Lecture-25

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Internal Combustion Engines

Cooling Systems

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Significance

- In a spark ignition engine, cooling must be satisfactory to avoid pre-ignition and knock. In a compression ignition engine, since a normal combustion is aided, cooling must be sufficient to allow the parts to operate properly. In short, cooling is a matter of equalization of internal temperature to prevent local overheating as well as to remove sufficient heat energy to maintain a practical overall working temperature.

Reasons for Cooling

- to promote a high volumetric efficiency
- to ensure proper combustion, and
- to ensure mechanical operation & reliability.

Effect of Over-cooling

- the thermal efficiency is decreased due to more loss of heat carried by the coolant
- the vapourization of the fuel is less resulting in lower combustion efficiency
- low temperature increases the viscosity of lubricant causing more loss due to friction.

Types of Cooling System

- **Air cooling *(or direct cooling)* system**
- **Liquid cooling *(or indirect cooling)* system**

Remark: **Aviation engines, motor cycle engines and scooter engines are air cooled; while the stationery and automobile engines are liquid cooled.**

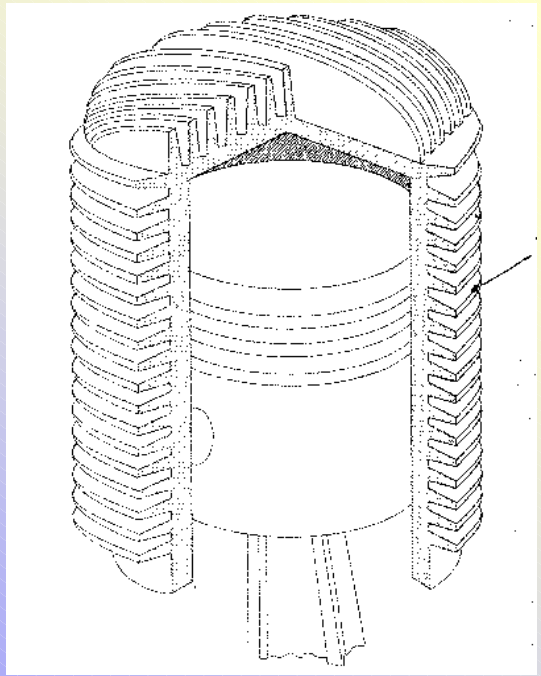
Air cooling system

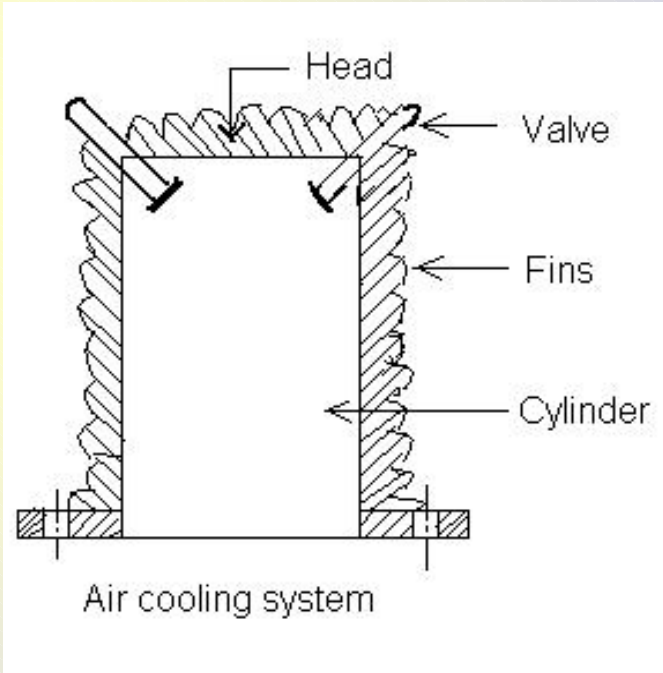
- Air cooled engines depend on airflow across their external surfaces of the engine cylinders to remove the necessary heat. The amount of heat dissipated depends upon:

  - the area of cooling surface in contact with the air
  - mass flow rate of air
  - temperature difference between cylinder and air and
  - conductivity of metal.

