# An Experimental Study on the Effect of Parametric Variation on Cold Mass Fraction of Diverging Vortex Tube

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***Abstract-*** *Vortex tube is a simple device which takes in compressed air and splits it to two air streams i.e. cold and hot air streams. Cold air coming out of vortex tube can be used for refrigeration and air conditioning purpose, so vortex tube can be a substitute for conventional refrigeration and air conditioning systems. Cold mass fraction of vortex tube is considerably influenced by its geometrical and thermo physical parameters. Present study deals with the experimental investigation on the effect of these geometrical and thermo physical parameters on Cold mass fraction of vortex tube. Vortex tube with length to diameter ratio (L/D) 15, 16, 17 and 18, conical valve angle(θ) 30°, 45°, 60°, 75° and 90°, cold end orifice diameter(do) 5, 6 and 7mm have been experimented with inlet pressure(p) 2 to 6 bar for optimum Cold mass fraction. The maximum cold mass fraction is obtained as 0.9825 at 5 bar pressure at L/D ratio of 17 ,6mm orifice diameter 90 degree conical valve angle, The minimum cold mass fraction is of 0.2273 at 2 bar pressure at L/D ratio of 16 , for 60 degree conical valve angle with 5 mm orifice diameter.*

***Keywords:-*** Cold Mass Fraction, vortex tube, performance, refrigeration.

## I. INTRODUCTION

The vortex tube can be a promising alternative for conventional refrigeration systems. Vortex tube utilizes pressurized air and gives cold and hot air streams. Vortex tube consists of hollow tube known as vortex chamber, conical valve and orifice at cold end. Vortex chamber can be of straight, divergent or convergent section. Cold end with one or more no. of nozzles and hot end with hot air control plug. geometrical simplicity , low cost, easy maintenance, small size, lightweight, fast response, high efficiency, capability to reach a target temperature instantaneously are some of the advantages of vortex tube. Vortex tubs are used in applications like: Plastic blow molding, spot and panel cooling, vacuum forming [1], cleaning, drying and separating gas mixtures [2] [3] [4], DNA application and liquefying natural gas [5].

Pressurized air enters at one end of the vortex chamber through the air inlet nozzle or nozzles tangentially. The pressure energy of the air is converted to velocity and air forms a vortex at the inside periphery of vortex chamber and the inner layers of air press upon the outer layers by centrifugal force and compress the air at outer periphery, which travels to the other end of chamber where the flow is restricted by a hot end control valve and flow reversal takes place. Thus temperature of outer layer increases and air at the inner layer expands thus temperature of inner layers decreases. The hot air exit is placed near the outer radius near the hot air control valve and the cold exit is placed at the center of the tube at the nozzle end. By adjusting a control valve on hot end it is possible to vary the amount of the incoming air that leaves through the cold exit, known to as the cold fraction. The streams of air leaving through the hot and cold ends of the tube are at higher and lower temperature, respectively, than the air entering the nozzle. This effect is referred to as the temperature separation effect or energy separation.

This shows that tube area available at hot and cold air exit and flow pattern affects the cold mass fraction and temperature separation phenomenon. In the present work an attempt is made to experimentally investigate the effect of these parameters on the cold mass fraction.

K Dincer et al. [6] experimented with conical valves with angles 30°, 60°, 90°, 120°, 150°and 180° and concluded that the biggest temperature difference value of 51°C is observed with the plug which has a tip angle of 30° or 60°. Kirmaci [7] studied the effects of the nozzle number and found that best cold air temperature 263.15K (-9.85°C) is obtained with 2 numbers of nozzles. Prabhakaran and vaidyanathan [8] concluded from his experiments that when the diameter of the orifice is 6 mm (0.5 D) out of orifice diameter 5 mm, 6 mm and 7 mm, it produces maximum cold air temperature reduction of 26.5°C. Prabhakaran and vaidyanathan [8] performed experiments to investigate the effect of Nozzle Nozzles diameter.

with different diameter 2mm, 3 mm and 5 mm were experimented and reported that best cold air temperature difference of 16.8 is obtained with the nozzle diameter of 3mm. Chang et al.[9] carried out experiments to investigate the influence of divergence angle on the performance of vortex tube and concluded that the performance of vortex tube can be improved by using a divergent hot tube. The experimental results show that the 4° divergent vortex tube yields the highest temperature reduction of 42°C.

