ENGINE COOLING SYSTEMS

Topics covered in this chapter

- Engine cooling systems
- Common faults and their diagnosis and repair
- Blocked radiator core
- Combustion gas leakage into coolant
- Coolant loss
- Antifreeze and its composition
- Vehicle interior heating and air-conditioning systems

During combustion, when the engine is operating at full throttle, the maximum temperature reached by the burning gases may be as high as 1500-2000^{o}C. The expansion of the gases during the power stroke lowers their temperature considerably, but during the exhaust stroke the gas temperature may still be approximately 800^{o}C as shown by Fig 1. All the engine components with which these hot gases come into contact will absorb heat from them in proportion to:

- Flue gas temperature;
- Area of surface exposed to the flue gases
- Duration of the exposure.

OVERHEATING

For all these reasons the heat will raise the temperature of the engine components. If the temperature of the exhaust gas is above red heat it will be above the melting point of metals such as aluminium, from which the pistons are made. Unless steps are taken to reduce these temperatures a number of serious problems could arise:

- ❖ The combustion chamber walls, piston crown, the upper-end of the cylinder, and the region of the exhaust port are exposed to the hottest gases and will therefore reach the highest temperatures. This will create distortion, causing a leakage of gas, water, or oil. It may even cause the valve to burn or the cylinder head to crack and as a consequence there will be a loss of power output.
- ❖ The oil film will be burnt, causing excessive carbon to form. The loss of lubrication of the piston and rings will cause excessive wear or the piston to seize in the cylinder.
- ❖ Power output will be reduced because the incoming mixture will become heated, so reducing its density. It may also cause detonation (this is an uncontrolled explosion in the cylinder), making it necessary to reduce the compression ratio.

- ❖ Some part of the surface of the combustion chamber could become hot enough to ignite the incoming charge before the spark occurs (called pre-ignition), which could cause serious damage to the engine if allowed to continue.

For these reasons the engine must be provided with a system of cooling, so that it can be maintained at its most efficient practicable operating temperature. This means that the average temperature of the cylinder walls should not exceed about 250ºC, whereas the actual temperature of the gases in the cylinder during combustion may reach 10 times this figure. One of the other things to remember is that the engine should not be run too cool, as this would reduce thermal efficiency (this is how good the engine is at converting heat into mechanical power), increase fuel consumption and oil dilution, and cause wear and corrosion of the engine.

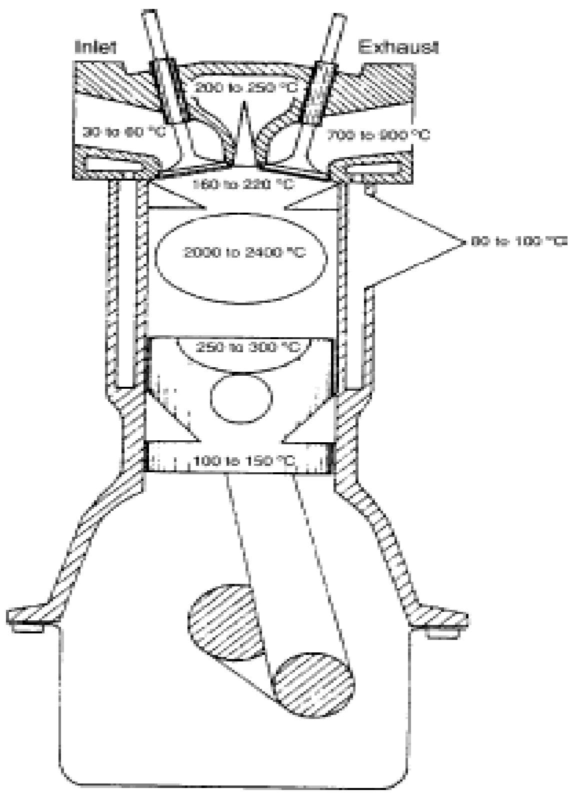


Figure 1: Engine operating temperature ranges

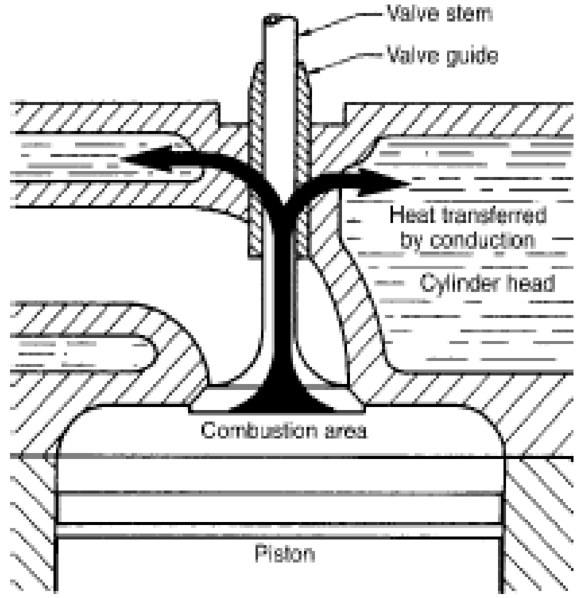


Figure 2: Heat is transferred by conduction from the valve stem to the valve guide. Both objects are solid.

Heat transfer

The cooling system works on the principles of heat transfer. Heat will always travel from hot to cold (e.g. from a hot object to a cold object; this would be by conduction). This transfer occurs in three different ways:

- ❖ **Conduction**

- ❖ **Convection**
- ❖ **Radiation.**
- ➢ Conduction is defined as the transfer of heat between two solid objects, e.g. valve stem to valve guide, as shown in Fig. 2. Since both objects are solid, heat is transferred from the hot valve stem to the cool valve guide by conduction and also from the guide to the cylinder head.
- ➢ Convection is the transfer of heat by the circulation of heated parts of a liquid or gas. When the hot cylinder block transfers heat to the coolant it produces a change in its density and causes the warmer, less dense water to rise, thus setting up convection currents in the cooling system.
- ➢ Radiation is defined as the transfer of heat by converting it to radiant energy. Radiant heat is emitted by all substances and may be reflected or absorbed by others.

This ability will depend upon the colour and nature of the surface of the objects e for example, black rough ones are best for absorption of heat and light polished ones best for reflection of heat. The cooling system relies on all three of these principles to remove excess heat from the engine.

<u>Over-cooling</u>

As we have seen, various problems can occur if the engine temperature gets too high, but if the temperature becomes too low then another set of problems can occur:

- ➢ Fewer miles per gallon, as the combustion process will be less efficient.
- ➢ There will be an increase in the build-up of carbon (as the fuel enters the cylinder it will condense and cause excessive build-up of carbon on the inlet valves).
- ➢ There will be an increase in the varnish and sludges formed within the lubrication system. Cooler engines make it easier for these to form.
- ➢ A loss of power, because if the combustion process is less efficient the power output will be reduced.
- ➢ The fuel not being burned completely, which will cause fuel to dilute the oil and cause excessive engine wear.

The purposes of the cooling system can be summarized as follows:

- ➢ To maintain the highest and most efficient operating temperature within the engine
- ➢ To remove excess heat from the engine

- To bring the engine up to operating temperature as quickly as possible - in heavy-duty driving, an engine could theoretically produce enough heat to melt an average 100kg engine block in 20 minutes.

Types of cooling systems

There are two main types of cooling systems in common use, air and water. Both dissipate (radiate) heat removed from the cylinder into the surrounding air. Air cooling is described immediately below and water cooling later in the chapter.

