S.E. MECH.-APPLIED THERMODYNAMICS

IC ENGINE COOLING SYSTEMS(PART OF UNIT 5)

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Engine heat distribution and the necessity of a cooling system –

- Energy released by combustion of fuel in the cylinder is dissipated in three ways : 35 to 45% heat energy doing useful work on the piston, 30 to 40% heat expelled with the exhaust gases, and 22 to 28% heat carried away by heat transference.
- Thus, approximately 25% of heat generated must be transmitted from the enclosed cylinder through the cylinder walls and head to the surrounding atmosphere.
- If the heat flow rate through the metal is low, the temperature of the inner surfaces will rise to a point where the heat destroys the lubricating properties of the oil film on the cylinder walls. Simultaneously, thermal stresses may be established which may distort the cylinders and head and drastically reduce the working strength and wearing properties of the pistons.
- To control the rate of heat removal from the cylinders, either a direct or an indirect air-cooling system is provided so that the temperature around the cylinder walls and combustion chamber remains relatively constant over the engine's normal speed and load range.
- The object of the cooling system, therefore, is to extract and transfer heat from the engine to the atmosphere at a rate which matches the rate at which energy is liberated by the burning of the fuel charge.
- A well designed cooling system should provide adequate cooling, but not excessive cooling. Too much cooling is undesirable because
  1. It can lead to poor combustion and fuel economy due to insufficient vapourization of fuel.
  2. It results in increased frictional losses dur to high viscosity of lubrication oil.
  3. It can change the valve clearance and settings, as valves are set to operate properly above a certain temperature.

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Operating temperature conditions of the engine –

Different parts of the engine operate at different temperatures, so some regions inside the enclosed cylinder are more prone to overheating than others. A broad guide to the mean operating temperatures of the gas chare and the various zones in the cylinder is as follows-

- Intake air – 30 to 60 °C
- Peak combustion gas – 2000 to 2400 °C
- Exhaust gas - 700 to 900 °C
- Cylinder wall near cylinder head – 160 to 220 °C
- Cylinder wall near crankcase - 100 to 150 °C
- Centre of cylinder head - 200 to 250 °C
- Centre of piston crown - 250 to 300 °C
- Cylinder block coolant - 80 to 100 °C

Types of cooling systems –

1. Direct air cooling, where cool circulating air is made to come in contact with the exposed and enlarged external surfaces of the cylinder and head and thereby dissipate their heat to the surrounding air.
2. Indirect cooling (liquid cooling), where a liquid coolant is used to transmit the heat from the cylinders and head to a heat exchangers, usually referred to as the radiator. Movement of air through this radiator then extracts and dissipates the unwanted heat to the surroundings.

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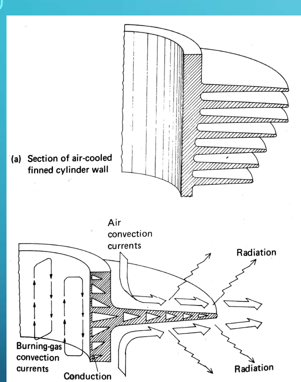

Fig. 1 Finned cylinder wall

Direct air cooling system –

- Refer Fig. 1. Radial ribs or fins are used to increase the external surface area of the cylinder so as to transfer heat from the cylinder to the surrounding atmosphere.
- Length of these fins is greatest where the cylinder is hottest – near the cylinder head and progressively reduces towards the cooler operating crankcase. The fins are usually straight and tapered with rounded outer edges.
- Heat from combustion is received by the cylinder walls, the combustion chamber, and the piston crown by both direct radiation and convection. Heat is conducted through the metal walls from the inner surface to the outer surface.
- Movement of air over the fins results in carrying away of heat energy by air convection currents. In addition, some heat energy is transferred by direct radiation form the cylinder fins to the surroundings.

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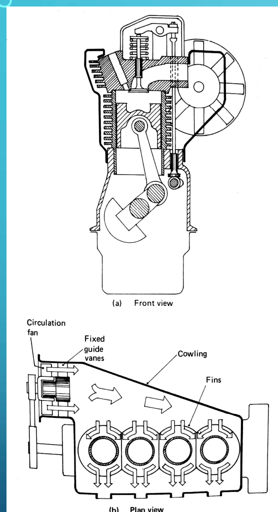

Fig. 2 Air cooling system for an in-line 4 cylinder engine

Description of an air cooled system – Refer Fig. 2

- Air cooled engines mounted on a motorcycle frame usually rely on the natural air stream caused by the forward movement to circulate air around the cylinders, head, and crankcase.
- With multi-cylinder engines enclosed under a bonnet or boot, a more positive method of cooling is necessary. Controlled air cooling is usually achieved by incorporating a fan which blows fresh air over the external finned surfaces of the engine.
- To improve effectiveness of the blown air, the sides of the finned cylinders and heads are enclosed by a sheet metal or plastic covering, known as the cowling. The shape of the cowling guides the forced convection current around all the cylinders and provides a direct exit after the air has extracted and absorbed the heat from the engine.
- Some other engine configurations employ baffles to improve the air distribution between cylinders and to direct additional air to critical components such as the oil cooler.

