An Experimental Modeling And Investigations Of Vortex Tube Using UPVC Material

Sagar N. Jadhav, Vishal D. Wagh, Mahesh N. Patil, Balaji V. Kawale, P.P. Patunkar

Department of Mechanical Engineering, Sinhgad Institute of Technology and Sciences, Pune, India 411041
Email: koolshaggy20@gmail.com, vishal.wagh.1234@gmail.com, vmaheshpatil222@gmail.com, pppatunkar_sits@sinhgad.edu

ABSTRACT: An experimental investigation has been done to vortex tube refrigeration set-up. The vortex tube is counter flow type which is being designed and fabricated. Vortex tube is a simple mechanical device used for the refrigeration as well as heating purpose. It uses a compressed gas which is being segregated into two streams of hot gas and cold gas at opposite ends. Here air is used as a working fluid. Various parameters affect the performance of Ranque-Hilsch vortex tube (RHVT). These parameters can be classified into two types viz. working parameters and geometrical parameters. The working parameters include inlet pressure of compressed air, cold mass fraction, ambient air temperature while the geometrical parameters includes diameters of nozzle, hot side and cold side, lengths of hot side and cold side, conical angle of valve. The effect of mentioned parameters is being discussed in this paper. UPVC (unplasticised polyvinyl chloride) material is being used as piping material since it has a very low thermal conductivity. The performance of vortex tube is being studied and investigated in this paper.

Keywords : Ranque-Hilsch vortex tube; Design-Fabrication; UPVC; Performance investigation

1 INTRODUCTION

Vortex tube was invented by French physicist G.J. Ranque in 1931 [1]. But due to its inefficiency the patent and idea was rejected and it was highly unpopular. Later in 1947, German engineer R Hilsch modified the design [2]. Henceforth, there had been a lot of research on the energy separation process of the vortex tube but there was no concordance [3]. Vortex tube is a simple mechanical device used for separating a compressed fluid generally air into streams of hot and cold air respectively. Air is commonly used fluid in the vortex tube but it can employ other gases as well. In this analysis air is considered as working fluid. Inlet nozzles are located near the cold end side while hot end is located from the inlet nozzles. An orifice plate is located near the cold end to restrict the flow towards hot direction only. At the hot end of the tube the conical valve is provided to limit the amount of air to be sent to the atmosphere. This conical valve is adjustable. Compressed air is injected tangentially into tube through the nozzles and air is subjected to whirling action creating free vortex due to the periphery of the tube. Since an orifice plate is provided near the cold side of the tube and concentric to hot tube, air is forced to move towards hot side of the tube which partly escapes due to the conical valve while remaining air strikes the valve and returns towards the cold end in linear way [4]. During this process, the central stream loses its energy to the peripheral stream. This phenomenon along with pipe friction is responsible for getting the cold air stream at cold side. The temperature at the hot end can be adjusted by varying the position of the conical valve. The figure 1 reveals the working principle of the Vortex tube [5].

