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Analysis of the effect of geometry of vortex tube on cold side and hot side air stream temperatures

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ABSTRACT

Vortex tube generates hot and cold streams from the compressed air, without any moving part or chemical reaction. In this paper, the performance of a vortex tube is first determined experimentally, for an L/D ratio of 5, and is simulated in CFD package. CFD analysis is then carried out for various L/D ratios (8, 9 and 10) of vortex tube, and the temperature variations are determined. The results are compared and the effect of L/D ratio on vortex tube is studied.

KEY WORDS: Vortex Tube, CFD, CFD Analysis, Effect of L/D ratio.

1. INTRODUCTION

Vortex tube is a device that generates cooling effect at one side and heating effect at the other side simultaneously, when compressed air is allowed inside. It has no moving parts or chemical reactions. This phenomenon was first invented by Georges J. Ranque in 1933 and improved by Rudolf Hilsch in 1947. The applications of vortex tube can be found in industrial spot cooling systems, refrigeration system, air cooling systems, heating, dehumidification, foodstuffs cooling, weld cooling etc.

Vortex tube generally consists of chamber, nozzle, diaphragm, valve, hot air side and cold air side, as shown in the figure (Figure 1). There is no other part inside the chamber; the fluid dynamic or thermodynamic effects, therefore, makes the temperature difference. When compressed air is passed through a nozzle, pressure energy of compressed air is converted into kinetic energy. Air, at high velocity, enters the chamber tangentially, causing a vortex flow or centrifugal spin along the inner wall of the chamber. Part of the hot and high velocity air flows to hot air side through the control valve. The remainder of this air flows back through high velocity air stream, giving up heat, to the cold air side. The quantity of cold air and the temperature difference can be varied by adjusting the valve opening.

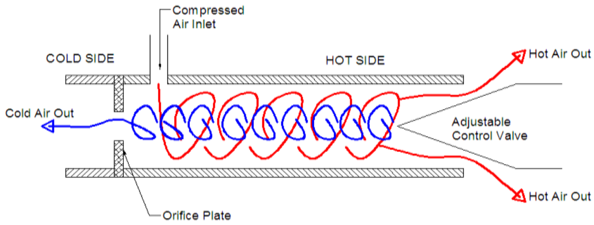

Figure.1. Schematic diagram of a vortex tube

2. METHODOLOGY

An experimental set-up is made to understand the effect of L/D ratio on the separation of the hot and cold air from the compressed air. The set-up consists of a vortex tube, compressor unit and thermocouple, as shown in the figure (Figure 2) below.

Figure.2. Experimental set-up

The vortex tube used in the experimental set-up and its dimensions are shown in the figures (Figure 3, 4) below.

Figure.3. Vertex tube used in the experimental set-up

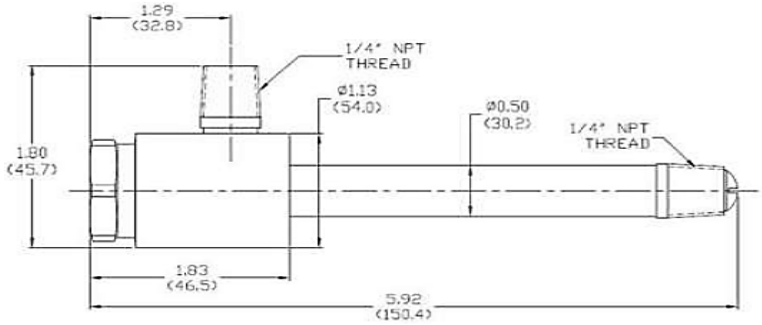

Figure.4. Geometry of vortex tube used in the experimental set-up

Vortex tube nozzle is connected to the compressor through an FRL unit, where the pressure can be adjusted. Thermocouple is connected to both hot and cold side streams. In this work, the temperature readings of cold and hot sides are observed by varying pressure values from 1 bar to 5 bar.

After the experimental readings are observed for the vortex tube (Figure 4), it is modeled and analyzed using CFD package. The 3D CAD model of vortex tube is modeled in Solidworks and the model is shown in the figure (Figure 5) and the mesh is generated using GAMBIT package (Figure 6). The CFD analysis is then conducted in ANSYS-Fluent package. The package uses axi-symmetric swirl, time unsteady k-turbulence model. Air is selected as the working medium with the following properties: viscosity 1.7894x10^{-5} kg/ms, density 1.225 kg/m^3, thermal conductivity 0.0242 W/mK and specific heat 1.0064 kJ/kgK. The inlet boundary conditions are set as follows: mass flow rate 0.006 kg/s, axial, radial and tangential component of flow direction 0.8, 0.31 and 0.5 respectively and turbulence kinetic energy 1 m/s. Turbulent and energy equations are used to solve. The obtained values (Figure 7) are validated with the observed experimental values. The analysis is extended for different L/D ratios and the results are discussed in the next section.

