Experimental Investigation of Multi Nozzle Vortex Tube

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Abstract— Ranque-Hilsch vortex tube (RHVT) is a simple device capable of splitting a compressed gas stream into a cold and a hot outlet stream without any peripheral source of energy supply. This paper presents results of Maximum coefficient of performance at given L/D ratio of 22.5 by varying cold mass fraction from 0.1 to 0.9 for 1,2,3,4 number of nozzles carried out on Ranque–Hilsch vortex tube (RHVT). Different parameters such as cold mass fraction, conical valve angle 30º, 45º, 60º, 90º, number of nozzles are investigated. It shows that coefficient of performance increases with increase in cold mass fraction. Also it is observed that valve angle has significant effect on performance of vortex tube. At the end of study it is found that the maximum coefficient of performance is 0.1747 at valve angle 30^0 for nozzle 4.

Keywords— Ranque-Hilsch, Vortex Tube, Temperature Separation, Cold mass fraction

I. INTRODUCTION

Vortex tube is a simple thermo-mechanical tool which produces hot and cold air streams. It is simple and compact to fabricate as it contains no moving parts. It gives a refrigeration effect so that it becomes an attractive means for researchers. Vortex tube consists of inlet nozzle, vortex chamber, cold end orifice and hot end with diffuser and tube. It is based on phenomenon of separation of compressed air into low temperature section and hot temperature section by means of energy separation. When high pressure air is tangentially enforced into vortex tube through inlet nozzles, a swirling flow is created inside the vortex tube. When gas swirls towards the center of tube it is expanded and cooled. In the vortex tube part of air passes towards the hot end and another part exists through cold exhaust directly. The part of gas in vortex tube reverses to the obstruction created and move from hot end to cold end. At hot end gas escapes at higher temperature and that at cold end gas escapes at lower temperature than inlet temperature.

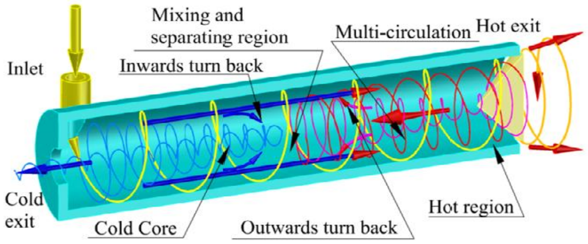

Fig. 1: Structure of vortex tube with flow pattern within the tube [14]

Georges J. Ranque discovered the phenomenon of temperature separation in a swirling vortex flow in 1930. Since then it has been known as the Ranque effect and has been a popular research topic within the scientific community. Ranque anticipated that compression and expansion effects are the main reasons for the thermal severance in the tube [1]. Later, the geometrical parameters and performance optimization of the tube were investigated by Hilsch [2]. He added the effect of inner friction to the Ranque's model of compression and expansion. The vortex tube is also referred to as the Ranque vortex tube (RVT), Hilsch vortex tube (HVT), Maxwell–Demon vortex tube (MDVT)and Ranque–Hilsch vortex tube (RHVT).

II. LITERATURE REVIEW

Researchers carried several efforts to understand the flow behavior and energy transfer mechanism take place in the vortex tube. In literature experimental and numerical investigations are available given as follows,

Mete Avcı [3] carried out an experimental study find out effects of nozzle aspect ratio and nozzle number on performance of vortex tube. Under different inlet pressures single nozzle set with AR 0.25, 0.44 and 0.69 and nozzles 2,3 were tested. Working media used is dry air. The Experimental results reveal that increase in nozzle aspect ratio leads to larger mixing zone, which decreases temperature difference between cold end and hot end. Single nozzle vortex tube gives better performance than 2 and 3 nozzles.

Eiamsa-ard S. et al. [4] performed the effect of the snails with the inlet nozzle number of 1,2, 3 and 4 nozzles offer higher temperature separation and cooling efficiency in the RHVT as compared to the conventional tangential inlet nozzles (4 nozzles). This is because the use of the snail instead of the conventional tangential inlet nozzles can reduce pressure loss and thus provides stronger vortex/swirling flow in the RHVT. The obtained results suggest that to achieve higher cold air temperature reduction and cooling efficiency, the cold mass fraction should be adjusted to be around 30 to 40%. As such a condition, the mixing of the hot air and the cold air within the RHVT can be suppressed.