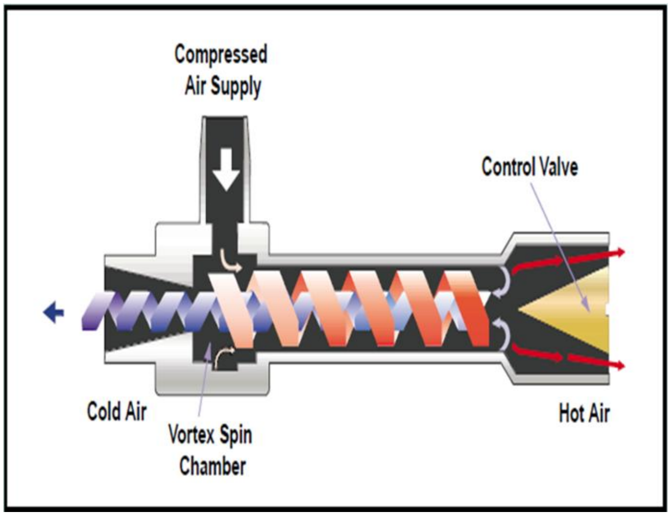

Fig. 1. *Schematic of counter flow vortex tube*

2 LITERATURE SURVEY

Since vortex tube's energy separation phenomenon is a complex one various research has been carried out all over the world by researchers. Research has been conducted over energy separation phenomenon, effects of gas properties on the performance of the vortex tube, effects of geometrical parameters on the cold and hot end temperatures and recently curved vortex tube was popular interest for the researchers. Divergent hot tube was also being experimented to understand the consequences. CFD analysis helped to understand the energy separation and flow analysis phenomenon upto certain extent. Saidi et al. designed and fabricated a test set-up which examined the effect of geometrical parameters on the performance of vortex tube [6]. There work includes effects of change in lengths and diameters of hot and cold tubes, shape of entrance nozzle. Behera et al. developed three-dimensional numerical model to understand the flow characteristics and energy separation phenomenon [7]. Valipour and Niazi carried out the experimental modeling of curved vortex tube. Gulyaev et al. used 2.3° divergent hot tube near the cone valve which got them better refrigeration results [8]. Gao et al. designed a simple vortex tube using nitrogen gas as working fluid for investigating temperature, pressure and velocity distributions [9].

2 PROBLEM STATEMENT

The main objective of this paper is to showcase the results of the experimental modeling of the vortex tube. Experimenting with UPVC material, changing of cone angle of the valve etc. are few major newly sampled changes. These alterations affect the outlet exit temperature at hot end and cold end.

3 EXPERIMENTATION IN DETAILS

The schematic model of our vortex tube is being shown in the figure 2. Geometrical parameters are mentioned below.

3.1 Geometrical Parameters

The geometrical parameters for our vorter tube set-up are as mentioned below-

TABLE 1
Geometrical Parameters of vortex tube

Sr. no	Design Parameters	Dimension/value
1	Diameter of Vortex tube, D	26mm
2	Orifice diameter, Dc	12mm
3	Number of inlet nozzles, n	2
4	Diameter of inlet nozzles, Dn	3mm
5	Dc/D	0.5
6	Dn/D	0.125
7	Length of hot side tube,Lh	50D=1200mm
8	Inlet pressure, Pi	5,6,7,8,9,10,11,12 bar

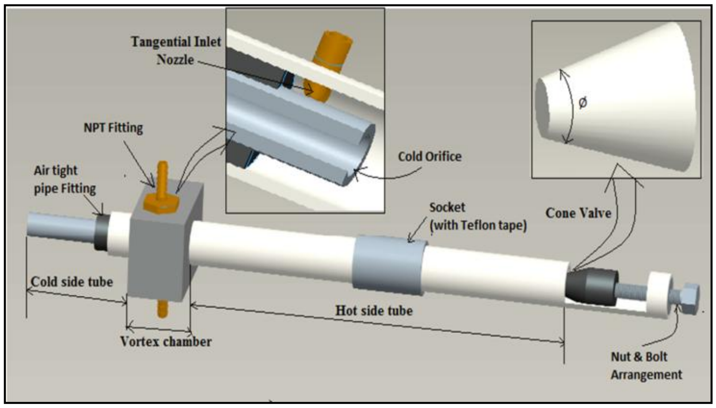

Fig. 2. Model of vortex tube

3.2 Materials of the Component

TABLE 2
Material of the components

Sr. No	Component	Material
1	Hot tube	UPVC
2	Cold tube	UPVC
3	Cone	Nylon
4	Nozzle	Brass
5	Block	Nylon

The Material UPVC (Unplasticised polyvinyl chloride) was being chosen because of the following reasons-

- Low thermal conductivity.
- Less friction due to smoother surfaces.
- Good insulating properties.
- Easy for machining.
- It is Economical.

Properties of UPVC material-

i. Thermal Conductivity- 0.13 W/mK
ii. Specific heat – 0.025 Kcal/Kg°C
iii. Density- 1.43 g/cm^3
iv. Softening point - 80°C

3.3 Experimental set-up

The figure 3 shows the experimental set-up of our vortex tube. The experimental configuration is connected to two-stage reciprocating compressor.The inlet nozzles are connected to the block in transverse plane. Hot tube and cold tube are connected to the block. The block is constructed in such a unique way so that it can support the nozzles and hot and cold tubes properly. The outlet of the compressor is connected to the inlet nozzles through the conducting ducts. Pressure gauges are connected at various positions to measure the pressure at various points. The temperatures at the hot end and cold end are measured through temperature indicator. Manometers are installed to calculate the mass flow rate of the compressed air [10].

Fig. 3. Experimental set-up

4 OBSERVATIONS

Various observations have been obtained for different parameters of the vortex tube. Table 3 reveals hot end and cold end temperatures for different inlet pressure. Figure 4 and figure 5 shows the varaiation in ΔTc and ΔTh with the variation in inlet pressure. As the cone angle was reduced and better results were obtained [11]. As we advance the cone inside the hot tube upto certain level we get optimium temperature range. The angle was kept 13° for obtaining optimium results.