So valve angles are chosen in step of 15° from 30° to 90°, orifice diameters are selected as 5, 6, 7 mm where 6 is holding d/dc 0.5 relation, L/D is selected in close range 15 to 18. The nozzle number, nozzle diameter and divergence angle has been set as 2, 3mm and $4^0$ respectively, the purpose is to combine most of the optimized parameters from the literature for getting true optimum performance.

M.H. Saidi et al conducted experiments to investigate the effect of geometrical parameters on the operational characteristics of vortex tube, vortex tubes with different tube sizes.Variation of efficiency with $L/D$ of vortex tube for $\mu$0.55 and nozzle with 4 intakes. He concluded that forL/D $\leq$ 20 energy separation decreases leading to decrease in cold air temperature difference and efficiency decreases as well. For L/D ≥ 55:5, the variation of efficiency with $L/D$ is not considerable. Consequently, the optimum value of$L/D$ is within the following ranges$20 \leq L/D \leq 55.5$.

Above review reveals that best performance geometrical parameters are as follows. Length to diameter ratio is 20-30.2 number of nozzle, a no. of nozzle increases turbulence with in the vortex chamber increases and best results for divergent tube are found for 2 nozzles with air as working fluid. Cold orifice diameter 5, 6, 7 mm, Best results are found with these orifices for orifice below 5mm diameter back pressure causes lower temperature reduction due to expansion and above 7mm hot air near the tube wall mixes with cold air thereby decreasing the cold air temperature drop. Nozzle diameter 3mm. conical valve angle 30°-60.Internal divergence angle 4°. Dimensionless diameter 0.5

## II. EXPERIMENTAL METHOD

### A. Experimental Setup

The schematic of the experimental setup used in the experiments is shown in Figure 1 .The experimental setup consist of a compressor, an air reservoir, pressure regulator to regulate the pressure of air, rota-meters for measuring the flow rates of inlet air and cold air, pneumatic pipes, connectors, vortex tube, electronic temperature display, RTD thermocouples for measuring the temperatures of inlet air, cold air and hot air with digital temperature indicator having least count of 0.1°C. To measure the flow of air through the system rota meter is used having least count 10 LPM as flow measuring device. A detail of measuring instruments is shown in Table 1.

### B. Experimental Procedure

Pressurized air is provided as input to vortex tube, air is passed through the pressure regulator to regulate the pressure as per requirement then it is passed through the rota meter to record the flow rate of air. Then air is split into to pass through two tangential nozzles to the vortex chamber which comes out as cold and hot air through cold and hot ends. Hot end conical valve is adjusted to regulate the cold air flow to get minimum clod air temperature. Cold air is then passed through second rota meter to record cold air flow rate.

