the coolant from the waste oil. Check with recycling companies authorized by local or state governments for the exact method recommended for disposal in your area. See Figure 13-16.

REPLACING COOLANT

Coolant should be replaced according to the vehicle manufacturer's recommended interval. For most new vehicles using OAT or HOAT-type coolant, this interval may be every five years or 150,000 miles (241,000 km) whichever occurs first. Japanese-brand vehicles usually have a replacement interval of three years or 36,000 miles (58,000 km) whichever occurs

FIGURE 13-16 Used antifreeze coolant should be kept separate and stored in a leak-proof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.

first. If the coolant is changed from long-life-type coolant to conventional IAT-type coolant, then the replacement interval needs to be changed to every two years or 24,000 miles (39,000 km), whichever occurs first. Always check service information for the exact recommended replacement interval for the vehicle being serviced.

RADIATOR

Two types of radiator cores are in common use in domestic vehicles—the serpentine fin core and the plate fin core. In each of these types the coolant flows through oval-shaped **core tubes.** Heat is transferred through the tube wall and soldered joint to **cooling fins.** The fins are exposed to airflow, which removes heat from the radiator and carries it away. See Figures 13-17 through 13-19.

Older automobile radiators were made from yellow brass. Since the 1980s, most radiators have been made from aluminum. These materials are corrosion resistant, have good heat-transferring ability, and are easily formed.

Core tubes are made from 0.0045- to 0.012-inch (0.1- to 0.3-millimeter) sheet brass or aluminum, using the thinnest possible materials for each application. The metal is rolled into round tubes and the joints are sealed with a locking seam.

The main limitation of heat transfer in a cooling system is in the transfer from the radiator to the air. Heat transfers from the water to the fins as much as seven times faster than heat transfers from the fins to the air, assuming equal surface exposure. The radiator must be capable of removing an amount of heat energy approximately equal to the heat energy of the

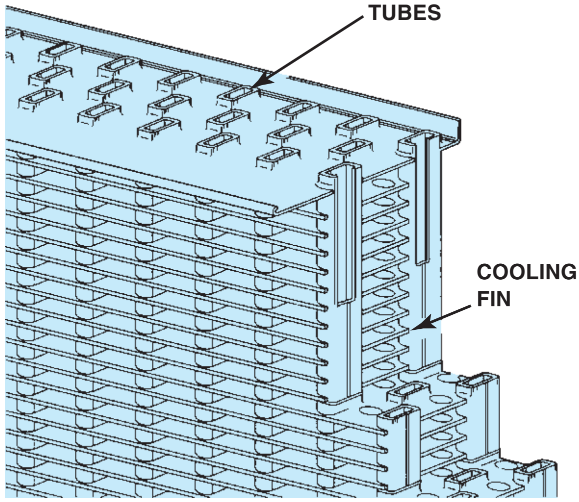


FIGURE 13-17 The tubes and fins of the radiator core.

power produced by the engine. *Each horsepower is equivalent to 42 Btu (10,800 calories) per minute.* As the engine power is increased, the heat-removing requirement of the cooling system is also increased.

With a given frontal area, radiator capacity may be increased by increasing the core thickness, packing more material into the same volume, or both. The radiator capacity may also be increased by placing a shroud around the fan so that more air will be pulled through the radiator.

NOTE: The lower air dam in the front of the vehicle is used to help direct the air through the radiator. If this air dam is broken or missing, the engine may overheat, especially during highway driving due to the reduced airflow through the radiator.

Radiator headers and tanks that close off the ends of the core were made of sheet brass 0.020 to 0.050 inch (0.5 to 1.25 millimeters) thick and now are made of molded plastic. When a transmission oil cooler is used in the radiator, it is placed in the outlet tank, where the coolant has the lowest temperature (Figure 13-20).

PRESSURE CAP

The filler neck is fitted with a pressure cap. The cap has a spring-loaded valve that closes the cooling system vent. This causes cooling pressure to build up to the pressure setting of the cap. At this point, the valve will release the excess pressure to prevent system damage. See Figure 13-21 on page 190.

Engine cooling systems are pressurized to raise the boiling temperature of the coolant. *The boiling temperature will increase by approximately 3°F (1.6°C) for each pound of increase in pressure.* At standard atmospheric pressure, water

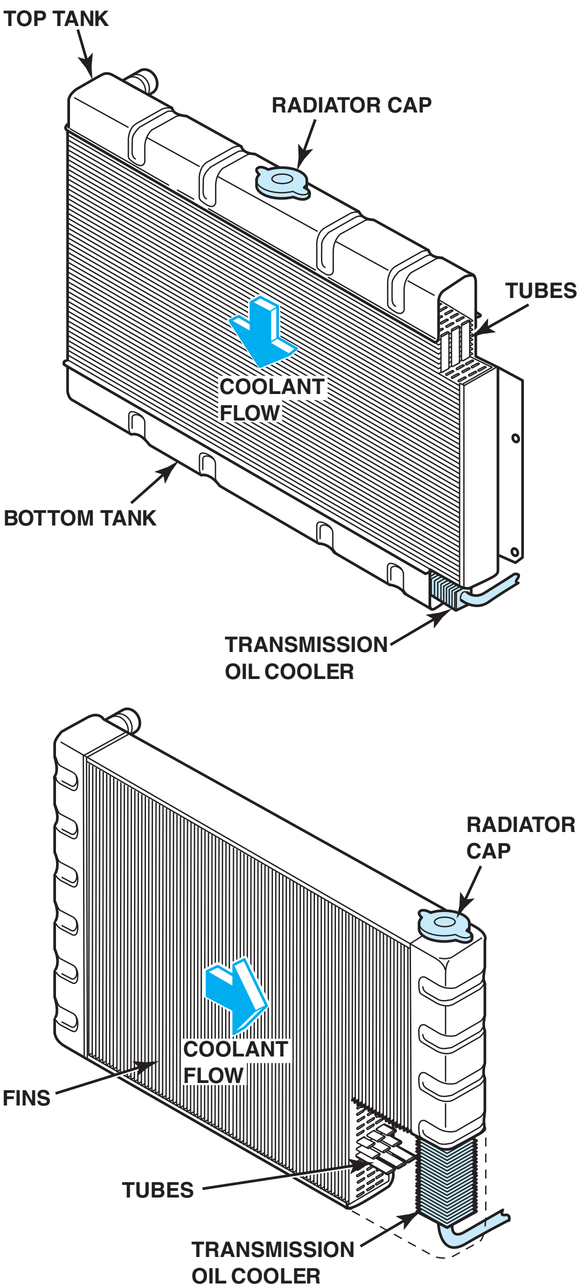


FIGURE 13-18 A radiator may be either a down-flow or a cross-flow type.

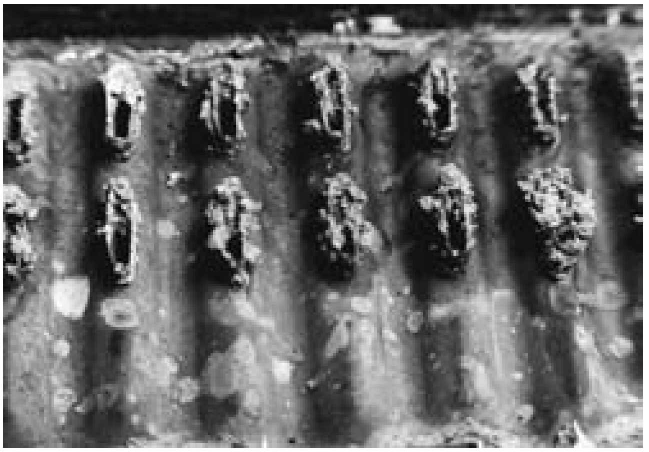


FIGURE 13-19 Cutaway of a typical radiator showing restriction of tubes. Changing antifreeze frequently helps prevent this of problem.

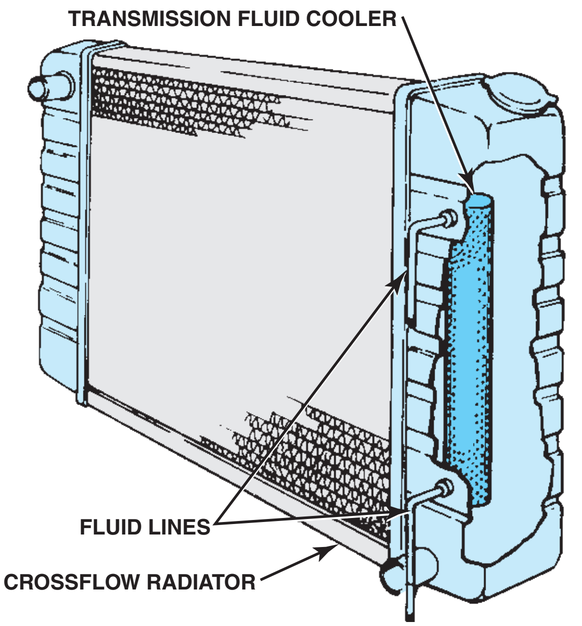


FIGURE 13-20 Many vehicles equipped with an automatic transmission use a transmission fluid cooler installed in one of the radiator tanks.

will boil at 212°F (100°C). With a 15 PSI (100 kPa) pressure cap, water will boil at 257°F (125°C), which is a maximum operating temperature for an engine.