Cooling fins in air cooled system

- **The area of cooling surface is increased by forming thin fins, either integrally by machining them on the outer walls of the engine cylinder and cylinder head or by attaching separate fins to them.**





Air cooling system

Air cooling system - Advantages

- The absence of radiator, cooling jackets, coolant and pumps make the engine lighter.
- The engine can be operated in cold climate where liquid may freeze.
- In places where water is scarce, air cooled engine is an advantage.
- Handling of liquid coolant requires piping and pumping auxiliaries.
- Air cooled engines have no coolant leakage or freezing problems.

Air cooling system - Disadvantages

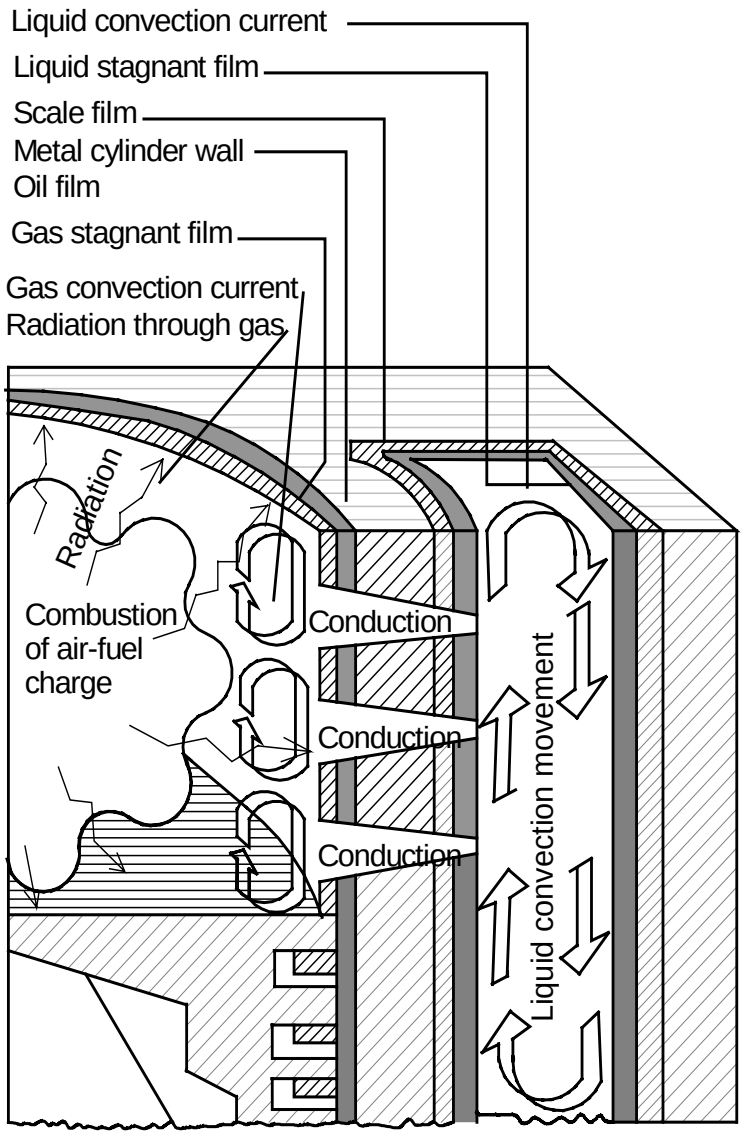
- Relatively large amount of power is used to drive the cooling fan.
- Engines give low power output.
- Cooling fins under certain conditions may vibrate and amplify the noise level.
- Cooling is not uniform.
- Engines are subjected to high working temperature.

Liquid cooling systems - Types

- Direct or non-return system
- Thermosyphon system
- Forced circulation cooling system
- Evaporative cooling system

