A Review Paper on Analysis of Vortex Tube Cold Outlet For Radiator Cooling

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Abstract – *Possibilities for integration of vortex tube with automotive radiator for more effective cooling of automotive engine is the aim of the overview. An automotive radiator/heat exchanger is a device which helps maintain the working temperature of the engine. The vortex tube is a device which provides low temperature and high temperature output with pressure as an input.*

Key Words: **Radiator, Heat exchanger, Vortex tube, Engine cooling, Overheating.**

1. INTRODUCTION TO VORTEX TUBE

Ranque–Hilsch vortex tube is a simple mechanical device which could generate cold and hot air streams simultaneously by utilizing compressed air as a working fluid. The splitting of flow into regions of low and high temperature range is referred to as the temperature separation effect. Vortex tube consists of compressor, pressure gauge, control valve, thermocouple and temperature indicator. Compressed air enters into the vortex tube tangentially. Due to which swirling flow takes place in vortex chamber. The compressed air expands in vortex tube and divides into cold and hot stream. The cold air leaves the cold end orifice which is near inlet nozzle and hot air discharges at far end of the tube i.e. hot end. Thermocouples measure temperature at cold end and hot end. The performance of vortex tube depends on two basic parameters, first is the working parameter such as inlet pressure of compressed air, and the other one is geometric parameters such as number of nozzles, diameter of nozzle, cone valve angle, length of hot side tube, cold orifice diameter, and as well as material of vortex tube.

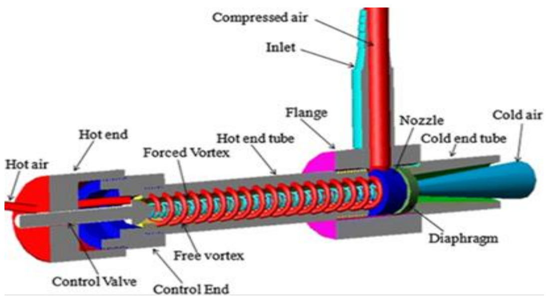

Fig -1: Vortex Tube

1.1 General concepts of RHVTs

The general temperature separation phenomenon of hot and cold streams in a counter-flow RHVT is depicted. It is environmentally friendly device that uses natural working fluids this means no CFC and HCFC grouped refrigerants. In order to operate the vortex tube, only compressed fluid is used as a working fluid. It is effective and not complicate (no moving part, free and simple maintenance etc.). Vortex is generated in the tube hall due to pressure difference between tube wall and tube center. As a result of this situation, cold stream moves through the center when hot stream moves through the periphery of the vortex tube. Reversed flow stream in the vortex tube takes place due to Occurrence of high rotational speed. The vortex tube can be used to in cooling of electronic controls and circuits, cooling of LPG and LNG in any applications and cooling of drilling, turning operations Surely a temperature separation always exists but researchers explains this situation from different angles. These assertions are given that, the compression and expansion of the working fluid and viscous shear between high and low pressure fluid and angular motion of the flow at the center and tube wall causes the temperature separation and heat transfer occurs due to temperature gradients in the vortex tube and also turbulent incompressible flow

1.2 Components of vortex tube

Components of a vortex tube are,

1. Nozzle
2. Diaphragm
3. Control valve
4. Hot air side
5. Cold air side

1. Nozzle: A nozzle is a device which controls the direction or characteristics of a fluid flow

2. Diaphragm: A diaphragm is a sheet of a semi-flexible material anchored at its periphery and most often round in shape. It serves as either a barrier between two chambers, moving slightly up in one chamber or down in the another depending on differences in pressure, or as a device that vibrates upon application of certain frequencies.

3. Control valve: A device for controlling the flow of fluids (liquids, gases) in a pipe or other enclosure. Control is by means of a movable element that opens, shuts, or partially obstructs an opening in a passageway. Valves are of seven main types: globe, gate, needle, plug (cock), butterfly, poppet, and spool.