Air cooling

In this system heat is radiated from the cylinder and head directly into the surrounding air. The rate at which heat is radiated from an object is dependent on:

i. The difference in temperature between the object and the surrounding air.
ii. The surface area from which the heat is radiated (since (i) must be limited, the surface area of the cylinder and head exposed to the air must be increased, by forming fins on their external surfaces; Fig. 3).
iii. The nature of the surface.

It is also necessary to remove the heated air from around the cylinder and deliver a constant supply of cool air around and between the fins. This means that the cylinders must be sufficiently widely spaced to permit a suitable depth of finning all around them, and the engine must be placed where the movement of the vehicle can provide the necessary supply of cool air. A large fan is often used and the engine is surrounded by large cowls to direct air to where it is required, e.g. around the cylinder head and valve area.

The choice of air or liquid cooling has always been controversial. Air is cheaper, lighter, and more readily obtainable than water e though to remove a given quantity of heat demands four times the weight and 4000 times the volume of air than it does water. It also gives less control of the engine temperature and air-cooled engines tend to be noisier. But air can be collected and rejected, whereas water must be carried on the car, and the jacketing, hoses, pump and radiator of a water-cooled engine will probably weigh more than the substantial fins of an air-cooled engine.

However, the fins force the cylinders of an air-cooled engine to be more widely separated than those of a water-cooled engine, so the crankshaft and crankcase must be longer and therefore heavier. For an engine of many cylinders, this is one of the greatest objections to air cooling.

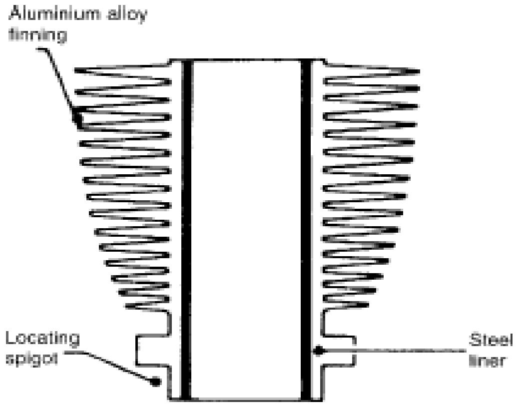


Fig.3: Air-cooled finned cylinder wall.

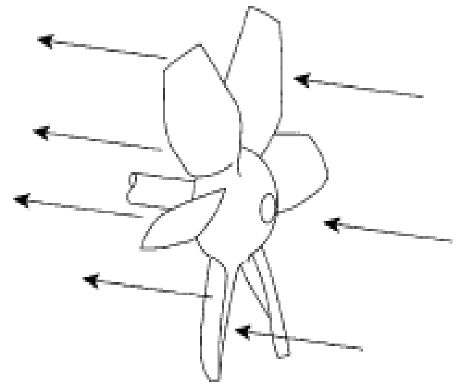


Fig. 4: Axial air flow fan.

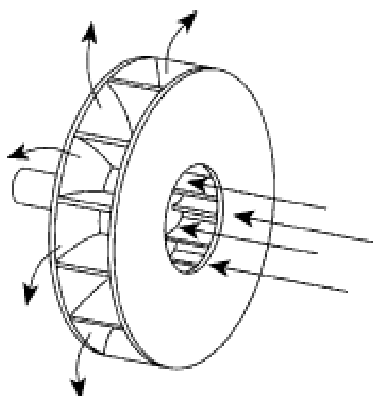


Fig. 5: Radial air flow fan.

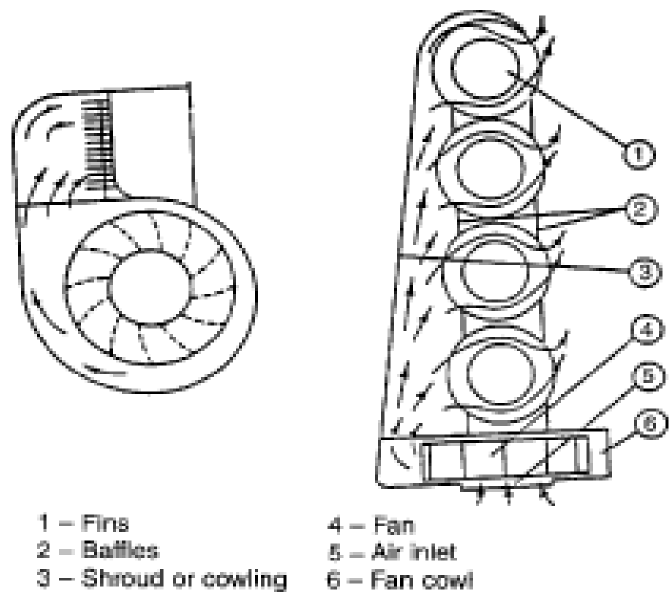


Fig. 6: Simple in-line air-cooled engine using radial-type fan.

Engine Air-Cooling System

Circulation of cooling air

With air cooling the engine structure is directly cooled by forcing air over its high-temperature surfaces. These are finned to present a greater cooling surface area to the air, which in non-motor-cycle applications is forced to circulate over them by means of a powerful fan.

The engine structure is almost entirely enclosed by sheet metal ducting (called a cowl), which incorporates a system of partitions (called baffles); these ensure that the air flow is properly directed over the cylinders and cylinder heads. To obtain uniform temperatures the air is forced to circulate around the entire circumference of each cylinder and its cylinder head. The direction of air flow will be along the cooling fins, the greatest number of which are found towards the top of the cylinder (around the exhaust valve), as this is the hottest part of the engine.

The complete system forms what is known as the plenum chamber, in which the internal air pressure is higher than that of the atmosphere. The heated air is discharged from the plenum chamber to the atmosphere, or redirected to heat the car interior. In order to provide the necessary air flow around the cylinders of an enclosed engine, a powerful fan is essential.

TYPES OF AIR-COOLING FANS

1. Axial flow

This is a simple curved blade type in which the direction of air flow is parallel to the axis of the fan spindle (Fig. 4).

2. Radial flow

Often called a centrifugal, this type (Fig. 5) is more commonly used because it is more effective and a fan of smaller diameter can be used for a given air flow. This type of fan has a number of curved radial vanes mounted between two discs, one or both having a large central hole. When the fan is rotated, air between the vanes rotates with it and is thrown outwards by centrifugal force.

Fig. 6: shows a simple air-cooled system for a four-cylinder in-line engine. A centrifugal fan, driven at approximately twice crankshaft speed, is mounted at the front of the engine and takes in air through a central opening (5) in the fan casing. This air is delivered into the cowl (3), where it is directed over the fins of the cylinders (1). Baffles (2) ensure that the air passes between the fins, where it picks up heat, thus cooling the cylinders.

The in-line engine is the most difficult to cool by air. V-type or horizontally opposed engines are easier to cool as the cylinders are spaced further apart to leave room for the crankshaft bearings and this allows more room between the cylinders for a good air flow, whilst at the same time keeping the total engine length fairly short.

LIQUID COOLING (WATER)

In this arrangement the outer surfaces of the cylinder and head are enclosed in a jacket, leaving a space between the cylinder and the jacket through which a suitable liquid is circulated. The liquid generally used is water, which is in many ways the most suitable for this purpose, even though it has a number of drawbacks. Whilst passing through the jacket the water absorbs heat from the cylinder and head, and it is cooled by being passed through a radiator before being returned to the jacket.

