"Experimental Investigation of the Performance of a Vortex Tube with Snail Inlet Double Nozzle & Flat Face Conical Valve"

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ABSTRACT

Vortex tube is a simple device which takes in compressed air and splits it in to two air streams i.e. cold and hot air streams. Performance of vortex tube is considerably influenced by its geometrical and thermos-physical parameters. In this study the effect of various geometrical parameters on the performance of vortex tube has been investigated experimentally. In view of this an experimental setup is developed and which facilitate the testing of single and double nozzle vortex tube at various, design and operating parameter, Vortex tube with length to diameter ratio (L/D) 15.5,17.5, and19.5, conical valve angle (θ) 45°and 60°,cold end orifice diameter (do) 5mm,6mm and 7mm are manufactured. Vortex Tubes have been experimented with inlet pressure (p) 2 bar to 6 bar for maximum cold end temperature difference, COP and efficiency (η). Best performance is obtained for L/D 19.5, conical valve angle 45° and cold orifice diameter at 5mm.

Keywords: *vortex tube; cold mass fraction; nozzles; control valve angle; cop; geometrical parameters.*

I. INTRODUCTION

The vortex tube is a simple device which takes compressed air and splits it to two air streams i.e. cold and hot air streams. Vortex tube consists of hollow tube known as vortex chamber. Vortex chamber can be a straight, divergent or convergent tube. Vortex tube also consist of cold end with one or more no. of nozzles , hot end with hot air control plug [1] a cutaway drawing of a counter-flow vortex tube is shown in Figure 1. Compressed 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.

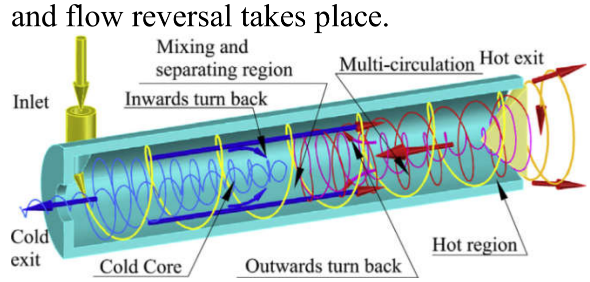

Figure 1 Cut-way of vortex tube [3]

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 stagnation temperature, respectively, than the air entering the nozzle. This effect is referred to as the temperature separation effect or energy separation [1].

1.1 Classification of Vortex Tube

There are two types of flow paths in vortex tubes such as parallel flow and counter flow. In Figure 2 and Figure 3 the schematic representation of the parallel flow and counter flow vortex tube is shown.

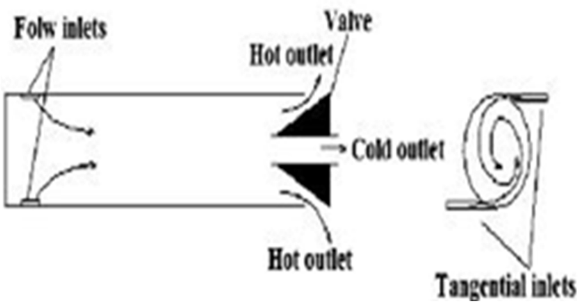

Figure 2: Parallel Flow Vortex Tube [2]

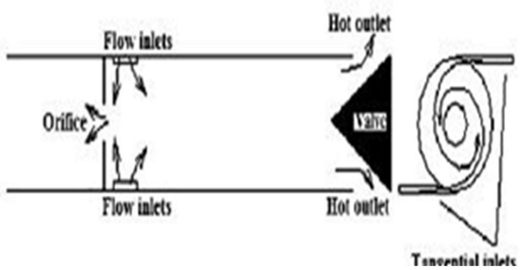

Figure 3: Counter flow vortex tube [2]

The energy separation of counter flow vortex tube is shown in Figure 3.The working principle of the counter flow vortex tube can be explained as follows: Working fluid is tangentially introduced into the vortex tube through the nozzles, makes a circular movement inside the vortex tube at high speeds, due to circular cross section of the tube, and depending on its inlet pressure and speed. A pressure difference occurs between the tube wall and the tube center caused by the friction of the fluid circling at high speeds, though the radial pressure difference also is partially responsible for the separation of the two streams. As a result, fluid in the center region transfers energy to the fluid at the tube wall, depending on the geometric structure of the vortex tube. The cooled fluid leaves the vortex tube by moving against the main flow direction, whereas the heated fluid leaves the tube in the main direction [2]