❖ Direct or non-return system

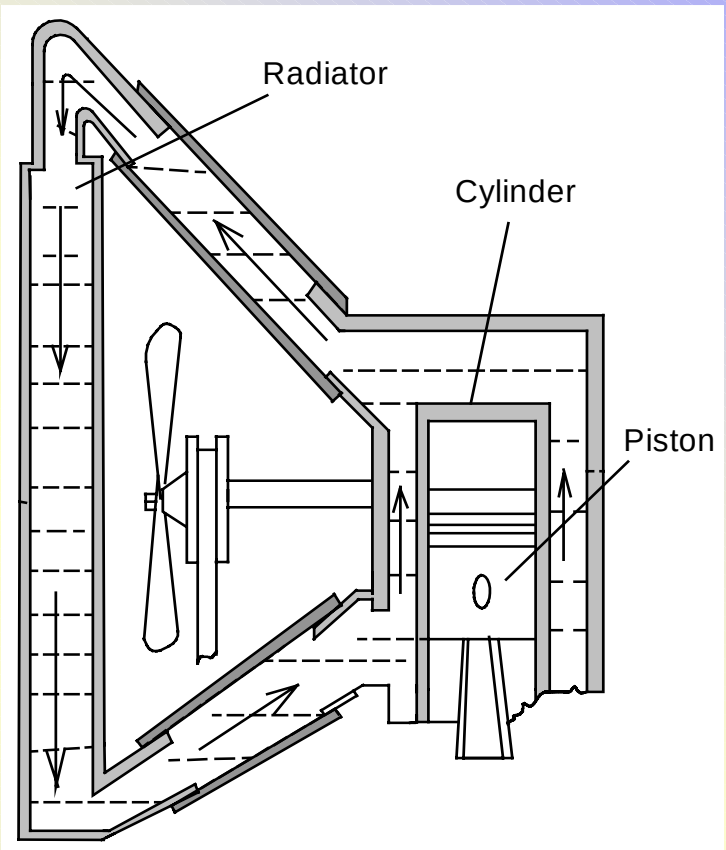
❑ **The heat released from the combustion of air-fuel mixture is transferred in all directions to the walls of the combustion chambers, cylinders and pistons by direct radiation, by convection currents of gas rubbing against a stationary gas film, and then by conduction through this stagnant boundary layer of gas and an oil film to the metal wall.**



Heat Transfer through a liquid cooled cylinder wall

Thermo-syphon system

- In this system, a fan rotated by the crankshaft draws cold air from outside through the radiator. The radiator is connected to the engine block by means of two pipes. The hot water passes through some thin pipes built in the radiator, where it gets cooled. Thus, the fluid circulates through the system in the form of convective currents.

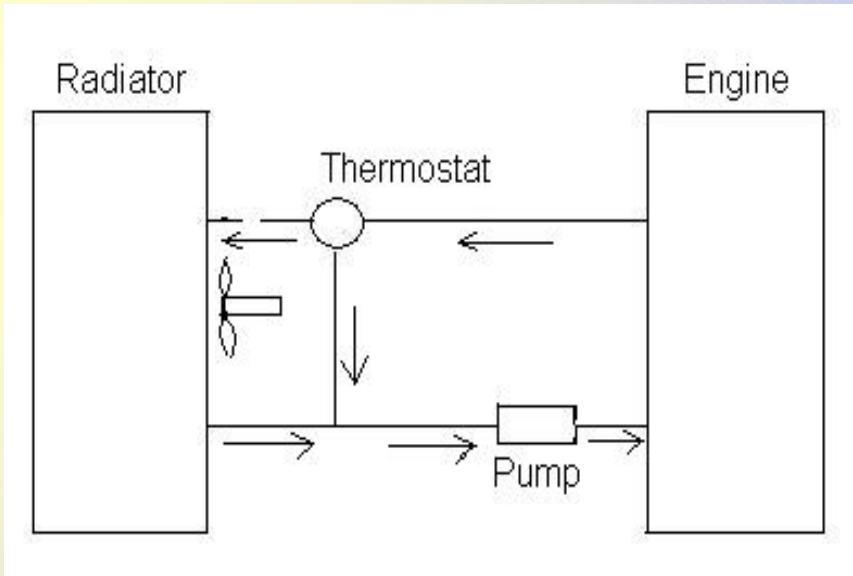


Schematic diagram of a thermosyphon system

Forced circulation cooling system

- This system is used in a large number of vehicles like cars, buses, trucks and other heavy vehicles. Here, circulation of water takes place with convection currents helped by a pump.

- The water or coolant is circulated through jackets around the parts of the engine to be cooled, and is kept in motion by a centrifugal pump, driven from the engine. A thermostat is used to control the water temperature required for cooing.