K.Dincer et.al.[5] were carried out experimental investigation of performance of hot cascade type Ranque-Hilsch vortex tube. In this study three Ranque-Hilsch vortex tube were used which have 9 mm inside diameter and length divided by diameter ratio was 15. There performance was examined as one of the classical RHVT. Performance analysis was according to temperature difference between the hot outlet and the inlet. The Δ T hot values of hot cascade type Ranque Hilsch vortex tubes were greater than Δ T hot, values of classical RHVT which were determined experimentally.

Kiran D.Devade and A.T.Pise [6] performed experimental investigation on short divergent vortex tube for producing refrigerant effect. Experimentation had been performed with varying their parameters of vortex tube to enhance the refrigeration effect. The vortex tube of short length having L/d = 6 and 2 nozzles of equal diameters 2.5 mm diametrically opposite having divergent hot end was developed. Vortex tube was tested with conical valve 30^0, 45^0, 60^0, 90^0 at pressures ranging from 2 to 6 bars. Short length vortex tube was found reasonable temperature drop as compared to other ie. upto 11^0C for a 45^0 valve at 6 bar pressure i.e, total drop of 36 percentage in temperature and the rise of 12 % is observed. The cold mass fraction was held constant at 0.8. The cooling effect was observed 53.24 J and COP was 0.05656.

Burak markal et. al .[7] conducted experimental study to investigate the effects of conical valve angle on thermal energy separation in counter flow vortex tube. Experiment carried out on vortex tube of valve angle 30^0, 45^0, 60^0, 75^0 and by changing the inlet pressures from 3 to5 bars in 6 steps. The L/D ratios of tubes were 10, 20, 30 and 40. The length of helical flow generator were 10 mm, 15 mm, 20 mm, 25 mm and 30 mm taken. The performance of vortex tube was comparatively investigated as the function of cold mass fraction. It was found that the valve angle and L/D ratio has great significance on the performance of vortex tube than the length of helical swirl flow generator height.

N Agarwal et.al. [8] Performed experimental investigation of vortex tube using natural substances. An experimental investigation was carried out with three different working fluid air, nitrogen and carbon dioxide. For the testing vortex tube of L/D 12.5, 17.5 and 22.5, inlet nozzle diameter 2 mm diameter of tube 10 mm, cold end diameter 3 mm, 4mm, 5mm, and conical valve angle 45^0 were used. The result shows that the maximum cold temperature drop obtained at 0.6 cold mass fractions. At L/D ratio 17.5 optimal thermal performance was observed. The COP and cooling capacity both increased with cold mass fraction upto 0.6. Vortex tube performed better performance with carbon dioxide than nitrogen and air.

K.D. Devade and A.T. Pise [9] performed a comparative study of short state divergent vortex tube and long convergent vortex tube. Vortex tube of L/D ratio 8 as a straight divergent type tube and L/D 14 as convergent type tube was used. The tube were experimented with supply pressure of 2,3,4,5 bar and orifice diameter 5, 6, 7 were used to evaluate the effect of L/D ratio hot and conical valve diameters and orifice diameters along with positive and negative cone angle. The hot tube cone angle was maintained at 60 for both converging and diverging type tube. It was found that converging type tube performance was optimizing cold mass fraction as well as cold length temperature out of the two converging type tube was more efficient and produces higher COP of 0.202 than that of straight divergent type of tube which produces COP of 0.0567.

Hemant V Darokar et. al .[10] proposed a new geometry for cold end side which has the form of convergent helical nozzles 8 mm to 3 mm, divergent angle 60^0 at hot end tube with length 225 mm and diameter 12.5. Cold end were manufactured with 7 mm orifice diameter and 6 no. of nozzles. The effect of inlet pressure (2 bars to 5 bars) in step of 1 bar, conical valve 30^0, 45^0, 60^0, 90^0 on the performance of vortex tube was analyzed. At the end of study maximum COP and isentropic efficiency found to be 0.376 and 23 % for 45^0 conical valves at 5 bar pressure.

