

Analysis of Temperature Decrement of Engine Coolant by Utilizing Vortex Tube in Automotive Radiator

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Abstract: Overheating of the bus engine is a major problem especially in summer which affects the performance of the bus engine and radiator. In some cases, the excessive heating of the engine can also damage the radiator coils of the bus which decrease its life span. The radiator fan alone is not capable to efficiently dissipate the high temperatures. Possibilities for integration of vortex tube with automotive radiator for more effective cooling of automotive engine is the aim of this research. 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. The vortex tube is utilized as a heat exchanger to precool the engine coolant before supplied to the radiator.

Keywords: Radiator, Heat exchanger, Vortex tube, Engine cooling, Overheating.

I. Introduction

I.1 Introduction To Vortex Tube

Ranque–Hilsch vortex tube is a simple mechanical device with no moving parts which generates cold and hot air/gas streams simultaneously by using compressed air/gas 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 is supplied into the vortex tube tangentially. Due to tangential entrance of compressed air, 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. Vortex tube can be used as a refrigerating device, and it is also used for spot cooling applications in industry. Since then vortex tube is recognized as the “Ranque Vortex Tube”, Because of its low maintenance and manufacturing cost, vortex tube is widely used in industrial applications.

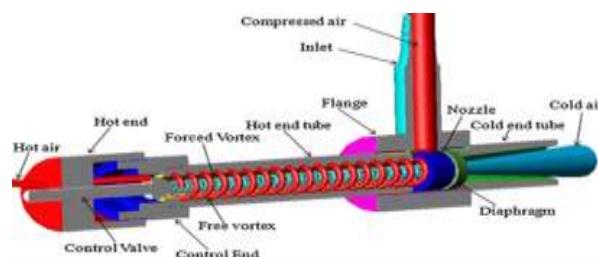


Fig 1: Vortex Tube.

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 part of nozzle and which gives 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.

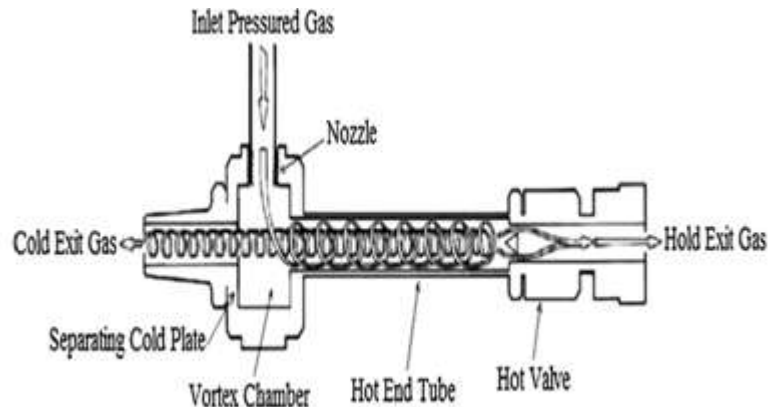


Fig2: Components of vortex tube

.3 Working of A Vortex Tube

Compressed air gas is inducted through the tangential nozzle. Due to the tangential shape of the nozzle the 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 generates heat by absorbing it and leaves the vortex tube through hot end 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.

II. 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 consists of end caps on the sides, which lowers 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.

