FABRICATION AND OPTIMIZATION OF PERFORMANCE OF VORTEX TUBE PARAMETERS

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ABSTRACT

Abstract: The vortex tube is a very simple device which separates a compressed gas into a cold and a hot stream. The compressed gas is injected tangentially into the tube inlet by means of nozzles. The gas develops the swirling motion into the tube. The gas leaving the tube near the wall will be warmer and that leaving the tube from the center will be cooler. The general motivation of this paper is to clarify the numerous assumptions on the vortex tube, its effect by the analysis of new measurements. The paper gives complete results with reference to performance parameters of vortex tube. The performance analysis of vortex tube having different geometrical entities is studied such as:

1. **By changing the number of nozzles in the vortex tube.**
2. **Using Tangential Inlet.**
3. **Effect of these design parameters on hot and cold end is being experimented.**

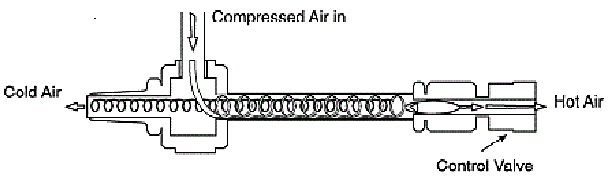
Keywords: Vortex Tube, Vortex Chamber, Cold End Temperature Difference, Cold Orifice Diameter, Ranque-Hilsch Vortex Tube.

I. INTRODUCTION

Refrigeration has large impact on industry, lifestyle, agriculture and settlement patterns. Refrigeration is a process of moving heat, the work of heat transport is traditionally driven by mechanical work, but can be also driven by, refrigerants, magnetism, electricity, laser or other means. Conventional refrigeration systems are using Freon as refrigerant. As they are the main cause for depleting ozone layer, extensive research work is going on alternate refrigeration systems and alternate refrigerants. Hence, the need of development of vortex was mandatory as it is a compact device which leads to the improvement in environmental condition.

Vortex tube(VT) is a device that generates cold and hot air stream from the source of compressed air. It contains the parts: inlet nozzle, vortex chamber, cold-end orifice, hot-end control valve and tube. When high pressure gas is tangentially injected into the vortex chamber through the inlet nozzles, a swirling flow is created inside the vortex chamber. In the vortex chamber, part of the gas swirls to the hot end and another part exist through the cold end directly. Part of the gas in the vortex tube reverses for axial component of the velocity and move from the hot end to the cold end. At the hot end, the air escapes with higher temperature, while at the cold end, the air has lower temperature compared to that of the inlet temperature pass through the orifice. This was discovered by Ranque (1933) and later developed by Hilsch (1947). In memory of their contribution the Vortex tube is also known as Ranque-Hilsch vortex tube (RHVT). In general, the vortex tube has been known by different names. The most well-known names are: vortex tube, Ranque vortex tube (first discoverer), Hilsch vortex tube or Ranque–Hilsch vortex tube (who improved the performance of the vortex tubes after Ranque), and Maxwell–Demon vortex tube (derived from the name of Maxwell and Demon group who together studied the molecule of hot air moving within the tube). Although there are various names, only "VT (Vortex Tube)" will be used in this article.