Thermo-syphon system

When heated, the water becomes less dense and therefore lighter than cold water. Thermo-syphon is the action of the water being heated, rising, and setting up convection currents in the water. The thermo-syphon system is no longer used in the modern motor vehicle as it has a number of disadvantages:

- To ensure sufficient circulation, the radiator must be arranged higher than the engine to ensure that the heated coolant will rise into the top of the radiator header tank and the cooled water in the radiator will flow into the bottom of the engine.
- Water circulation will be slow, so a relatively large amount of water must be carried.
- Large water passages must be used to allow an unrestricted flow of water around the system.
- This system is usually now confined to small stationary engines such as those used to power narrow boats, small generators, water pumps.

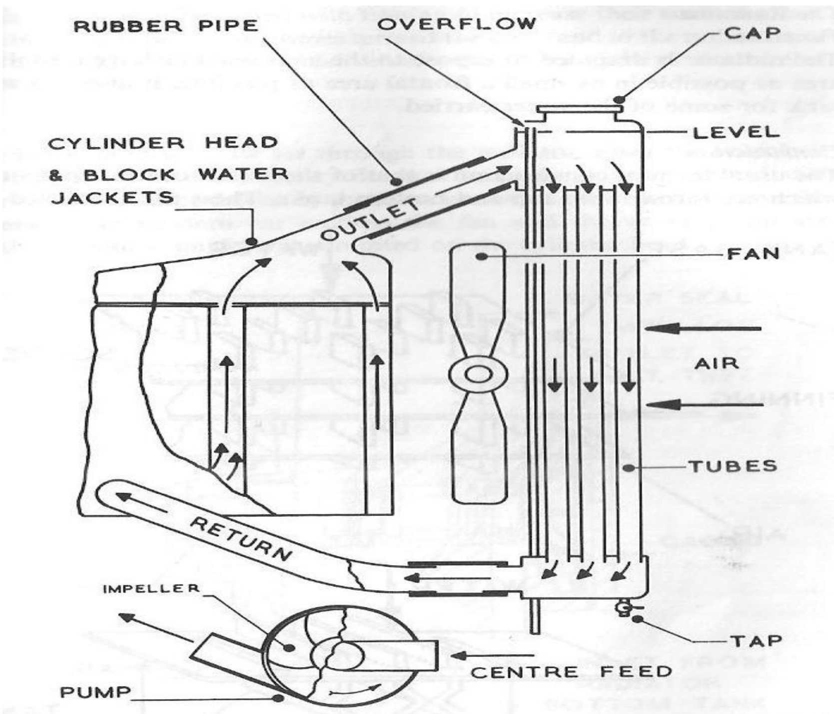


Fig. 7: Thermo-syphon system

Pump-assisted circulation

Most modern engines use a pump to provide a positive circulation of the coolant. This is shown in Fig. 8 and gives the following advantages:

1. A smaller radiator can be used than in the thermo-syphon system.
2. Less coolant is carried as the water is circulated faster and therefore the heat is removed more quickly.
3. Smaller passages and hoses are used.

4. The radiator does not need to be above the level of the engine, giving a lower bonnet line; this the advantage of less wind resistance, giving a better fuel consumption.
5. The water flow in positive direction then, engine will operate at a more even temperature.

<u>Comparison of air- and water-cooled systems</u>

Advantages of air cooling

- An air-cooled engine is generally lighter than an equivalent water-cooled engine.
- It warms up to its normal running temperature very quickly.
- The engine can operate at a higher temperature than a water-cooled engine.
- The system is free from coolant leakage problems and requires no maintenance.
- There is no risk of damage due to freezing of the coolant in cold weather.

Disadvantages of air cooling

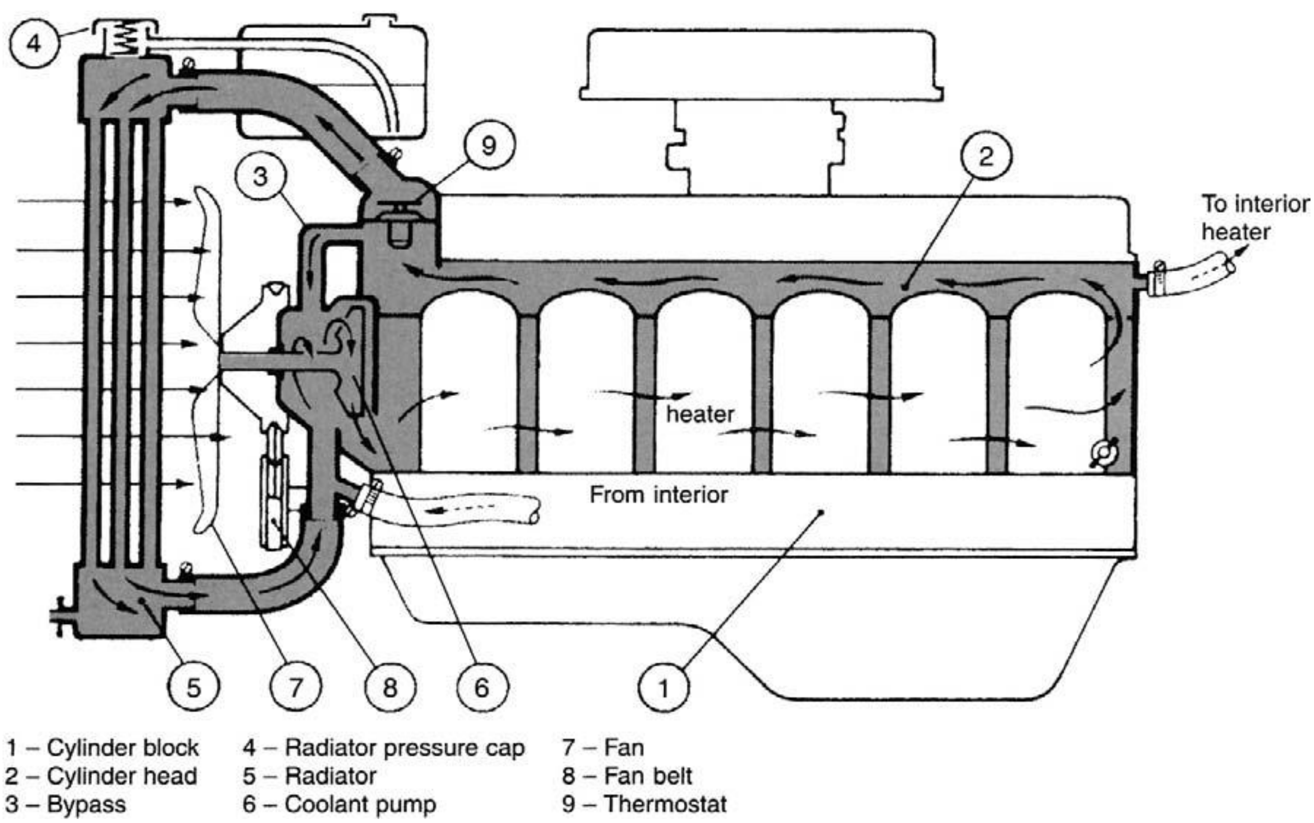
- A fan and suitable cowls are necessary to provide and direct the air flow. The fan can be noisy and absorbs a large amount of engine power. The cowl makes it difficult to get at various parts of the engine when servicing is required.
- The engine is more liable to overheating under difficult conditions than a water-cooled engine.
- Mechanical engine noises tend to be amplified by the fins.
- The cylinders usually have to be made separately to ensure proper formation of the fins. This makes the engine more costly to manufacture.
- Cylinders must be spaced well apart to allow sufficient depth of fins.
- It is more difficult to arrange a satisfactory car heating system.

