Optimization of Vortex Tube By Selecting Different Parameters

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Abstract- *This paper discusses the experimental investigation of vortex tube performance as it relates to cold mass fraction, inlet pressure and L/D ratio. Vortex tube is device that separates compressed air in cold and hot streams useful in industry. For the energy separation in the vortex tube, different explanations are proposed. The effective parameters are geometrical and thermo-physical. The study focuses on the effecton double inletnozzle, varyingCold mass fraction, inlet pressure and L/D ratioby changing D (Diameterof vortex tube) to optimize the geometrical parameters.*

Keywords- Vortex Tube, L/D ratio, Cold mass fraction.

I. INTRODUCTION

Vortex tube also known as Ranque-Hilsch vortex tube is device that separate flow of compressed air into hot and cold streams without using any moving part.Vortex tube was invented in 1933 by metallurgist and physicist Ranque. His ideas were not widely read and remained unknown until 1945 when German physicist Hilsch published paper describing the actions of the vortex tube and improved the design. He proposed that the Ranque effect was incarnation of Maxwell's Demon. Hilsch received wide acclaim and now device is known as Ranque-Hilsch Vortex tube. It has one or more inlet nozzles, a vortex chamber, cold-end and hot end orifices. Specially designed vortex tube combined with effect of pressure, creates high rate rotations.

The main part of vortex tube is hollow cylinder, in which compressed air injected tangentially. The hot and cold end provides exhaust at both ends of tube. The hot nozzle is located at periphery while cold nozzle is centrally aligned with the tube. In counter-flow vortex tube exits are placed at opposite ends and at the same ends in uni-flow vortex tube. The compressed air is injected by nozzle tangentially in to tube develops swirling motion. Gas leaving at tube wall gets warmer while at central part it will be cooler. Centrifugal separation of the two split flow elements and their adiabatic expansion causes the energy separation in the vortex tube system.

The vortex tube was useful as a breakthrough device with application throughout the industry. It can be used in many industrial applications such as cooling equipment of computer numerical control (CNC) machines, refrigerators, cooling suits, heating processes, etc., as it is simple, compact, light and silent. Since it has no moving parts, it does not cause to break or wear the unit and therefore it requires little maintenance.

YunpengXue [4] has conducted experimental and computational analysis of counter-flow Vortex tube. He concluded that temperature drop of cold air can be the result of sudden expansion near the entrance, and temperature rise in hot air might be result of friction of multi-circulation near hot exit.

M. Yilmaz [5] overviewed the past investigations of the design criteria of vortex tubes and the detailed information was presented on the design of them.In this article, an overview of the past investigations of the design criteria of vortex tubes was studied, to draw together the mass of literature, and to provide detailed information on the design of vortex tubes.

Prabhakaran J. [7] investigated that the main factors affecting the performance of vortex tube are inlet pressure, L/D ratio, cold mass fraction, diameter of nozzle and orifice. In this paper, the performance of the vortex tube is investigated with different diameters of orifice and nozzle.

Jiri Linhart et al [8] studied the Vortex tube properties and analyzed that in fluid flow there are basically two causes of pressure variation in addition to the weight effect. These are acceleration and viscous resistance.

Table 1 Properties of various gases

Gas	Prandtl Number	Sp. heat ratio	Molar mass	Gas constant
Air	0.73	1.403	28.97	0.287
CO_2	0.78	1.304	44	0.1889
NH_3	0.85	1.310	20	0.4157

There are two types of flow in vortex tube, such as parallel flow and counter flow. The working principle of counter flow can be defined as; a compressible fluid, which is tangentially introduced into the vortex tube through nozzle, starts to make circular movement inside the vortex tube at very large speed, caused by cylindrical form of the tube, depending on its inlet pressure. A pressure difference occurs between tube wall and the tube center caused by friction of fluid circling at high speed, through the radial pressure gradient also is partially responsible for separation of two streams. The speed of fluid near the tube wall is lower than the speed at tube center because of the wall friction. As a result, fluid in center region transfers energy to the fluid at the tube wall, depending on the geometric structure of the vortex tube.

