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# DESIGN AND ANALYSIS OF COUNTER FLOW VORTEX TUBE

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**Abstract -** *Vortex tube is a mechanical device, without any moving parts. It separates the compressed air stream in to a low temperature flow and a high temperature flow, such separation of flow in two regions low side and high side is known as the temperature or energy separation effect. Vortex tube has many applications, for example, electronic systems cooling, machining processes cooling, in aviation and environmental chambers. This paper presents the design, analysis and modifications of parametric design based on parameters and data found in the literature. This paper describes the experimental study of the temperature separation phenomenon in a vortex tube. Effects of (1) using insulation on tube, (2) the cold and hot orifice diameter, (3) tube length, (4) using different material, and (5) Surface roughness on the temperature reduction of the tube were experimentally investigated.*

***Key Words***: Vortex Tube, design, analysis, temperature, energy separation effect

## 1. INTRODUCTION

The Vortex Tube (VT) is a device that generates cold and hot air from compressed air. It was invented by Georges J. Ranque in 1933[1]. The German engineer Rudolf Hilsch suggested the working vortex tube design in 1947 [2]. It is a simple device having low cost, with no moving parts, no electricity and there is a possibility to adjust the temperature [3,4]. The main drawbacks are its low thermal efficiency, the noise and the availability of compressed air. Vortex Tube is commonly used in aviation, space/mining suits cooling, spot cooling, when compressed air is available, like cutting tools of CNC machines, laboratory equipment, etc. Compressed air is sent through the tangential inlet nozzle so that the vortex motion can be created inside the tube, fig. 1.

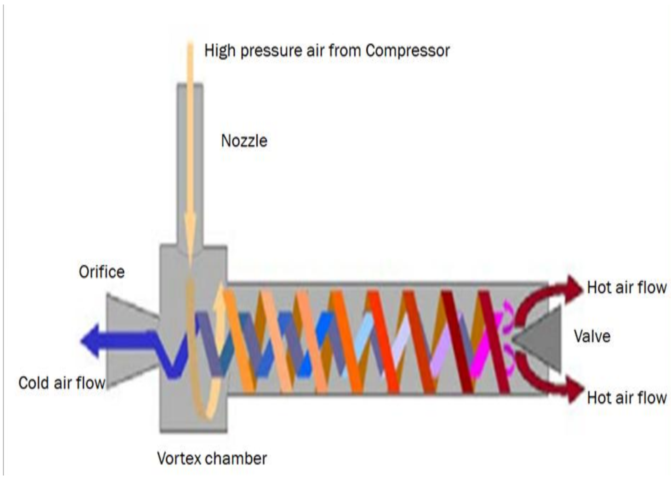


**Fig -1:**Vortex Tube Block Diagram

## 2. WORKING PRINCIPAL

Compressed air is passed through the nozzle as shown in previous image. Then air expands through the nozzle and acquires high velocity and swirl motion is created in vortex chamber. Then due to its design, the air moves towards the partly closed valve end. As it reaches the valve, the Kinetic Energy is converted into the pressure energy and state of stagnation is reached. But the stagnation pressure is higher as compared to the pressure at left side; therefore the reversal in flow takes place. During this process, heat is transferred from reversed stream to forward stream. Therefore, reversed air stream gets cooled below the inlet temperature of the air, while forward air stream gets heated up. The cold stream escapes through the back side orifice, while hot stream is passed through the opening of the valve. By controlling the opening and closing of the valve, the quantity of the air and its temperature can be varied.[3]

## 3. LITERATURE REVIEW

The Vortex Tube can be used in a temperature control work and is very effective and economical where the compressed air is readily available [1]. There is no better advantage of this where the characteristics like low weight, combination of cooler and heater are desired and the compressed air which is the only main cost present with it. Refrigeration plays a major role in developing the countries, generally it is preferred for food preservation, also for providing the comfortable environment especially it is used for air conditioning. It plays a vital role in storage of ice, blood, medicines, preservation of photographic films, archaeological documents etc. by using Freon or R134a R-11 to R-50 as a refrigerant, which are the main sources of the ozone layer depletion. After a very long time an extensive research is carried out for an alternative refrigeration system. The vortex tube is found to be an excellent solution or alternate solution for refrigeration system.[2] The vortex tube performance mainly depends on following parameters, firstly air or working parameters such as inlet pressure of compressed air and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, valve angle and also material of vortex tube affects Coefficient of Performance (COP).[3,4] UV Kongre et al analyzed the vortex tube model in Ansys software. In their work, the design and transient thermal analysis were done by using ansys. Ansys gives much better approximation of experimental data to modeling data. Also different materials were tested for their utility for vortex tube manufacturing sustainable for further future development.[3] MV Dudhe et al experimented results of the energy separation in vortex tubes for different nozzle diameters keeping the rest geometrical parameters constant. It is experimentally manifested that the nozzle diameter greatly affects the separation performance and efficiency. The most important point revealed in this paper is that there is an optimum nozzle diameter that gives the best performance of vortex tube. An experimental investigation has been performed to realize the thorough behavior of a vortex tube cooling system. The counter flow vortex tube has been designed, manufactured and tested.[4]

