

An Experimental Study on Operating Parameter on Counter flow Vortex Tube

A.S. Gadhav¹, Dr. S. S. Kore²

P.G. Student, Department of Mechanical Engineering, G.S. Moze COE, Balewadi, Pune¹

Professor, Department of Mechanical Engineering, Sinhgad Institute of Technology, kondwa, Pune²

Abstract

The vortex tube (also called the Ranque–Hilsch vortex tube) is a mechanical device operating as a refrigerating machine without any moving parts, by separating a compressed gas stream into two low pressure stream, the temperature of which are respectively higher and lower than inlet stream. Such a separation of the flow into regions of low and high total temperature is referred to as the temperature (or energy) separation effect. The vortex tube performance depends on two types of parameters, firstly air or working parameters such as inlet pressure of compressed air, cold mass fraction and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, cone valve angle and also material of vortex tube affects Coefficient of Performance (COP). This paper discusses the experimental investigation of effect of above working parameters on the performance of Ranque-Hilsch vortex tube. The brass material has been used for manufacturing of the vortex tube as it has better thermal conductivity and less fluid friction losses. In this experimental study the performance of vortex tube has been tested with compressed air at various pressures from 2-8 bar, which supplied through single tangential inlet nozzles. The L/D ratio of hot side tube varies 12.5 , 13.5 and 17.5 and cold mass fraction varied from 0 – 1.

Keywords: Energy separation process, COP, Ranque-Hilsch vortex tube.

1. Introduction

One of the practical applications of thermodynamics is refrigeration where heat is transferred from low temperature region to high temperature region through the working fluid known as refrigerant. Vapour compression and vapour absorption refrigeration systems are two commonly employed conventional systems in almost all the major applications of refrigeration and air-conditioning. However, environmental problems such as ozone depletion and global warming caused due to CFC refrigerants have compelled us to look for other non-conventional systems. Vortex tube is one of the non-conventional systems where natural substances such as air is used as working medium to achieve refrigeration.

The vortex tube (also called the Ranque–Hilsch vortex tube) is a mechanical device operating as a refrigerating machine without any moving parts, by separating a compressed gas stream into two low pressure stream, the temperature of which are respectively higher and lower than inlet stream. Such a separation of the flow into regions of low and high total temperature is referred to as the temperature (or energy) separation effect.

Much earlier, the great nineteenth century physicist James Clerk Maxwell, postulated that since heat involves the movement of molecules, we might someday be able to get hot and cold air from the same device with the help of a “friendly little demon” who will sort out and separate the hot and cold molecules of air. The vortex tube was invented by accident in 1928 by George Ranque, a French metallurgist as well as physicist, who was experimenting with a vortex type pump; he had developed; when he noticed warm air exhausting from one end and cold air from other. Ranque started a small firm to exploit the commercial potential of this strange device that produced hot and cold air without moving any parts. Ranque was granted a French patent for this device in 1932 and a United States patent in 1934^[1, 2].

The initial reaction of the scientific and engineering communities to his invention was disbelief and apathy. Since the vortex tube was thermodynamically highly inefficient, it was abandoned for several years. Vortex tube slipped into obscurity until 1945; when a German physicist and engineer, Hilsch reported on account of his own comprehensive experimental and theoretical studies aimed at improving the efficiency of the vortex tube. He systematically examined the effect of the inlet pressure and the geometrical parameters of the vortex tube on its performance and presented a possible explanation of the energy separation process^[4].

Since vortex flow phenomenon taking place in a vortex tube is compressible and complex, the simulation and solution of turbulent vortex flows is a difficult and challenging task. Thus, the vortex tube has been variously known as the “Ranque vortex tube”, the “Hilsch Tube”, the “Ranque-

Hilsch Tube” and “Maxwell’s Demon”. By any name, it has in recent past gained acceptance as a simple, reliable and low cost answer to a wide variety of industrial spot cooling problems.

2. Problem Statement

An experimental study has been conducted to evaluate the effect of working parameters such as inlet air pressure (P_i), Cold mass fraction (μ) and length of hot side tube (L_h) on the performance of Ranque-Hilsch vortex tube. In this work, the counter flow vortex tube has been designed, manufactured and tested. Different parameters were evaluated like temperature reduction on cold side, temperature rise on hot side, refrigerating effect and isentropic efficiency. The performance of vortex tube has been tested with compressed air at various inlet pressures from 2-8 bar which supplied through single tangential inlet nozzles. The L/D ratio of hot side tube varies 12.5, 13.5 and 17.5 and cold mass fraction varied from 0 – 1.

