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Investigations on Thermal Performance of Straight Multi-nozzle Ranque-Hilsch Vortex Tube

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Abstract

The vortex tube is a device used for generation of cold and hot air streams from compressed air. This simple device is very efficient in separation of air streams into two different temperatures streams. Cold air coming out of vortex tube can be used for air conditioning and refrigeration purpose. Cold mass fraction of vortex tube is considerably influenced by its thermo physical and geometrical 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 with 4 and 6 inlet nozzle. Vortex tube with length to diameter ratio (L/D) 15'0°, 15'4°, 16'4°, 17'4° and 18'4° where 0° and 4° are diverging angle, cold end orifice diameter(do) 5, 6 and 7mm have been experimented with inlet pressure(p) 2, 3, 4, 5 and 6 bar for optimum Cold mass fraction. The maximum cold mass fraction for 4 inlet nozzle is obtained as 0.99047 at 6 bar pressure at L/D ratio of 15'0, 6 mm orifice diameter and 60 degree conical valve angle. The minimum cold mass fraction is of 0.05 at 2 bar pressure at L/D ratio of 15'0, 7 mm orifice diameter and 75 degree conical valve angle. The maximum cold mass fraction for 6 inlet nozzle is obtained as 0.952 at 6 bar pressure at L/D ratio of 15'0, 5 mm orifice diameter and 30 degree conical valve angle. The minimum cold mass fraction is of 0.044 at 2 bar pressure at L/D ratio of 15'0, 6 mm orifice diameter and 45 degree conical valve angle.

Keywords:*Cold mass fraction, Refrigeration, Vortex tube*

1. Introduction

In 1930s Georges J. Ranque discovered the phenomenon of temperature separation in a swirling vortex flow. He proposed the reasons for the temperature separation in the tube are compression and expansion of air in the tube [1] [2]. Later, the geometrical parameters and performance optimization of the tube were investigated by Hilsch [3]. He added the effect of inner friction to the Ranque's model of compression and expansion.

Several different studies have been conducted to describe the energy separation phenomenon and maximum cooling effect. The effect of working tube radius on vortex tube performance and the optimum working tube radius has been determined by Rafiee [4]. Seyed and Sadeghiazad [4], carried out an experimental study about characteristic analysis of the performance of a counter flow RHVT with regard to control valve angle. Kırmacı [5], examined the influence of orifice nozzle number and inlet pressure on heating and cooling performance of vortex tube using air and oxygen as test fluids. His results indicated that the temperature difference between the hot and cold fluid decreases with increasing nozzle number.

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°. Vaidyanathan and Prabhakaran [7] 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. Chang et al. [8] carried out experiments to investigate the influence of divergence angle on the performance of vortex tube and states that the performance of vortex tube can be improved by using a divergent hot tube. So divergent angle 0° and 4° were chosen and L/D is selected in close range 15 to 18 with 4 and 6 inlet nozzle. Orifice diameter ranges from 5 to 7 mm and conical valve angle of 30°, 45°, 60°, 75° and 90°. Pressure range for experiment was 2 to 6 bar.

2. Experimental Method

2.1 Experimental Setup and Procedure

Schematic diagram was shown in Fig. 1. It comprises of air compressor, pressure regulator, rotameter, air splitter and vortex tube.

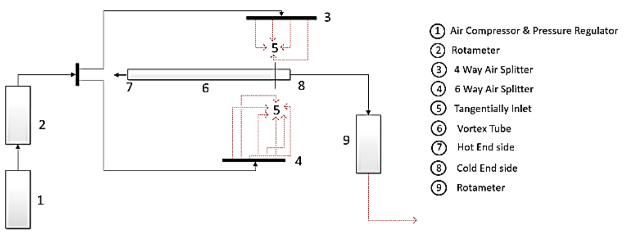


Figure 1 Block Diagram

Experiment was conducted on vortex tube having divergent angle of 0 and 4 degree. Inlet nozzle of 4 and 6 inlets was selected. L/D ratio selected was 15, 16, 17 and 18. Orifice diameter of 5mm, 6mm and 7mm was used and 30°, 45°, 60°, 75° and 90° conical valve angle was selected.

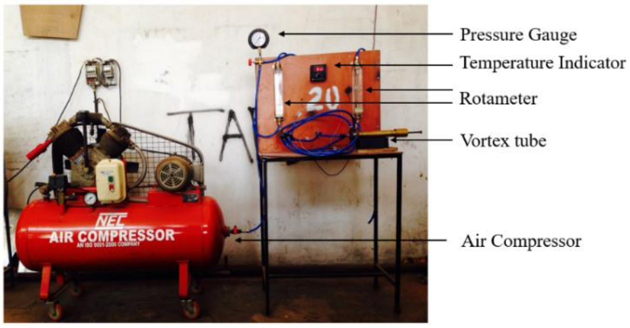


Photo 1 Experimental Setup

Photo 1 shows the experimental setup. The required amount of compress air was release in the experimental setup via pressure regulating valve and went to rotameter where mass flow rate was measure. The compress air goes to air splitter where it gets divided into 4 or 6 channel as per requirement. Then it goes to vortex tube either by 4 nozzle inlet or 6 nozzle inlet as per experimentation. The conical valve angle at hot end side was adjusted with the help of screw arrangement to get lowest cold air temperature at cold end side. The mass flow rate of cold air was measure with another rotameter attached downstream of the setup.