The high coolant system temperature serves two functions.

1. It allows the engine to run at an efficient temperature, close to 200°F (93°C), with no danger of boiling the coolant.
2. The higher the coolant temperature, the more heat the cooling system can transfer. The heat transferred by the cooling system is proportional to the temperature difference between the coolant and the outside air. This characteristic has led to the design of small, high-pressure radiators that are capable of handling large quantities of heat. For proper cooling, the system must have the right pressure cap correctly installed.

NOTE: **The proper operation of the pressure cap is especially important at high altitudes. The boiling point of water is lowered by about 1°F for every 550-foot increase in altitude. Therefore in Denver, Colorado (altitude 5,280 feet), the boiling point of water is about 202°F, and at the top of Pike's Peak in Colorado (14,110 feet) water boils at 186°F.**

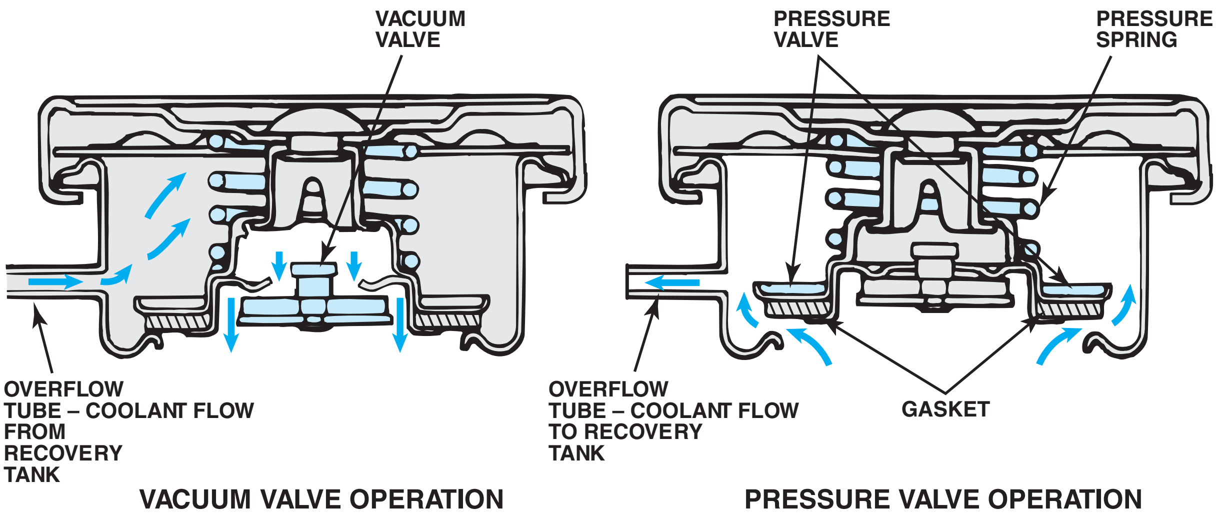


FIGURE 13-21 The pressure valve maintains the system pressure and allows excess pressure to vent. The vacuum valve allows coolant to return to the system from the recovery tank.

FIGURE 13-22 Some vehicles use a surge tank, which is located at the highest level of the cooling system with a radiator cap.

TECH TIP

WORKING BETTER UNDER PRESSURE

A problem that sometimes occurs with a high-pressure cooling system involves the water pump. For the pump to function, the inlet side of the pump must have a lower pressure than its outlet side. If inlet pressure is lowered too much, the coolant at the pump inlet can boil, producing vapor. The pump will then spin the coolant vapors and not pump coolant. This condition is called *pump cavitation.* Therefore, a radiator cap could be the cause of an overheating problem. A pump will not pump enough coolant if not kept under the proper pressure for preventing vaporization of the coolant.

SURGE TANK

Some vehicles use a **surge tank,** which is located at the highest level of the cooling system and holds about 1 quart (1 liter) of coolant. A hose attaches to the bottom of the surge tank to the inlet side of the water pump. A smaller bleed hose attaches to the side of the surge tank to the highest point of the radiator. The bleed line allows some coolant circulation through the surge tank, and air in the system will rise below the radiator cap and be forced from the system if the pressure in the system exceeds the rating of the radiator cap. See Figure 13-22.

METRIC RADIATOR CAPS

According to the *SAE Handbook*, all radiator caps must indicate their nominal (normal) pressure rating. Most original equipment radiator caps are rated at about 14 to 16 PSI (97 to 110 kPa).

However, many vehicles manufactured in Japan or Europe have the radiator pressure indicated in a unit called a **bar.** One bar is the pressure of the atmosphere at sea level, or about 14.7 PSI. The following conversion can be used when replacing a radiator cap to make certain it matches the pressure rating of the original.

Bar or Atmospheres	*Pounds per Square Inch (PSI)*
1.1	16
1.0	15
0.9	13
0.8	12
0.7	10
0.6	9
0.5	7

NOTE: Many radiator repair shops use a 7-PSI (0.5-bar) radiator cap on a repaired radiator. A 7-PSI cap can still provide boil protection of 21°F (3°F × 7 PSI = 21°F) above the boiling point of the coolant. For example, if the boiling point of the antifreeze coolant is 223°F, 21°F is added for the pressure cap, and boilover will not occur until about 244°F (223°F + 21°F = 244°F). Even though this lower-pressure radiator cap does provide some protection and will also help protect the radiator repair, the coolant can still boil *before* the "hot" dash warning light comes on and, therefore, should not be used.

COOLANT RECOVERY SYSTEM

Excess pressure usually forces some coolant from the system through an overflow. Most cooling systems connect the overflow to a plastic reservoir to hold excess coolant while the system is hot. See Figure 13-23.

When the system cools, the pressure in the cooling system is reduced and a partial vacuum forms. This pulls the coolant from the plastic container back into the cooling system, keeping the system full. Because of this action, this system is called a **coolant recovery system.** The filler cap used on a coolant system without a coolant saver is fitted with a vacuum valve. This valve allows air to reenter the system as the system cools so that the radiator parts will not collapse under the partial vacuum.

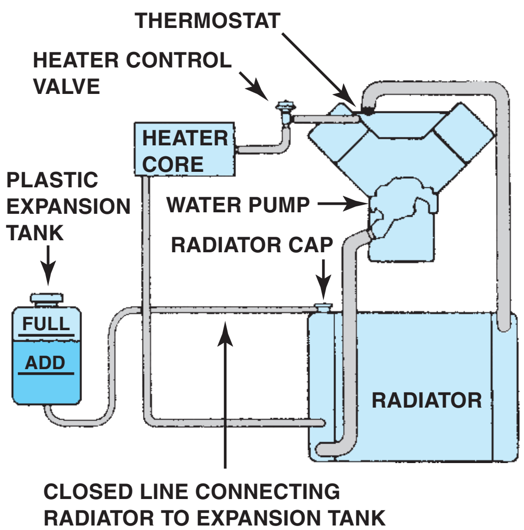
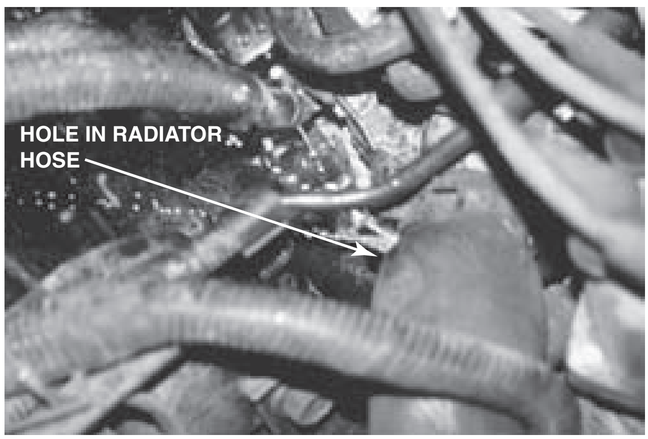


FIGURE 13-23 The level in the coolant recovery system raises and lowers with engine temperature.