Advantages of water cooling

- The temperatures throughout the engine are more uniform, thus keeping distortion to a minimum.
- Cylinders can be placed closer together, making the engine more compact.
- Although a fan is usually fitted to force air through the radiator, it is much smaller than the type required for an air-cooled engine. It therefore absorbs less power and is quieter in operation.
- There is no cowl to obstruct access to the engine.
- The water jacket absorbs some of the mechanical noise, making the running engine quieter.
- The engine is better able to operate under difficult conditions without overheating.

Disadvantages of water cooling

- Weight not only of the radiator and connections but also of the water; the whole engine installation is likely to be heavier than an equivalent air-cooled engine.
- Because the water has to be heated, it takes longer to warm up after starting from cold.
- If water is used, the maximum temperature is limited to about 85°C to 90°C to avoid the risk of boiling water. However, modern cooling systems are pressurized and this permits higher temperatures and better efficiency.
- If the engine is left standing in very cold weather, precautions must be taken to prevent the water freezing in the cylinder jackets and cracking them.
- There is a constant risk of a coolant leakage developing.
- A certain amount of maintenance is necessary for example, checking water level, anti-frost precautions, cleaning out deposits, etc.



F*ig.8: Coolant is pumped from the water pump, through the cylinder block and heads.*

RADIATOR

The function of the radiator is to expose to the air stream as large cooling area as possible in a small a frontal area as possible. It also acts as a tank for some of the water carried. The usual form of construction is that of sheet steel or brass pressing which are formed into top and bottom tanks. These are connected by brass or copper tubes fitted with finning to their surface areas. The block of tubes is sometime called core, in car radiators the cores may be of the tubular or of the film types. Radiators for automotive vehicles using liquid cooling systems consist of two tanks with a heat exchanging core between them. The upper tank contains an outside pipe called an inlet. The filler neck generally is placed on the top of the upper tank; attached to this filler neck is an outlet to the overflow pipe. The lower tank also contains an outside pipe that serves as the radiator's outlet. Operation of the radiator is as follows.

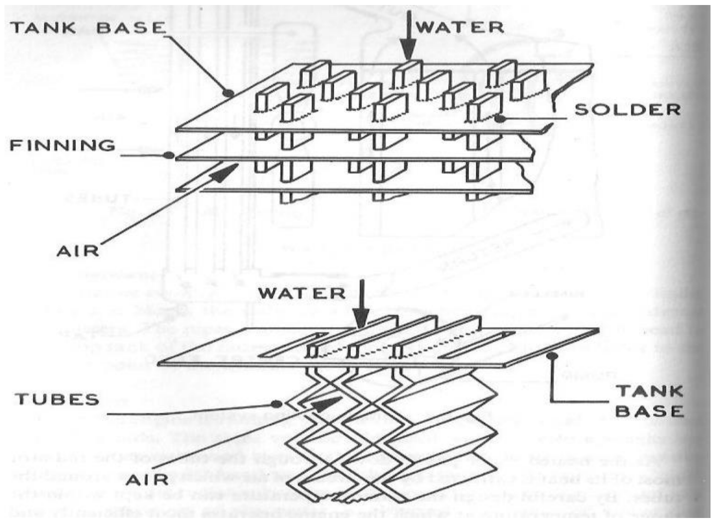


Fig. 8: Types of radiator; a) Tubular; b) Film.

- ❖ The upper tank collects incoming coolant and, through the use of an internal baffle, distributes it across the top of the core.
- ❖ The core is made up of numerous rows of small vertical tubes that connect the upper and lower radiator tanks. 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 airflow between the tubes and over the fins.
- ❖ The lower tank collects the coolant from the core and discharges it to the engine through the outlet pipe
- ❖ The overflow pipe provides an opening from the radiator for escape of coolant or steam if pressure in the system exceeds the regulated maximum. This will prevent rupture of cooling system components. Some radiators are designed with their tanks on the sides in a vertical position. They are connected by a core that contains horizontal tubes. This radiator configuration is called a cross flow radiator and operates in the same manner as the

conventional vertical flow radiator, though it should be noted that there is no thermo-siphon effect with a cross flow radiator.

WATER PUMP

All modern cooling systems have water pumps to circulate the coolant. The pump, usually located on the front side of the engine block, receives coolant from the lower tank and force sit through the water jacket into the upper radiator tank. The pump is a centrifugal type and has an impeller with blades that force coolant outward as the impeller rotates. It usually is driven by the engine crankshaft through a V-belt.

Advantages of a centrifugal pump as a water pump are that it is inexpensive, circulates great quantities of coolant for its size, and is not clogged by small amounts of foreign matter. Another advantage is that a centrifugal pump permits a limited amount of thermo-siphon action after the engine is shut down to help prevent boil over. The pump housing usually is cast from iron or aluminum. The impeller can be made from iron, aluminum, or plastic. It rides on a shaft that is supported in the housing on a sealed double row ball bearing. The pump shaft also has a spring-loaded seal to prevent coolant leakage.

FAN AND SHROUDING

The fan pulls a large volume of air through the radiator core so that engine heat can be dissipated effectively. In most cases the fan works in an enclosure called a shroud to ensure maximum efficiency of the fan. There are two methods of driving a fan. One method is to attach it to the end of the water pump shaft. The other method that is becoming increasingly popular is to utilize an electric motor.

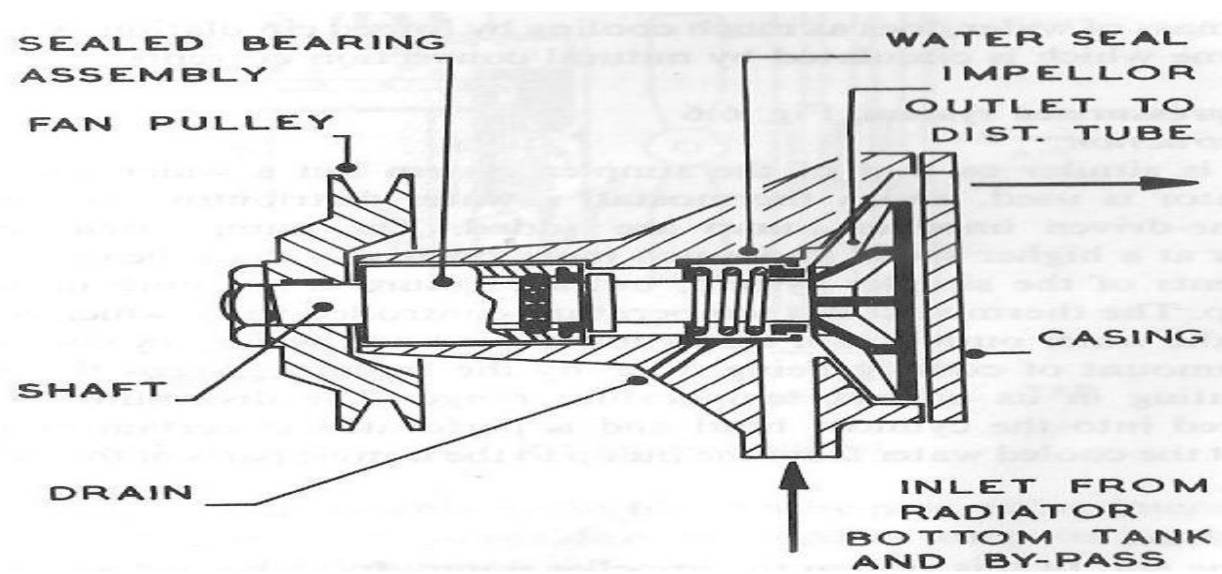


Fig. 9: Impeller water pump and fun pulley.