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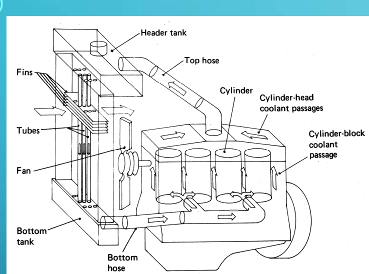

Fig. 3 Thermo-syphon liquid cooling system

Thermo-syphon liquid cooling system – Refer Fig. 3

- Heat released by combustion is transferred in all directions to the metal walls of the combustion chambers, cylinders, and pistons by radiation, convection and conduction.
- Liquid coolant is circulated around the cylinders to carry away the heat energy. As it heats up, it expands and becomes less dense relative to liquid which is not in contact with the hot metal walls; therefore the lighter hot coolant rises to the highest point in the system, which is the header tank over the radiator tubes.
- At the same time, the liquid in the radiator tubes is cooled by the air stream passing around the tubes and over the fins, consequently the density of the liquid in the tubes increases, so that the cooled liquid sinks to the bottom.
- The heavier cooled liquid replaces the hot and less dense liquid in contact with the cylinder walls.
- Once the engine has warmed up, a convection current flows between the engine and the radiator and so forms an enclosed circulating loop known as the thermo-syphon cooling system.
- Function of the radiator is to transfer the heat from the liquid to the surrounding atmosphere. Top of the radiator is connected by a hose to the cylinder head where the heated liquid rises and collects, and the bottom of the radiator is joined by a hose to the lower region of the cylinder block coolant passages.

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Thermo-syphon liquid cooling system (Continued) –

- The simple radiator is flat and rectangular in shape and consists of columns of spaced out copper or aluminium alloy tubes held in position at the ends by an upper header tank and a bottom tank. Attached to these tubes are layers of horizontal copper or aluminium sheets known as fins, which improve the effectiveness of heat dissipation.
- The upper header tank acts as a reservoir for the coolant and distributes the collected hot liquid evenly among the vertical tubes.
- The bottom tank collects the cooled liquid coolant from each tube and passes it through a single outlet back to the engine's coolant passages surrounding the cylinders.
- Upper and lower flexible fabric-reinforced rubber hoses connect the radiator to the engine cylinder head and cylinder block coolant jackets These flexible hoses are necessary to absorb the relative movement between the radiator (which is bolted to the engine body) and the suspended engine (which tends to vibrate while operating)
- An outer casing wall, known as the coolant jacket is formed around the cylinders to retain the liquid circulating around the cylinders. Similarly, coolant passages are cast inside the cylinder head so that the coolant can flow around the combustion chamber walls, the inlet and exhaust ports and their valve seats, and the spark plugs or injector holes.
- A fan is positioned between the radiator and the engine to supplement the normal air movement. This provides a continuous air stream over the tubes and fins of the radiator to dissipate the heat being circulated by the coolant.

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Limitations of thermo-syphon cooling system –

- Under certain conditions (such as pulling under load at low speed), the rate of coolant circulation created by convection current can not match the rate of transfer of heat from the cylinder walls to the coolant.
- For adequate heat transfer, the radiator header tank should be situated at a higher level than the cylinder head. This would be impossible with modern body styles.
- Without coolant circulation control, the engine tends to be overcooled and very rarely reaches the optimum operating temperature.
- The large quantity of coolant enclosed in the cooling system prolongs the engine's warm up period.
- The large header tank, used to compensate for the low rate of coolant circulation, tends to overheat and so coolant is lost through evaporation.