PRESSURE TESTING

Pressure testing using a hand-operated pressure tester is a quick and easy cooling system test. The radiator cap is removed (engine cold!) and the tester is attached in the place of the radiator cap. By operating the plunger on the pump, the entire cooling system is pressurized. See Figure 13-24.

(a)



(b)

FIGURE 13-24 (a) Using a hand-operated pressure tester to pressurize the entire cooling system. (b) Notice the coolant leaking out of a hole in the radiator hose. This is the reason why the owner of this minivan noticed a "hot coolant" smell.

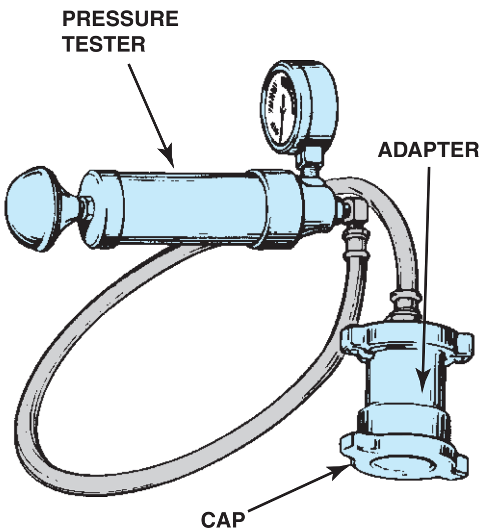


FIGURE 13-25 The pressure cap should be checked for proper operation using a pressure tester as part of the cooling system diagnosis.

CAUTION: Do not pump up the pressure beyond that specified by the vehicle manufacturer. Most systems should not be pressurized beyond 14 PSI (100 kPa). If a greater pressure is used, it may cause the water pump, radiator, heater core, or hoses to fail.

If the cooling system is free from leaks, the pressure should stay and not drop. If the pressure drops, look for evidence of leaks anywhere in the cooling system including:

1. Heater hoses
2. Radiator hoses
3. Radiator
4. Heat core
5. Cylinder head
6. Core plugs in the side of the block or cylinder head

Pressure testing should be performed whenever there is a leak or suspected leak. The pressure tester can also be used to test the radiator cap. An adapter is used to connect the pressure tester to the radiator cap. Replace any cap that will not hold pressure. See Figure 13-25.

COOLANT DYE LEAK TESTING

One of the best methods to check for a coolant leak is to use a fluorescent dye in the coolant. Use a dye designed for coolant. Operate the vehicle with the dye in the coolant until the engine reaches normal operating temperature. Use a black light to inspect all areas of the cooling system. When there is a leak, it will be easy to spot because the dye in the coolant will be seen as bright green. See Figure 13-26 for a cooling system inspection checklist that can be used to help locate cooling system–related problems.

TECH TIP

USE DISTILLED WATER IN THE COOLING SYSTEM

Two technicians are discussing refilling the radiator after changing antifreeze. One technician says that distilled water is best to use because it does not contain minerals that can coat the passages of the cooling system. The other technician says that any water that is suitable to drink can be used in a cooling system. Both technicians are correct. If water contains minerals, however, it can leave deposits in the cooling system that could prevent proper heat transfer. Because the mineral content of most water is unknown, distilled water, which has no minerals, is better to use. Although the cost of distilled water must be considered, the amount of water required (usually about 2 gallons [8 liters] or less of water) makes the expense minor in comparison with the cost of radiator or cooling system failure.

WATER PUMP OPERATION

The water pump (also called a coolant pump) is driven by a belt from the crankshaft or driven by the camshaft. Coolant recirculates from the radiator to the engine and back to the radiator. Low-temperature coolant leaves the radiator by the bottom outlet. It is pumped into the warm engine block, where it picks up some heat. From the block, the warm coolant flows to the hot cylinder head, where it picks up more heat.

NOTE: Some engines use **reverse cooling.** This means that the coolant flows from the radiator to the cylinder head(s) before flowing to the engine block.

Water pumps are not positive displacement pumps. The water pump is a **centrifugal pump** that can move a large volume of coolant without increasing the pressure of the coolant. The pump pulls coolant in at the center of the **impeller.** Centrifugal force throws the coolant outward so

COOLING SYSTEM INSPECTION CHECKLIST

Drive Belts
- ❑ Glazing, deterioration, cracks, fraying, or other damage
- ❑ Age, replace every 4 years
- ❑ Pulley alignment
- ❑ Tension

Hoses
- ❑ Hardness, cracks, brittleness, cuts, or other damage
- ❑ Sponginess or interior damage
- ❑ Loose connections or leakage
- ❑ Age, replace every 4 years

Coolant Leakage
- ❑ Core plugs
- ❑ Water pump shaft seal
- ❑ Water pump gaskets
- ❑ Thermostat gasket
- ❑ Hose connections

Radiator
- ❑ Leaks or corrosion at the tank seams or on the radiator tubes
- ❑ Clogged or bent radiator core fins
- ❑ Blocked air intake paths
- ❑ Loose or missing mounting bolts
- ❑ Coolant recovery tank installation
- ❑ Coolant level and concentration
- ❑ Coolant age, replace every 2 years
- ❑ Rust, oil, or other coolant contamination
- ❑ Pressure test

Radiator Cap
- ❑ Secure filler neck fit
- ❑ Correct pressure rating
- ❑ Brittle or damaged seal
- ❑ Sufficient spring action
- ❑ Pressure test

Heater Assembly
- ❑ Rust or corrosion on the core
- ❑ Hose connections
- ❑ Hose condition
- ❑ Heater control valve operation, leakage, and mounting
- ❑ Secure core assembly mounting
- ❑ Coolant leakage
- ❑ Condition of the air ducts

Water Pump
- ❑ Coolant leakage at the shaft
- ❑ Coolant leakage at the gasket
- ❑ Secure hose connections
- ❑ Pulley and belt alignment
- ❑ Excessive play

Radiator Fan
- ❑ Bent or cracked fan blades
- ❑ Binding between the fan and shaft
- ❑ Fan clutch or electric fan operation

Fan Shrouds and Air Deflectors
- ❑ Location and mounting
- ❑ Condition
- ❑ Clearance

Unusual Noises
- ❑ Engine thump—coolant flow restriction
- ❑ Screeching—loose drive belt or bad water pump bearing
- ❑ Buzz or whistle—poor radiator cap seal or vibrating fan shroud
- ❑ Ringing or grinding—water pump shaft bearing, loose pulley, or tensioner bearing
- ❑ Gurgling radiator—plugged radiator or air in the coolant

FIGURE 13-26 Cooling system inspection checklist.

that it is discharged at the impeller tips. This can be seen in Figure 13-27.

As engine speeds increase, more heat is produced by the engine and more cooling capacity is required. The pump impeller speed increases as the engine speed increases to provide extra coolant flow at the very time it is needed.

Coolant leaving the pump impeller is fed through a **scroll.** The scroll is a smoothly curved passage that changes the fluid flow direction with minimum loss in velocity. The scroll is connected to the front of the engine so as to direct the coolant into the engine block. On V-type engines, two outlets are usually used, one for each cylinder bank. Occasionally,

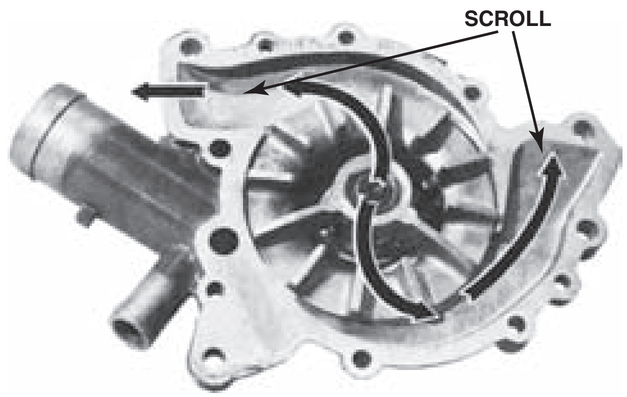


FIGURE 13-27 Coolant flow through the impeller and scroll of a coolant pump for a V-type engine.

FREQUENTLY ASKED QUESTION

HOW MUCH COOLANT CAN A WATER PUMP PUMP?

A typical water pump can move a maximum of about 7,500 gallons (28,000 liters) of coolant per hour, or recirculate the coolant in the engine over 20 times per minute. This means that a water pump could be used to empty a typical private swimming pool in an hour! The slower the engine speed, the less power is consumed by the water pump. However, even at 35 miles per hour (56 kilometers per hour), the typical water pump still moves about 2,000 gallons (7,500 liters) per hour or 1/2 gallon (2 liters) per second! See Figure 13-28.