II. EXPERIMENTAL SETUP

The schematic diagram of the experimental setup used in the experiments is shown in Figure.4 Vortex tubes experimented in the present work are designed and manufactured on the basis of literature survey. Experiments are conducted on three different tubes with varying L/D ratio with two different hot end conical valve plugs and three different cold end orifices with varying cold end exit diameter are used for optimization of cold end temperature difference for pressure ranging 2-6bar.

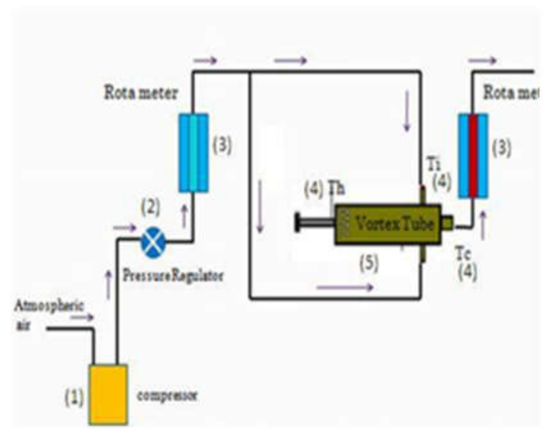

Figure 4: Experimental Setup line diagram

The experimental setup consist of a compressor, a compressed air reservoir,Rota meters, pneumatic pipes, connectors, vortex tube, electronic temperature display, thermo couples. Table 3.7 shows specifications of components used in setup. The compressed air from the compressor is supplied to the pressure regulator through the air reservoir. In pressure regulator air pressure is adjusted to the desired level with the help of pressure gauge. After pressure regulator air is supplied to the Rota meter 1 to measure the flow rate at inlet to the vortex tube. This air is then split into two to feed it to the inlet nozzles of vortex tube. By adjusting the conical valve of the tube fraction of the cold air coming out of vortex tube can be regulated. Flow of the cold air can be measured using Rota meter 2.Temperatures of cold and hot air streams is measured using thermocouples.

III. DESIGN AND CONSTRUCTIONAL DETAILS OF VORTEX TUBE

Takahama [4] has proposed the following correlations for optimized RHVT for larger temperaturedifference,given as;

$Din/D \leq 0.2$ .... (i)

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

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

Vortex tube is designed on the basis of empirical approach and literature survey Table 1 shows the value of selected parameters for the vortex tube

Table .1 Vortex tube selected geometrical parameter

Sr. No	Parameter	Selected value for Double nozzle tube	Selected value for Single nozzle tube
1	L/D	15.5,17.5,19.5	17.5
2	D	12.5mm	12.5mm
3	Dn	3mm	3mm
4	Do	5mm,6mm,7mm	5mm
5	N	2	1
6	Θ	45º, 60º	45º

IV. RESULTS AND DISCUSSION

Now experiment was performed on single inlet nozzle vortex tube and double inlet vortex tube, at various inlet pressures from 2 to 6 bars for diameters of cold end orifice 5mm and L/D = 17.5. to get best result out of it.

4.1 Effect of single and double nozzle on T_c for 5mm orifice diameter

The analysis has been done to investigate the effect of single and double nozzle for length to diameter ratio (L/D) 17.5 and 5mm orifice diameter.