## 4. DESIGN

3D parts are designed in CAD Software. We used Solidworks Premium 2020 because it is the most popular CAD software right now which gives better results than other CAD software.

Following dimensions are used-

Hot tube length- 100mm
Hot tube outer and inner diameter- 15mm and 12mm respectively
Generator diameter inner and outer- 20mm and 25mm
Nozzle diameter- 5mm
Cold tube diameter- 10mm
Valve diameter- 10mm
Full length- 134mm

After the modeling of each part, they were transferred to the assembly window and all the parts were assembled.

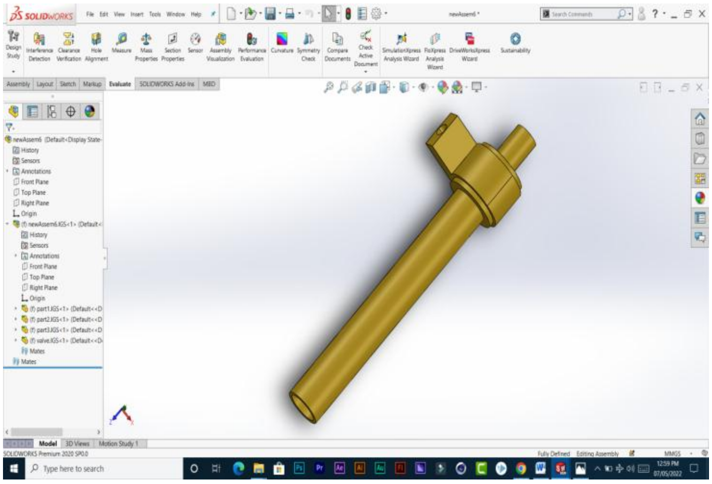

**Fig -2:** Assembled model in Solidworks

## 5. ANALYSIS IN ASNSYS

After the assembly of model it was exported in IGS(Initial graphics exchange specification) file format. It was done to import it in other CAD/CAE softwares. Then the IGS file was imported in Ansys workbench software. We used Ansys workbench 17.0 version.

For this we used Fluent flow analysis system.

## 5.1 EXTRACTED FLUID DOMAIN

After our geometry imported in design modeller window, we used Fill cavity method, After the fill cavity method, we got our fluid body. The following picture(Fig.3) is the fluid domain of our geometry.

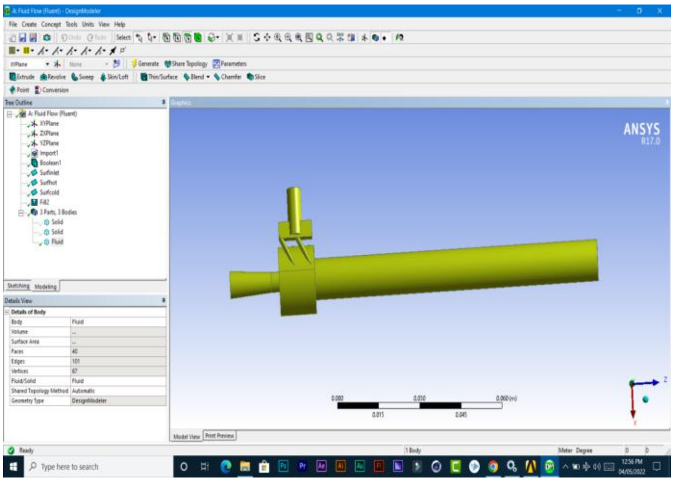


**Fig -3:** Extracted fluid domain model

## 5.2 MESHING

Then we updated the geometry and moved into Meshing window. We used tetrahedron meshing method.