FIGURE 13-28 A demonstration engine running on a stand, showing the amount of coolant flow that actually occurs through the cooling system.

diverters are necessary in the water pump scroll to equalize coolant flow between the cylinder banks of a V-type engine to equalize the cooling.

COOLANT FLOW IN THE ENGINE

Coolant flows through the engine in one of two ways—parallel or series. In the **parallel flow system,** coolant flows into the block under pressure and then crosses the gasket to the head through main coolant passages beside *each* cylinder. The gasket openings of a parallel system are shown in Figure 13-29.

In the **series flow system,** the coolant flows around all the cylinders on each bank. All the coolant flows to the *rear* of the block, where large main coolant passages allow the coolant to flow across the gasket. Figure 13-30 shows the main coolant passages.

The coolant then enters the rear of the heads. In the heads, the coolant flows forward to an outlet at the *highest point* in the engine cooling passage. This is usually located at the front of the engine. The outlet is either on the heads or in the intake manifold. Some engines use a combination of these two coolant flow systems and call it a **series-parallel flow system.** Any steam that develops will go directly to the top of the radiator. In series flow systems, **bleed holes** or **steam slits** in the gasket, block, and head perform the function of letting out the steam.

The coolant can also be directed through an oil filter adapter to help warm the engine oil when the engine is first started in cold weather as well as cool the engine oil when the oil is hot. See Figure 13-31.

WATER PUMP SERVICE

A worn impeller on a water pump can reduce the amount of coolant flow through the engine. See Figure 13-32. If the seal of the water pump fails, coolant will leak out of the hole as seen in Figure 13-33 on page 196. The hole allows coolant to escape without getting trapped and forced into the water pump bearing assembly.

If the bearing is defective, the pump will usually be noisy and will have to be replaced. Before replacing a water pump that has failed because of a loose or noisy bearing, be sure to do all of the following:

1. Check belt tension.
2. Check for bent fan.
3. Check fan for balance.

If the water pump drive belt is too tight, excessive force may be exerted against the pump bearing. If the cooling fan is

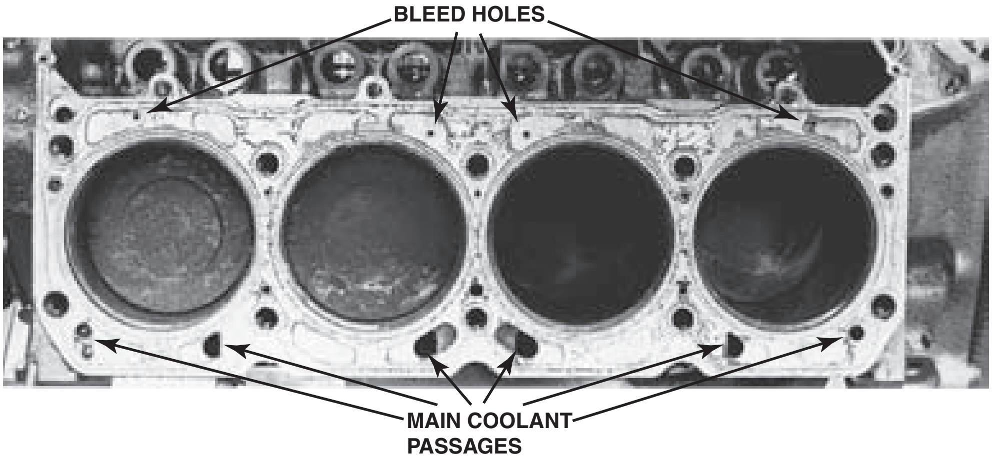


FIGURE 13-29 Gasket openings for a cooling system with a parallel type of flow.

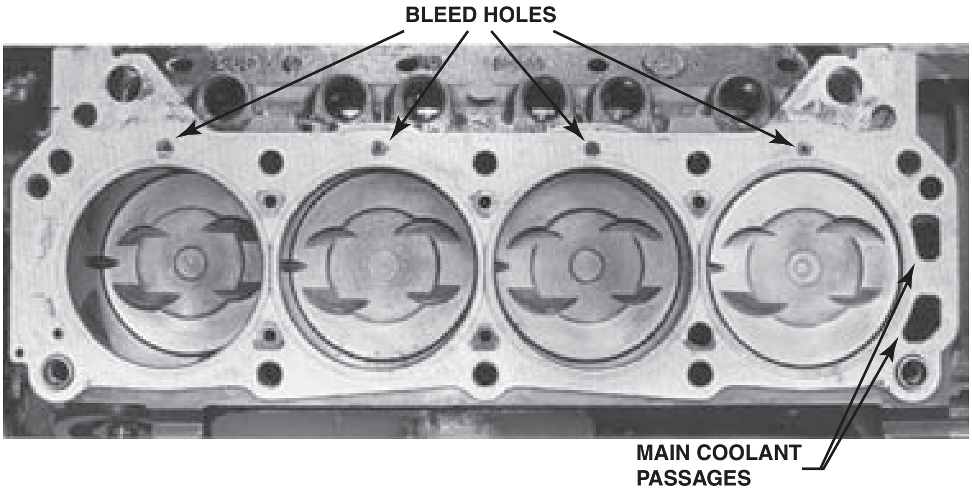


FIGURE 13-30 Gasket openings for a series-type cooling system.

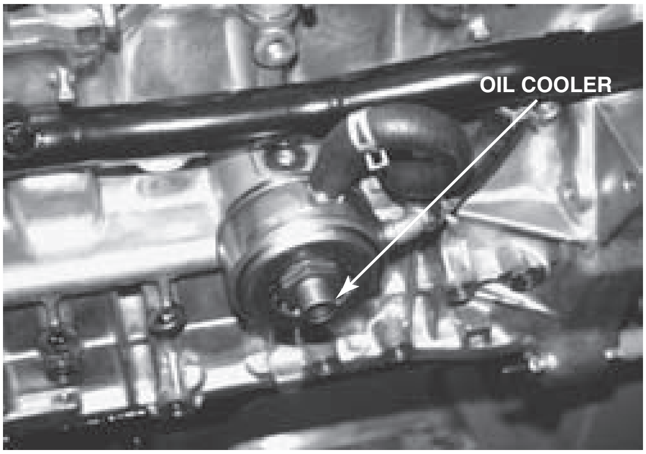


FIGURE 13-31 An engine oil cooler. Coolant lines connect to the oil filter adapter to transfer heat from the hot engine oil to the cooling system. Because the coolant usually reaches operating temperature before the oil during cold weather, this cooler can also heat the cold engine oil so it reaches normal operating temperature quicker, thereby helping to reduce engine wear.

FIGURE 13-32 This severely corroded water pump could not circulate enough to keep the engine cool. As a result, the engine overheated and blew a head gasket.

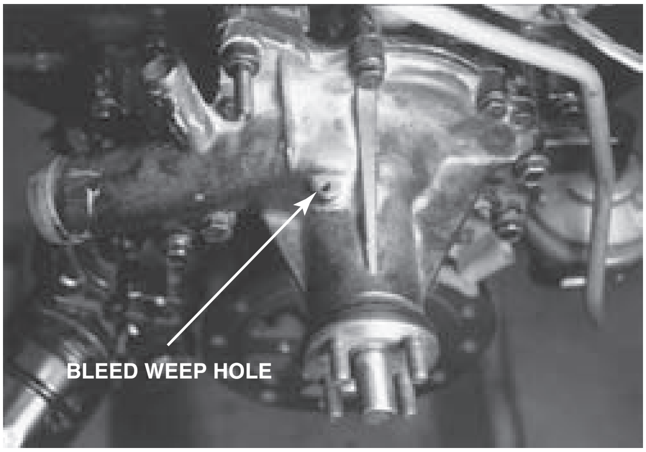


FIGURE 13-33 The bleed weep hole in the water pump allows coolant to leak out of the pump and not be forced into the bearing. If the bearing failed, more serious damage could result.

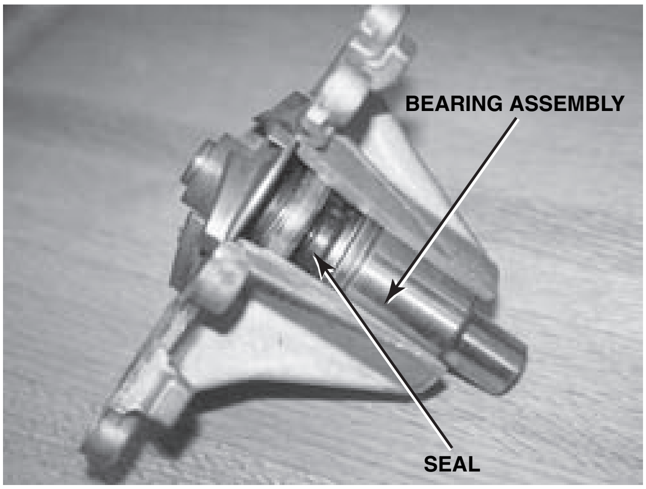


FIGURE 13-34 A cutaway of a typical water pump showing the long bearing assembly and the seal. The weep hole is located between the seal and the bearing. If the seal fails, then coolant flows out of the weep hole to prevent the coolant from damaging the bearing.

bent or out of balance, the resulting vibration can damage the water pump bearing. See Figure 13-34.