Kiran D.Devade and A.T. Pise [11]: Performed experimental investigation on effect of cold orifice diameter and geometry of hot end valve on performance of converging type Ranque Hilsch vortex tube. They have raveled two different approaches one for attaining high cold mass fraction and other for attaining cold end temperature. The geometry was different for both. The result show that increase in cold mass fraction and cold end temperature. The overall change in cold end temperature drop was 63 %. The COP of converging tube increased 102 % than straight diverging tube for conical valve 40^0, supply pressure 5 bars and cold orifice diameter 7 mm lowest temperature observed i.e, 5^0C at CMF 0.9.

Upendra Behra et. al [12] carried out CFD analysis and experimental investigation for optimizing the parameters of Ranque-Hilsch vortex tube, different types of nozzle profile are evaluated by CFD analysis, swirl velocity, axial velocity, radial velocity components and flow pattern including secondary circulation flow had been evaluated. The optimum cold end diameter, L/D ratio and maximum hot gas temperature and minimum cold gas temperature obtained with CFD.

Eiamsa-ard S. et al. [13] reported the effects of various inlet pressure and different working gases (air, oxygen, and nitrogen) on temperature different in a tube were studied. The increase of the number of inlet nozzles leads to higher temperature separation in the vortex tube. Using a small cold orifice (d/D= 0.2, 0.3, and 0.4) yields higher backpressure. Optimum values for the cold orifice diameter (d/D), the angle of the control valve (f), The length of the vortex tube (L/D) and the diameter of the inlet nozzle (d/D) are found to be approximately d/D=0.5, f=501, L/D=20, and d/D=0.33, respectively, which are expected to be fruitful for vortex tube designers.

III. PROBLEM STATEMENT

In the present work it is decided to experimentally verify the performance of vortex tube in the atmospheric conditions for good range of various working and geometrical parameters. The dependency of temperature and refrigeration effect is obtained by the experiment. For this experiment a vortex tube of L/D ratio 22.5, cold orifice diameter 5mm is used. Different parameters are experimentally tested for 1, 2, 3 and 4 nozzles with different valve angles (30^0, 45^0, 60^0, and 90^0) at different cold mass fraction 0.1 to 0.9.

IV. DATA REDUCTION

Performance of vortex tube depends upon cooling and heating effect given as below

$$\Delta T_c = T_{in} - T_c \qquad (1)$$

$$\Delta T_h = T_h - T_{in} \qquad (2)$$

The total temperature difference obtained with addition of equations 1 and 2

$$\Delta T = T_h - T_c \qquad (3)$$

Cooling effect which is produced by a machine is known as refrigeration effect and is calculated as

$$R_E = \dot{m}_c * C_{P_C} * (T_{in} - T_c) \qquad (4)$$

Compressor work is the mechanical energy provided for cooling and heating and is given as

$$W_{comp} = \dot{m}_a * R * T_{in} * ln\left(\frac{P_s}{P_i}\right) \qquad (5)$$

Vortex tube performs both function as heat pump and a cooling device. The efficiency is expressed as coefficient of performance of vortex tube given as function of refrigeration effect and compressor work.

$$COP = \frac{R_E}{W_{comp}}$$

V. DESIGN AND CONSTRUCTIONAL DETAILS

Vortex tube is manufactured in material brass because brass has good thermal conductivity. The constructional details are as given in Table 1

Table 1. Design details of vortex tube

Sr. No.	Design Parameters	Dimensions and numbers
1	Diameter of vortex tube, D	13 mm
2	Length of vortex tube, L	292.5 mm
3	L/D ratio	22.5
4	Diameter of nozzle inlet	3 mm
5	Number of inlet nozzle	1,2,3,4
6	Conical valve angle	30^0, 45^0, 60^0, 90^0
7	Cold mass fraction	0.1to 0.9
8	Cold end orifice diameter	5 mm