Fig: Vortex Tube



II. LITERATURE SURVEY

N. Agrawal, S.S. Naik, Y.P. Gawale [1] has carried an experimental investigation on Ranque Hilsch vortex tube (RHVT). Influential parameters such as L/D ratio, cold mass fraction, inlet pressure etc. are investigated. Further, three different working media (air, nitrogen and carbon dioxide) are also tested. The maximum cold temperature drop is also obtained at cold mass fraction/ratio of 60%. The vortex tubes perform better with carbon dioxide compared to air and nitrogen owing to its high molecular weight and low specific heat ratio. R.Madhu Kumar et. Al[2] showed Vortex tube is a non-conventional cooling device, having no moving parts which will produce cold air and hot air from the source of compressed air without affecting the environment. When a high pressure air is tangentially injected into vortex chamber a strong vortex flow will be created which will be split into two air streams. It can be used for any type of spot cooling or heating application. In this paper, vortex tube with cylindrical and conical hot tubes performance is compared.It was found that the vortex tube with a conical angle of about 2.5° surpassed the cylinder tube by 25%~30% in COP. The conical vortex tube reaches the same or more performance than the normal tube but with a smaller length. The effect of the conical hot tube on the cold temperature drop, hot temperature raise, and COP of the Vortex tube are analysed. The Cold drop temperature ΔTc increases with increase in inlet air pressure. The Hot temperature raise ΔTh increases with increase in inlet air pressure. The COP of the vortex tube increases with increase in inlet pressure. O. M. Kshirsagar, V. V. Ankolekar. V. N. Kapatkar[3] studied Effect of Geometric Modifications on the Performance of Vortex Tube. In this paper the experimental results indicate that there is an optimum diameter of cold-end orifice for achieving maximum energy separation. It was observed that for cold fraction ≤60%, the effect of cold end orifice diameter is negligible and above 60% cold fraction it becomes prominent. An increase in the pressure at the entrance of the vortex tube results in an increase in the performance of the vortex tube with 2, 4, 6 nozzles. The best performance is obtained with the vortex tube which has 4 nozzles. From the experimentation of K. Dincera et. al.it is found that the biggest ΔT values are observed with the plug which has a tip angle of 30° or 60°. Mohammad O. Hamdan, Basel Alsayyed, Emad Elnajjar[7] studied the effect of nozzle parameters on the energy separation of the vortex tube. The results indicate that maximum energy separation is achieved with tangential nozzle orientation while the symmetry/asymmetry of nozzles has a minimal effect on the performance of the energy separation. For current selected conditions and parameters, the study shows that the optimum number of nozzles for maximum energy separation is around 4 nozzles.It concluded that 1) The inlet pressure is the driving force for the energy separation. Experimental data show that a higher temperature difference and a higher COP are achieved as inlet pressure increases. However, the increase in COP depends on other parameters related to the vortex tube. 2) The cold mass fraction is an important parameter influencing the performance of the energy separation in the vortex tube. And there is an optimum value to obtain maximum temperature difference which is not the same for maximum energy load separation or COP. 3)The effect of number of nozzle is very important. For constant inlet pressure test, it is clear that there an optimum number of nozzles for maximum COPHP which depends on the vortex tube operating condition and parameters. For the current vortex geometry, the increase in the number of nozzles shows an direct effect on COP.

III. VORTEX TUBE DESIGN

A. Vortex tube terminology:

Vortex tube consists of following parts as shown in fig.2
(a) Nozzle (Inlet)
(b) Cold orifice (Cold outlet)
(c) Hot valve (Hot outlet)
(d) Tube

B. Vortex tube Design Parameters:
L/D ratio = 15
Nozzle Inlet Dia = 2mm
Cold end Dia = 3mm
No. of Nozzles = 1,2,3 nozzles
Conical Valve Angle = 45°