Schematic diagram of a forced circulation system

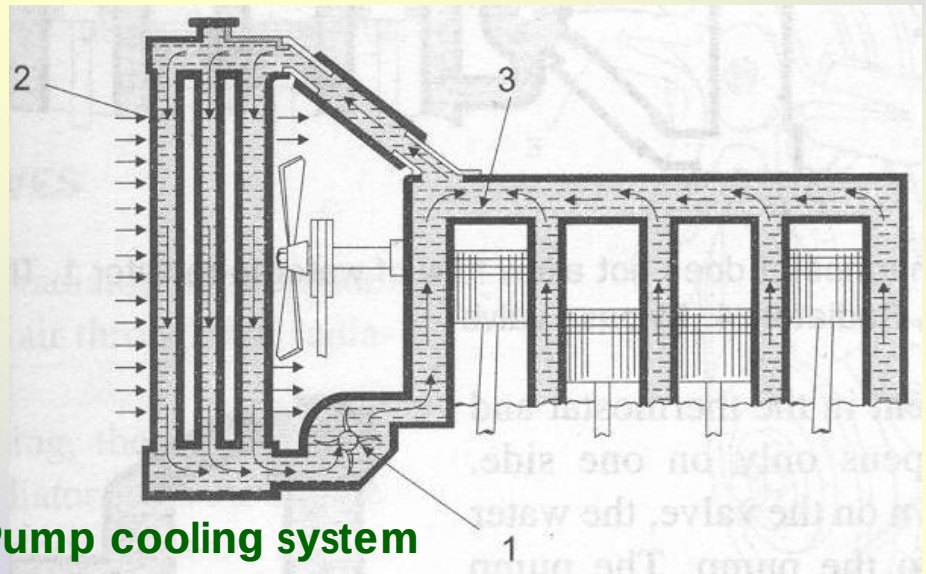
Pump-cooling or forced cooling

- Pump is introduced between radiator and engine block
- Rotated by crankshaft by means of a belt
- Water is circulated with force => heat is removed quickly

Limitation

Cooling is independent of temp. =>Engine is overcooled (range of temp.=75-90^{0}C)

Can be overcome by using thermostat.

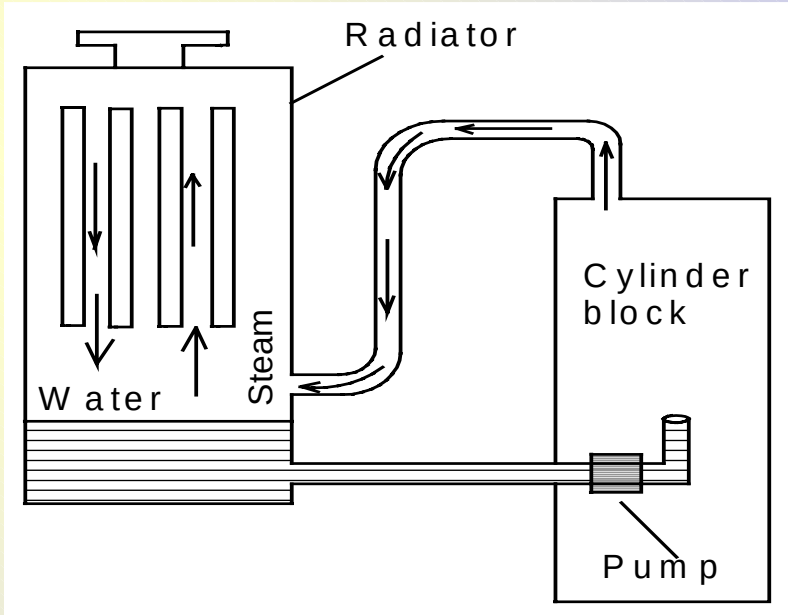


Pump cooling system

Evaporative cooling system

- In this system, the engine will be cooled because of the evaporation of the water in the cylinder jackets into steams.

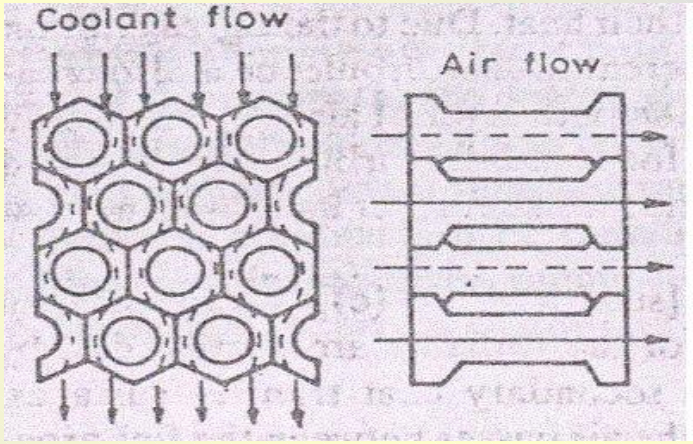
- The advantage is being taken from the high latent heat of vaporization of water by allowing it to evaporate in the cylinder jackets. This system is used for cooling of many types of industrial engines.