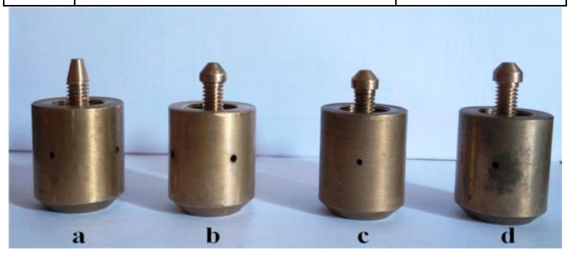

Fig. 2: Conical valve a) 30^0 b) 45^0 c) 60^0 d) 90^0


Fig. 3: Inlet nozzles used for experimentation

VI. EXPERIMENTAL SET UP

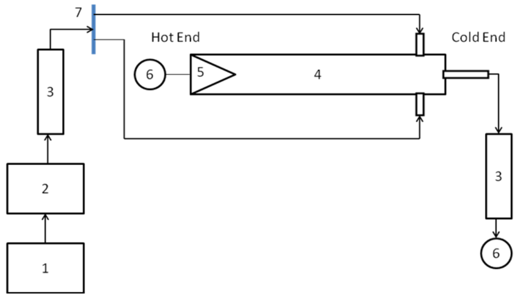

Fig. 4: Block diagram of Experimental Setup

Block diagram of test rig is shown above. It comprises of Air compressor (1), FRL unit (2), air rotameter (3), air splitter (7), vortex tube (4), conical valve (5), Temperature indicator (6), and hot and cold end side. In the present study compressed air will be inducted into the inlet of nozzles and thus air enters tangentially into the vortex chamber through inlet nozzles. The air will swirl inside the vortex chamber and thus energy separation is created inside tube and stream of hot air and cold air is generated and thus the thermocouples are placed at hot end and cold end which will indicate temperatures of hot and cold end respectively. Thus by changing nozzles and tubes data will be recorded simultaneously. The mass flow rate at inlet and outlet will be measured and recorded to calculate cold mass fraction.

VII. RESULT AND DISCUSSION

a) The Effect of CMF on COP for $\theta = 30^0$

Figure 5 shows the relation between cold mass fraction and COP. It can be seen that the maximum COP get at nozzle 4, because as nozzle number increases it enhances the energy separation because of intense swirl produced and the minimum COP found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 22.5 and valve angle 30^0 kept constant. It is observed that COP increases with increase in nozzle number; the maximum COP found is 0.1747.

This can be due to as cold mass fraction increases the cooling efficiency also increases. Here the maximum temperature drop is obtained at cold mass fraction 0.9 as stagnation point is farthest from cold end i.e, nearer to hot end where energy separation takes place.

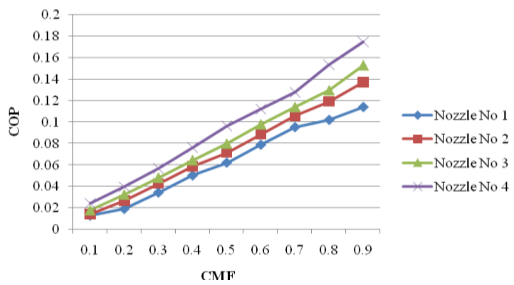

Fig.5: Variation of COP vs. CMF at $\theta = 30^0$

b) The Effect of CMF on COP for $\theta = 45^0$

Figure 6 shows the relation between cold mass fraction and COP. It can be seen that the maximum COP get at nozzle 4, at cold mass fraction 0.9 and the minimum COP found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 22.5 and valve angle 45^0 kept constant. It is observed that COP increases with increase in nozzle number; the maximum COP found is 0.1442. Here the maximum temperature drop is obtained at cold mass fraction 0.9 as stagnation point is farthest from cold end i.e, nearer to hot end where energy separation takes place due to cold mass fraction is more the stagnation point is near to hot end, also as nozzle number increases it enhances the energy separation because of intense swirl produced so increases thermal performance of vortex tube.