3. Design and Constructional Details of Vortex Tube

Takahama^[22] has proposed the following correlations for optimized RHVT for larger temperature difference, given as;

$$D_{in} / D \leq 0.2 \dots\dots\dots (i)$$

$$D_c^2 / ND_{in}^2 \leq 2.3 \dots\dots\dots (ii)$$

$$D_c < D - 2 D_{in} \dots\dots\dots (iii)$$

Considering all design parameters, the three different diameters of tubes are chosen at constant length as, $D = 10\text{mm}$, 13mm , 14mm and $L/D = 12.5, 13.5, 17.5$

$$\therefore D = 10 \text{ mm}$$

Using Equation (i)

$$D_n \leq D \times 0.2$$

$$\therefore D_n \leq 10 \times 0.2$$

$$\therefore D_n \leq 2 \text{ mm}$$

Diameter of inlet nozzle, $D_n = 2 \text{ mm}$

Using Equation (ii)

$$D_c^2 \leq 2.3 \times ND_n^2$$

Considering $N = 1 \quad D_c^2 \leq 2.3 \times 2^2$

$$D_c^2 \leq 9.2$$

$$D_c \leq 3.03 \text{ mm}$$

Diameter of cold end orifice, $D_c = 3 \text{ mm}$

In order to find out the optimum dimensions for vortex tube three different L/D ratios i.e.

12.5, 13.5, 17.5 are selected and also the cold orifice diameter are 3 mm, 4 mm and 5 mm are also selected.

The geometrical design parameters used in the experimentation are listed below in Table 1.

The counter-flow vortex tube consists of inlet nozzles, vortex chamber, separating cold orifice plate, hot side cone valve, hot and cold end tubes. The Brass material has been used for manufacturing of the vortex tube as it has better thermal conductivity, less fluid friction losses, easy to machining and moderate overall cost. A conical valve was provided on the right hand side of the tube to regulate the flow.

Table. 1 Detailed design Parameter

Parameter	Specification
Length of tube	125 mm, 135 mm, 175 mm
Diameter of tube	10 mm
Diameter of cold end	3 mm, 4 mm, 5 mm
Diameter of inlet nozzle	2 mm
Cone angle of hot valve	45 degree
Number of nozzle	1

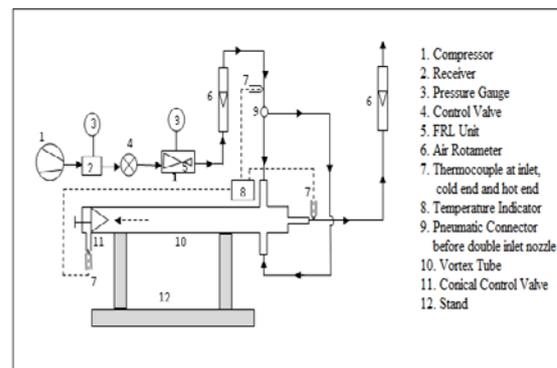


Fig. 1 Schematic diagram of Experimental Setup

The schematic diagram of the experimental test facility is shown in Fig. 1. Compressed air from the compressor (1) passes through the control valve (4) and pressure regulator filter section (5) and enters the vortex tube (10) tangentially. To ensure the tangential 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 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 far end of the tube i.e. hot end (11). The control valve

(needle valve) control 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). In order 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 as shown in Fig. 2.

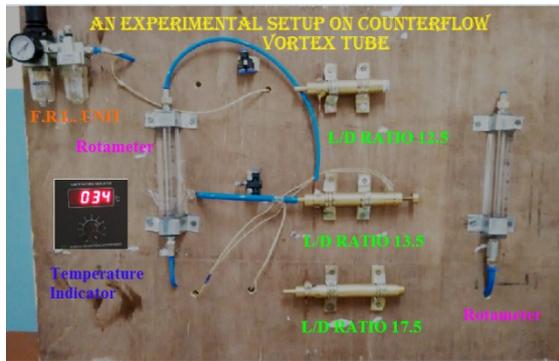


Fig.2 Photographs of experimental setup



Fig.3 Photographs of double inlet nozzle vortex tube

4. Result and Discussion

Experiments are performed under following conditions;

- Inlet pressures range : 2 bar – 8 bar
- Cold mass fraction : 0 – 1
- L/D Ratio by varying diameter : 12.5, 13.5, 17.5
- Number of inlet nozzle : 1
- Working substance : Air

Effect of cold orifice diameter at L/D = 12.5:

Experiment was performed on single inlet nozzle vortex tube, at various inlet pressures from 2 to 8 bars for three diameters of cold end orifice; 3 mm, 4 mm and 5 mm. For the first case of $L/D = 12.5$