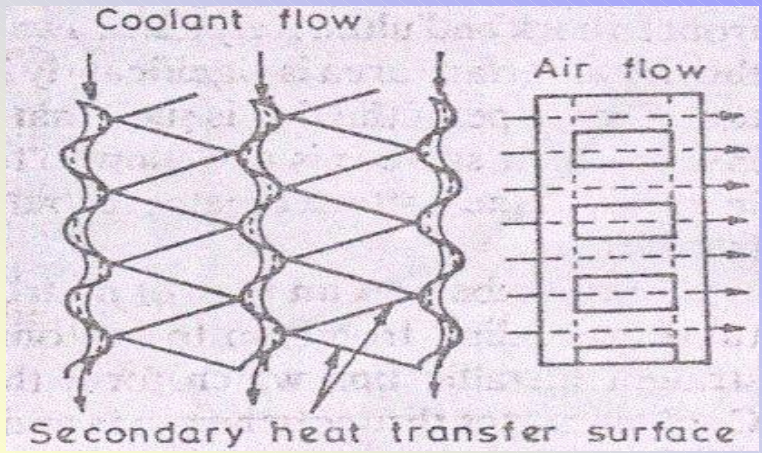
Schematic diagram of an evaporative cooling system

Parts of cooling systems - Radiator

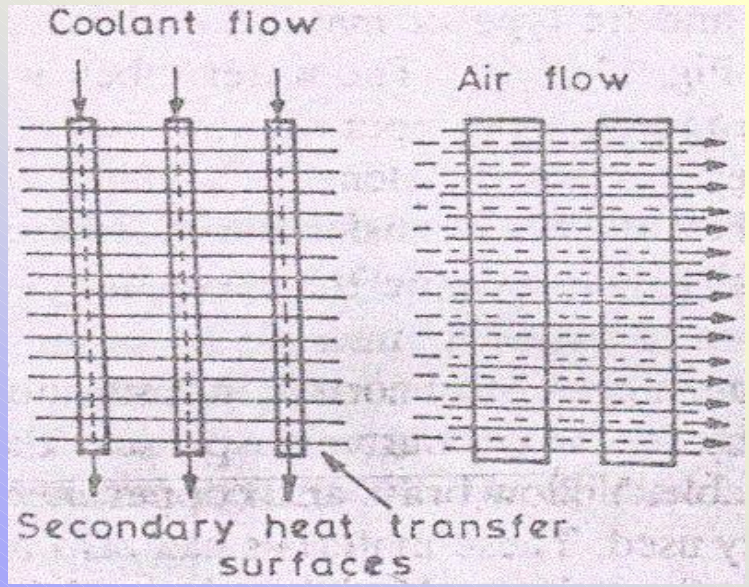
- Rejects the coolant heat to the surrounding air
- Disperses the heated coolant into fine streams so that small quantities of coolant are brought in contact with large metal surface areas, which in turn are cooled by air stream
- Two types of radiators
  - (1) Down-flow type
  - (2) Cross-flow type
- Availability of space dictates the choice of radiator, both are equally efficient.
- Various design of radiator cores are used for cooling the water