COOLING FANS

Air is forced across the radiator core by a cooling fan. On older engines used in rear-wheel-drive vehicles, it is attached to a fan hub that is pressed on the water pump shaft.

Many installations with rear-wheel drive and all transverse engines drive the fan with an electric motor. See Figure 13-35.

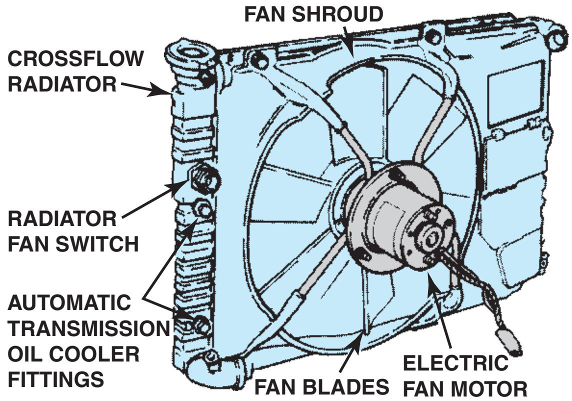


FIGURE 13-35 A typical electric cooling fan.

NOTE: **Most electric cooling fans are computer controlled. To save energy, most cooling fans are turned off whenever the vehicle is traveling faster than 35 mph (55 km/h). The ram air from the vehicle's traveling at that speed should be enough to keep the radiator cool. Of course, if the computer senses that the temperature is still too high, the computer will turn on the cooling fan, to "high," if possible, in an attempt to cool the engine to avoid severe engine damage.**

The fan is designed to move enough air at the lowest fan speed to cool the engine when it is at its highest coolant temperature. The fan shroud is used to increase the cooling system efficiency. The horsepower required to drive the fan increases at a much faster rate than the increase in fan speed. Higher fan speeds also increase fan noise. Fans with flexible plastic or flexible steel blades have been used. These fans have high blade angles that pull a high volume of air when turning at low speeds. As the fan speed increases, the fan blade angle flattens, reducing the horsepower required to rotate the blade at high speeds. See Figure 13-36.

THERMOSTATIC FANS

Since the early 1980s, most cooling fans have been computer-controlled electric motor units. On some rear-wheel-drive vehicles, a thermostatic cooling fan is driven by a belt from the crankshaft. It turns faster as the engine turns faster. Generally, the engine is required to produce more power at higher speeds. Therefore, the cooling system will also transfer more heat. Increased fan speed aids in the required cooling. Engine heat also becomes critical at low engine speeds in traffic where the vehicle moves slowly.

The thermal fan is designed so that it uses little power at high engine speeds and minimizes noise. The thermal fan has a **silicone coupling** fan drive mounted between the drive pulley and the fan.

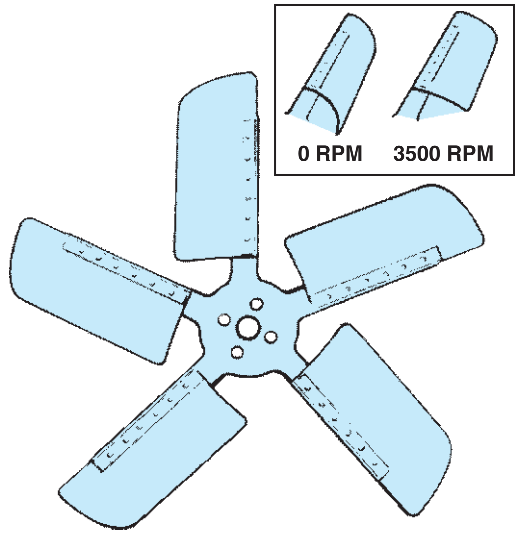


FIGURE 13-36 Flexible cooling fan blades change shape as the engine speed changes.

NOTE: Whenever diagnosing an overheating problem, look carefully at the cooling fan. If silicone is leaking, then the fan may not be able to function correctly and should be replaced.

A second type of thermal fan has a **thermostatic spring** added to the silicone coupling fan drive. The thermostatic spring operates a valve that allows the fan to freewheel when the radiator is cold. As the radiator warms to about 150°F (65°C), the air hitting the thermostatic spring will cause the spring to change its shape. The new shape of the spring opens a valve that allows the drive to operate like the silicone coupling drive. When the engine is very cold, the fan may operate at high speeds for a short time until the drive fluid warms slightly. The silicone fluid will then flow into a reservoir to let the fan speed drop to idle. See Figure 13-37.

ELECTRONICALLY CONTROLLED COOLING FAN

Many rear-wheel-drive vehicles use an electric cooling fan. For example, a typical GM engine cooling fan system consists of one cooling fan and two relays. The cooling fan has 2 windings in the motor. One winding is for low speed and the other winding is for high speed. Voltage is supplied to the relays through the 30-ampere cooling fan 1 and 30-ampere cooling fan 2 fuses. The engine control module (ECM) controls the low-speed fan operation by grounding the cool fan 1 relay control circuit. When the cooling fan 1 relay is energized, voltage is sent to the cooling fan low-speed winding. The ECM controls the high-speed fan operation by grounding the cool fan 2 relay control circuit.

TECH TIP

CAUSE AND EFFECT

A common cause of overheating is an inoperative cooling fan. Most front-wheel-drive vehicles and many rear-wheel-drive vehicles use electric motor-driven cooling fans. A fault in the cooling fan circuit often causes overheating during slow city-type driving.

Even slight overheating can soften or destroy rubber vacuum hoses and gaskets. The gaskets most prone to overheating damage are rocker cover (valve cover) and intake manifold gaskets. Gasket and/or vacuum hose failure often results in an air (vacuum) leak that leans the air–fuel mixture. The resulting lean mixture burns hotter in the cylinders and contributes to the overheating problem.

The vehicle computer can often compensate for a minor air leak (vacuum leak), but more severe leaks can lead to driveability problems; especially idle quality problems. If the leak is severe enough, a lean diagnostic trouble code (DTC) may be present. If a lean code is not set, the vehicle's computer may indicate a defective or out-of-range MAP sensor code in diagnostics.

Therefore, a typical severe engine problem can often be traced back to a simple, easily repaired, cooling system–related problem.

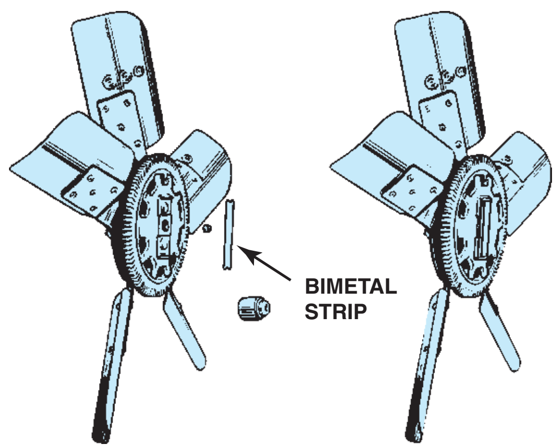


FIGURE 13-37 The bimetallic temperature sensor spring controls the amount of silicone that is allowed into the drive unit, which controls the speed of the fan.

When the cooling fan 2 relay is energized, voltage is sent to the cooling fan high-speed winding. The cooling fan motor has its own ground circuit. The ECM commands low-speed fans ON under the following conditions:

- Engine coolant temperature (ECT) exceeds approximately 223°F (106°C).
- A/C refrigerant pressure exceeds 190 PSI (1,310 kPa).

After the vehicle is shut off, the ECT at key-off is greater than 140°C (284°F) and system voltage is more than 12 volts. The fans will stay on for approximately 3 minutes. The ECM commands high-speed fans ON under the following conditions:

- ECT reaches 230°F (110°C).
- A/C refrigerant pressure exceeds 240 PSI (1,655 kPa).
- When certain diagnostic trouble codes (DTCs) set.

To prevent a fan from cycling ON and OFF excessively at idle, the fan may not turn OFF until the ignition switch is moved to the OFF position or the vehicle speed exceeds approximately 10 mph.