4. Hot air side: Hot side is cylindrical in cross section and is of different lengths as per design.

5. Cold air side: It is a cylindrical portion which passes the cold air.

6. Chamber: Chamber is a portion of nozzle and facilities the tangential entry of high velocity air-stream into hot side. The chambers are not generally of circular form, but they are converted into circular form gradually.
The diaphragm and nozzle are place inside the vortex tube inside the vortex chamber to make the ease of high pressure air brook to acquire velocity and to form a free vortex. The tangential nozzle plays a major role in obtaining the spiral motion the air stream, the air enters tangentially into the vortex tube due to the specific shape of the nozzle and producing a vortex form. Hot streams are due to the free vortex moving close to the tube periphery. The free vortex compressed because of the expansion of the forced vortex to the walls gains heat and leaves through the hot end. To work as a throttle valve to reduce the temperatures of the cold streams further leaving towards the cold end the diaphragms or washer of small circular plate with a hole at the center are used. Diaphragm is placed beside the nozzle towards cold end. The diameter of the diaphragm hole affects the cold end temperatures to a considerable extent. Control valve is situated at the hot end. Control valve is in conical shaped valve intended to deflect the free vortex to the other end. The conical angle of the control valve plays a major role in splitting the air streams into cold and hot streams. It also controls the amount of air or gas to be deflected towards the hot and cold ends. The cold fractions can be decided by controlling the controlling valve opening and closing towards the hot end.
The shape of the nozzle plays major role in vortex creation thereby the efficiency of the vortex tube. The Performance of the vortex tube increases with increase in number of nozzles. But there observed to be a limit to the nozzle number because of the geometrical constraints of the vortex tube.

1.3 Working of a vortex tube

Compressed air gas is inducted through the tangential nozzle and sectional view of vortex tube can be seen. Due to the shape of the tangential nozzle air expands and flows in spiral form. The vortex flow is called as free vortex flows close to the periphery of the vortex tube towards hot side. Control valve at the end of the hot side deflects the free vortex creating a forced vortex diverted back towards the cold end close the central axis of the tube with a speed reaching 1,000,000 rpm.

By partly closing the control valve the pressure of the air near the valve is made more than the outside. Through the core of the hot side a reversed axial flow starts from high-pressurized region. Free and forced vortex streams transfer energy because of the difference in their pressures and as the free vortex is compressed against the vortex tube walls because of the forced vortex expansion. Because the pressure difference is directly proportional to the temperature, the free vortex leaves the vortex tube through hot end by absorbing all the heat and forced vortex loses heat and leaves through cold end. The cold stream is escaped through the diaphragms hole reducing their temperatures further in to the cold side, while hot stream is passed through the opening of the control valve.

1.4 Types of vortex tube

1. Counter Flow Vortex Tube

Counter flow vortex tube gives cold and hot flows on its opposite ends. The flow of forced and free vortices will be in opposite directions in counter flow vortex tube. It is very efficient due to the heat exchange taking place between opposite directions. This type is most commonly used one.

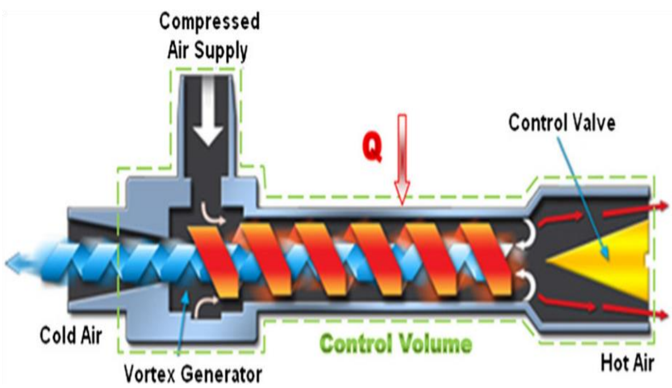

Fig -2 Counterflow Vortex Tube

2. Uni-flow Vortex Tube

As the cold exhaust is situated at the same side of the hot exhaust, it is named "uni-flow". The hot air and cold air flows in same direction in uni-flow vortex tube. Less heat exchange takes place between the same direction flowing air streams so, it is less efficient. The hot and cold air comes out of the vortex tube in one direction only. From the experimental investigation it was found that the performance of the uni flow system is worse than that of the counter flow system. So, most of the time, the counter flow geometry was chosen.