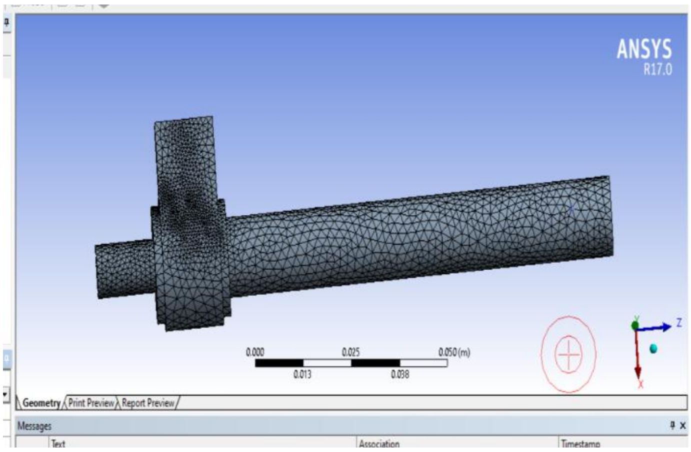


**Fig -4:** Meshing model

### 5.3 FLUENT SOLVER

After the successful meshing we updated our geometry and moved into Fluent Solver window. Then we checked the Energy equation for temperature measurements. We are using turbulent flow, that's why we used K-epsilon model and checked viscous heating for proper vortex flow as shown in Fig.5.

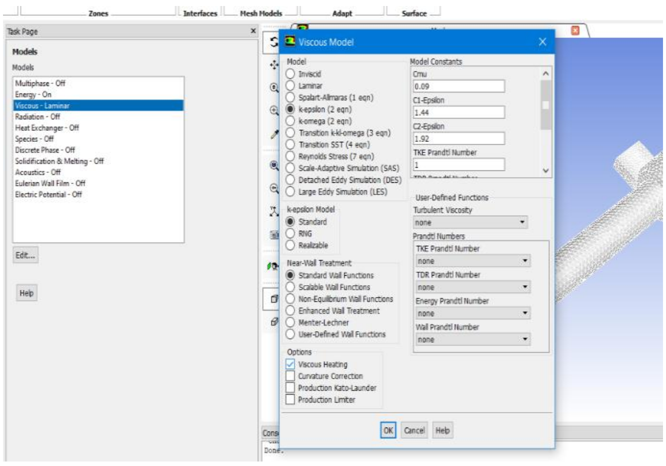

**Fig -5:** Setup in Fluent Solver

### 5.4 BOUNDARY CONDITIONS

| NAMED SELECTIONS | CONDITIONS |
|---|---|
| Inlet | Pressure – 4 bar<br>Velocity - 0.1 m/s<br>Temperature – 295k |
| Hot outlet | Guage Pressure – 0 bar<br>Rest default |
| Cold outlet | Guage Pressure – 0 bar<br>Rest default |
| Wall | Stationary wall<br>No slip<br>Roughness 0<br>Material name - Steel |

## 6. RESULT

### 6.1 STEEL MATERIAL WITH ORIGINAL DIMENSIONS

Cellzone conditions and boundary conditions were applied as shown previous..

Max Temperature obtained – 316k
Min Temperature obtained – 280k

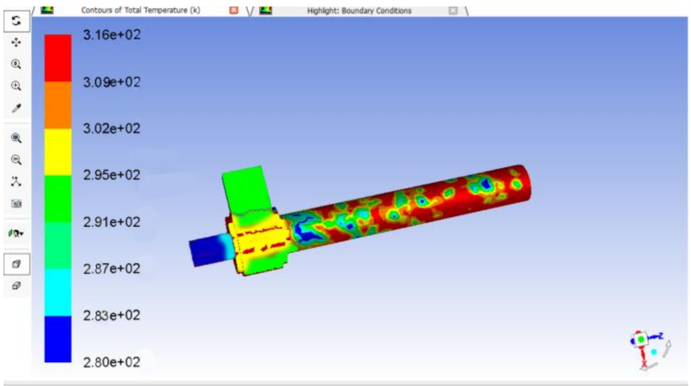


**Fig -6:** Result 1(Steel material)

### 6.2 STEEL MATERIAL AND LENGTH INCREASED BY 40mm

Now the length is increased by 40mm, therefore the hot tube length which was previously 100mm, now became 140mm.

Max Temperature obtained – 322k
Min Temperature obtained – 270k

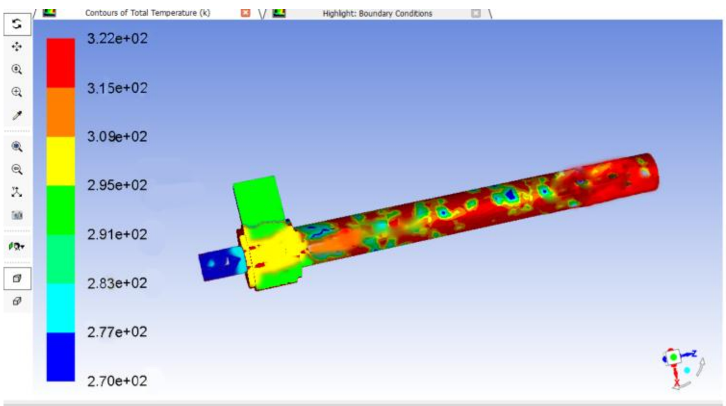


**Fig -7:** Result 2(Length increased)

### 6.3 COPPER MATERIAL WITH ORIGINAL DIMENSIONS

Now copper material was defined when applying cellzone conditions.