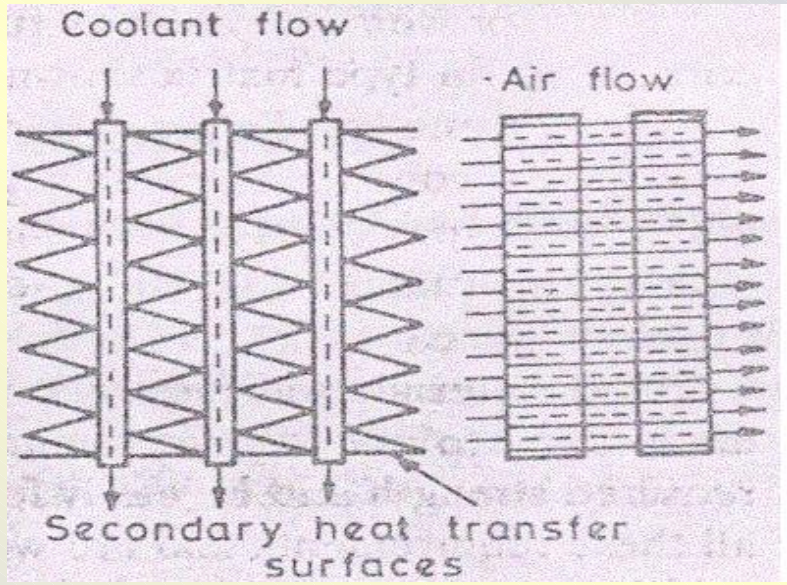
Honeycomb block type core



Film type of radiator core



Tube and fin type core



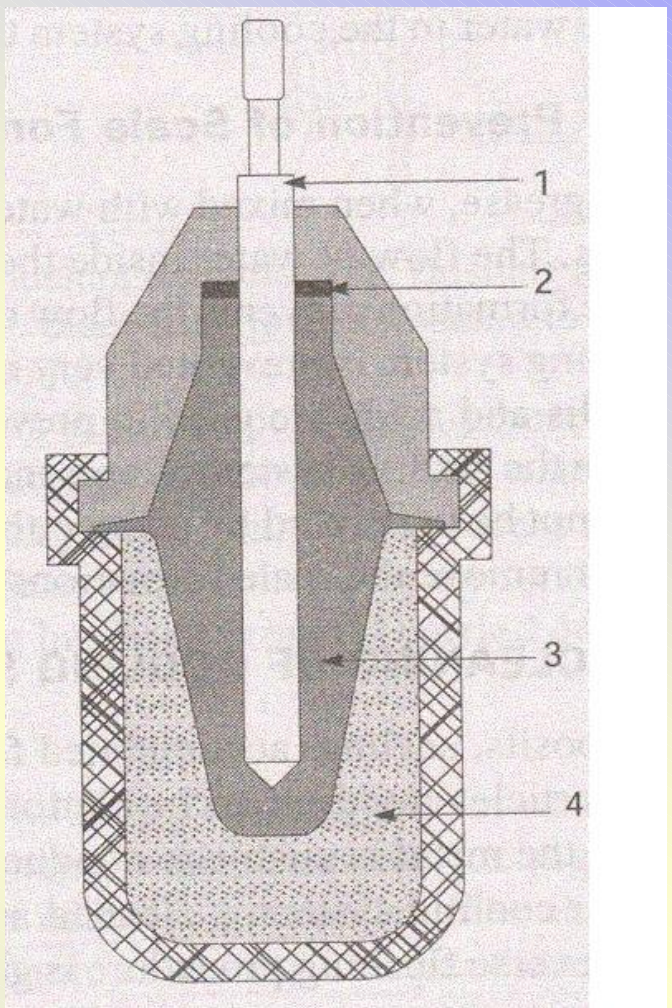
Tube and corrugated type core

Materials for radiator

- Good corrosion resistance
- Good thermal conductivity
- Must possess the required strength
- Must be easily formable
- Yellow brass, copper are used (soldered easily => easy repair)
- Aluminium is used where weight is critical

Wax Thermostat

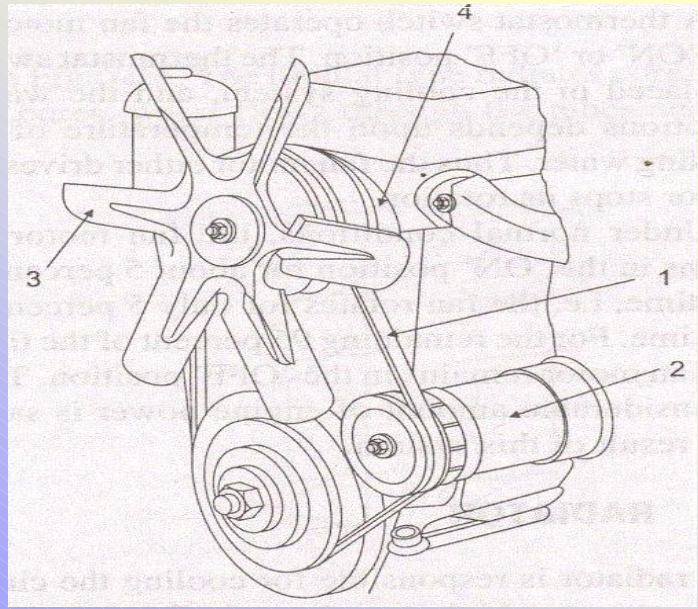
- Can operate reliably within the specified temperature range.
- Heat is transmitted to wax, which has high coefficient of thermal expansion.
- Upon being heated, wax expands and the rubber plug presses the plunger forcing it to move vertically upwards.