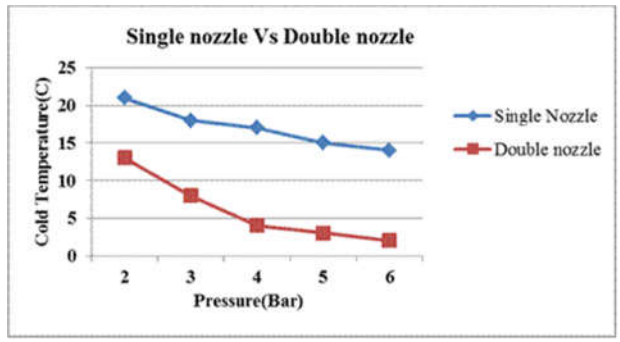

Fig.5 p Vs T_c for L/D=17.5,at d_o=5, for θ=45°

4.2 Effect of single and double nozzle on T_h for 5mm orifice diameter

Figure 6 shows the variation of cold air temperature Th with pressure Pi for tube with L/D ratios17.5 for conical valve angle θ=45°.

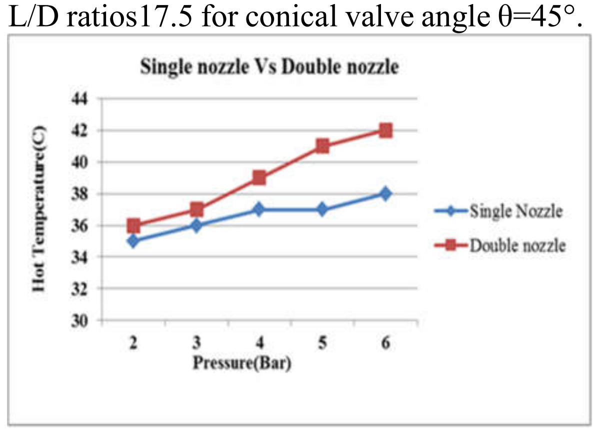

Fig.6 p Vs T_h for L/D=17.5,at d_o=5, for θ=45°

4.3. Effect of L/D ratio

The L/D ratio is varied with change in length by keeping diameter constant. The L/D ratios selected as 15.5, 17.5 and 19.5 for the constant diameter of 12.5 mm and length as 193.75mm, 218.75mm and 243.75 mm respectively.

4.3.1.Effec of L/D ratio on T_c for 5 mm orifice diameter

The analysis has been done to investigate the effect of length to diameter ratio (L/D) for three various lengths of vortex tubes and 5mm orifice diameter.

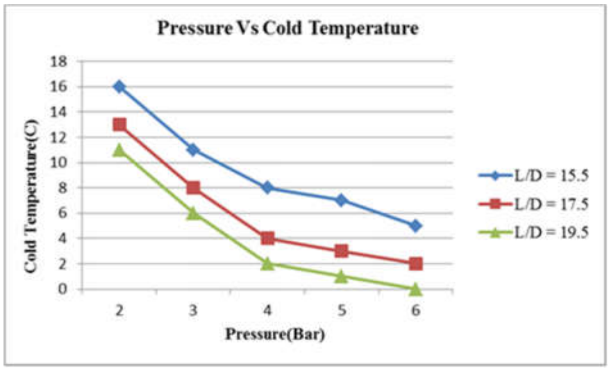

Fig.7 p Vs Tc for different L/D for θ=45°at do=5mm

4.3.2.Effec of L/D ratio on T_h for 5 mm orifice diameter

Figure 8. shows the variation of hot air temperature T_h with pressure P_i for tube with different L/D ratios for conical valve angle θ=45°.

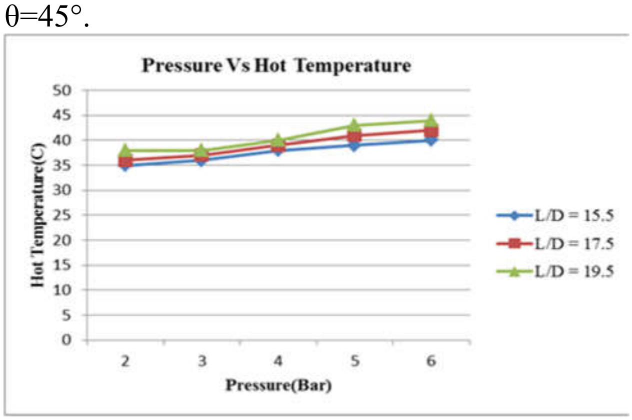

Fig.8 p Vs T_h for different L/D for θ=45° at d_o=5mm

4.3.3.Effect of L/D ratio on COP for 5 mm orifice diameter

Figure .9 shows the variation of COP with pressure Pi for tubes with different L/D ratios for conical valve angle θ=45°.