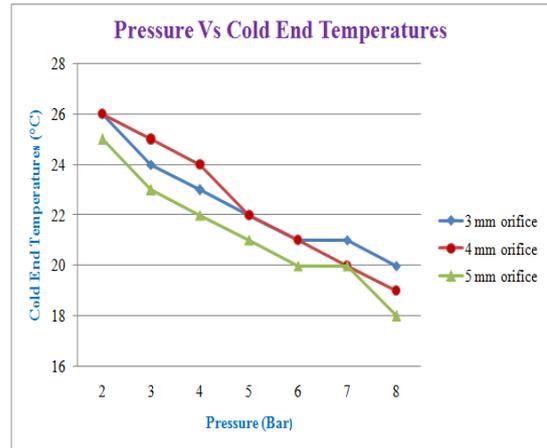


Fig. 4 Effect of cold orifice diameter on cold end temperatures at $L/D = 12.5$

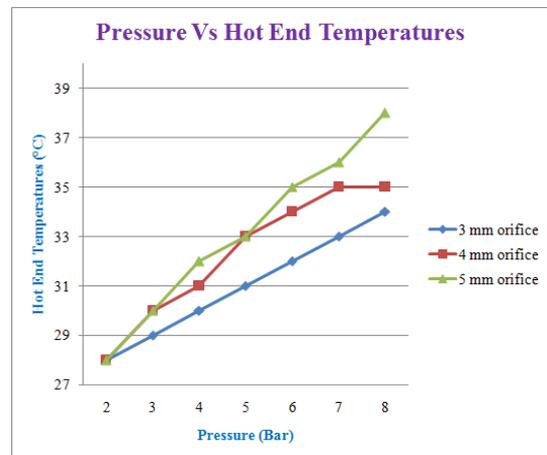


Fig. 5 Effect of cold orifice diameter on hot end temperatures at $L/D = 12.5$

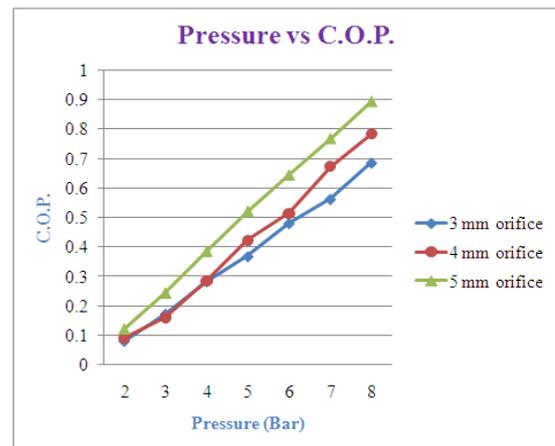


Fig. 6 Effect of cold orifice diameter on c.o.p. at $L/D = 12.5$

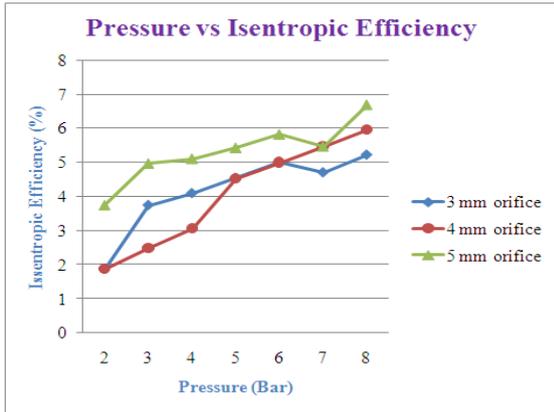


Fig. 7 Effect of cold orifice diameter on isentropic efficiency at $L/D = 12.5$

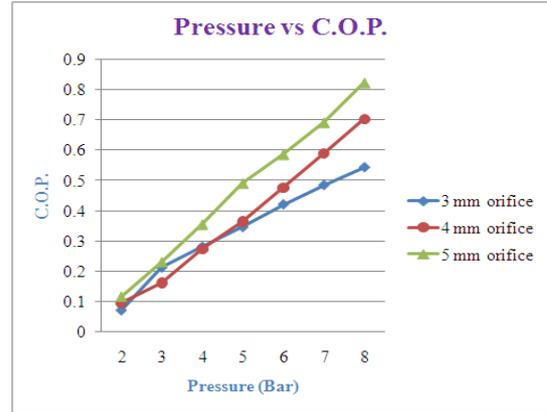


Fig. 10 Effect of cold orifice diameter on c.o.p. at $L/D = 13.5$

Effect of cold orifice diameter at $L/D = 13.5$:

Experiment was performed on single inlet nozzle vortex tube, at various inlet pressures from 2 to 8 bars for three diameters of cold end orifice; 3 mm, 4 mm and 5 mm. For the first case of $L/D = 13.5$

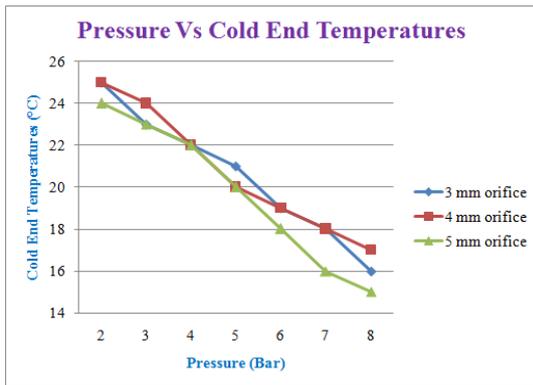


Fig. 8 Effect of cold orifice diameter on cold end temperature at $L/D = 13.5$

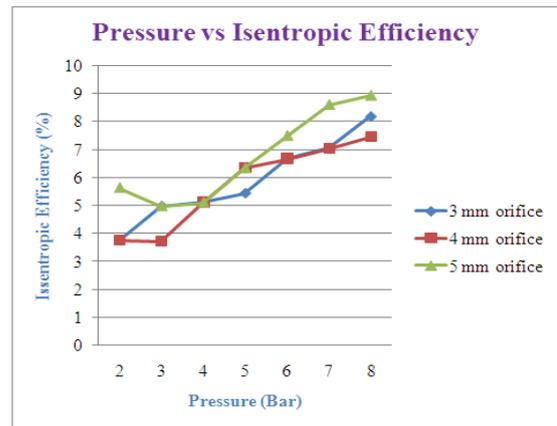


Fig. 11 Effect of cold orifice diameter on isentropic efficiency at $L/D = 13.5$

Effect of cold orifice diameter at $L/D = 17.5$:

Experiment was performed on single inlet nozzle vortex tube, at various inlet pressures from 2 to 8 bars for three diameters of cold end orifice; 3 mm, 4 mm and 5 mm. For the first case of $L/D = 17.5$