Thermostat

This is a temperature-sensitive valve that controls the water flow to the radiator. There are two main reasons for its use:

- To enable the engine to warm up quickly from cold.
- To control the rate of flow and so maintain a constant temperature in the engine.

Two types are in common use, the wax type and the bellows type.

Wax type Thermostat

This is used in the pressurized system as it is not sensitive to pressure like the bellows type. A special wax is used, contained in a strong steel cylinder. The reaction pin is surrounded by a rubber sleeve and is positioned inside the cylinder. As the temperature increases the wax begins to melt, changing from a solid to a liquid, and at the same time it expands. This forces the rubber against the fixed reaction pin, opening the valve against spring pressure, thus allowing the water to circulate through the radiator. There is a small hole in the valve disc to assist in bleeding the system as filling takes place. The 'jiggle pin' closes the hole during engine warm-up. This thermostat is shown in Fig.

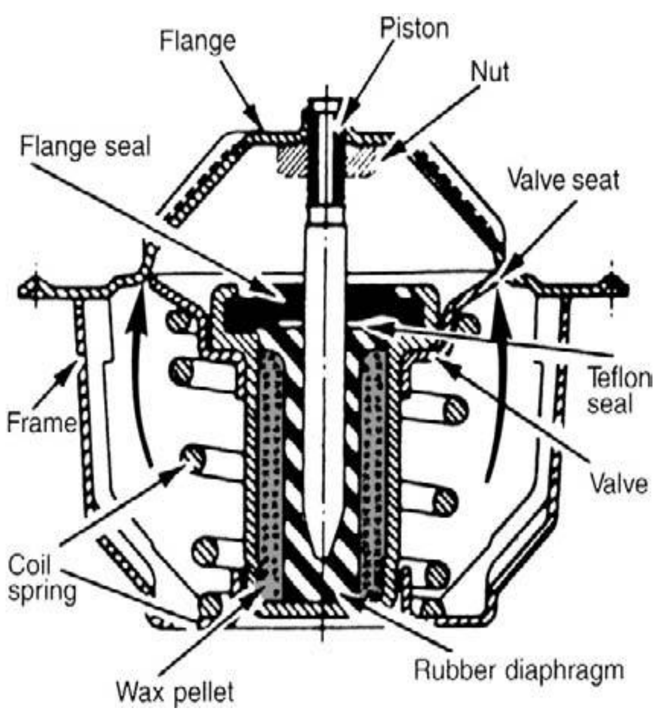


Fig. 8: Wax Type Thermostat.

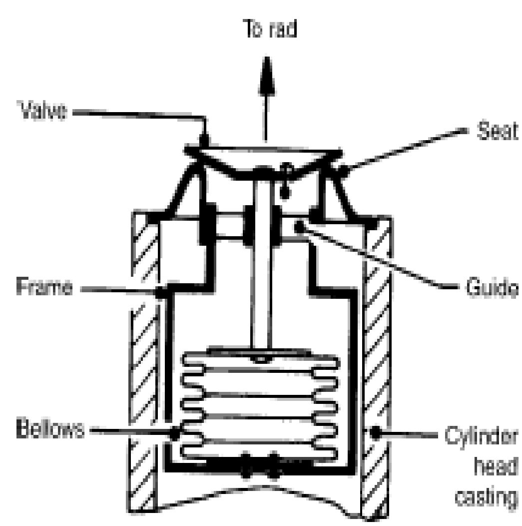


Fig. Bellows-type thermostat.

Bellows type

As shown in Fig. 13.14, the bellows type consists of a flexible metal bellows that is partly filled with a liquid having a boiling point lower than that of water (e.g. alcohol, ether, or acetone). Air is removed from the bellows, leaving only the liquid and its vapour. The pressure in the bellows is then only due to the vapour pressure of the liquid. This varies with temperature and is equal to atmospheric pressure at the boiling temperature of the liquid, less at lower temperatures and more at higher temperatures. As the temperature of the water increases, the liquid in the bellows begins to turn to a vapour and increases in pressure; this expands the bellows and opens the valve, allowing water to pass to the radiator.

Note

This type is not suitable for pressurized systems as the valves are pressure sensitive. The wax element type does not have this disadvantage.

Questions

1. Write a schedule for removing, testing, and replacing a thermostat that is suspected of being faulty.
2. What are the symptoms, fault, cause, and remedial action that should be taken when the driver complains of the heater blowing hot and cold?
3. Remove, test, and replace a thermostat according to your work schedule drawn up in (1) above. State the type of unit fitted, the temperature at which it opened/closed, and check with the manufacturer's data.

Testing thermostats

The thermostat cannot be repaired and so must be replaced if found to be faulty. It can be tested by placing the thermostat in a beaker of water and gradually heating it. A thermometer is used to check the temperature of the water (Fig. 13.15).

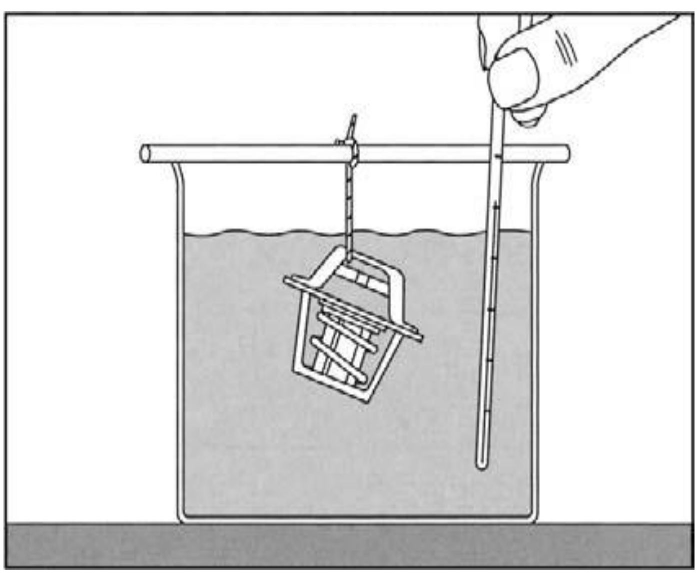


Fig. 13.15 Thermostat suspended in water container.

The thermostat should begin to open when the temperature marked on the valve is reached. An increase of approximately 10-20^{o}C will elapse before the valve is fully open.

Pressurized cooling systems

Pressurized cooling systems are used because they allow the engine to operate at a higher temperature. Figure 13.16 shows the layout and main components of a modern pressurized system.

Pressure cap

The cap contains two valves; one is the pressure valve the other is the vacuum valve (Fig. 13.17). As the temperature of the water increases it expands and in a sealed system this expansion increases the pressure until it reaches the relief pressure of the cap. As the system cools down it contracts and opens the vacuum valve, drawing in air. If no vacuum valve was fitted the depression in the system, caused by the contracting effect of the water as it cools, could cause the rubber hoses in the system to collapse. Most pressure caps operate at 28-100 kN/m. The pressure is usually stamped on the cap, indicating the maximum relief pressure for the system to which it is fitted. Figure 13.17(c) shows a pressure cap in the open position.