Fig. 3- Uni Flow Vortex Tube

1.5 Effect of geometric parameters on vortex tube

The principle geometric parameters are vortex tube length, diameter, cold orifice diameter, number of intake nozzles and their areas of opening. There effects on species separation are discussed below in details.

1. Effect of vortex tube diameter:

Promvonge et al. had observed when diameter of the RHVT was varied, keeping both feed inlet pressure condition and vortex tube length fixed, back pressure at the inlet of the RHVT varied inversely with the diameter. When the diameter of the RHVT was higher, the back pressure remained low and hence specific volume was high. This in turn would reduce the azimuthal component of velocity in both the axial and peripheral layers of gas and a flat pressure profile would be obtained. Hence it could be concluded that the rate of pressure diffusion in the radial direction was reduced which in turn reduced the species separation in the binary gas mixture. On the other hand a smaller diameter RHVT would produce high back pressure and hence the specific volume of air would reduce. Therefore, the velocities between the peripheral and the axial regions would not differ as the specific volume is low. This would reduce the centrifugal pressure difference between the two streams in the peripheral and the axial regions and thus the rate of mass transfer between those streams would remain low. Hence we would get an optimum value of the RHVT diameter which would produce maximum separation. Similar results had been reported by Marshall.

2. Effect of cold orifice diameter:

Eiamsa-ard and Promvonge had discussed in details the effect of cold orifice diameter on the flow field inside a RHVT. According to them higher back pressure in the vortex tube would be generated when the cold orifice diameter was small, resulting, as discussed in the previous section, in lower species separation. On the contrary, when the cold orifice was large it would draw air directly from the inlet and thus azimuthal velocities in the axial as well as peripheral layers would be dampened. This would result into lower species separation. Nimbalkar and Muller had pointed that a swirling secondary loop was formed when the cold orifice diameter was smaller than the diameter of the axial backflow core, and a return flow was generated at the cold end, inside the RHVT. This return flow could force a mixing of axial gas stream depleted with heavier component of the mixture with the peripheral gas stream enriched with heavier component. Hence species separation was reduced at lower cold orifice diameter. When the cold orifice diameter was equal to the diameter of the axial backflow core, this return flow was not generated. At this value of cold orifice diameter optimum species separation was possible. Again when cold orifice diameter was made bigger than the axial backflow core diameter the enriched peripheral stream entered the axial zone and mixed with the axial depleted stream. Thus species separation was reduced at higher value of cold end orifice diameter.

3. Effect of intake nozzle number and area:

It has been observed for a given geometry of RHVT and fixed inlet condition, as the numbers of intake nozzles were increased, the intensity of turbulence and pressure loss at the entrance of the vortex chamber were also gradually increased. Hence it could be concluded that with increasing number of nozzles the turbulent mixing of two partially separated streams of heavier and lighter components of the inlet gas mixture had increased. Also with increase in pressure loss the azimuthal velocity head was decreased which had resulted into lower centrifugal diffusion. Hence with increasing number of intake nozzles the overall separation effect in a RHVT had decreased. Similar results had been obtained by Mohammadi and Farhadi for the separation of Liquefied Petroleum Gas (LPG) from a mixture of LPG and nitrogen. Im and Yu had suggested that nozzle exit velocity would decrease as their opening area was increased. This would result into generation of lower intensity vortex inside the vortex chamber. As the vortex generation was reduced this would result into fall in species separation due to reduction in centrifugal field.

1.6 Effect of operating parameters

The principle operating parameters are inlet flow rate, inlet pressure and cold mass fraction. There effects on species separation.

1. Effect of inlet flow rate and inlet pressure:

Saidi and Valipour had shown that by increasing the inlet pressure of the RHVT the flow velocity at the outlet of the entrance nozzle could be increased up to the point where choking of the flow took place. Ahlborn et al. had shown that the inlet flow rate was a function of normalized pressure drop. Hence it could be concluded that for a fixed value of outlet pressure the inlet flow rate was directly proportional to the inlet pressure. It had been observed that practically in many cases though the compressor connected to the vortex tube could generate the required inlet pressure but the supply flow rate fell short due to lack in compressor capacity. Hence it is required to be ensured that both the inlet pressure and flow rate can be generated by the compressor. Chatterjee et al. had experimentally shown that there was an optimum value of inlet pressure or inlet flow rate at which maximum species separation was observed for a given generator and fixed value of the hot end valve opening. At lower inlet pressure as the pressure was gradually increased the swirling velocity of gas streams also increased. This would give rise to higher centrifugal pressure diffusion and species separation would gradually increase. As inlet pressure was further raised to a higher value more and more heavier species would get collected at the peripheral streams and this would cause a reduction of difference in partial pressure of the heavier species between peripheral and axial regions. Hence at higher inlet pressure species separation would reduce considerably and the separation factor would go through a maxima.