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Pump assisted liquid cooling system – Refer Fig. 4

- The basic thermo-syphon system is slightly modified by incorporating an engine-driven centrifugal pump in series with the engine coolant lower return hose.
- With this modification, the coolant can be made to flow not only upwards but also along the full length of the cylinder block coolant passages. This helps to prevent uneven cooling or overheating of individual cylinders.
- Increasing the coolant flow rate also enables the radiator to work more efficiently, so it can be made smaller in size, and it is also unnecessary to mount the radiator any higher than the engine cylinder head.
- Controlling engine warm up is partially achieved by placing a thermostat valve in series with the top hose. When the engine is closed, the valve is closed – this prevents the bulk of the liquid circulating. Once normal working conditions are reached, the thermostat automatically senses the desired working temperature and opens the valve, the bulk circulation then begins.
- To prevent excessive pressure build-up in the engine coolant passages, a bypass pipe circulates about one tenth of the liquid directly between the cylinder head thermostat housing and the inlet side of the pump. This also eliminates local boiling of trapped coolant due to lack of circulation.

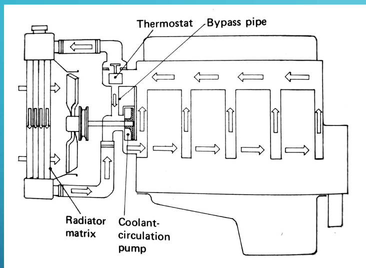

Fig. 4 Pump assisted liquid cooling system

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Antifreeze coolant solutions –

- Originally all liquid cooled engines used water as the coolant. However, water freezes when the temperature drops below 0 °C. On freezing, it occupies approximately 10% more volume. If the water in the cylinder block and head passages were to freeze, it would rigidly solidify and exert pressure against the metal walls; this pressure would be sufficient to rupture or crack the block and head at weak points and would split open the radiator tubes.
- To prevent damage to the engine and radiator during winter weather, suitable liquids or compound substances are added to the water to lower the freezing temperature of the coolant below the temperature of the winter climate. These solutions are called anti-freeze solutions.
- The most popular antifreezes use the high boiling point glycols - usually ethylene glycol (boiling point 195 °C) – which lower the freezing point of water in proportion to the solution strength. These solutions do not suddenly convert from liquid to solid at one temperature but gradually change in the form of mushy soft ice over a range of temperatures.
- Typical solution strengths for ethylene glycol and water is 50%, which means 1 part antifreeze and 1 part of water. This allows coolant circulation down to -37 °C and prevents ice damage down to -50 °C.

Corrosion inhibitors –

- These are chemical compounds which provide corrosion protection, acidity control of the coolant and water softening to avoid the formation of scale caused by mineral deposits.
- Commonly used cooling system corrosion inhibitors are chromates, borates, nitrates, nitrites, benzotriazole and tolyltriazole.
- The corrosion inhibitors protect the metallic surfaces of the cooling system against corrosion attack.

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Comparison of air and liquid cooling systems –

Air cooling – Advantages –

Air cooled engines –

- Can operate extremely well in both hot and cold climates.
- Can operate at higher working temperatures than equivalent liquid cooled engines.
- Rapidly reach their working temperature from cold.
- Are marginally lighter than the similar sized liquid cooled engines.
- Have no coolant leakage or freezing problems.

Air cooling – Disadvantages –

- Relatively large amount of power is required to drive the cooling fan.
- Large quantities of intake air passing into the cooling system can make the engine noisy.
- Cooling fins may under certain conditions vibrate and amplify noise.
- Pitch between cylinder centres has to be greater than in liquid cooled engines, to permit all fins to extend between cylinders.
- Each cylinder has to be individually cast, whereas a rigid monoblock construction is used by liquid cooled engines.
- An oil heat exchanger is frequently necessary to prevent overheating of the lubricant.
- The guide cowling and baffles surrounding the cylinders may hinder maintenance.

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Comparison of air and liquid cooling systems (Continued) –

Liquid cooling – Advantages –

- Liquid cooled engines provide greater temperature uniformity around the cylinders, so there is less distortion compared with air cooled engines.
- Combined power consumption of the coolant pump and the fan in liquid cooled engines is far less than that of the fan in air cooled engines.
- The cylinders can be situated closer together, providing a very rigid and compact unit compared to the air cooled engine.
- Mechanical noise from the engine is damped by both the coolant and the jackets.
- Liquid cooled units are more reliable for heavy duty work than air cooled engines.
- Hot coolant can easily be piped to heat the interior of the vehicle.

Liquid cooling – Disadvantages –

- Liquid cooled joints are subject to leakage.
- Precautions must be taken to prevent coolant freezing.
- Liquid cooled units take longer to warm up than the air cooled units.
- Maximum liquid coolant temperature is limited to its boiling point, whereas air cooled engines can operate at slightly higher temperatures.
- The coolant passages tend to scale, and the hoses and radiator tubes deteriorate with time.

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