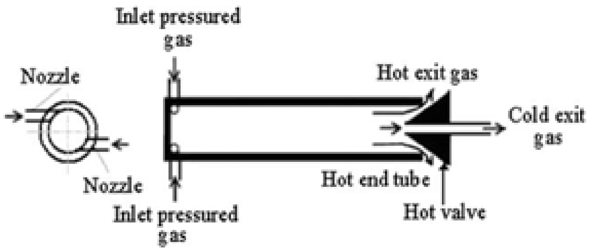

Fig.1The schematic representation of a parallel flow vortex tube principle

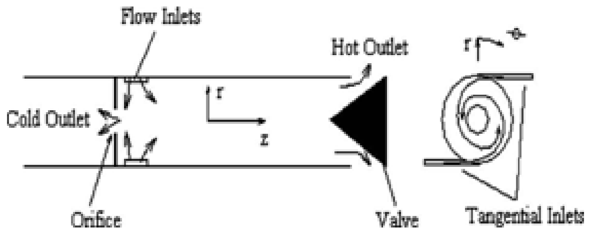

Fig.2 The schematic representation of counter flow vortex tube principle

In this study, the performance of a counter flow vortex tube is determined regarding the measured cold outlet temperature and the hot outlet temperature gradient. The difference of this study from the previous studies is to determine the performance of the counter flow type vortex tube with nozzle number 2 by use of the processing conditions such as inlet pressure in a large pressure scale with very small increments, cold mass fraction with small increments, and different L/D ratios.

II. PROBLEM STATEMENT

Vortex tube is an altogether different vortex tube to achieve cooling. Vortex tube is simple. However, its working is quite complex in nature. The thermodynamics and physics behind the vortex tube are yet to be understood completely. Many theories have been suggested to explain the physics of the vortex tube. There are various types of configuration are tested using different gases. However, air is most commonly used as the working medium of the vortex tube. L/D ratio and cold mass fraction are the two important performance parameters of the vortex tube. We need to optimize these parameters to develop vortex tube that can be used as a miniature device for Electronics Cooling. One of the objectives is to develop an ecofriendly and economical refrigerator working on vortex effect to nullify CFC harms.

III. OBJECTIVE

The objectives of proposed is to investigate the vortex tube experimentally using air as natural working fluids with double inlet nozzle. Further the performance parameters such as L/D ratio, cold mass fraction, inlet pressure are tested and optimized.

IV. METHODOLOGY

A. Manufacturing of tube

a. Selection of material

The vortex tubes are manufactured by using various materials like metals, polymer plastic, etc. Plastic is light in weight and easy to handle, but it has less machinability than metals. Metals are easily available and have better rigidity. They also have good machinability. We are going to select Brass, as it is cheaper than copper. It can be produced by soldering brass nozzles to tubes directly.

Properties of Brass are,

- Alloy Type: Binary
- Content: Copper (67%) &Zinc (33%)
- Density: 8.3-8.7 g/cm^3
- Melting Point: 900-940 °C
- Hardness: 3-4
- Thermal conductivity: 109 W/mK

b. Geometric Parameters

Length and diameters are selected for different L/D ratios. Then other parameters are calculated by using relation as below.

$$\frac{D_{in}}{D} \leq 2 \qquad \text{......................i}$$

$$\frac{D_c^2}{N\, D_{in}^2} \leq 2.3 \qquad \text{......................ii}$$

$$D_c < D - 2D_{in} \qquad \text{..............iii}$$

Table 2 Vortex Tube Parameters with Specification

Parameter	Specification
Length of tube	170 mm
Diameter of tube	10.5mm, 12mm, 14mm
Diameter of cold end	3 mm,4 mm, 5 mm
Diameter of inlet nozzle	2 mm
Cone angle of hot valve	45 degrees
Number of nozzle	2

V. EXPERIMENTAL STUDY

In this study, the vortex tubes with 2 inlet nozzles are used. Three different tubes with different L/D ratios are manufactured and used in experiments. Brass is used as manufacturing material. Brass has good machinability and can be soldered well. Each tube has same outer diameter and length with varying internal diameters.