2. Effect of cold mass fraction:

The effect of cold mass fraction on the gas separation had been investigated by Mohammadi and Farhadi both experimentally and computationally for a mixture of gases and it had been reported that the molar recovery percent of the heavier species at hot end increased slightly with increase in cold mass fraction. In this experiment, geometry of the RHVT and flow inlet conditions were kept unchanged. An explanation of this phenomenon can be found from the expression of elementary separation factor for an aerodynamic process of species separation like RHVT, that Becker had provided. For a multi-component mixture, the expression.

2. INTRODUCTION TO RADIATOR

Automotive engine cooling system reduces the excess heat produced during the operation of engine. Engine surface temperature is regulated by it for achieving the optimum efficiency. Engine cooling system consists of the radiator, water pump, cooling fan, pressure cap and thermostat. Radiator is the most important of the cooling system.
The radiator is a device which dissipates the heat of the coolant coming out of the engine by absorbing the heat. It is designed such a way that it holds a large amount of water in tubes or passages which provides a large area in contact with the atmosphere. It has a radiator core, with water-carrying tubes and it is provided with large cooling area, which connects the receiving tank (end cap) at the top and to a dispensing tank at the bottom. Side flow radiators have their "endcaps" on the sides, which allows a lower hood line. In this operation the water pumped from the engine is received by the top tank, where it spreads over the tops of the tubes. As the water passes down through the tubes, it loses its heat to the airstream which passes around the outside of the tubes. To help spread the heated water over the top of all the tubes, a baffle plate is generally placed in the upper tank, directly into the inlet hose from the engine. Sooner or later, almost everyone has to deal with an overheating car. Since water is readily available, it is not beyond the ability of most people to add some to their radiator if it's low. But serious burns can occur hence proper precautions must be taken. Here are a hardly some points trading with an overheated radiator.

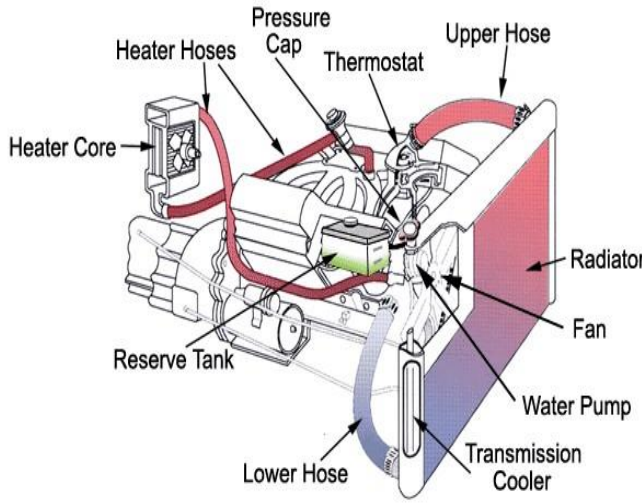

Fig -4 Automobile Cooling System

2.1 Heat exchanger

Heat exchanger is a device for transfer of heat from one fluid to another fluid without mixing them. The barter of heat may be liquid to liquid or gas to gas etc. e.g. in a car radiator heat exchange takes place between air and water flowing through radiator tube in a steam condenser heat exchanger takes place between steam and water. The exchange of heat in diesel engine oil cooler is between lubricating oil and water. In an air free heater used in steam power plant, heat exchange is between hot flue gases and cool air. The purpose of all these devises is either to effectively recover the heat energy in the hot fluids as in the air preheater or as in the car radiator cooling it to desired extent. This can be accomplished by providing effective heat between two fluids.

2.2 Classification of heat exchangers:

The heat exchangers are classified based on the types of fluid, the number of fluids and the heat transfer rate. Some of the major types of heat exchangers and their construction features are explained briefly.