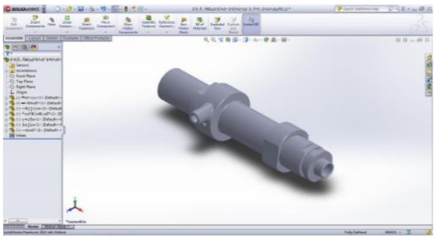

Figure.5. CAD model of vortex tube generated in Solidworks

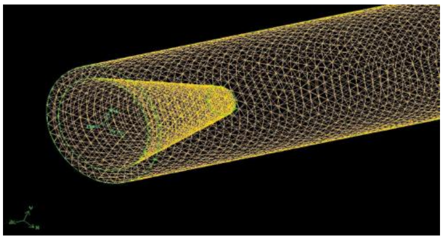

Figure.6. Mesh generation in GAMBIT

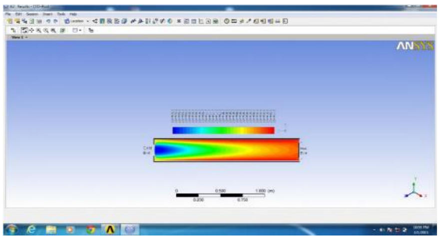

Figure.7. CFD solution of the vortex tube

3. RESULTS & DISCUSSION

The experimental observations of vortex tube were first noted for L/D ratio of 5. The readings were obtained by varying the pressure of compressed air. The readings are tabulated (Table 1) below.

Table 1: Experimental readings of L/D ratio 5

Pressure (Bar)	Cold side air temperature (°C)	Hot side air temperature (°C)	Temperature difference (°C)
1	24	61	37
2	14	64	50
3	12	75	63
4	10	78	68
5	7	81	74

From the experimental results, it is understood that when the pressure increases, the temperature at the cold side reduces. For example, in the table (Table 1), the cold side temperature is lesser for the pressure of 5 bar than that of the pressure of 4 bar. For L/D ratio of 5, the coldest temperature is 7°C, hottest temperature is 81°C and the corresponding pressure is 5 bar. This pressure is considered for further processing in CFD package.

The CAD model of vortex tube (Figure 3) was modeled; grid generated and is analyzed in ANSYS-Fluent package for L/D ratio of 5, and for 5 bar pressure. The result obtained from ANSYS-Fluent is shown in the figure below (Figure 8).

The coldest and hottest temperature values, from the results, are 280 K (7 ºC) and 354 K (81 ºC). The obtained values were compared with the experimental values. The experimental and CFD results seem to be approximately same. Thus, the CFD model is validated for L/D ratio of 5, and can effectively be used for other L/D ratios.

The CAD models were then prepared with L/D ratios of 8, 9 and 10. The temperature values at hot and cold sides are determined in CFD package and the results are shown in the following figures (Figure 9, 10, 11). The CFD values are tabulated (Table 2).

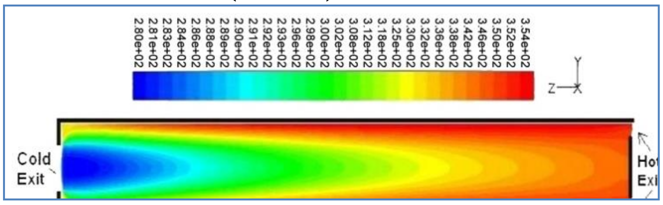

Figure.8. Temperature variations of hot and cold stream obtained from CFD package

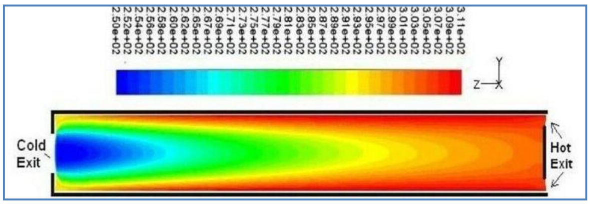

Figure.9. Temperature variations of vortex tube of L/D ratio of 8

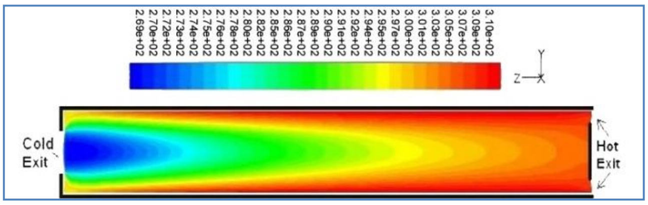

Figure.10. Temperature variations of vortex tube of L/D ratio of 9

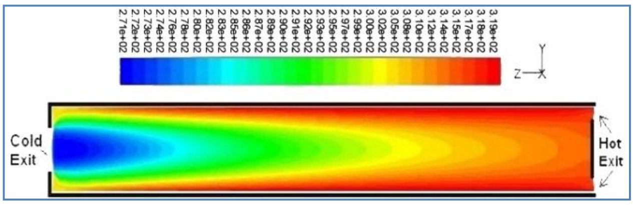

Figure.11. Temperature variations of vortex tube of L/D ratio of 10

Table.2.CFD simulated temperature values for different L/D ratios

L/D Ratio	Length	Diameter	Cold Side Air Temperature (K)	Hot Side Air Temperature (K)	Temperature Difference
8	160	20	250	311	61
9	135	15	269	310	41
10	200	20	271	319	48

It is found, from the table (Table 2), that the when L/D ratio increases the cold and hot temperature values increases, thus the cooling effect decreases. Therefore, it is wise to use L/D ratio as less as possible to obtain the better cooling effects from a vortex tube.

4. CONCLUSION

The effect of various L/D ratios on the cooling performance, when the compressed air passed into the vortex tube through a nozzle, was discussed in this research work. A vortex tube, of L/D ratio of 5, was first determined experimentally; the same was simulated in CFD package and the results were validated. The work was then extended to different L/D ratios (8, 9 and 10), and the results were obtained from CFD package. It is observed from the results that L/D of 8 gives better cooling temperature of about 250 K compared to that of other L/D ratios (9 and 10). Therefore, it is concluded that it is wiser to use low L/D ratio to obtain maximum cooling effect from a vortex tube.

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