The inlet pressure and the hot and cold outlet pressures of vortex tube have been measured by pressure gauge. The mass flow rates at hot and cold end outlets are measured by rotameter. The temperature of pressurized air at the inlet and cold and hot outlets were measured by use of digital thermometer with precision tolerance and obtained temperatures values have been converted into kelvins. Temperature probes of the digital thermometer were placed into hole, which was drilled at the center of the vortex tube and 10 mm away from the cold and the hot outlets. The cavities between the probes and the hole were filled to prevent the leakage. A conical valve has been mounted on the hot outlet of the tube to adjust the mass flow rate of the hot air. With the help of this valve, cold mass fraction m_c was being adjusted.

Before starting the experimental studies and collecting reading for different pressures, the conical valve on the hot outlet was kept in fully open position. And then the air compressor was started and by use of the throttle valve placed on the vortex tube inlet side, the required pressure value was reached. The compressed air flow is continued, until the constant temperature values have been reached at the cold outlet and hot outlet of the vortex tube. At this stage, the mass flow rates and pressures of the air at the cold and hot outlets were measured by using rotameters and pressure gauges, respectively. This experimental cycle was made three times for the entire inlet pressures selected 2 to 8 bar with 2 bar increments and for the cold mass fractions with small increments with the different orifices selected with different L/D ratios. The mean values of the measured results have been used to obtain the energy separation. The results will give the optimum dimensions of vortex with better efficiency.

A. Experimental Setup

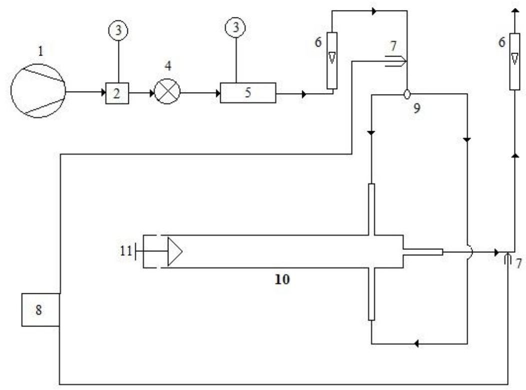

Fig.3 Schematic diagram of experimental setup

1. Compressor
2. Receiver
3. Pressure Gauge
4. Control Valve
5. FRL Unit
6. Air Roatameter
7. Thermocouples at inlet and cold end
8. Temperature Indicator
9. Pneumatic connector before double inlet nozzle
10. Vortex Tube
11. Conical Control valve at hot end

The schematic diagram of the experimental test facility is shown in Fig.3. Compressed air from the compressor (1) passes through the control valve (4) and pressure regulator filter section (5) and enters in the vortex tube (10) tangentially. To ensure the tangentially entry of the compressed air in the vortex tube to have proper swirling of the air special care was taken. The compressed air expands in the vortex tube and divides in to cold and hot streams. The cold air leaves the cold end orifice near the inlet nozzle while the hot air discharges the periphery at the far end of the tube i.e. hot end (11). The control valve (needle valve) controls the flow rate of the hot air (11). Two rotameters (Eureka made) (6) measures the mass flow rates of the hot and cold air. Thermocouples numbered (7) measure the temperature of the leaving cold and hot air in the vortex tube. The pressure of inlet gas is measured by pressure gauge (2) and the temperature of inlet gas is measured by thermocouple (7). To uniformly divide the compressed air, a pneumatic connector is used which divide the incoming stream in to two separate streams and supplies to two nozzles of the vortex tube.

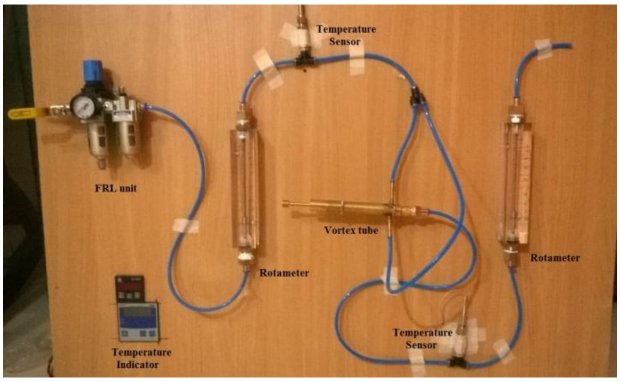

Fig.4 Photograph of experimental setup

Experimentation will be carried out by using the vortex tubes with L/D ratios of 12, 14.5, 16 for different cold orifice diameters, cold mass fraction and pressures from 2 to 8 bar with 1 bar increments. Results will give the optimum dimensions in L/D ratio, cold orifice diameter for given cold mass fraction at givenpressure.