1. Tubular heat exchanger:

A shell and tube heat exchanger consists of a number of circular tubes parallel to that of a shell. The important features of a shell and tube heat exchanger, in this, the tube fluid passes only once and shell fluid passes through the shell. One shell tube passes in which the tube fluid passes twice through the smell.in some cases tubes are kept one in another concentrically such that one fluid passes through the inner tube and the other fluid passes through the annular space between the tubes. This is known as parallel flow and if the fluids pass opposite to one another bit is known as counter flow

2. Plate type heat exchanger:

In plate type heat exchanger as the name implies two plates are used for manufacturing it. The hot fluid pass from one side and cold fluids pass through other side of a plate exchanging heat through it. In some cases, the plates are made in the form of corrugated sheets through which the fluid passes. Cross flow, counter flow and parallel flow arrangements are possible. In some other types the plates are fixed with number of fins to enhance the rate of heat transfer.

3. Tube type heat exchanger:

For heat exchange between a gas and other fluid these kinds of tube heat exchangers are most useful. Like in car radiators, evaporators and condensers of small refrigeration systems etc. Tubes with fins on their surface or round tubes are used. These kinds of heat exchangers are known as cross flow radiators. The flow of fluid through the tubes is unmixed whereas the flow of fluid over the tube is considered as mixed one. The flow of two fluids acts in two perpendicular planes.

4. Regenerative Type Heat Exchanger:

A porous medium generally of metal balls, pebbles, powder etc. called bed or matrix through which hot and cold fluids are passed alternatively. Thus during the flow of hot fluid bed absorbs heat and when cold fluid is passed the heat is transferred from the bed to fluid. During rotation the bed periodically passes through hot stream and then through the cold stream. However, this kind of rotary regenerators are useful for gas-to-gas exchange and not useful for liquid since the heat capacity of the bed is less for liquids. However, most of the heat exchangers can be brought under a common classification i.e., cross flow heat exchangers and counter flow, parallel flow.

5. Compact heat exchanger:

When the surface area to volume ratio of a heat exchanger is greater than 750m2/m3 then the exchanger is known as compact heat exchanger. Most of the times the gas with low heat transfer coefficient is used. it requires large surface area and a compact heat exchanger is best suitable. In the case of compact heat exchangers, the pressure drop of fluid is high and is of important consideration. In many cases the heat transfer characteristics and friction factor of such configurations are found experimentally. Several Researchers have done extensive work on compact heat exchangers and developed charts to obtain Friction factors and heat transfer for a specified matrix and Reynolds number. Hence for a compact heat exchanger the value of u can be obtained from these charts and applying either NTU Method or LMTD method the requirement of size and rate of heat transfer etc. studied.

2.3 Water Cooling Systems

It has two main purposes in the working of an engine:

a) It takes away the excessive heat generated in the engine and saves it from overheating.
b) For efficient and economical working It keeps the engine at working temperature.

There are four types of water cooling systems:

(I) Non-return or Direct system.
(ii) Thermo-Syphoned system.
(iii) Hopper system and
(iv) Forced/Pumped circulation system.

Though the present tractor has a forced circulation system, it is still worthwhile to get acquainted with the other three systems.

1. Non-Return Water Cooling System:

This is suitable for Huge plants and where large amount of water is available. The water is supplied to the engine cylinder directly from storage tank. The hot water is simply discharges instead of cool down for reuse. The example can be taken as low H.P. engine, coupled with the irrigation pump.

2. Thermo-Syphon Water Cooling System:

The working principle that hot water rises up as it is lighter and the cold water goes down as it is heavier. For the easy flow of water towards the engine the radiator is placed at a higher level than the engine. The heat is absorbed to the water jackets from where it is taken away to the circulating water due to convection. Due to increased temperature of water jacket, it rises to the top of the radiator. For continues circulation in the system, cold water from the radiator takes the place of the rising hot water. It helps the engine to keep at working temperature. Disadvantages of Thermo-Syphon System are rate of circulation is too slow, circulation commences only when there is a marked difference in temperature and the circulation stops as the level of water falls below the top of the delivery pipe of the radiator. Because of these reasons this system has become outgoing and generally not in use.