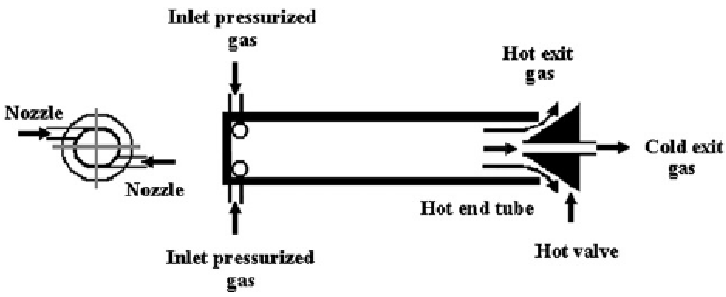


Fig: Vortex Tube Terminologies

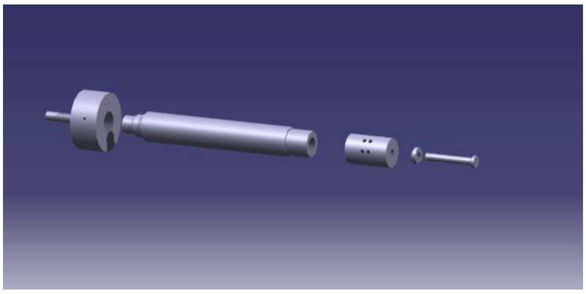


Fig: CAD model of Vortex Tube

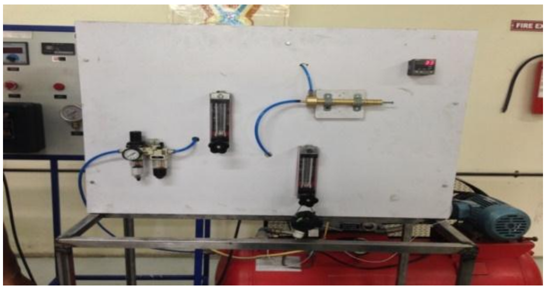


Fig: Experimental Set up of Vortex Tube

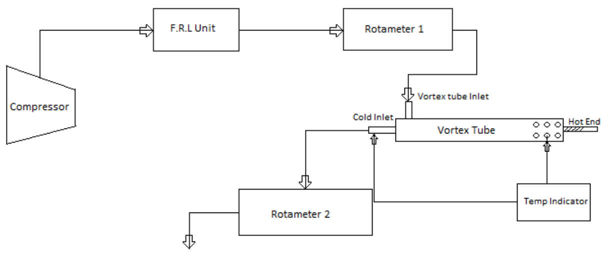


Fig: Schematic Diagram of Experimental set-up

Experimentation is carried on three different vortex tubes having different number of tangential inlets i.e. 1,2 and 3 of L/D =15 are tested with the tube diameter as 10 mm and inlet nozzle diameter as 2 mm. Cold end diameter is kept 3mm and cone angle of hot valve was taken as 45°. An in-house experimental test facility is developed as shown in Fig. 4 along with the geometrical details. Compressed air from the compressor passes through the FRL Unit and enters in the rotameter 1 and through it after adjusting the inlet mass flow rate it enters the vortex tube tangentially. The compressed air expands in the vortex tube and gets divided into cold and hot streams. The cold air leaves the cold end orifice near the inlet nozzle while the hot air discharges at the periphery at the other end of the tube i.e. hot end. The control valve (needle valve) controls the flow rate of the hot air. Two rotameters i.e. rotameter 1 and rotameter 2 measures the mass flow rates of the supply and cold air. K type thermocouples are used to measure the temperature of the leaving cold and hot air in the vortex tube. The pressure of inlet gas is measured by pressure gauge.

Fig: Manufactured Vortex Tube

Parameters used to evaluate performance of vortex tube are define as follows:

1) Cold mass fraction:

It is the mass flow rate of cold gas divided by mass flow rate of the inlet gas:-

$$\epsilon = \frac{\dot{m}_c}{\dot{m}_{in}}$$

2) Cold temperature drop and hot temperature difference:-

$$\Delta T_c = T_{in} - T_c \text{ And } \Delta T_h = T_h - T_{in}$$

3) Cooling efficiency of vortex tube using the principle of adiabatic expansion of ideal gas:-

$$\eta_{is} = \frac{(T_{in} - T_c)}{T_{in}\left[1 - \left(\frac{P_{atm}}{P_{in}}\right)^{\frac{\Upsilon - 1}{\Upsilon}}\right]}$$

4) Coefficient of performance using the principle of isentropic expansion of ideal gas:-

$$\text{COP} = \frac{\mu C_p (T_{in} - T_c)}{\left(\frac{\Upsilon}{\Upsilon - 1}\right) R T_{in} \left(\left(\frac{P_{atm}}{P_{in}}\right)^{\left(\frac{\Upsilon - 1}{\Upsilon}\right)} - 1\right)}$$

IV. RESULTS AND DISCUSSIONS

Experiments are conducted on three different vortex tubes with L/D ratio of 15 and by varying number of nozzles i.e 1, 2, 3 nozzles. Inlet pressure is also varied from 3 to 6 bar in the increment of 1 bar. For the testing, cold mass fraction is varied in the range of 40 % to 90% with the step size of 10%. Air is used as working gas and the vortex tube is made of brass material.