The experimentation is carried out with all four diverging vortex tube with various orifice diameters with each valve and with pressures ranging from 2 to 6 bars to record cold and hot air temperatures and flow rates. Tube with / ratio 15, cold end with 5mm and conical valve with θ equal to 30° is experimented at 2 bar pressure to record inlet air, cold air and hot air temperatures and inlet air and cold air flow rates. Now pressure of inlet air is increased to 3, 4, 5 and 6 bars to record temperatures and flow rates. Conical valve is replaced with valve having 45° and *p* is set to 2 bars to record temperatures and flow rates then p is increased to 3, 4, 5 and 6 bars to record the same. For next set of readings conical is valve replaced with valve having θ equal to 60° and *p* set to 2 bars to record temperatures and flow rates then *p* is increased to 3, 4, 5 and 6 bars to record the same. Next two readings are taken for θ equal to 75° and 90°. Now cold end is replaced with cold end having 6mm. It is first experimented at 2 bar pressure to record inlet air, cold air and hot air temperatures and inlet air and cold air flow rates. Now pressure of inlet air is increased to 3, 4, 5 and 6 bars to record temperatures and flow rates. Conical valve is replaced with valve having 45° and *p* is set to 2 bars to record temperatures and flow rates then p is increased to 3, 4, 5 and 6 bars to record the same. For next set of readings conical is valve replaced with valve having θ equal to 60° and *p* set to 2 bars to record temperatures and flow rates then *p* is increased to 3, 4, 5 and 6 bars to record the same. Next two readings are taken for θ equal to 75° and 90°. Now cold end is replaced with cold end having 7mm. It is first experimented at 2 bar pressure to record inlet air, cold air and hot air temperatures and inlet air and cold air flow rates. Now pressure of inlet air is increased to 3, 4, 5 and 6 bars to record temperatures and flow rates. Conical valve is replaced with valve having 45° and *p* is set to 2 bars to record temperatures and flow rates then p is increased to 3, 4, 5 and 6 bars to record the same. For next set of readings conical is valve replaced with valve having θ equal to 60° and *p* set to 2 bars to record temperatures and flow rates then *p* is increased to 3, 4, 5 and 6 bars to record the same. Next two readings are taken for θ equal to 75° and 90°.

The same set of procedure is followed for tube having L/D 16, 17 and 18 and observations are reduced to performance parameters using data reduction

Table 1 Range of measuring instruments used in experimentations

| Instrument | Range |
|---|---|
| Rota meters | 0 to 500LPM |
| Pressure Regulator | 0 to 10 bar |
| RTD | -50 to 150°C |

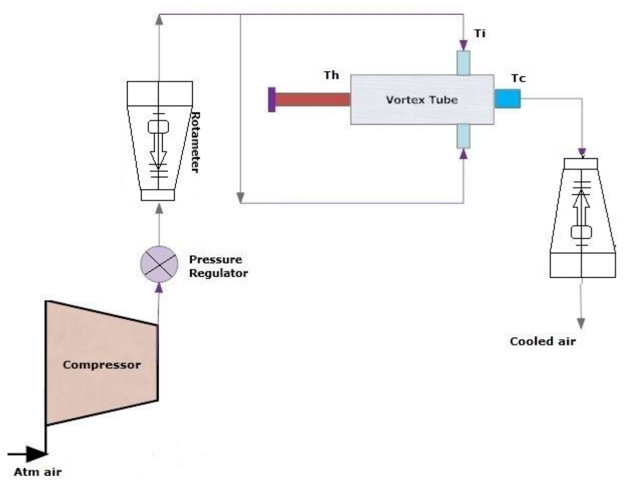


Figure 1 Experimental Setup

**C. Data Reduction**

**Cold mass fraction(μ):** Ratio of mass of cold air outlet to the total mass inlet to the vortex tube.

$$\mu = \frac{m_c}{m_i}$$

**Stagnation point:** In fluid dynamics, a stagnation point is a point in a flow field where the local velocity of the fluid is zero. Corresponding Temperature and pressure are known as stagnation temperature and stagnation pressure respectively.

**Coefficient of performance($COP$):** Coefficient of performance is the ratio of Refrigerating effect to energy supplied. Theoretically COP of vortex tube can be given as:

$$COP = \eta_{ab}\eta_{comp}\left(\frac{p_a}{p_i}\right)^{\frac{(\gamma-1)}{\gamma}}$$

**Relative temperature drop($\Delta T'_{rel}$):** Ratio of temperature drop of cold stream in the vortex tube to the temperature drop in tube due to expansion.

$$\Delta T_{rel} = \frac{\Delta T_c}{\Delta T'_c}$$

**Area ratio:** Ratio of Available area for cold air exit to the area available for hot air exit of tube.

$$A_r = \frac{A_c}{A_h}$$

**III.RESULTS AND DISCUSSION**

Experiments are conducted with different vortex tubes with varying L/Dratio with various θand $d_o$for different p andthe effects are presented and discussed in terms of Cold mass fraction **μ**. Here the graphs drawn with the help of Minitab 16 software since the we have considered all the parameters i.e., $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 30$, for one set in which red line is for 5 mm orifice diameter. Similarly 6mm and 7 mm orifice diameters represented by blue and dark green colors. In the way we will change $\theta = 45, 60, 75, 90$.And respective graphs have been plotted.