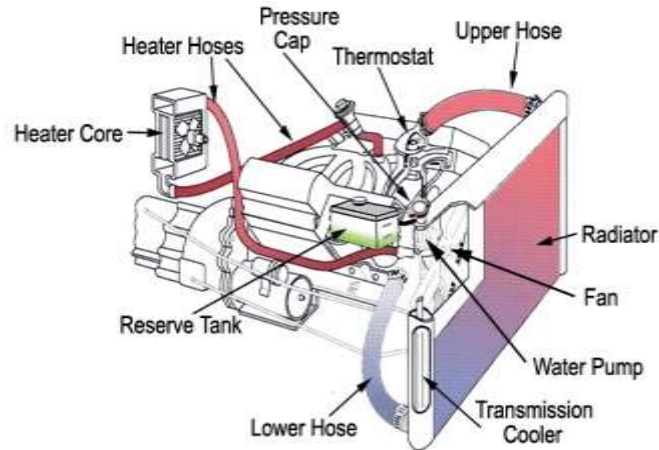


Fig3: Automobile Cooling System

III. Experimental Setup

Vortex tube is used to precool the coolant which comes from the engine. Thus vortex tube is situated before the inlet of radiator. Hence the temperature of the coolant is reduced before supplied to the radiator. The temperature of coolant is too high due to absorbed heat of engine this coolant is then passed to the engine radiator. There is an engine driven compressor which supplied the compressed air at 6 bar and at atmospheric temperature to the storage tank. This compressed air is then supplied to the Vortex tube where it converts into hot air and cold air. The thermostat is placed between the Vortex tube and radiator which has inlet from engine coolant and Vortex tube. Thermostat is preset to a temperature of 65 degrees. As soon as temperature increases 65degree the thermostat allows the flow of cold air from Vortex tube to radiator and thereby reduction in temperature is achieved. The working principle is represented in following figure-

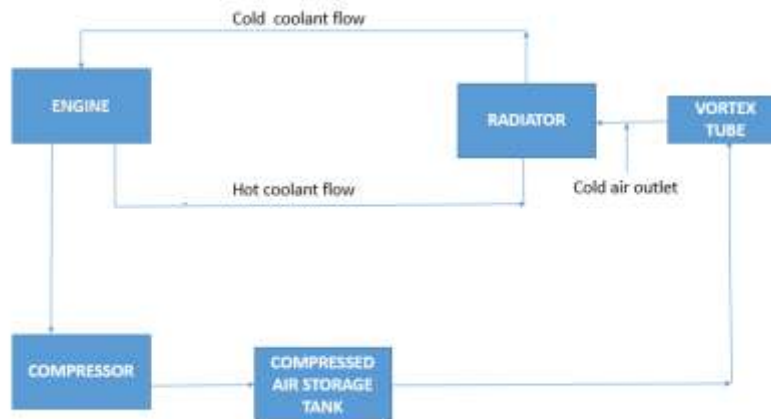


Fig4: System Experimental setup

IV. Experimental Work

The Required results can be analyzed and compared by performing the CFD analysis. The first step is to make solid model of a hollow tube through which the coolant will pass shown in fig. Then to give the input to a particular area the domains are specified as shown in fig.6, So that temperature of coolant at inlet/hot inlet temperature can be mentioned to obtain required temperature at hot outlet. The material of the tube can be change by specifying its domain. To make vortex tube as a heat exchanger, instead of modelling outer tube to the inner tube the whole surrounding is kept at the temperature equal to temperature of cold air from Vortex tube as shown in fig.7. The number of iterations are performed to get the desired output by specified input. The graph of iterations performed is shown if fig.5