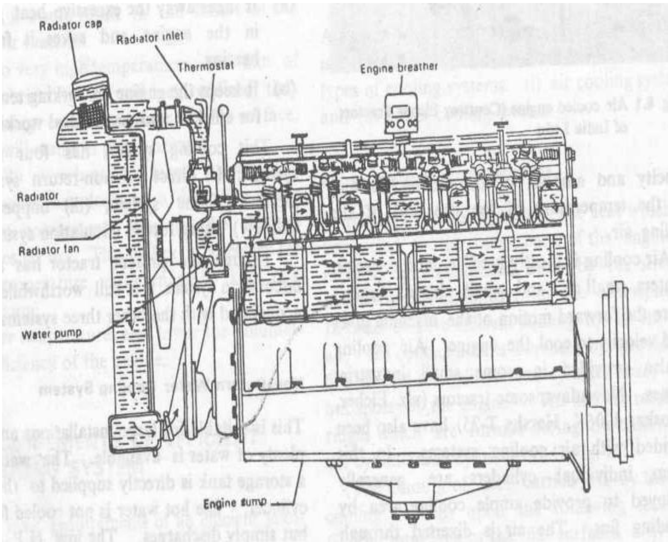

Fig -5 Water Cooling System

3. Hopper Water Cooling System:

The working principle of this system is same as the thermo-syphon system. In this system the water is contained in a jacket of Hooper, which surrounds the engine cylinder. In this system, cold water being replaced as soon as water starts boiling. An engine fitted with this system cannot run for several hours without it being refilled with water.

4. Force Circulation Water Cooling System:
This construction of this system is similar to the thermo-syphon system except that it makes use of a centrifugal pump which is used to circulate the water throughout the water jackets and radiator. The water flows to the water jacket of the engine from the lower portion of the radiator through the centrifugal pump. After the circulation water comes back to the radiator, it loses its heat by the process of radiation. This system is employed in cars, trucks, tractors, etc.

2.3.1 Parts of Liquid Cooling System

The main parts in the water-cooling system are,

- Water pump.
- Fan.
- Radiator and pressure cap.
- Fan belt.
- Water jacket.
- Thermostat valve.
- Temperature gauge and
- Hose pipes.

1. Water Pump:

This is a centrifugal type of pump which is centrally mounted at the front of the cylinder block and it is usually belt driven. This type of pump consists of parts such as body or casing, impeller, shaft, bearings, or bush, water pump seal and pulley. The suction side of the pump is connected to The bottom of the radiator. The power is transmitted to the pump spindle from a pulley mounted at the end of the crankshaft. Seals of various designs are used in the pump to prevent loss of coolant.

2. Fan:

The fan is often mounted on the water pump pulley. It has two purposes in the cooling system of an engine. (1) It draws atmospheric air through the radiator and eventually increases the efficiency of the radiator by cooling hot water. (2) It blows fresh air over the outer surface of the engine, which absorbs heat conducted by the engine parts and increases the efficiency of the cooling system.

3. Radiator:

The function of the radiator is to reduce the temperature of the water received from the engine. There are three main parts of radiator: (i) upper tank, (ii) lower tank and (iii) tubes. Hot water from the upper tank, which comes from the engine, flows downwards through the tubes. The heat present in the hot water is passed to the copper fins provided around the tubes. An overflow pipe, connected to the upper1 tank, permits excess water or steam to escape.

There are three types of radiators:

(i) Gilled tube radiator.
(ii) Tubular radiator (Fig. b) and
(iii) Honey comb or cellular radiator (Fig. c)

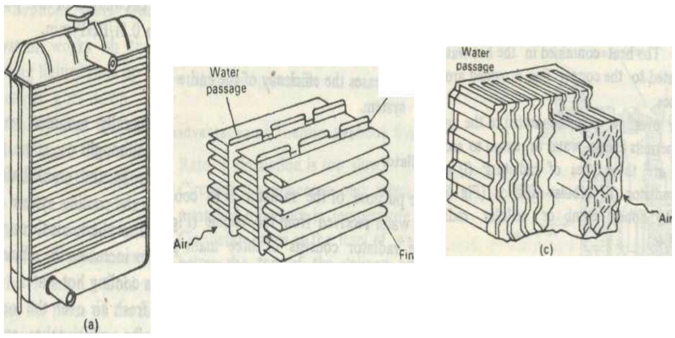

Fig -6 Various Types of Radiator

i. Gilled tube radiator:

This is perhaps the oldest type of radiator, although it is still in use. In this, water flows inside the tubes. Each tube has a large number of annular rings or fins pressed firmly over its outside surface.

ii. Tubular radiator:

The major difference between a gilled tubes radiator and a tubular radiator is that in tubular one there are no separate fins for individual tubes. The radiator vertical tubes pass through thin copper sheets which runs horizontally.

iii. Honey comb or cellular radiator:

It consists of a large number of separate air cells which are surrounded by water. The clogging of any passage affects only a part of the cooling surface. In the tubular radiator, if one of the tube is clogged then cooling effect of the entire tube is lost.

4. Thermostat valve:

It is a type of check valve which opens and closes with the change in temperature. When the normal operating temperature is reached, the thermostat valve opens and allows hot water to flow towards the radiator (Fig. 8.5a). Standard thermostats are designed to start opening at 70 to 75°C and they fully open at 82°C. High temperature thermostats, with permanent anti-freeze solutions (Pristine, Zerex, etc.), start opening at 80 to 90°C and fully open at 92°C.
The three types of thermostats are bellow type, bimetallic type and pellet type. Bellow type valve which consists of flexible bellows that are filled with alcohol or ether. When the bellows is heated, the liquid vaporizes, creating enough pressure to expand the bellows. When the unit is cooled, the gas condenses. The pressure reduces and the bellows collapse to close the valve. A coil spring closes the valve when the pellet contracts.

2.4 NANO-FLUIDS AS COOLANT IN AUTOMOBILE RADIATOR

Nano fluids helps to improve automotive and heavy-duty engine cooling performance by enhancing the efficiency, reducing the weight and reducing the convolution of thermal management systems. The enhanced cooling rates for automotive and truck engines can be utilized to remove more heat from higher horsepower engines.
But According to researchers following are the Challenges to use Nano fluids as a coolant in Automobile Radiator:

1. Stability of nanoparticles dispersion-

Homogeneous suspension preparation remains a technical challenge because the nanoparticles form aggregates due to strong van der Waals interactions. For stable Nano fluids, physical or chemical treatments are used such as an addition of surfactant, applying strong force on the clusters of the suspended particles or surface modification of the slinged particles.

2. Increased pressure drop and pumping power-

The efficiency of Nano fluids application is defined by the pressure drop developed during the flow of coolant which is one of the important parameter. Coolant pumping power and pressure drop are closely analogous with each other. There are few properties which could affects the coolant viscosity, pressure drop, density. It is expected that coolants with higher viscosity and density experience higher pressure drop. This has granted to the disadvantages of Nano fluids application as coolant liquids.

3. High cost of Nano fluids-

Higher production cost of Nano fluids is one of the reasons that may baffle the application of Nano fluids in various industries. There are two methods to produce Nano fluids either by one step or two steps methods. But both methods require advanced equipment's. Hence it is not a cost effective method to use Nano fluid as a coolant in Radiator.

4. Difficulties in production process-

Above discussed endeavors to manufacture Nano fluids have frequently produced by either single step method that simultaneously makes and disperses the nanoparticles into base fluids, or a two-step method which involves producing nanoparticles and subsequently dispersing them into a base fluid. Using either of these two approaches, nanoparticles are produced from approaches that includes either iron exchange or by using reduction reactions. Furthermore, it is difficult or impossible to separate the base fluids which contains various ions and reaction products that are difficult to separate from the fluids.

3. CONCLUSION

After studying various research papers related to the radiator and vortex tube we can conclude that the cold stream output of the vortex tube can be utilized for optimum cooling of the radiator coolant and hence the engine of an automobile.
Nano fluids have been widely used to achieve better performance of the radiator but it is very difficult to manufacture the nanoparticles of the Nano fluids and it strictly requires an expertise in the field of nanotechnology. For this purpose, a vortex tube can serve as a better alternative as it is a simple, reliable and effective device with less or none maintenance due to the lack of any moving parts.

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