A. Effect of $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 30$, by varying Pressure 2, 3,4,5,6 bar on Cold mass fraction

The maximum cold mass fraction is of 0.9412 at 6 bar pressure at L/D ratio of 16, 7mm orifice diameter. The minimum cold mass fraction is of 0.2391 at 3 bar pressure at L/D ratio of 18, for 30 degree conical valve angle with 6 mm orifice diameter.

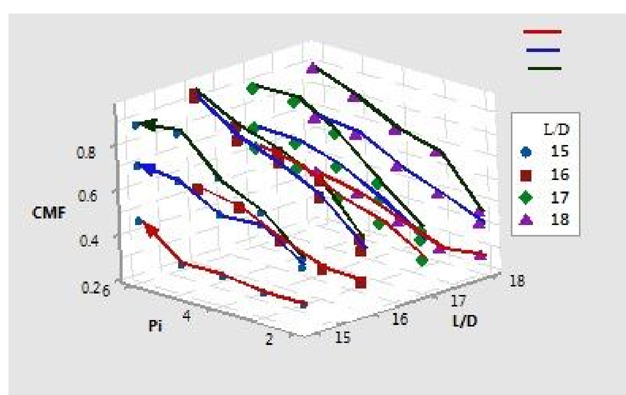


Figure 2. CMF Vs Pi Vs L/D for 30 degree Conical Valve angle.

B. Effect of $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 45,$ by varying Pressure 2, 3,4,5,6 bar on Cold mass fraction

The maximum cold mass fraction is of 0.9628 at 6 bar pressure at L/D ratio of 17, 7mm Orifice diameter , The minimum cold mass fraction is of 0.2564 at 2 bar pressure at L/D ratio of 18 , for 45 degree conical valve angle with 6 mm orifice diameter.

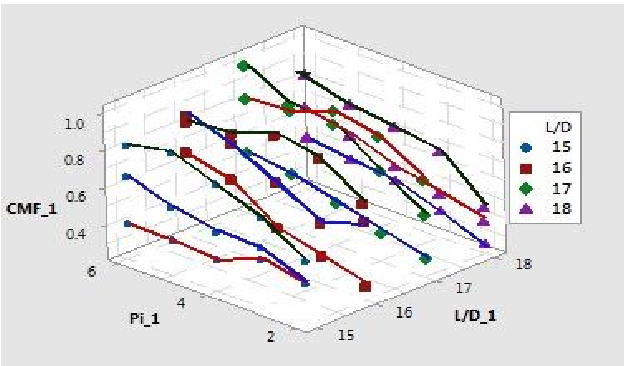


Figure 3. CMF Vs Pi Vs L/D for 45 degree Conical Valve angle.

C. Effect of $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 60,$ by varying Pressure 2, 3,4,5,6 bar on Cold mass fraction

The maximum cold mass fraction is of 0.9677 at 5 bar pressure at L/D ratio of 17 ,7mm orifice dimeter , The minimum cold mass fraction is of 0.2273 at 2 bar pressure at L/D ratio of 16 , for 60 degree conical valve angle with 5 mm orifice diameter.

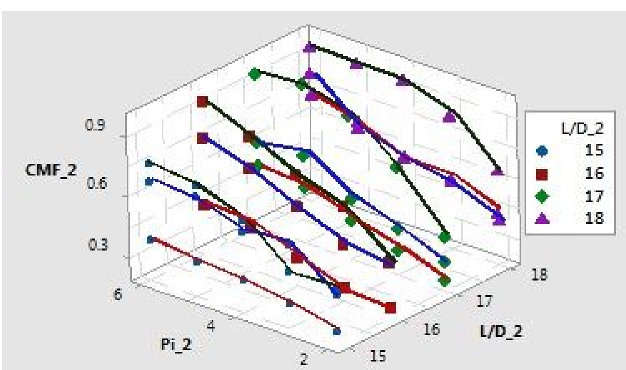


Figure 4. CMF Vs Pi Vs L/D for 60 degreeConical Valve angle.