Fig5: Tube after meshing

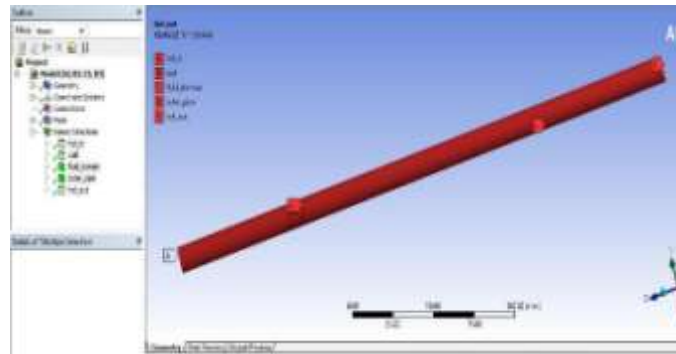


Fig6: Introduction of all domain

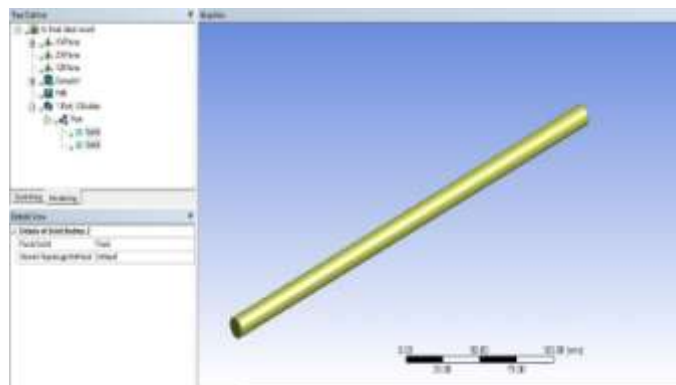


Fig7: Vortex tube with surrounding as a cold inlet

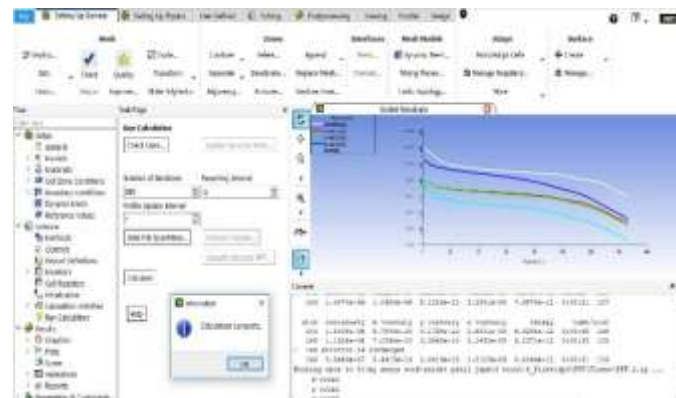


Fig8: Number of iterations performed

V. Numerical Analysis

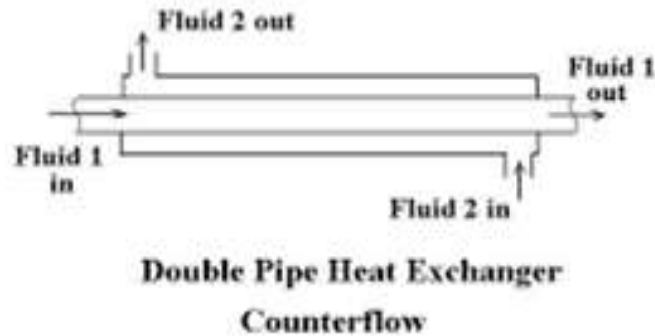


Fig9: Double Pipe Heat Exchanger

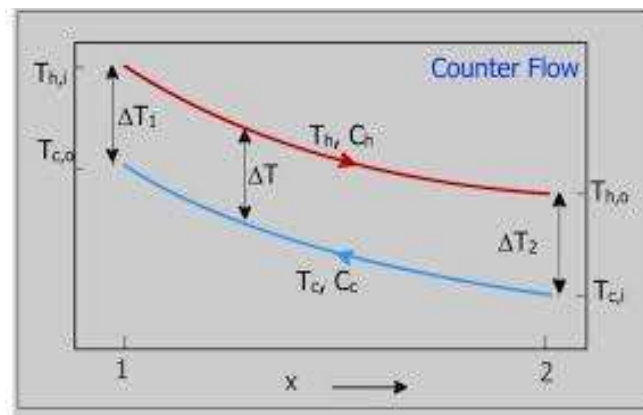


Fig10: Flow of fluids in counter flow heat exchanger

❖ Without vortex tube

$$T_{h1} = 60 \text{ } ^\circ\text{C}$$

$$T_{c1} = 30 \text{ } ^\circ\text{C}$$

$$C_{ph} = 4.187 \text{ KJ/kg} = 4187 \text{ J/kg}$$

$$C_{pc} = 1.005 \text{ KJ/kg} = 1005 \text{ J/kg}$$

$$m_h = 3 \text{ lit/min} = 0.01 \text{ kg/s}$$

$$m_c = 3.8 \cdot 10^{-3} \text{ kg/s}$$

$$\begin{aligned} C_h &= m_h \cdot C_{ph} \\ &= 0.01 \cdot 4187 \\ C_h &= \underline{41.87 \text{ W}} \end{aligned}$$

$$\begin{aligned} C_c &= m_c \cdot C_{pc} \\ &= 3.8 \cdot 10^{-3} \cdot 1005 \\ C_c &= \underline{3.819 \text{ W}} \end{aligned}$$

$$\begin{aligned} NTU &= UA / C_{\min} \\ &= (500 \cdot 3.76 \cdot 10^{-3}) / 3.819 \\ NTU &= \underline{0.6} \end{aligned}$$

$$C_{\min} / C_{\max} = 3.819 / 41.87 = \underline{0.0912}$$

$$\begin{aligned} \xi &= C_h (T_{h1} - T_{h2}) / C_{\min} (T_{h1} - T_{c1}) \\ 0.7 &= 41.87 (60 - T_{h2}) / 3.819 (60 - 10) \\ T_{h2} &= \underline{58.0845 \text{ } ^\circ\text{C}} \quad (331.0845\text{K}) \end{aligned}$$