Electric Cooling Fan (Trailblazer)

The Chevrolet Trailblazer and similar vehicles are equipped with a cooling fan that is ECM controlled. The fan relay is supplied with a pulse width modulation (PWM) signal (12 to 14 volts) to control fan operation by controlling the fan clutch supply voltage circuit. See Figure 13-38. The power train control module (PCM) uses a PWM signal to control the speed of the cooling fan by controlling the position of the oil control valve inside the clutch. If the cooling fan RPM is too high when the PCM is commanding 0%, DTC P0495 will set.

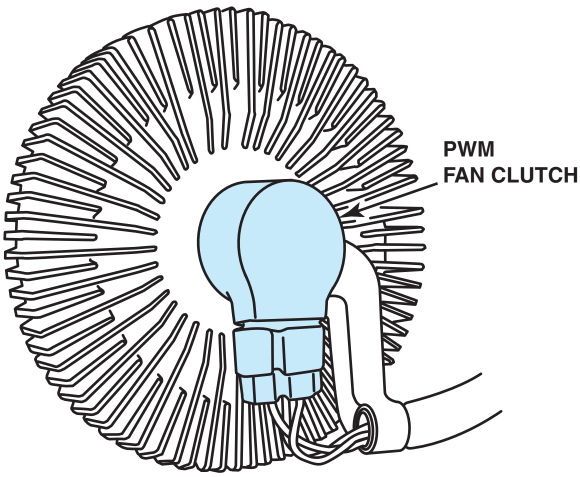


FIGURE 13-38 A pulse-width modulated (PWM) fan clutch is used on some rear-wheel-drive vehicles, such as the Chevrolet Trailblazer.

HEATER CORE

Most of the heat absorbed from the engine by the cooling system is wasted. Some of this heat, however, is recovered by the vehicle heater. Heated coolant is passed through tubes in the small core of the heater. Air is passed across the heater fins and is then sent to the passenger compartment. In some vehicles, the heater and air conditioning work in series to maintain vehicle compartment temperature. See Figure 13-39.

HEATER PROBLEM DIAGNOSIS

When the vehicle's heater does not produce the desired amount of heat, many owners and technicians replace the thermostat before doing any other troubleshooting. It is true that a defective thermostat is the reason for the *engine* not to reach normal operating temperature. Many other causes besides a defective thermostat can result in lack of

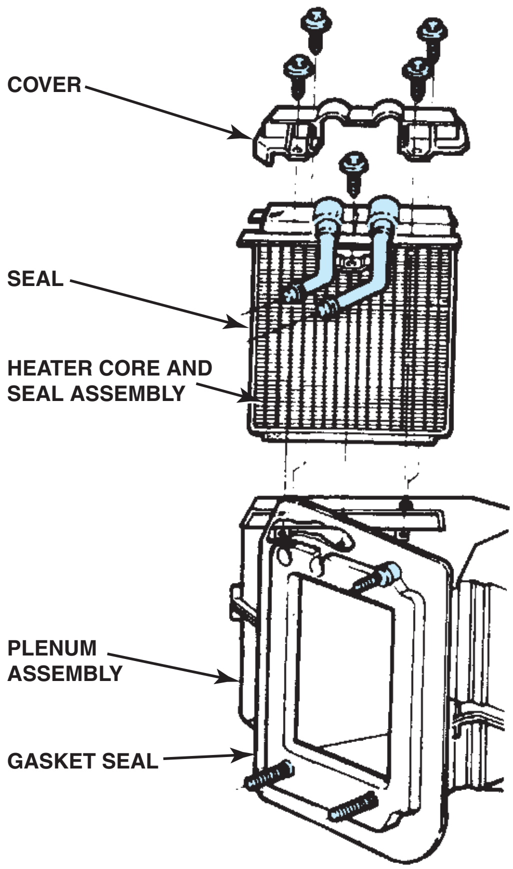


FIGURE 13-39 A heater core is similar to a small radiator but is mounted within the dash.

heat from the heater. To determine the exact cause, follow this procedure:

Step 1 After the engine has been operated, feel the upper radiator hose. If the engine is up to proper operating temperature, the upper radiator hose should be too hot for you to keep your hand on it. The hose should also be pressurized.

- **a.** If the hose is not hot enough, replace the thermostat.
- **b.** If the hose is not pressurized, test it. Replace the radiator pressure cap if it will not hold the specified pressure.
- **c.** If okay, see step 2.

Step 2 With the engine running, feel both heater hoses. (The heater should be set to the maximum heat position.) Both hoses should be too hot to hold. If both hoses are warm (not hot) or cool, check the heater control valve for proper operation. If one hose is hot and the other (return) is just warm or cool, remove both hoses from the heater core or engine and flush the heater core with water from a garden hose.

NOTE: Heat from the heater that "comes and goes" is most likely the result of low coolant level. Usually with the engine at idle, there is enough coolant flow through the heater at higher engine speeds, however, the circulation of coolant through the heads and block prevents sufficient flow through the heater.

COOLANT TEMPERATURE WARNING LIGHT

Most vehicles are equipped with a heat sensor for the engine operating temperature. If the "hot" light comes on during driving (or the temperature gauge goes into the red danger zone), then the coolant temperature is about 250° to 258°F (120° to 126°C), which is still *below* the boiling point of the coolant (assuming a properly operating pressure cap and system). If this happens, follow these steps:

Step 1 Shut off the air conditioning and turn on the heater. The heater will help rid the engine of extra heat. Set the blower speed to high.

Step 2 If possible, shut the engine off and let it cool. (This may take over an hour.)

Step 3 Never remove the radiator cap when the engine is hot.

Step 4 Do *not* continue to drive with the hot light on, or serious damage to your engine could result.

Step 5 If the engine does not feel or smell hot, it is possible that the problem is a faulty hot light sensor or gauge. Continue to drive, but to be safe, stop occasionally and check for any evidence of overheating or coolant loss.

REAL WORLD FIX

HIGHWAY OVERHEATING

A vehicle owner complained of an overheating vehicle, but the problem occurred only while driving at highway speeds. The vehicle, equipped with a General Motors *QUAD 4*, would run in a perfectly normal manner in city-driving situations.

The technician flushed the cooling system and replaced the radiator cap and the water pump, thinking that restricted coolant flow was the cause of the problem. Further testing revealed coolant spray out of one cylinder when the engine was turned over by the starter with the spark plugs removed.

A new head gasket solved the problem. Obviously, the head gasket leak was not great enough to cause any problems until the engine speed and load created enough flow and heat to cause the coolant temperature to soar.

The technician also replaced the oxygen (O_2) sensor, because coolant contains phosphates and silicates that often contaminate the sensor. The deteriorated oxygen sensor could have contributed to the problem.

COMMON CAUSES OF OVERHEATING

Overheating can be caused by defects in the cooling system. Some common causes of overheating include:

1. Low coolant level
2. Plugged, dirty, or blocked radiator
3. Defective fan clutch or electric fan
4. Incorrect ignition timing
5. Low engine oil level
6. Broken fan belt
7. Defective radiator cap
8. Dragging brakes
9. Frozen coolant (in freezing weather)
10. Defective thermostat
11. Defective water pump (the impeller slipping on the shaft internally)

COOLING SYSTEM MAINTENANCE

The cooling system is one of the most maintenance-free systems in the engine. Normal maintenance involves an occasional check on the coolant level. It should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and fan drive belts.

CAUTION: The coolant level should only be checked when the engine is cool. Removing the pressure cap from a hot engine will release the cooling system pressure while the coolant temperature is above its atmospheric boiling temperature. When the cap is removed, the pressure will instantly drop to atmospheric pressure level, causing the coolant to boil immediately. Vapors from the boiling liquid will blow coolant from the system. Coolant will be lost, and someone may be injured or burned by the high-temperature coolant that is blown out of the filler opening.

The coolant-antifreeze mixture is renewed at periodic intervals. Some vehicle manufacturers recommend that coolant system stop-leak pellets be installed whenever the coolant is changed. See Figure 13-40.

CAUTION: General Motors recommends the use of these stop-leak pellets in only certain engines. Using these pellets in some engines could cause a restriction in the cooling system and an overheating condition.

Accessory Drive Belt Tension

Drive belt condition and proper installation are important for the proper operation of the cooling system.

Belt Tension Measurement

There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

FIGURE 13-40 General Motors recommends that these stop-leak pellets be installed in the cooling system if the coolant is replaced on some engines, especially the Cadillac 4.1, 4.5, and 4.9 L, V-8s.

1. **Belt tension gauge.** A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least 5 minutes. Adjust the tension of the accessory drive belt to factory specifications or use the table below for an example of the proper tension based on the size of the belt. Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3-inch span.