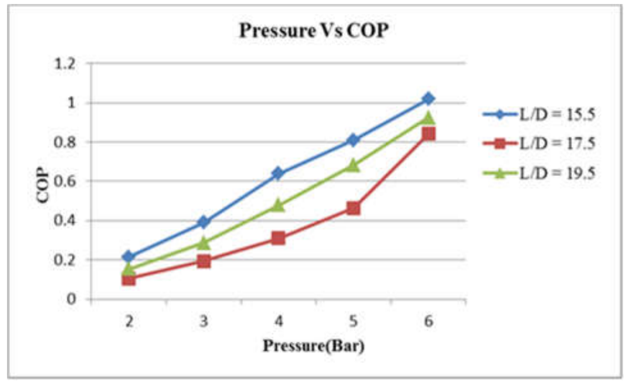

Figure .9 p Vs COP for different L/D for θ=45° at do=5mm

4.3.4.Effec of L/D ratio on efficiency for 5 mm orifice diameter

Figure .10 shows the variation of efficiency (η) with pressure P_i for tubes with different L/D ratios for conical valve angle θ=45°.

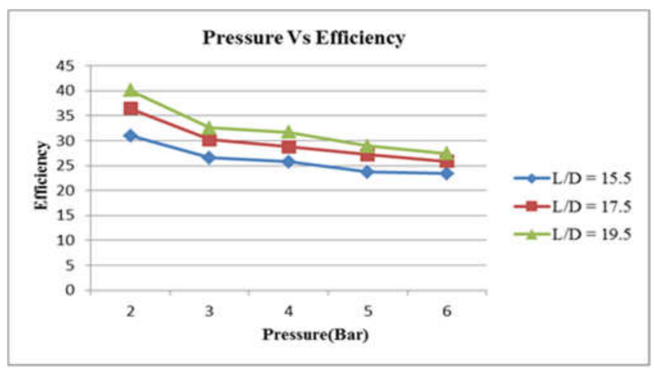

Figure .10 p vs η for different L/D for θ=45° at do=5mm

4.4. Effect of Orifice diameter

Experiment was performed on double inlet nozzle vortex tube, at various inlet pressures from 2 to 6 bars for three diameters of cold end orifice; 5 mm, 6 mm and 7mm.

4.4.1.Effect of orifice diameter on cold temperature for L/D = 19.5

Figure .11 shows the effect of d_o on T_c and for L/D = 19.5 and θ=45° for tube with d_o = 5mm, 6mm and 7mm.

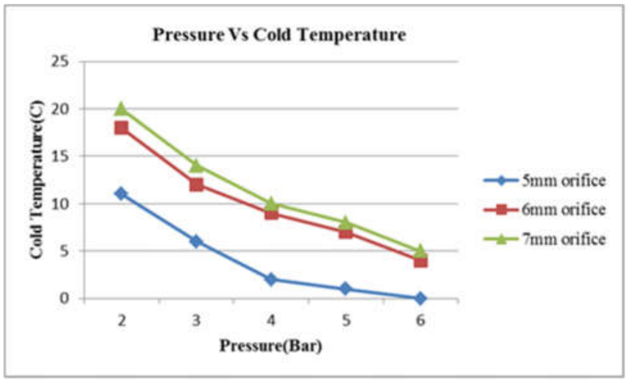

Figure .11 p Vs Tc for different do for L/D=19.5 at θ=45°

4.4.2.Effect of orifice diameter on hot temperature for L/D = 19.5

Figure .12 shows the effect of d_o on T_h and for L/D = 19.5 and θ=45° for tube with d_o= 5mm, 6mm and 7mm.