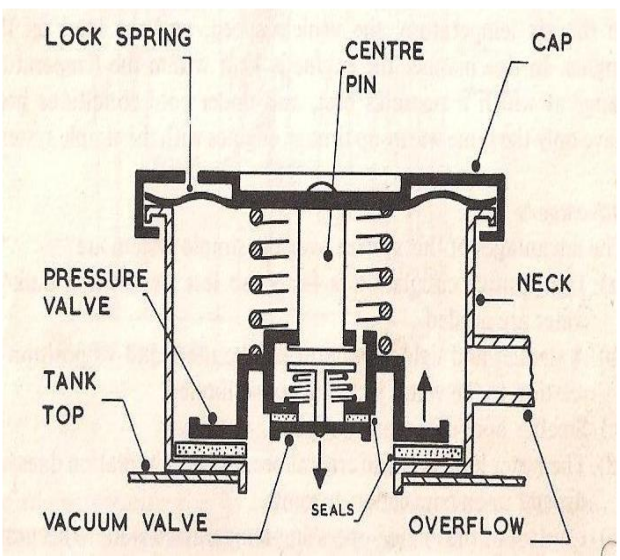


Fig. Pressure cap

The advantages of using a pressurized system are:

- Elimination of coolant loss by surging of the coolant during heavy braking.
- Prevention of boiling during long hill climbs, particularly in regions much above sea level.
- Rising of the working temperature, improving engine efficiency.
- Allowing the use of a smaller radiator to dissipate the same amount of heat as a larger one operating at a lower temperature.

Safety note

Never remove the cap when the coolant temperature is above 100°C as this will allow the water to boil violently; the resulting jet of steam and water from the open filler can cause very serious scalds. The system should be allowed to cool down and the cap removed slowly. It is designed so that the spring disc remains seated on the top of the filler neck until after the seal has lifted. This allows the pressure to escape through the vent pipe before it can escape from the main opening.

Semi-sealed system

The advantage of the modern sealed cooling system is that it reduces the need for frequent inspection of the coolant level and the risk of weakening the antifreeze solution by topping up. Although the provided a semi-sealed system, the fully sealed system has in effect a means of recovering the coolant that is lost when the engine is at its operating temperature and the pressure cap is lifted. It consists of an expansion tank that is mounted independently from the radiator and vented to the atmosphere. A flexible hose connects the overflow pipe of the radiator to a dip tube in the overflow tank. As the coolant heats up the pressure valve in the cap opens and excess coolant passes to the expansion tank. When the system cools down the coolant is drawn back into the radiator again through the vacuum valve in the cap. This is shown in Fig. 13.19.

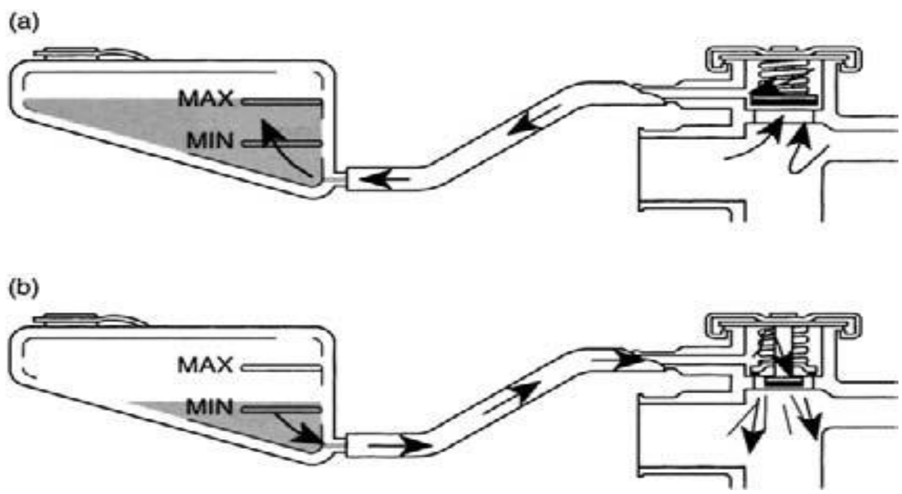


Fig. 13.19 Operating function of the overflow bottle. (a) Water heating up. (b) Water cooling down

Fully sealed system

In the fully sealed system, the pressure cap is fitted to the expansion tank and a simple cap is used on the radiator. The operation of the system is much the same as in the semi-sealed system. The reservoir is vented to the atmosphere and should be approximately two-thirds full. If the coolant falls below the minimum level indicated on the tank, air may be drawn into the radiator.

Fan drives

The drive for the fan is normally located on the water pump shaft. Its purpose is to draw sufficient air through the matrix for cooling purposes in heavy traffic on a hot day and to ensure adequate cooling at engine idling speeds. At moderate speeds e say, driving down the motorway e the engine does not require the same amount of assistance from the fan, as the natural flow of air passing through the radiator will often be sufficient to cool the water. Power would be lost unnecessarily to the fan under these conditions. A number of different methods of controlling fan operation and speed are becoming more popular. Automatically controlled fans are generally classified into four types:

- Free-wheeling
- Variable speed
- Torque limiting
- Variable pitch.

Free-wheeling

The free-wheeling type is mounted on the coolant pump shaft and may form part of an electromagnetic clutch with the drive pulley. Connected into the electrical supply circuit to the clutch assembly is a thermostatically controlled switch. When the fan is no longer required, the supply to the electromagnet is interrupted, so that it disengages and allows the fan to free-wheel on the pump shaft.

Variable speed

The variable-speed type generally has a viscous coupling, which permits motion or slip to occur between the driving and the driven members. The driving member consists of a disc mounted on the pump shaft. Attached to the fan is a sealed cylindrical casing or chamber, freely mounted on the pump shaft. The driving disc revolves within the coupling chamber, which is partially filled with a highly stable silicone fluid (this means it retains a nearly constant viscosity with varying operating temperatures). The disc initially revolves in the stationary mass of fluid and sets up a drag, so that the fluid begins to circulate in the chamber. As a result of centrifugal force it moves outwards to fill the gaps between the drive faces of the coupling members. Since these faces are very close to one another, drive is transmitted between them by the viscous drag of the silicone fluid. This drag is maintained with increasing fan speed, until the resisting torque imposed upon the fan by the air flow rises to an extent that causes shear breakdown of the fluid film, and the coupling slips. Fan speed is thus controlled by the slipping action of the coupling, which is predetermined by the viscosity of the fluid and the degree to which the coupling is filled. Where no provision is made for the quantity of oil, the coupling is termed a torque- limiting type. The layout of a viscous fan drive is shown in Fig. 13.23.