VI. RESULT AND DISCUSSION

An experimental set-up is developed to carry out the experiments of two nozzle vortex tubes using air as the working fluid. Three different configuration vortex tubes have been developed and tested. Experiments are performed under two parts, in first part experiment carried out using different diameters of cold orifice i.e.3, 4 and 5 mm to optimize cold orifice and in second part, experiments are carried out on optimized cold orifice by varying different geometric parameters such as diameter and single or double inlet nozzles for optimizing L/D ratio.

A. Effect of Geometrical Parameters

a. Effect of cold orifice diameter

Experiment was performed on double inlet nozzle vortex tube, at various inlet pressures from 5 to 8 bars for three diameters of cold end orifice; 3 mm, 4 mm and 5 mm. For the first case of 5 bar, from Fig.4.1, as cold mass fraction increases, the cold end temperature drop increases for each cold end orifice diameter up to the cold end temperature decreases. Among the all three cases, for 4mm cold end orifice diameter maximum cold end temperature drop of 25^0C is observed.

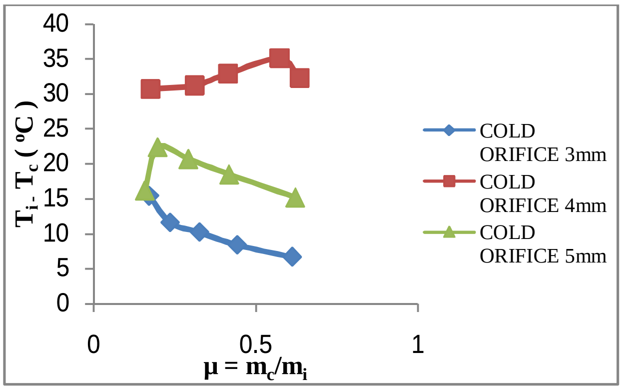

Fig.5Effect of cold orifice diameter on cold end temperature drop ($T_i – T_c$) at 8 bar

From above graph,as operating pressure increases, the cold end temperature drop increases.

b. Effect of L/D Ratio

L/D ratio is varied with change in diameter by keeping length constant. The L/D ratios selected as 12, 14.5 and 16 for the constant length of 170 mm and diameters as 10.5 mm, 12 mm and 14 mm respectively. Fig.6 shows that for L/D ratio, as pressure increases the cold end temperature drop also increases.

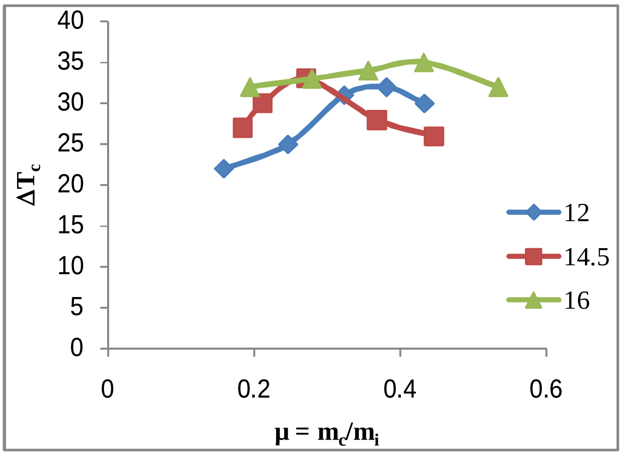

Fig.6 Temperature difference ΔT_c as function of cold mass fraction,μ, for different L/D ratios at pressure 8 bar

From Fig.7, it can be observed that as the pressure increases, the isentropic efficiency also increases due to increase in cold end temperature drop. For each corresponding pressure 8 bar, the ascending order of increase of isentropic efficiency as per L/D ratio is as 14.5, 12 and 16 respectively.