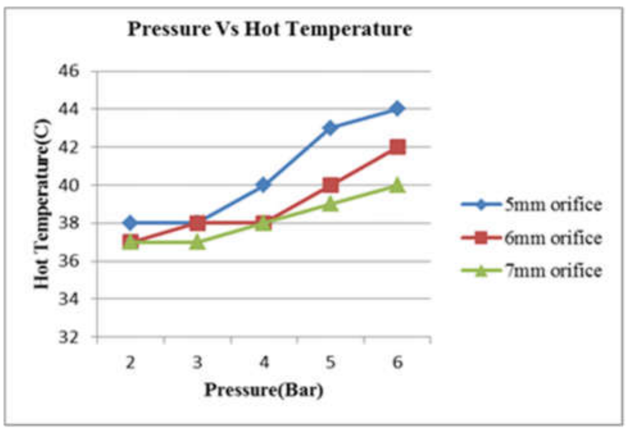

Figure .12 p vs Th for different do for L/D=17.5 at θ=45°

4.5. Effect of conical valve

The effects of the conical valve angle on thermal energy separation in a counter-flow vortex tube for two different values of the valve angles 45°and 60° has been tested. The effect of the valve angle for various values of the inlet pressure (2 to 6 bar) is carried out.

4.5.1. Effect of θ on cold temperature for L/D= 15.5

The analysis has been done to investigate the effect of conical valve angle (θ), for two conical angles of valves on Tc for tube with ratio 15.5

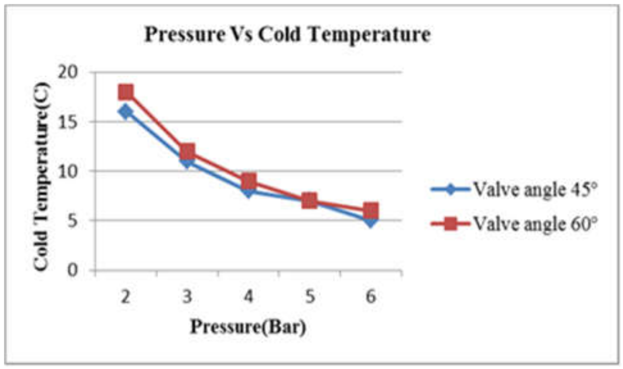

Figure 13. p vs.Tc for different θ at do= 5mm

4.5.2. Effect of θ on hot temperature for L/D= 15.5

The analysis has been done to investigate the effect of conical valve angle (θ), for two conical angles of valves on T_h for tube with ratio 15.5

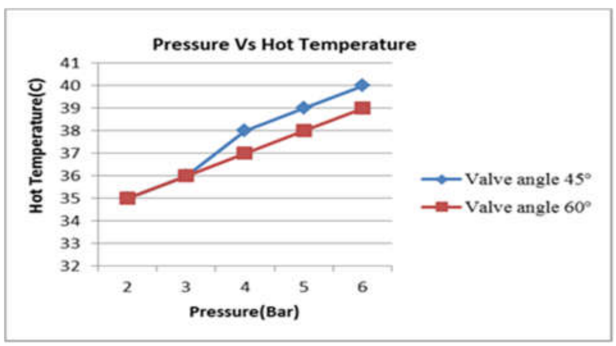

Figure 14. p vs.T_h for different θ at d_o =5mm

Figure 14. shows the variation of Th with pressure Pi for tubes with different conical valve angle θ. For 5mm orifice diameter

5. Conclusions

From the above study and analysis to investigate the effect of geometrical parameters on the performance of vortex tube following results can be concluded.

[1] Experimental investigation shows that the double inlet nozzle gives the maximum cold end temperature drop than single inlet nozzle

[2] In single nozzle vortex tube cold temperature (Tc) got 14°C whereas in double nozzle vortex tube Tc we got 2°C for L/D = 17.5 at 6 bar.

[3] As L/D ratio of vortex tube increases cold air temperature drop increases. Minimum cold temperature 0°C and maximum COP 1.089 is obtained at L/D ratio 19.5.

[4] As L/D ratio of vortex tube increases efficiency of vortex tube increases, so best efficiency of 40% is obtained for L/D 19.5.

[5] L/D ratio 19.5 gives better result than L/D ratio15.5 and L/D ratio 17.5.

[6] As cold orifice diameter increases, cold air temperature increases. Minimum temperature of 0°C and maximum hot temperature 44°C is obtained at orifice diameter 5mm.

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