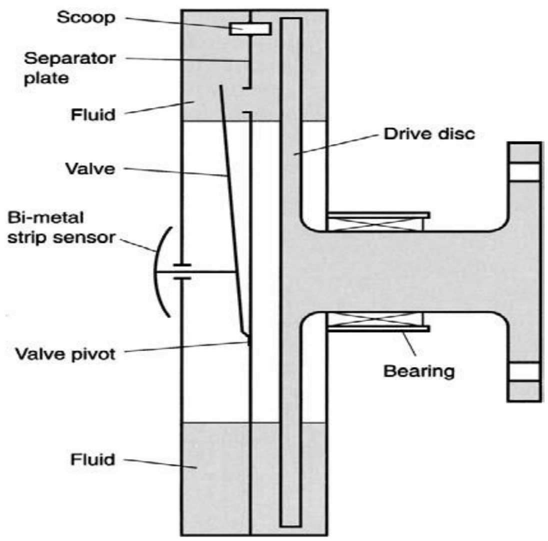


Fig. 13.23 Details of internal viscous fan drive

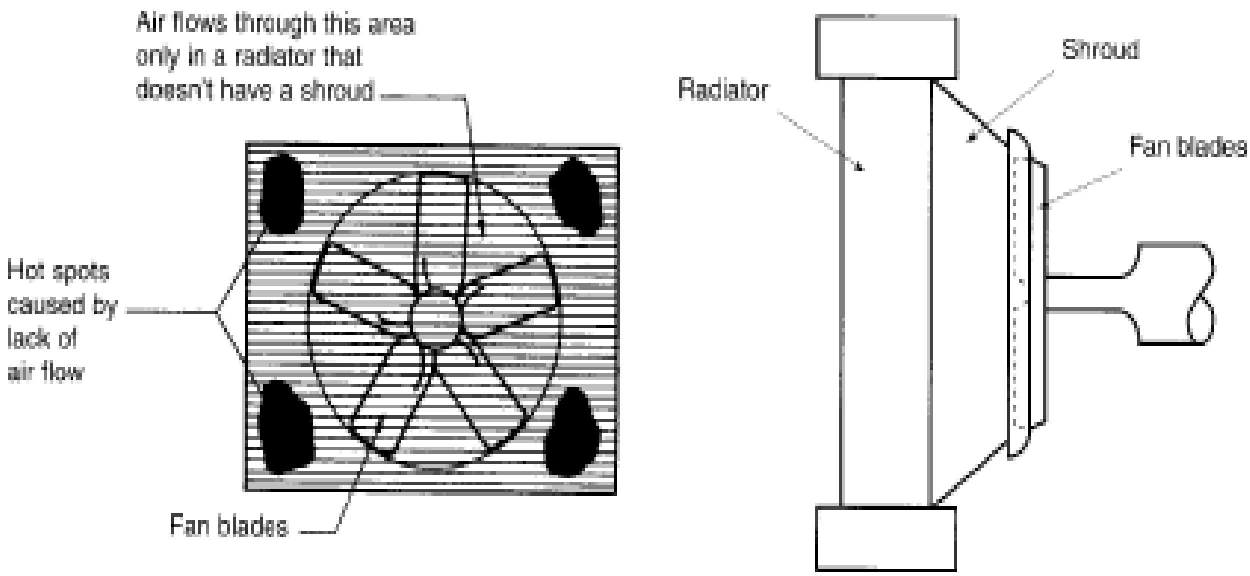


Fig. 22: Fan shrouds

Torque limiting

The torque-limiting type has the disadvantage of operating within a fixed speed range, regardless of cooling system demands. Thus, air circulation may be inadequate when car speed is low and engine speed is high. To overcome these difficulties, a temperature-sensitive fan control is used in some installations.

Variable pitch

In the variable-pitch fan the volume of air displaced is controlled by twisting its blades. The term pitch is considered as the distance the blade can twist, if it were turning one revolution in a solid substance (that is with no slip taking place). When the least amount of cooling is required, the blades are automatically adjusted to a low pitch, thereby reducing airflow to a minimum. The variable-pitch fan may be actuated by one of the following methods:

- Centrifugal
- Torque limiting
- Thermostatic means.

An alternative to the engine-driven fan is a separate electrically driven fan, which can be controlled automatically by the thermostat that responds to changes in engine coolant temperature. Although fan installations of this type absorb no engine power, they do impose an electrical load upon the car battery. It has a fixed higher operating speed and it may be noisier than a conventional driven fan, but it has the advantages of greater convenience of mounting position.

Learning tasks

1. What is the correct method for testing the pressure and vacuum valves in the cap? What would be the effect of fitting a cap with: (a) A stronger spring? (b) A weaker spring?
2. How would you test for water/oil contamination and which component would you suspect to be faulty?

Fans and their operations

Fans and temperature control

An important aspect of the cooling capabilities of the radiator is the volume of air, in unit time, which can because to flow through the matrix. Hence, the purpose of the cooling fan is to maintain adequate air flow through the matrix, at low and engine idling speeds. The speed of the fan ranges from slightly less to rather more than that of the engine. Excessive fan speeds are avoided because of noise and the power required to drive it.

Electrically driven fans

With this type of fan arrangement an electric motor is used together with a fan and a temperature-sensitive control unit.

The advantages of this arrangement are:

- The fan only operates when the engine reaches its predetermined temperature.
- The engine will be more efficient as the fan is not being driven all the time.

- The radiator and fan can now be fitted in any convenient position, ideal for transversely mounted engines.
- The fan assembly can be mounted in front of or behind the radiator.
- Engine temperature is more closely controlled as the temperature sensor will automatically switch the fan on and off within very close limits as required.

To improve the efficiency of the fan, a cowl is often fitted. Its function is to prevent heated air from reversing its flow past the fan and recirculation through the matrix, which could lead to engine overheating.

The fan can be formed from some of the following materials:

- One-piece steel pressing
- Aluminium casting
- Plastic moulding with a metal insert.

An uneven number of irregularly spaced blades (Fig. 13.21) are often employed to minimize fan noise. In all applications the fan assembly must be accurately balanced and the blades correctly aligned to avoid vibration.

Flexible fan blades

Used to reduce frictional power loss from the fan, these are made from fibre glass, metal, and moulded plastic such as polypropylene. The plastic fans are lighter, easier to balance, look better, are more efficient aerodynamically, have a reduced noise level, a reduction in vibration, and offer less risk of serious injury. They

Fault and their Possible cause

Overheating

1. Loose, broken, worn or incorrect fan-belt tension
2. Defective thermostat (closed and does not open)
3. Water impeller pump loose on shaft
4. Restricted circulation through radiator, hoses.
5. Radiator airways choked
6. Incorrect valve timing
7. Tight engine
8. Low oil level
9. Insufficient coolant in system

Overcooling

1. Temperature gauge incorrect
2. Defective thermostat (open and does not close)
3. Electric fan operating continuously

External leakage

1. Loose hose clips or split rubber hose
2. Damaged radiator (cracked joints or corroded core)
3. Water pump leaking (bearing worn)
4. Corroded core plugs
5. Damaged gaskets
6. Interior heater, hoses, valves
7. Temperature sensor connection leaking

Internal leakage

1. Defective cylinder head gasket
2. Cylinder head not correctly tightened
3. Cracked water jacket internal wall
4. Defective cylinder liner seals

Water loss

1. Boiling
2. Leaks in the internal and external parts
3. Restriction in radiator
4. Airways in radiator matrix blocked

Dirty coolant (corrosion)

1. Excessive impurity in coolant water
2. Infrequent draining and flushing of system (where required)
3. Incorrect antifreeze mixtures
4. Lack of inhibitor

Servicing and maintaining the cooling system

In addition to regular checks that should be made by the driver, the following items should be checked at regular intervals as specified in the service manual:

1. Check for evidence of coolant leaks. Examine all hoses and clips, radiator, engine core plugs (where visible), cylinder head gasket, water pump and gasket, thermostat housing, radiator filler cap, and overflow tank.

2. Check all hoses, including interior heater, for deterioration or cracks by flexing manually and by visual examination.
3. Check level of coolant against the indicator line in the overflow tank. The strength of the antifreeze solution should be checked by hydrometer and the specific gravity compared with the figures that are recommended for the conditions in which the vehicle normally operates.
4. Changing and flushing out the coolant. The corrosion inhibitors that are contained in the antifreeze liquid lose their effectiveness after a time and it is recommended that the system should be drained and flushed before refilling with new antifreeze. It is recommended that the system is 'back flushed' by removing the bottom hose and applying a low pressure water supply that will pass water through the system, in the reverse direction, until it becomes clean.
5. Check that the temperature gauge is operating correctly.
6. Check that the water pump drive belt is in good condition and correctly tensioned.