Wax Thermostat

Cooling fan

- **Maintain an adequate air flow across the radiator matrix.**
- **Serves the purpose when natural draft is not sufficient to cool e.g., at low speed but heavy load, when vehicle ascends uphill etc.**
- **Driven by a belt run by crankshaft.**

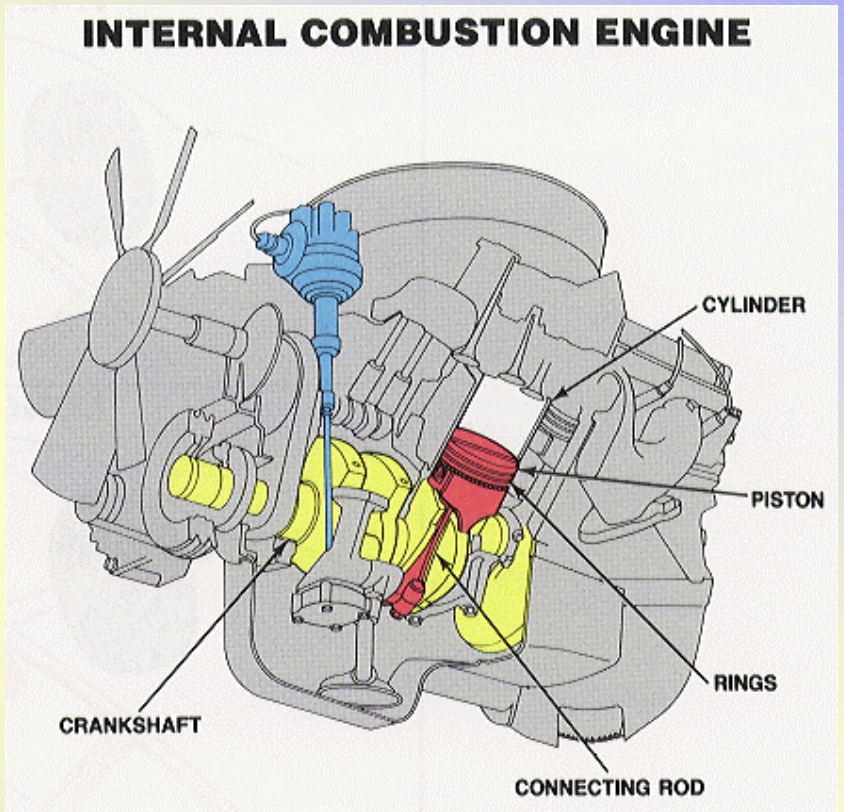


Cooling fan

Limitations

- **Rising level of noise.**
- **Increasing power consumption with engine speed.**
- **Tendency to overcool.**

Cooling fan


INTERNAL COMBUSTION ENGINE
CYLINDER
PISTON
RINGS
CRANKSHAFT
CONNECTING ROD

Liquid cooling system - Advantages

- **Because of even cooling of cylinder barrel and head (due to jacketing) makes it possible to reduce the cylinder head and valve seat temperatures.**
- **The volumetric efficiency of water cooled engines is higher than that of air- cooled engines.**
- **Compact design of engines with appreciably smaller frontal area is possible.**
- **In case of water cooled engines, installation is not necessarily at the front of the mobile vehicles, aircraft etc. as the cooing system can be conveniently located.**

Liquid cooling system - Disadvantages

- The system requires more maintenance.
- The engine performance becomes sensitive to climatic conditions.
- The power absorbed by the pump is considerable and affects the power output of the engine.
- In the event of failure of the cooling system serious damage may be caused to the engine.