❖ **With vortex tube**

$$T_{h1} = 60 \text{ }^\circ\text{C}$$

$$T_{c1} = 10 \text{ }^\circ\text{C}$$

$$C_{p_h} = 4.187 \text{ KJ/kg} = 4187 \text{ J/kg}$$

$$C_{p_c} = 1.005 \text{ KJ/kg} = 1005 \text{ J/kg}$$

$$m_h = 3 \text{ lit/min} = 0.01 \text{ kg/s}$$

$$m_c = 3.8 \times 10^{-3} \text{ kg/s}$$

$$C_h = m_h \cdot C_{p_h}$$
$$= 0.01 \cdot 4187$$

$$C_h = \underline{41.87 \text{ W}}$$

$$C_c = m_c \cdot C_{p_c}$$
$$= 3.8 \times 10^{-3} \cdot 1005$$

$$C_c = \underline{3.819 \text{ W}}$$

$$NTU = UA/C_{\min}$$
$$= (500 \cdot 3.76 \cdot 10^{-3}) / 3.819$$

$$NTU = \underline{0.6}$$

$$C_{\min} / C_{\max} = 3.819 / 41.87 = \underline{0.0912}$$

$$\xi = C_h(T_{h1} - T_{h2}) / C_{\min}(T_{h1} - T_{c1})$$
$$0.7 = 41.87(60 - T_{h2}) / 3.819(60 - 10)$$
$$T_{h2} = \underline{56.80 \text{ }^\circ\text{C} (329.80\text{K})}$$

VI. Results And Discussion

After the mathematical analysis and the CFD validation it can be seen that the temperature drop varies with the change in working parameters such as hot inlet temperature, cold inlet temperature, Mass flow rate, Diameter of vortex tube, length of vortex tube. Hence the optimum parameters should have selected for better performance which are given below-

- a) Hot inlet temperature - 333 K (60 °C)
- b) Mass flow rate – 0.01 kg/s
- c) Diameter – OD=12 mm ID=10 mm
- d) Length – 300 mm
- e) Hot outlet temperature (with vortex tube) – 329.80K (56.80 °C)
- f) Hot outlet temperature (without vortex tube) – 331.0845K (58.0845 °C)
- g) Obtained temperature drop (with vortex tube) – 282 K (6 °C)
- h) Obtained temperature drop (without vortex tube) – 277 K (4 °C)

VII. Future Scope

As the vortex tube is a non-conventional device, it has a vast and promising scope in future. It has various industrial as well as non-industrial applications.

- Various types are available in vortex tube which can be used to achieve the desired results in radiator system,
- The hot outlet of the vortex tube can be used for required heating operations within the system under work.
- Several modifications can be done in the system for it to work better with the vortex tube arrangement.

VIII. Conclusion

A sequence of experiments are performed in order to investigate the performance of the vortex tube under several design parameters mainly - (1) inlet pressure, (2) tube length, (3) tube diameter and (4) mass flow rate of coolant. The following conclusions are made from these analysis work :-

1. For the temperature separation the inlet pressure is an important driving force. Experimental study show that the greater temperature difference of the outlet streams is obtained until specific value is reached.
2. The length of the tube, diameter of the tube, mass flow rate, number of nozzles required affects the performance of the vortex tube, hence the optimum performance of the vortex tube is obtained by optimum selection of these parameters. Thereby achieving the effective cooling of the engine coolant.
3. Experimental study shows that when vortex tube is not used temperature drop obtained is 2 where as temperature drop by utilizing vortex tube is 4 which is greater and will give more cooling effect.

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