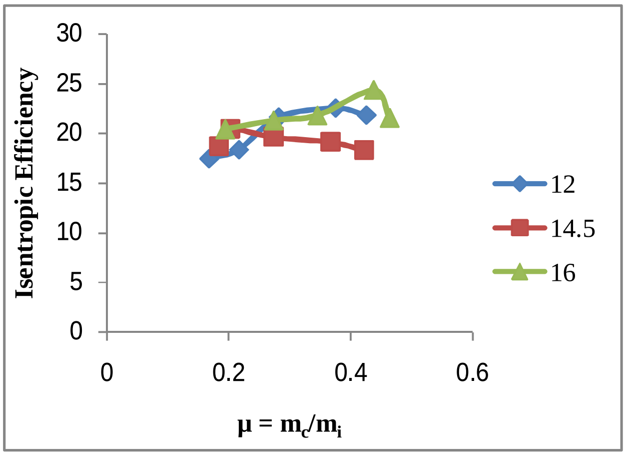

Fig.7Isentropic efficiency as function of cold mass fraction,μ, for different L/D ratios at pressure 8 bar

From Fig.8, it can be clearly observed that as the pressure increases, the cooling effect or Refrigeration capacity also increases due to increase in cold mass flow rate as well as cold mass fraction and cold end temperature drop. As we decrease the diameter by keeping length constant, the intermixing of two layers starts taking place and in turn we get reduced cooling effect.

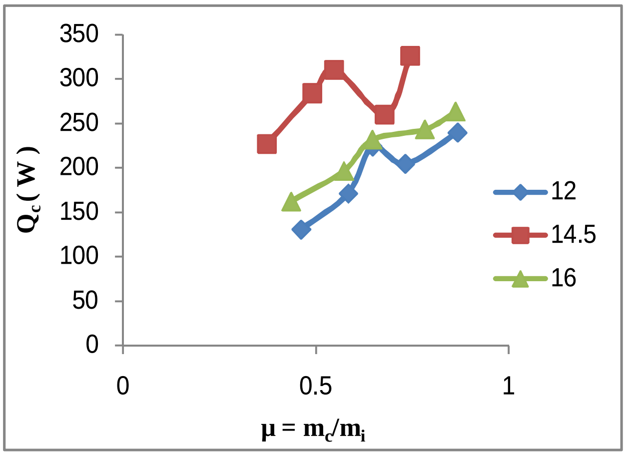

Fig.8 Cooling effect, Q_c, as function of cold mass fraction,μ, for different L/D ratios at pressure 8 bar

From Fig.9, it can be clearly seen that as the pressure increases, the COP also increases due to increase in the cooling effect or Refrigeration capacity as previously discussed. For each corresponding pressure from 8 bars, the ascending order of increase of COP as per L/D ratio is as 14.5, 12 and 16 respectively.

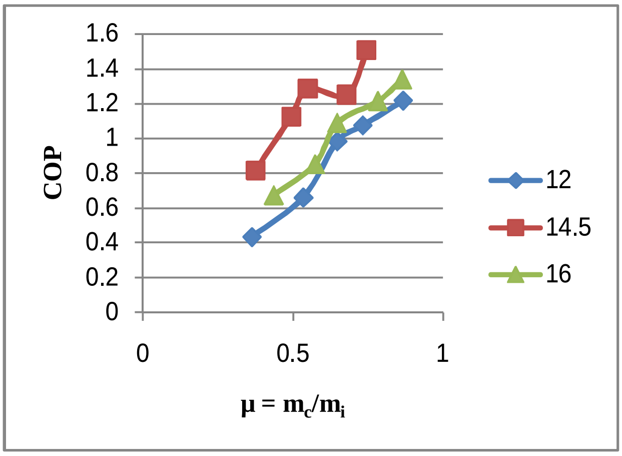

Fig.9COP as function of cold mass fraction,μ, for different L/D ratios at pressure 8 bar

VII. CONCLUSION

The vortex tube (also called the Ranque–Hilsch vortex tube) is a mechanical device operating as a refrigerating by separating a compressed gas stream into two low pressure streams with temperatures higher and lower than inlet stream. Such a separation of the flow into regions of low and high temperature is referred to as the energy separation effect.