Number of Ribs Used	Tension Range (lb)
3	45 to 60
4	60 to 80
5	75 to 100
6	90 to 125
7	105 to 145

TECH TIP

THE HAND CLEANER TRICK

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the V's of the belt and the angle of the V's on the pulley. A belt wears this interference angle off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick used to determine if the noise is belt related is to use gritty hand cleaner or scouring powder. With the engine off, sprinkle some powder onto the pulley side of the belt. Start the engine. The excess powder will fly into the air, so get out from under the hood when the engine starts. If the belts are now quieter, you know that it was the glazed belt that made the noise.

NOTE: Often, belt noise sounds exactly like a noisy bearing. Therefore, before you start removing and replacing parts, try the hand cleaner trick.

Often, the grit from the hand cleaner will remove the glaze from the belt and the noise will not return. However, if the belt is worn or loose, the noise will return and the belt should be replaced. A fast alternative method to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and therefore, unlike the gritty hand cleaner, water just finds the problem—it does not provide a short-term fix.

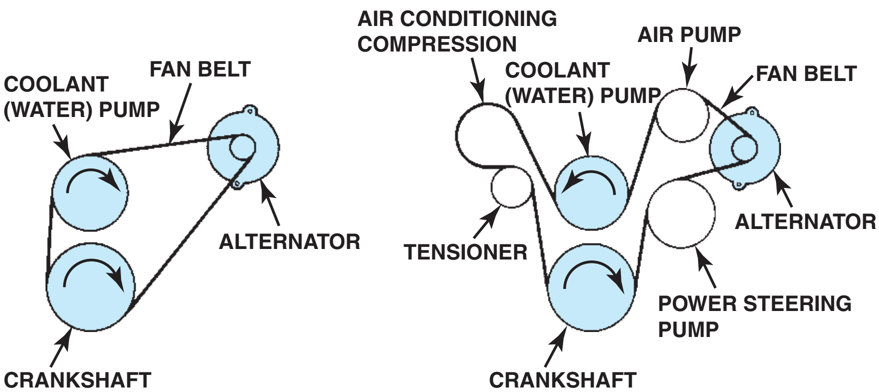


FIGURE 13-41 In the mid-1980s, many manufacturers started using serpentine belts. Older-model water pumps will bolt onto the engine, but the direction of rotation may be opposite. This could lead to overheating after the new pump is installed. If the wrong application of fan is installed, the blades of the fan will not be angled correctly to provide adequate airflow through the radiator.

FIGURE 13-42 Drive belt tension is critical for the proper operation of the water pump, as well as the generator (alternator), air-conditioning compressor, and other belt-driven accessories. A belt tension gauge should be used to make certain that accurate belt tension is achieved when replacing or retensioning any belt.

2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the location of the tensioner mark.
3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart and the flex or deflection should be 1/2 inch.

See Figures 13-41 and 13-42.

FLUSH AND REFILL

Manufacturers recommend that a cooling system be flushed and that the antifreeze be replaced at specified intervals. Draining coolant when the engine is cool eliminates the danger of being injured by hot coolant. The radiator is drained by opening a petcock in the bottom tank, and the coolant in the block is drained into a suitable container by opening plugs located in the lower part of the cooling passage.

Water should be run into the filler opening while the drains remain open. Flushing should be continued until only clear water comes from the system.

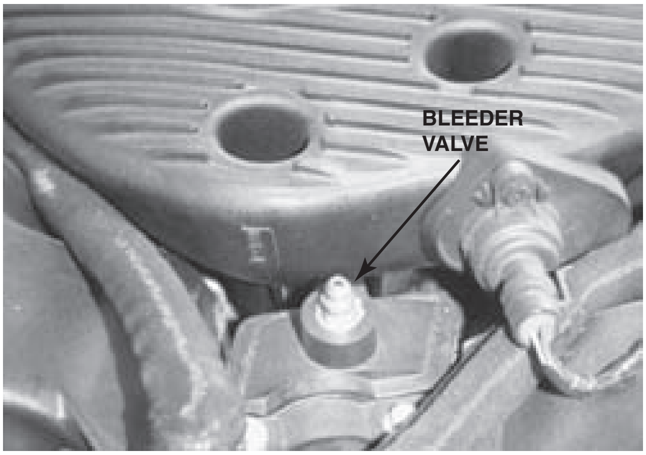
The volume of the cooling system must be determined. It is specified in the owner's handbook and in the engine service manual. The antifreeze quantity needed for the protection desired is shown on a chart that comes with the antifreeze. Open the bleeder valves and add the correct amount of the specified type of antifreeze followed by enough water to completely fill the system. See Figure 13-43.

The coolant recovery reservoir should be filled to the "level-cold" mark with the correct antifreeze mixture.

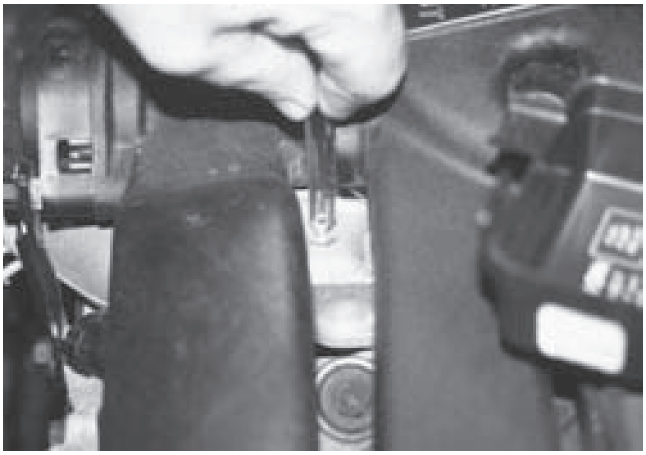
BURPING THE SYSTEM

In most systems, small air pockets can occur. The engine must be thoroughly warmed to open the thermostat. This allows full coolant flow to remove the air pockets. The heater must also be turned to full heat.

NOTE: **The cooling system will not function correctly if air is not released (burped) from the system after a refill. An easy method involves replacing the radiator cap after the refill, but only to the first locked position. Drive the vehicle for several minutes and check the radiator level. Without the radiator cap tightly sealed, no pressure will build in the cooling system. Driving the vehicle helps circulate the coolant enough to force all air pockets up and out of the radiator filler. Top off the radiator after burping and replace the radiator cap to the fully locked position. Failure to burp the cooling system to remove all the air will often result in lack of heat from the heater and may result in engine overheating.**



(a)



(b)

FIGURE 13-43 (a) Chrysler recommends that the bleeder valve be opened whenever refilling the cooling system. (b) Chrysler also recommends that a clear plastic hose (1/4" ID) be attached to the bleeder valve and directed into a suitable container to keep from spilling coolant onto the ground and on the engine and to allow the technician to observe the flow of coolant for any remaining oil bubbles.

HOSES

Coolant system hoses are critical to engine cooling. As the hoses get old, they become either soft or brittle and sometimes swell in diameter. Their condition depends on their material and on the engine service conditions. If a hose breaks while the engine is running, all coolant will be lost. A hose should be replaced anytime it appears to be abnormal. See Figure 13-44.

NOTE: **To make hose removal easier and to avoid possible damage to the radiator, use a utility knife and slit the hose lengthwise. Then simply peel the hose off.**

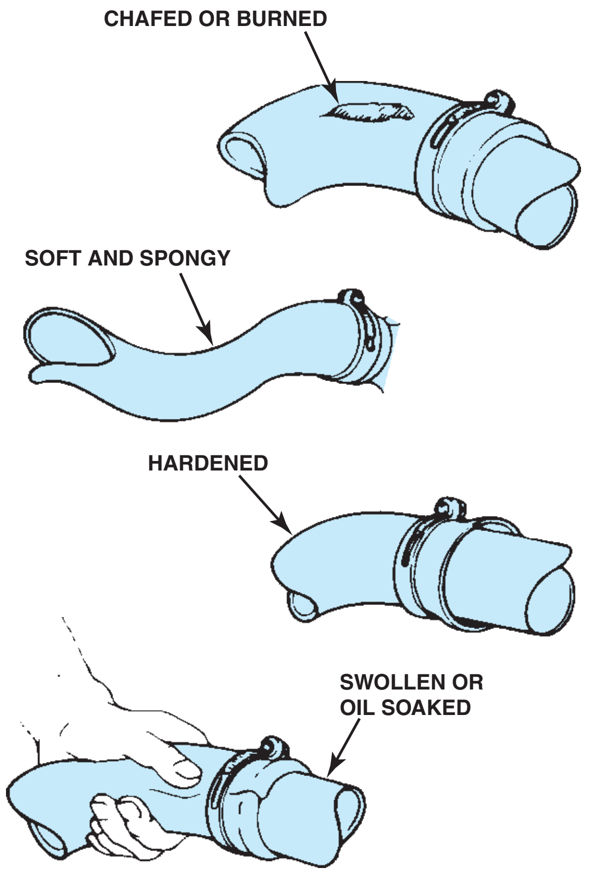


FIGURE 13-44 All cooling system hoses should be checked for wear or damage.