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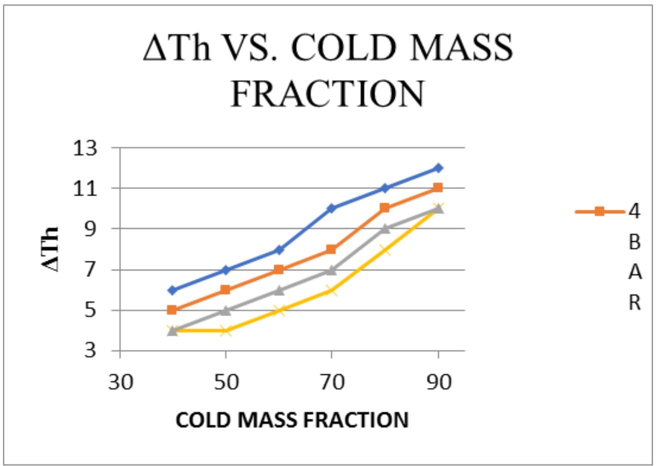
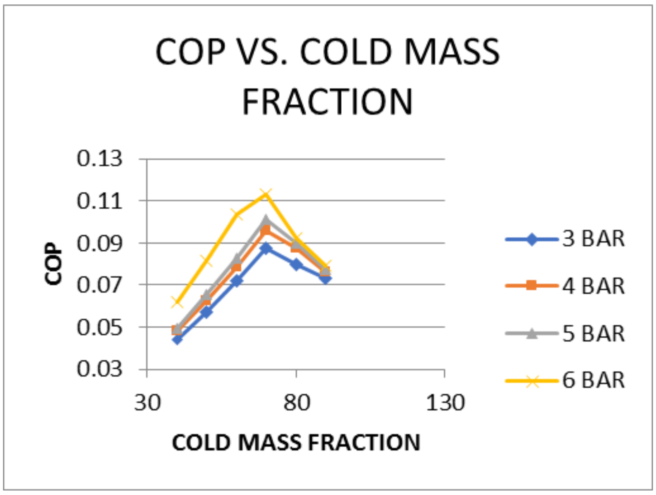
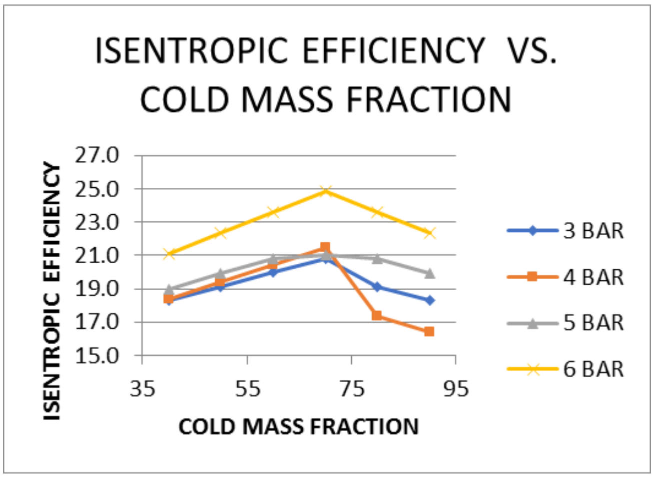
Table no. 1 : Performance characteristics of different vortex tube