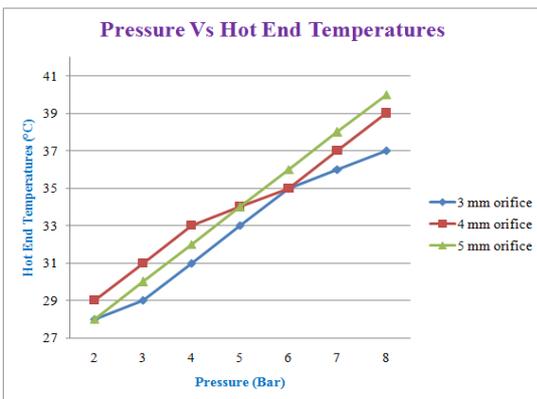


Fig. 9 Effect of cold orifice diameter on hot end temperature at $L/D = 13.5$

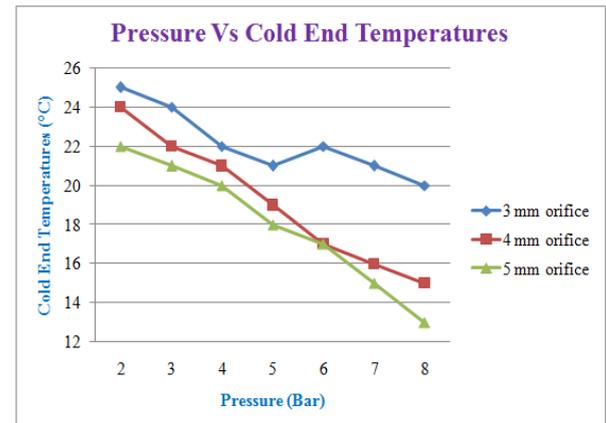


Fig. 12 Effect of cold orifice diameter on cold end temperature at $L/D = 17.5$

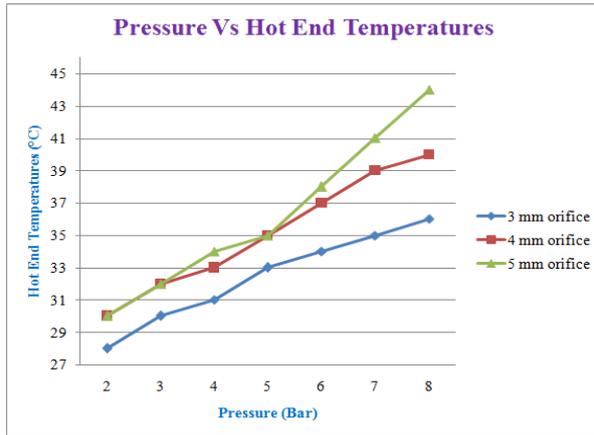


Fig. 13 Effect of cold orifice diameter on hot end temperature at L/D = 17.5

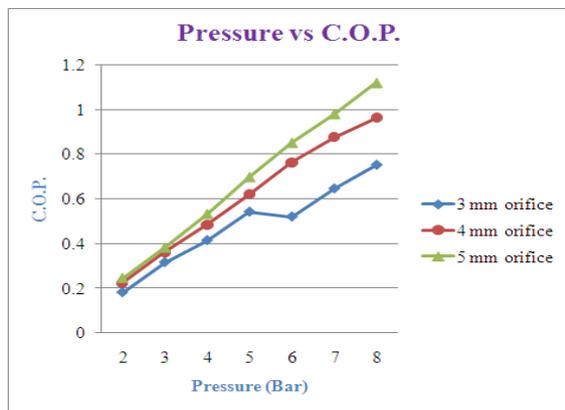


Fig. 14 Effect of cold orifice diameter on c.o.p. at L/D = 17.5

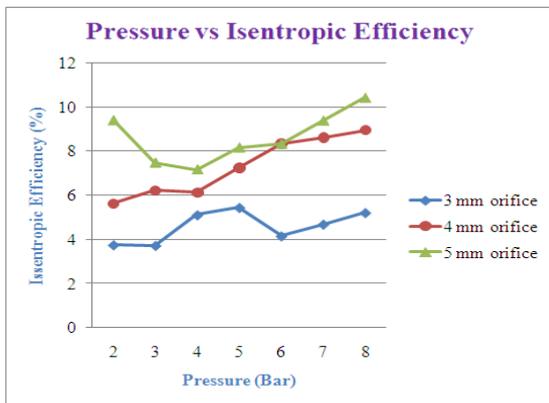


Fig. 15 Effect of cold orifice diameter on isentropic efficiency at L/D = 17.5

5. Conclusion

The following conclusions have been made from this experimentation:

1. The maximum temperature difference of 14°C is obtained on cold side while

17°C is obtained on hot side of Vortex tube.

2. The temperature drop increases with increase in inlet pressure.
3. The maximum isentropic efficiency = 10.43% and C.O.P. = 1.12 obtained at 17.5 L/D ratio.
4. The optimum value of L/D ratio is 17.5 as in this ΔT_c and ΔT_h is maximum.
5. The highest temperature drop is found between 0.45-0.65 cold air mass fraction.
6. At 8 bar Inlet pressure, 17.5 L/D ratio and 0.65 Cold mass fraction give the best result.

References

- [1] Ranque G.J., "Experiments on expansion in a vortex with simultaneous exhaust of hot air and cold air." *Le Journal De Physique*, vol. 4, (1933), pp. 1125-1130.
- [2] Hilsch R., "The use of expansion of gases in a centrifugal field as a cooling process." *Review of Scientific Instruments*, vol. 13, (1947), pp. 108-113.
- [3] Yilmaz M., Kaya M., Karagoz S., Erdogan S., "Areview of design criteria for vortex tubes." *Heat Mass Transfer*, vol. 45, (2009), pp. 613-632.
- [4] Promvong P., Eiamsa-ard S., "Investigation on the Vortex Thermal Separation in a Vortex Tube Refrigerator." Thailand.
- [5] Xue Y., Arjomandi, Kelso R., "A critical review of temperature separation in a vortex tube." *Experimental Thermal and Fluid Science*, Vol. 34, (2010), pp. 1367-1374.
- [6] Lewins J., Bejan A., "Vortex tube optimization theory." *Energy*, Vol. 24, (1999), pp. 931-943.
- [7] Deissler R.G., Perlmutter M., "Analysis of the flow and energy separation in a turbulent vortex." *International Journal of Heat Mass Transfer*, Vol. 1, (1960), pp. 173-191.
- [8] Eiamsa-ard S., Promvong P., "Numerical prediction of vortex flow and thermal separation in a subsonic vortex tube." *Journal of Zhejiang University SCIENCE A*, Vol. 7(8), (2006), pp. 1406-1415.
- [9] Takahama H., "Studies on vortex tubes." *Bull. JSME*, Vol. 8 (31), (1965), pp. 433-440.