Care should be taken to avoid bending the soft metal hose neck on the radiator. The hose neck should be cleaned before a new hose is slipped in place. The clamp is placed on the hose; then the hose is pushed fully over the neck. The hose should be cut so that the clamp is close to the bead on the neck. This is especially important on aluminum hose necks to avoid corrosion. When the hoses are in place and the drain petcock is closed, the cooling system can be refilled with the correct coolant mixture.

BACK FLUSHING A RADIATOR

Overheating problems may be caused by deposits that restrict coolant flow. These can often be loosened by **back flushing.** Back flushing requires the use of a special gun that mixes air with water. Low-pressure air is used so that it will not damage the cooling system. See Figure 13-45.

Deposits will come out of the filler opening and out of the hose connected to the upper hose neck. If, after flushing, some deposits still plug the radiator core, then the radiator will have to be removed and sent to a radiator repair shop for cleaning.

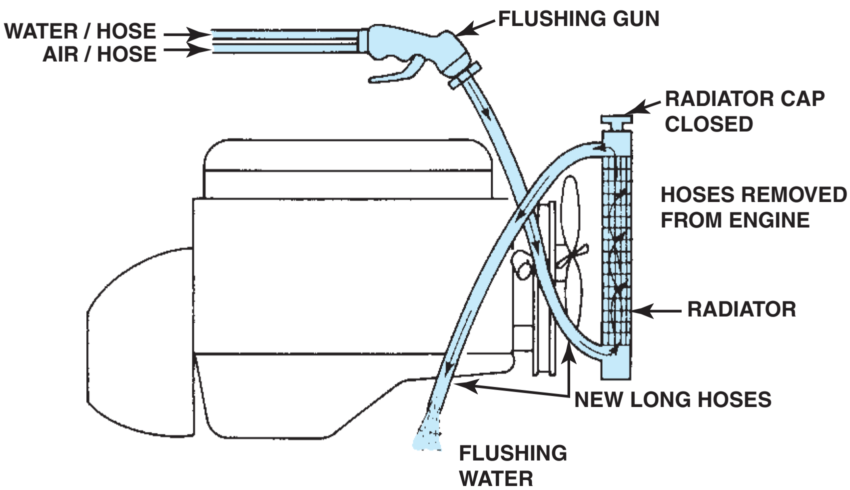


FIGURE 13-45 Setup to back flush a radiator.

TECH TIP

QUICK AND EASY COOLING SYSTEM PROBLEM DIAGNOSIS

If overheating occurs in slow stop-and-go traffic, the usual cause is low airflow through the radiator. Check for airflow blockages or cooling fan malfunction. If overheating occurs at highway speeds, the cause is usually a radiator or coolant circulation problem. Check for a restricted or clogged radiator.

CLEANING THE RADIATOR EXTERIOR

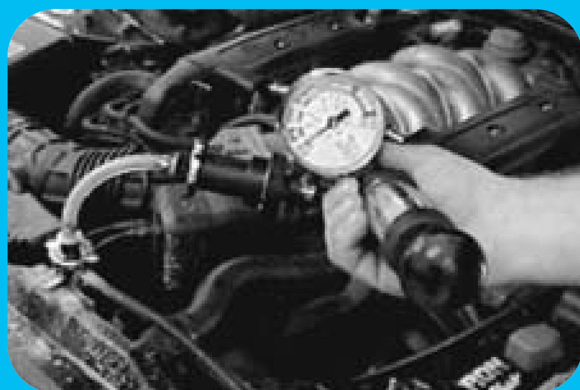
Overheating can result from exterior radiator plugging as well as internal plugging. External plugging is caused by dirt and insects. This type of plugging can be seen if you look straight through the radiator while a light is held behind it. It is most likely to occur on off-road vehicles. The plugged exterior of the radiator core can usually be cleaned with water pressure from a hose. The water is aimed at the *engine side* of the radiator. The water should flow freely through the core at all locations. If this does not clean the core, the radiator should be removed for cleaning at a radiator shop.

RADIATOR PRESSURE TEST Step-by-Step

STEP 1 This vehicle has an obvious coolant leak. The exact location or cause of the leak can be easily determined by performing a radiator pressure test.

STEP 2 After the engine has been allowed to cool, the radiator cap is removed and inspected for any obvious faults. The filler neck of the radiator and the overflow nose are also inspected visually.

STEP 3 The coolant recovery container should also be inspected. In this case the level of coolant was found to be low in the coolant recovery container but okay in the radiator.



STEP 4 An adapter is required to attach the radiator pressure tester to the radiator filler neck on this vehicle. The hand-operated pressure pump should be pumped until the pressure gauge indicates the same pressure as the rating on the pressure cap. The radiator cap was rated at 1.1 bar and because each bar is equal to 14.7 PSI the pressure tester was pumped until 16 PSI registered on the gauge.

STEP 5 The radiator cap itself can be tested by using an adapter and applying pressure to the cap using the pressure tester. In this case, the pressure cap failed to hold any pressure and was the cause for the coolant loss.

SUMMARY

1. The purpose and function of the cooling system is to maintain proper engine operating temperature.
2. The thermostat controls engine coolant temperature by opening at its rated opening temperature to allow coolant to flow through the radiator.
3. Antifreeze coolant is usually ethylene glycol-based. Other coolants include propylene glycol and phosphate-free coolants.
4. Used coolant should be recycled whenever possible.
5. Coolant fans are designed to draw air through the radiator to aid in the heat transfer process, drawing the heat from the coolant and transferring it to the outside air through the radiator.
6. The cooling system should be tested for leaks using a hand-operated pressure pump.
7. The freezing and boiling temperature of the coolant can be tested using a hydrometer.

REVIEW QUESTIONS

1. Explain why the normal operating coolant temperature is about 200° to 220°F (93° to 104°C).
2. Explain why a 50/50 mixture of antifreeze and water is commonly used as a coolant.
3. Explain the flow of coolant through the engine and radiator.
4. Why is a cooling system pressurized?
5. Describe the difference between a series and a parallel coolant flow system.
6. Explain the purpose of the coolant system bypass.
7. Describe how to perform a drain, flush, and refill procedure on a cooling system.
8. Explain the operation of a thermostatic cooling fan.
9. Describe how to diagnose a heater problem.
10. List 10 common causes of overheating.

CHAPTER QUIZ

1. Antifreeze is mostly _____.
   - **a.** Methanol
   - **b.** Glycerin
   - **c.** Kerosene
   - **d.** Ethylene glycol
2. As the percentage of antifreeze in the coolant increases, _____.
   - **a.** The freeze point decreases (up to a point)
   - **b.** The boiling point decreases
   - **c.** The heat transfer increases
   - **d.** All of the above occurs
3. Heat transfer is improved from the coolant to the air when _____.
   - **a.** The temperature difference is great
   - **b.** The temperature difference is small
   - **c.** The coolant is 95% antifreeze
   - **d.** Both a and c
4. A water pump is a positive displacement-type pump.
   - **a.** True
   - **b.** False
5. Water pumps _____.
   - **a.** Only work at idle and low speeds; the pump is disengaged at higher speeds
   - **b.** Use engine oil as a lubricant and coolant
   - **c.** Are driven by the engine crankshaft or camshaft
   - **d.** Disengage during freezing weather to prevent radiator failure
6. The procedure that should be used when refilling an empty cooling system includes the following _____.
   - **a.** Determine capacity, then fill the cooling system halfway with antifreeze and the rest of the way with water
   - **b.** Fill completely with antifreeze, but mix a 50/50 solution for the overflow bottle

c. Fill the block and one-half of the radiator with 100% pure antifreeze and fill the rest of the radiator with water

d. Fill the radiator with antifreeze, start the engine, drain the radiator, and refill with a 50/50 mixture of antifreeze and water

7. Which statement is *true* about thermostats?
   a. The temperature marked on the thermostat is the temperature at which the thermostat should be fully open.
   b. Thermostats often cause overheating.
   c. The temperature marked on the thermostat is the temperature at which the thermostat should start to open.
   d. Both a and b.

8. Technician A says that the radiator should always be inspected for leaks and proper flow before installing a rebuilt engine. Technician B says that overheating during slow city driving can only be due to a defective electric cooling fan. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. The normal operating temperature (coolant temperature) of an engine equipped with a 195°F thermostat is _____.
   a. 175° to 195°F
   b. 185° to 205°F
   c. 195° to 215°F
   d. 175° to 215°F