Use of Anti-freezers

- **During winter or when the engine is kept out of operation in cold places, the cooling water in the cylinder jackets, radiator tanks and leading pipes will freeze, expand and lead to their fracture. To prevent damage to the engine and radiator during winter weather, suitable liquids or compound substances *(known as anti-freezers)* which go into solution are added to the water to lower the freezing temperature of the coolant.**

- **Ethylene glycol is the most widely used automotive cooling-system antifreeze, although methanol, ethanol, isopropyl alcohol, and propylene glycol are also used.**

Requirements of anti- freezers

- They should thoroughly mix with water.
- They should not corrode the surfaces with which they are in contact.
- Their boiling point should be high so that the loss due to evaporation is minimum.
- They should not deposit any foreign matter in the jackets, hose, pipes or radiator.
- It should be chemically stable, a good conductor of heat, and a poor conductor of electricity.

TABLE 10-1 PROPERTIES OF ANTIFREEZE SOLUTIONS

ETHYLENE GLYCOL–WATER MIXTURES

% ETHYLENE GLYCOL by Volume	SPECIFIC GRAVITY at 101 kPa and 15°C	FREEZING POINT at 101 kPa		BOILING POINT at 101 kPa	
		°C	°F	°C	°F
0	1.000	0	32	100	212
10	1.014	− 4	24		
20	1.029	− 9	15		
30	1.043	−16	3		
40	1.056	−25	−14		
50	1.070	−38	−37	111	231
60	1.081	−53	−64		
100	1.119	−11	12	197	386

PROPYLENE GLYCOL–WATER MIXTURES

% PROPYLENE GLYCOL by Volume	SPECIFIC GRAVITY at 101 kPa and 15°C	FREEZING POINT at 101 kPa		BOILING POINT at 101 kPa	
		°C	°F	°C	°F
0	1.000	0	32	100	212
10	1.006	−2	28		
20	1.017	−7	19		
30	1.024	−13	8		
40	1.032	−21	−6		
50	1.040	−33	−28	108	225
60	1.048	−48	−55		
100	1.080	−14	6	188	370

	ENTHALPY OF VAPORIZATION (kJ/kg)	SPECIFIC HEAT (kJ/kg-K)	THERMAL CONDUCTIVITY (W/m-K)
Water	2202	4.25	0.69
Ethylene Glycol	848	2.38	0.30
Ethylene Glycol–Water Mixture (50/50)	1885	3.74	0.47
Propylene Glycol	1823	3.10	0.15
Propylene Glycol–Water Mixture (50/50)		3.74	0.37

Lubricating Oil as Coolant

- The lubricating oil used in an engine also helps to cool the engine. The hotter parts like piston face and back surface of piston crown is subjected to oil flow, usually done by spraying the oil by pressurized systems or by splash in non-pressurized system. Other components like camshaft and connecting rods are also cooled by oil circulation through oil passages.

Conclusions

- **A cooling system must be provided not only to prevent damage to the vital parts of the engine (due to high temperature), but the temperature of these components must be maintained within certain limits in order to obtain maximum performance from the engine. To keep the cylinders from overheating, they are surrounded with a water jacket on liquid cooled engines, or with a finned surface in air cooled engines. Most small and medium sized engines used in two-wheelers, automobiles, aircraft are air cooled, while the stationery and some automobile engines are liquid cooled.**

Conclusions

A typical automotive cooling system comprises:

- **a series of channels cast into the engine block and cylinder head, surrounding the combustion chambers with circulating water or other coolant to carry away excessive heat**

- **a radiator consisting of many small tubes equipped with a honeycomb of fins to radiate heat rapidly, that receives and cools hot liquid from the engine**

- **a centrifugal-type water pump to circulate coolant**

- **a thermostat that maintains constant temperature by automatically varying the amount of coolant passing into the radiator, and**

- **a fan, which draws fresh air through the radiator.**

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Web Resources

1. http://www.mne.psu.edu/simpson/courses
2. http://me.queensu.ca/courses
3. http://www.eng.fsu.edu
4. http://www.personal.utulsa.edu
5. http://www.glenroseffa.org/
6. http://www.howstuffworks.com
7. http://www.me.psu.edu
8. http://www.uic.edu/classes/me/ me429/lecture-air-cyc-web%5B1%5D.ppt
9. http://www.osti.gov/fcvt/HETE2004/Stable.pdf
10. http://www.rmi.org/sitepages/pid457.php
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13. http://www.nebo.edu/misc/learning_resources/ ppt/6-12
14. http://netlogo.modelingcomplexity.org/Small_engines.ppt
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21. http://www.me.udel.edu
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23. http://widget.ecn.purdue.edu/~yanchen/ME200/ME200-8.ppt -