D. Effect of $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 75,$ by varying Pressure 2, 3,4,5,6 bar on Cold mass fraction

The maximum cold mass fraction is of 0.9732 at 6 bar pressure at L/D ratio of 16, 7mm orifice diameter. The minimum cold mass fraction is of 0.2391 at 2 bar pressure at L/D ratio of 18, for 75 degree conical valve angle with 5 mm orifice diameter.

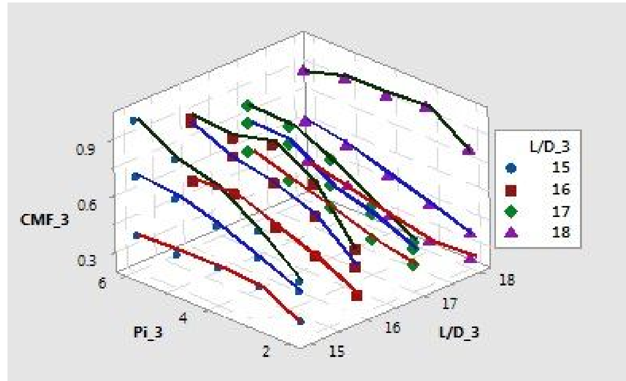


Figure 5. CMF Vs Pi Vs L/D for 75 degree Conical Valve angle.

E. Effect of $\frac{L}{D} = 15,16,17,18$ , $do = 5,6,7, \theta = 90,$ by varying Pressure 2, 3,4,5,6 bar on Cold mass fraction.

The maximum cold mass fraction is of 0.9825 at 5 bar pressure at L/D ratio of 17 ,6mm orifice diameter .The minimum cold mass fraction is of 0.3000 at 2 bar pressure at L/D ratio of 16 , for 90 degree conical valve angle with 5 mm orifice diameter.

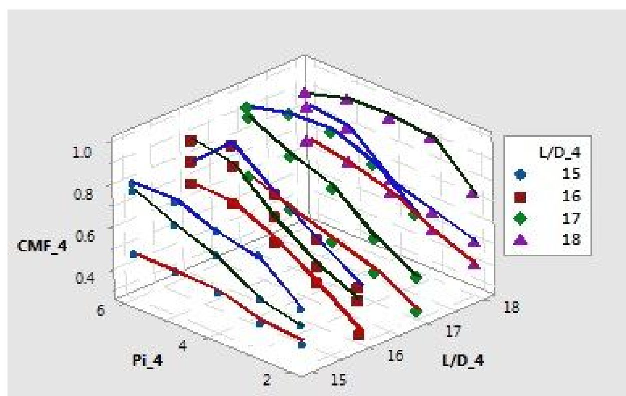


Figure 6. CMF Vs Pi Vs L/D for 90 degree Conical Valve angle.

## IV. CONCLUSION

From the discussed results it can be concluded that diverging type vortex tube gives satisfactory results. The maximum cold mass fraction is of 0.9825 at 5 bar pressure at L/D ratio of 17 ,6mm orifice diameter 90 degree conical valve angle, The minimum cold mass fraction is of 0.2273 at 2 bar pressure at L/D ratio of 16 , for 60 degree conical valve angle with 5 mm orifice diameter. The trend line also reveals that with increasing pressure cold mass fraction increases also highest cold mass fraction is obtained at the higher L/D ratio. This study and its results are limited to the fluid used number of nozzles, pressure and cold orifice diameter range, also for the effect oftubes with L/D ratio 15-18.Effect on tubes with L/D ratio beyond 18 has not been studied.

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