TABLE 3
Observation Table

Sr. no	Inlet pressure Pi (bar)	Cold Temperature Tc(°C)	Hot Temperature Th(°C)
1	5	23.74	32.86
2	6	21.33	33.26
3	7	19.71	34.02
4	8	16.37	34.55
5	9	14.26	35.43
6	10	12.29	37.78
7	11	9.30	38.86
8	12	4.95	40.09

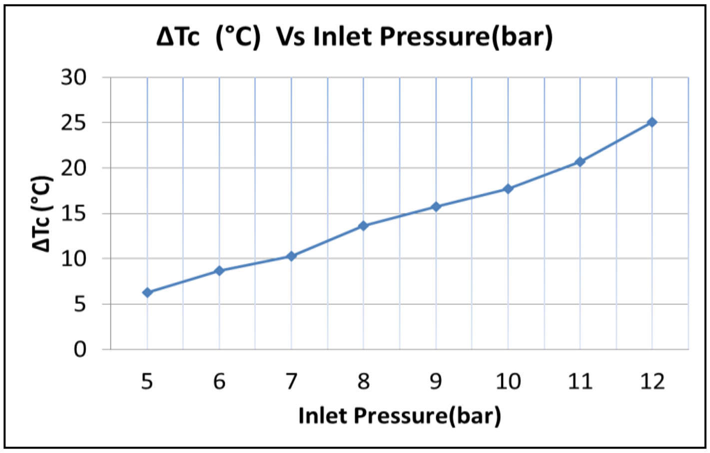

Fig. 4. *Increase in ΔTc with increase in inlet pressure Pi*

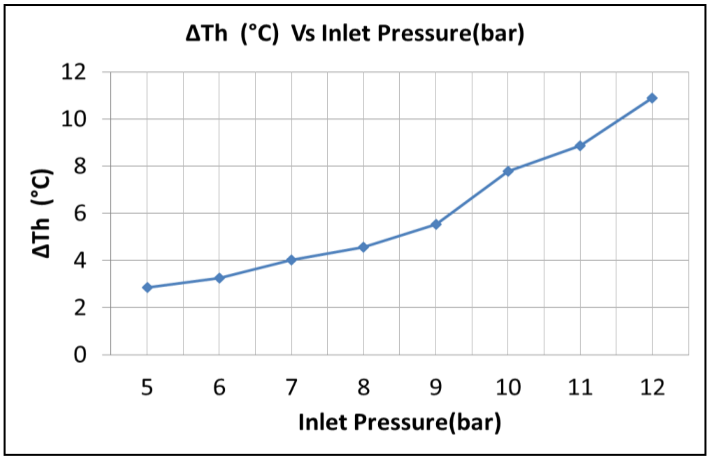

Fig. 5. *Increase in ΔTh with increase in inlet pressure Pi*

5 RESULTS AND DISCUSSIONS

5.1 The effect of change in inlet pressure on ΔTc

Figure 3 shows the effect of change in cold side temperature difference with the change in inlet pressure. It was observed that the temperature difference increased with the increase in the inlet pressure. L/D ratio was 40 so as to obtain optimum results. For an inlet pressure of 12 bar, the cold end temperature Tc was obtained as 4.95°C and the cold side temperature difference ΔTc was 25.05°C. For an inlet pressure of 5 bar, the cold end temperature obtained was 23.74°C and the cold side temperature difference was 6.26°C

5.2 The effect of change in inlet pressure on ΔTh

Figure 4 shows the effect of change in hot side temperature difference with the change in inlet pressure. It was observed that the temperature difference increased with the slight difference with the increase in inlet pressure. For an inlet pressure of 12 bar, the hot end temperature Th was obtained as 40.09°C and the hot side temperature difference was 10.89°C. For an inlet pressure of 5 bar the hot end temperature was obtained as 32.86°C and the hot side temperature difference was 2.86°C.

6 CONCLUSIONS

1. The minimum temperature of 4.95°C was obtained at cold end and maximum temperature of 40.09°C was obtained at hot end.
2. Temperature difference increases with increase in the increase in pressure.
3. Temperature at hot end increases with the decrease in the cone angle.
4. Maximum ΔTc and maximum ΔTh was obtained at L/D 50.

Acknowledgment

The authors present their gratitude towards the faculty members of Mechancial Engineering Department, Sinhgad Institute of Technology and Sciences, Pune, India for their support.

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