Photo 2 Vortex Tube of different L/D ratio with different diverging angle, different conical valve angle and different number of inlet nozzle

Photo 2 shows different set of vortex tube used in the experiment. Set consist of vortex tube of different L/D ratio with divergent angle as 15,0°, 15,4°, 16,4° , 17,4° and 18,4°. Different set of 4 nozzle inlet and 6 nozzle inlet having different orifice diameter was also shown. The screw arrangement at hot end side along with different conical valve angle was also include.

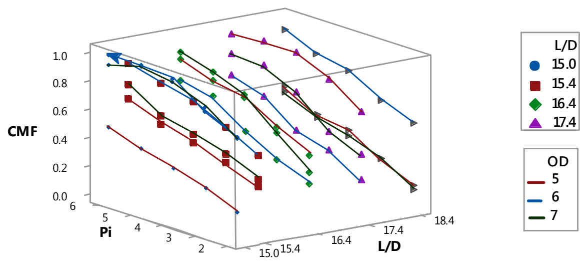
2.2 Data Reduction

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

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

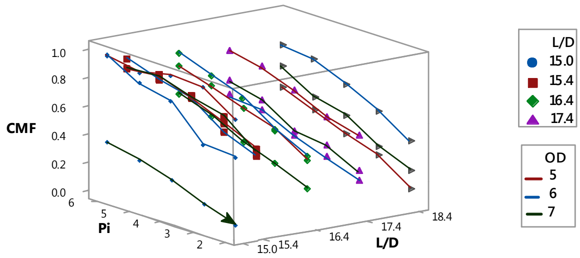
3. Results and Discussion

The maximum CMF achieved for 4 nozzle inlet was 0.99047 at L/D ratio 15 with divergent angle of 0° which was a straight tube, orifice diameter of 6 mm and conical valve angle of 60° at 6 bar inlet pressure. Graph 1 shows various CMF value achieved for same Pi and OD value for different L/D where maximum CMF for 4 nozzle inlet was achieved.



Graph 1 CMF vs. Pi vs. L/D for 4 Nozzle Inlet at 60 degree Conical Valve Angle

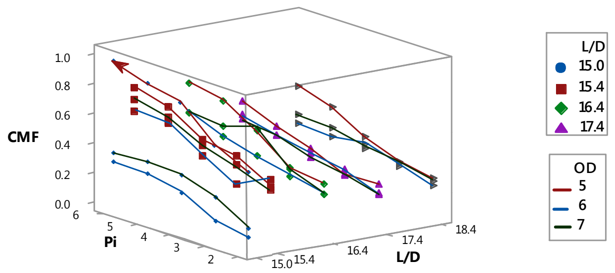
The minimum CMF achieved for 4 nozzle inlet was 0.05 at L/D ratio 15 with divergent angle of 0°, orifice diameter of 7 mm and conical valve angle of 75° at 2 bar inlet pressure. Graph 2 shows various CMF value achieved for same Pi and OD value for different L/D where minimum CMF for 4 nozzle inlet was achieved.



Graph 2 CMF vs. Pi vs. L/D for 4 Nozzle Inlet at 75 degree Conical Valve Angle

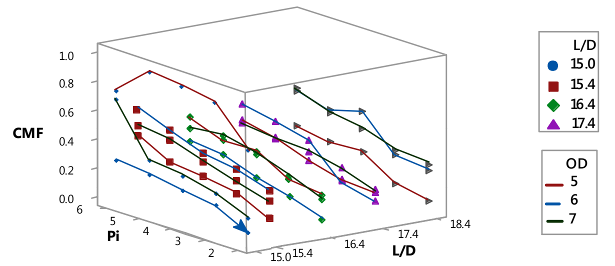
For 6 nozzle inlet, the maximum CMF achieved was 0.952 at L/D ratio 15 with divergent angle of 0° which was a straight tube, orifice diameter of 5 mm and conical valve angle of 30° at 6 bar inlet pressure. Graph 3 shows various CMF value achieved for same Pi and

OD value for different L/D where maximum CMF for 6 nozzle inlet was achieved.



Graph 3 CMF vs. Pi vs. L/D for 6 Nozzle Inlet at 30 degree Conical Valve Angle

The minimum CMF achieved for 6 nozzle inlet was 0.044 at L/D ratio 15 with divergent angle of 0°, orifice diameter of 6 mm and conical valve angle of 45° at 2 bar inlet pressure. Graph 4 shows various CMF value achieved for same Pi and OD value for different L/D where minimum CMF for 6 nozzle inlet was achieved.



Graph 4 CMF vs. Pi vs. L/D for 6 Nozzle Inlet at 45 degree Conical Valve Angle

4. Conclusions

Straight vortex tube which has divergent angle of zero degree proved to be more capable of producing the desire result of achieving higher CMF value as compare to vortex tube having divergent angle of four degree. It was also noticed that the minimum CMF value was achieved with the same straight vortex tube. This suggest that the separation of cold and hot air stream in vortex tube was achieved best in straight vortex tube. It was also found that the maximum and minimum CMF value achieved was higher for lower number of inlet nozzle. This could be because of turbulence level which was greater for higher number of inlet nozzle as compare to lower number of inlet nozzle. This result in better cold and hot air stream generation when lower number of inlet nozzle was used.

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