Safety note

Antifreeze contains toxic substances that are dangerous if taken internally; they can also be absorbed by prolonged skin contact. The following precautions should be taken:

- Antifreeze must never be taken internally. If antifreeze is swallowed accidentally, medical advice must be sought immediately.
- Protective measures such as the use of gloves should be taken to avoid skin contact with antifreeze.
- In the event of accidental spillage on to the skin, the antifreeze should be washed off immediately. If clothing is splashed with antifreeze it should be removed and washed thoroughly before being used again.
- For regular and frequent handling of antifreeze, protective clothing (plastic or rubber gloves, boots, and impervious overalls) must be used to minimize the risk of skin contact.

Fault diagnosis and repair

Possible faults

- Overheating
- Undercooling
- Frost damage.

Probable causes of overheating

- Low coolant level
- Leaks
- Combustion gas in the coolant

- Defective pressure cap
- Poor circulation of coolant
- Defective thermostat
- Defective water pump
- Defective radiator fan e electric motor, thermal switch, defective fan belt
- Collapsed hose
- Blocked air passages through the radiator grill.

Diagnostic checks

Low coolant level and leaks

Coolant leaks are the most likely cause of a low coolant level. In the first instance, carry out a visual check for obvious signs such as coolant on the floor under the vehicle, followed by a thorough examination of hoses, hose clips, gasket joints, the radiator, internal heater, and the water pump. If these checks are not conclusive, further checks such as the system pressure check can be applied.

A cooling system pressure check

Testing the pressure cap

The cooling system pressure cap can be tested by means of the hand-held apparatus shown in Fig. 13.30. The apparatus consists of a small hand-operated pump, a pressure gauge, and some adaptors that permit the pressure cap to be attached to it. When securely attached, the pressure is raised to its maximum and then recorded for comparison with the engine manufacturer's data, or the figure that is normally stamped on the pressure cap.

Pressure testing the entire system

The pressure cap test instrument can be used to place the cooling system under pressure, as shown in Fig. 13.31. The equipment for this test contains the hoses and adaptors that permit the instrument to be securely attached to the cooling system in place of the pressure cap. The pressure is then applied by means of the pump until it reaches the recommended test pressure which, in this example is 1.4 bar. This pressure may be different for other systems and it should be checked against the engine manual before the test proceeds. Once the system has been brought to the recommended pressure it is held there for approximately 10 seconds. This should be followed by visual examination of all possible leakage points.

Combustion gas leaking into coolant

Combustion gas may enter the cooling system by way of a defective cylinder head gasket, a leaking wet liner seal, a cracked cylinder head or block. If combustion gas is leaking into the cooling system it will give rise to overheating and loss of coolant. The presence of combustion gas in the coolant can be detected by several methods, which include the following:

- The cylinder leakage test
- Chemical analysis.

The cylinder leakage test

The cylinder leakage test (see Fig. 13.32) is performed by applying compressed air to the cylinders through an adaptor that fits into the spark plug or injector hole. The equipment for this test contains a pressure gauge and a leakage meter that shows leakage as a percentage. When all preliminary work has been completed, the adaptor and gauges are attached to the engine and the compressed air pressure is raised to approximately 7 bar. With the cooling system pressure cap removed, any leak from the cylinders into the cooling system should be evident. This test should only be conducted in accordance with the manufacturer's instructions.

Chemical analysis of coolant to check for combustion leaks

The upper chamber of the apparatus is filled with the test fluid up to the level that is indicated on the side of the vessel. A sample of steam from the engine cooling system is drawn into the upper sampling chamber and it is allowed to percolate through the test fluid. The test fluid is coloured blue and it changes to yellow if combustion gas (CO2) is detected in the coolant. Combustion gas leaks into the engine coolant may also be accompanied by coolant entering the combustion chamber; if this is the case it will probably cause the engine to misfire and emit white smoke from the exhaust system.

Poor circulation of coolant

Some probable causes of poor coolant circulation are:

- Defective thermostat
- Defective water pump
- Collapsed hose
- Defective radiator fan e electric motor, thermal switch, defective fan belt
- Blocked coolant passages in radiator and engine.

Defective thermostat

If the thermostat is stuck in the closed, or partly closed, position it will seriously impede coolant flow and will quickly cause the engine to overheat. At the opposite extreme, a thermostat that is stuck in the open position may cause delay in the engine reaching its normal working temperature, with consequent effects on cold running performance of the engine. The operation of the thermostat can be checked with simple equipment as shown in Fig. 13.15. The water is gradually heated while the temperature is observed; the opening of the valve can be observed as the valve begins to move away from its frame. The valve will begin to open at approximately 80°C, or at a figure that will be found in the appropriate service manual.

Defective water pump

Should the water pump (Fig. 13.34) bearings become worn, the shaft will drop out of alignment and this will damage the seal; this is the most likely cause of coolant leakage. Any leakage from the pump should be visible in the region where the pump shaft protrudes from the casing. When the pump drive belt is removed it should be possible to check for bearing wear by applying a rocking action to the drive pulley. The drive belt and pulley should also be checked to make sure that they are not worn and when the belt is refitted its tension should be set correctly to ensure that it does not impose excessive stress on the bearings.

Defective fan

The belt drive to the cooling fan may slip because it, or the pulley, is worn. The belt should not be too deep in the V-groove so that it touches the base of the groove. This may be caused by wear of the belt and it can be checked visually e the V-groove can be checked by placing an unworn belt in it to see if it is resting in the correct position. The belt itself should be tensioned enough to prevent slip, but not too tight so that it places stress on the pump bearings.

Electric fan

Electric cooling fans were originally controlled by a thermal switch, mounted in the radiator header tank that reacted to changes in engine temperature. Because they only operate when the temperature requires them to, they absorb less engine power than the belt-driven alternative. The electric cooling fan is designed to come on at about 95°C and turn off at about 90°C.

In computer-managed engine controls, the electronic control module (ECM) fan circuit (Fig. 13.35) may be designed so that the fan may continue running after the engine is switched off, to provide after cooling. In the system shown in Fig. 13.36 the fan can be operated at two different speeds: a low speed where the fan motor absorbs 200W and a higher speed when the power is 300W. In the event of a cooling system malfunction the ECM will output a standard fault code, which will indicate a circuit failure e full circuit diagnosis could then proceed with the aid of a circuit diagram and the necessary meters.

Blocked radiator

A reasonable assessment of the condition of the radiator core can be gained by passing a volume of water through it. A simple apparatus of the form shown in Fig. 13.37 used to be recommended by a vehicle manufacturer. If the flow rate is known it can be checked by using a stop clock to record the time taken for a given volume to pass through the radiator in the absence of such information the best that one could achieve is to observe the rate at which water leaves the radiator, when treated to a similar process. If the water appears not to flow freely it is reasonable to assume that the radiator tubes are partly blocked.

Blocked air passages through the radiator grill

If the areas around the fins and tubes of the radiator are obstructed the air flow across it will be reduced and this will result in a loss of heat transfer properties. A visual examination will normally reveal any obstructions to air flow. One manufacturer suggests using a low-pressure compressed air supply to gently blow material out of the radiator matrix.