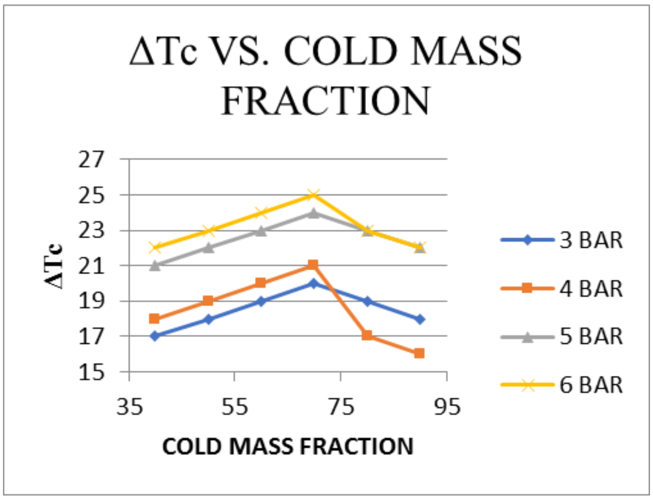
Sr.no	Types of Vortex Tube	Isentropic Efficiency (%)	COP
1	One Nozzle Vortex Tube	17.4	0.09
2	Two Nozzle Vortex Tube	24.8	0.113
3	Three Nozzle Vortex Tube	12.3	0.0683

As it can be seen that results obtained for 2 Nozzle vortex tube were better as compared to 1 and 3 nozzle tube. Various graphs plotted for 2 inlet vortex tube for varying working pressure are shown in this chapter..









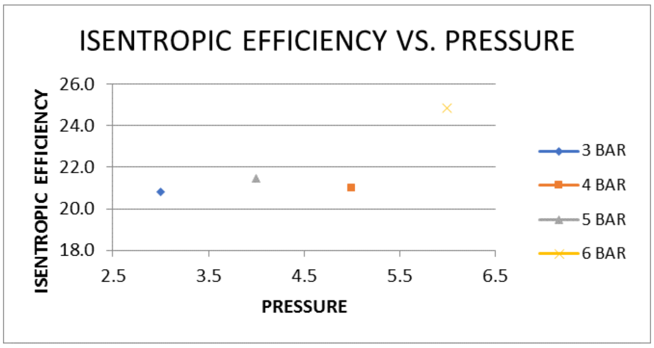


Fig 7 shows the graph of coefficient of performance(COP) versus Cold mass fraction(μ_c) for different working pressures, It is observed that as cold mass fraction increases COP also increases, and there is further decrease in COP after a particular point, in this case at 70% of cold mass fraction it starts decreasing. The maximum COP obtained is 0.113 at inlet pressure of 6 bar. Fig.8 shows variation in hot end temperature difference with variation of cold mass fraction. It can be seen that as there is increase in the cold mass fraction the hot end temperature difference also increases. Fig.9 shows that maximum isentropic efficiency is obtained for working pressure of 6 bar at 70% of cold mass fraction.The maximum efficiency obtained is 24.8. In this case isentropic efficiency increases till peak value of 70% of cold mass fraction and then further decreases. In Fig. 10 cold end temperature difference linearly increases along with cold mass fraction. Maximum cold end temperature difference is obtained for maximum pressure used for experimentation i.e. 6 bar and then decreases at peak value of 70% cold mass fraction. Fig.11 indicates the graph of isentropic efficiency versus pressure for constant cold mass fraction of 70%. It is observed that highest efficiency is obtained at higher pressure of 6 bar and it decreases as the pressure decreases.

V. CONCLUSION

Vortex tube with varying geometric entities was manufactured. The performance evaluation of Vortex tube was done experimentally. Material of tube was chosen to be brass due to its better machining properties. Also, brass has excellent thermal conductivity and is first choice for heat exchanger. Conical valve of 45 degree was selected for experimentation .The performance of vortex tube is affected with changing parameters such as inlet gas properties and geometrical entities. Different vortex tubes were tested for different working pressures varying from 3 bar to 6 bar. It was found that better results were obtained for higher pressure. The maximum cold temperature drop is obtained at cold mass fraction/ ratio of 70%. Also, maximum isentropic efficiency was obtained at lower working pressure of 3 bars. It was found that for given diameter and L/D ratio two inlet gives optimum results as compared to 1 and 3 inlet tube experimentally. Whereas, theoretically as number of nozzles increases difference between temperature at cold and hot end increases. In case of three inlet tube the results obtained experimentally do not match theoretical results as there were some manufacturing constraints.

VI. REFERENCES

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