Max Temperature obtained – 320k
Min Temperature obtained – 270k

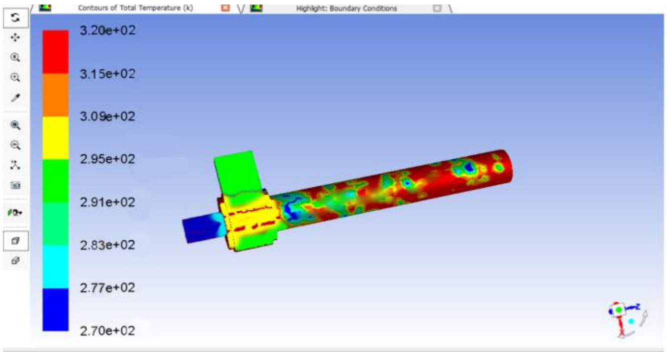


**Fig -8:** Result 3(Copper material)

## 6.4 GLASS WOOL INSULATION

Glass wool insulation of 8mm thickness used.

Max Temperature obtained – 322k
Min Temperature obtained – 268k

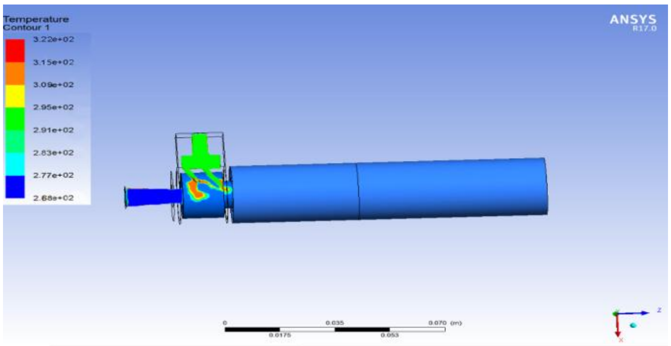


**Fig -9:** Result 4(Insulation)

## 6.5 SURFACE ROUGHNESS WITH ORIGINAL DIMENSIONS

Surface roughness of 0.1 RA(roughness average) defined inside the tube inner section.

Max Temperature obtained – 323k
Min Temperature obtained – 274k

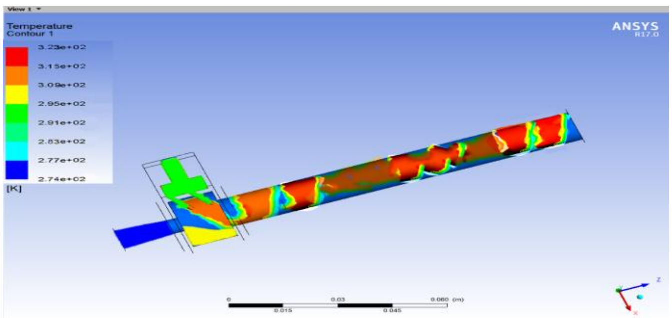


**Fig -10:** Result 5(Surface roughness)

## 7. CONCLUSION

In our work we found that pressure is directly proportional to the efficiency. Higher the pressure, higher is the difference of hot flow and cold flow. We have used 4 bar pressure in all the experiments. Generally 2 to 7 bar of compressed air is used based on the design of the tube. Some high grade industrial vortex tube can even sustain the pressure of 12 to 15 bar.

From the above experiment , we have discovered that copper gives better result compared to steel due to copper conductivity is higher than steel.

Effect of tube length is also directly proportional to efficiency but it is limited to some degree, as larger tube length results in moist air at the end of outlets.

Effect of insulation is as expected, insulation decrease temperature drop from tube wall to surroundings and efficiency obtained is better.

Some value of roughness inside the tube gave better result as compared to smooth surface finish. The reason is that heat transfer increases due to the effect of increase in the contact area.

If more than one inlets are used, then the resulting efficiency achieved will be higher as more amount of high pressurized air enters into the chamber.

Nozzle diameter should be balanced to achieve proper tangential motion. Generally small diameter is always desirable to avoid pressure loss but also not too small which hinders the proper tangential flow.

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