An experimental set-up is developed to carry out the experiments of double nozzle vortex tube using air as the working fluid. Three different configuration vortex tubes have been developed and tested. Each vortex tube is tested at various operating condition. A series of experiments are performed to evaluate the performance of the system and to optimize the geometrical parameters. Experiments are performed under two parts, in first part experiment carried out using different diameters of cold orifice i.e.3 mm, 4 mm and 5 mm to optimize cold orifice and in second part, experiments are carried out on optimized cold orifice by varying different geometric parameters such as diameter for optimizing L/D ratio.

Cold end orifices diameters 3 mm, 4 mm and 5 mm are tested but for 4 mm cold end orifice maximum cold end temperature drop of 25°C. Experimental investigation shows that the double inlet nozzle gives the maximum cold end temperature drop for the cold mass fraction of 0.45 – 0.55.

L/D ratio affects performance of vortex tube. The optimum value of L/D ratio is found to be 16 for 4 mmorifice of vortex tube and maximum cold end temperature drop obtained 35°C for 0.432 cold mass fractions.

VIII. NOMENCLATURE

m_i =Mass flow rate at inlet nozzle (lpm)
m_c = Mass flow rate at cold end (lpm)
D = Diameter of vortex tube
D_c = Cold orifice diameter
D_{in} = Inlet nozzle diameter
N = Number of nozzles
T_i= Inlet Air Temperature
T_c = Cold end temperature
ΔT_h=Hot end temperature difference (°C)
μ = Cold mass fraction ratio
η = Isentropic efficiency (%)
Q_c =Cooling capacity (W)
COP = Coefficient of performance

REFERENCES

[1] Skye H.M., Nellis G.F., Klein S.A., (2006), "*Comparison of CFD analysis to empiricaldata in a commercial vortex tube.*" International Journal of Refrigeration, Vol. 29, pg no.71–80.
[2] Nellis G. F., Klein S. A., (2002), "*The application of Vortex Tubes to RefrigerationCycle.*" International Refrigeration and Air Conditioning Conference, Paper537.
[3] Farouk T., Farouk B., (2007), "*Large eddy simulations of the flow field andtemperature separation in the Ranque–Hilsch vortex tube*" International Journal of Heat and Mass Transfer, Vol. 50, pg no. 4724–4735.
[4] Xue Y., Arjomandi, Kelso R., (2010), "*A critical review of temperature separation in avortex tub*."Experimental Thermal and Fluid Science, Vol 34, pg no.1367-1374.
[5] Yilmaz M., Kaya M., Karagoz S., Erdogan S., (2009), "*A review on designcriteria for vortex tubes*" Heat Mass Transfer, vol. 45, pg no. 613–632.
[6] Volkan Kırmacı, OnuralpUluer, (2009), "*An Experimental Investigation of the Cold Mass Fraction, Nozzle Number, and Inlet Pressure Effects on Performance of Counter Flow Vortex Tube*", Journal of Heat Transfer, Vol. 131 / 081701-1
[7] PRABAKARAN. J, VAIDYANATHAN.S, (2010),"*Effect of diameter of orifice and nozzleon the performance of counter flow vortex tube*",International Journal ofEngineering Science and Technology Vol. 2(4), 704-707.
[8] JiříLinhart, Mohamad Kalal, Richard Matas, (2005), "*Numerical Study of Vortex Tube Properties*", 16th International Symposium on Transport Phenomena.
[9] Aydin O., Baki M., "*An experimental study on the design parameters of acounterflow vortex tube*", Energy, Vol. 31, (2006), pp. 2763–2772.
[10] Nimbalkar S. U., Muller M. R., "*An experimental investigation of the optimumgeometry for the cold end orifice of a vortex tube*."Applied Thermal Engineering,Vol. 29, (2009), pp. 509–514.
[11] Baghdad M., Ouadha A., Imine O., Addad Y., "*Numerical study of energyseparation in a vortex tube with different RANS models*" International Journal ofThermal Sciences, Vol. 50, (2011), pp. 2377-2385.