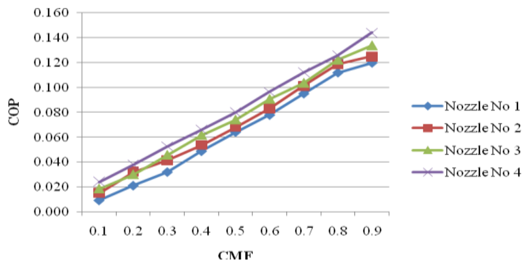

Fig.6: Variation of COP vs. CMF at $\theta = 45^0$

c) The Effect of CMF on COP for $\theta = 60^0$

Figure 7 shows the relation between cold mass fraction and COP. It can be seen that the maximum COP get at nozzle 4, at cold mass fraction 0.9 and the minimum COP found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 22.5 and valve angle 60^0 kept constant. It is observed that COP increases with increase in nozzle number; the maximum COP found is 0.1410. The value of COP increases with increase in CMF because the maximum temperature drop is obtained at cold mass fraction 0.9 as stagnation point is farthest from cold end end i.e., nearer to hot end where energy separation takes place due to cold mass fraction is more the stagnation point is near to hot end. As nozzle number increases it enhances the energy separation because of intense swirl produced so increases thermal performance of vortex tube.

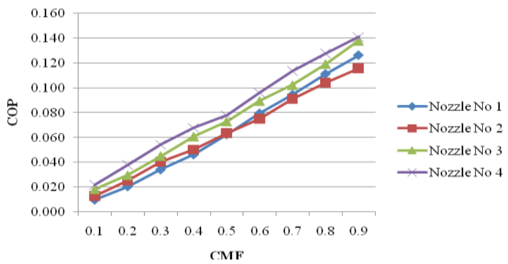

Fig.7: Variation of COP vs. CMF at θ = 60^0

d) The Effect of CMF on COP for θ = 90^0

Figure 8 shows the relation between cold mass fraction and COP. It can be seen that the maximum COP get at nozzle 4, at cold mass fraction 0.9 and the minimum COP found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 22.5 and valve angle 90^0 kept constant. It is observed that COP increases with increase in nozzle number; the maximum COP found is 0.1527. Here the maximum temperature drop is obtained at cold mass fraction 0.9 as stagnation point is farthest from cold end i.e, nearer to hot end where energy separation takes place. As nozzle number increases it enhances the energy separation because of intense swirl produced so increases thermal performance of vortex tube.

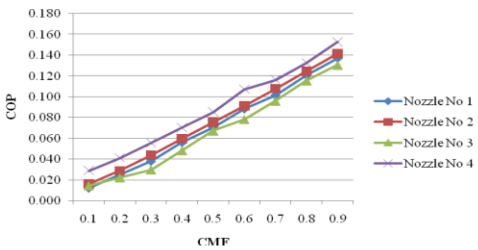

Fig.8: Variation of COP vs. CMF at θ = 90^0

e) The Effect of CMF on COP for L/D ratio 22.5

Figure 9 indicates the effect of valve angle and cold mass fraction on COP for vortex tube of L/D 22.5 at constant pressure 2 bar. It can be seen from below graph that COP is maximum at 30^0 valve angle and it is minimum at 60^0 valve angle. The maximum COP is 0.1747 at 30^0 valve angle and inlet nozzle number 4 with cold mass fraction 0.9.

The reason for this can be because at higher valve angles, flow becomes more unstable because of sudden change in direction of hot streams also position of stagnation point also changes which indirectly affect the thermal performance of tube.

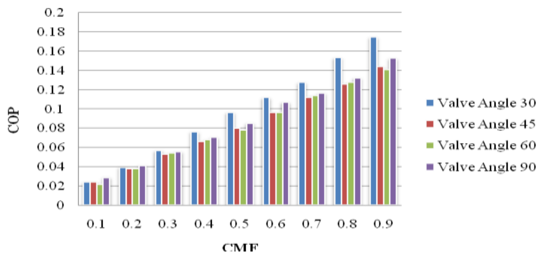

Fig.9: Variation of COP vs. CMF for different valve angle at L/D ratio 22.5

VIII. CONCLUSION

The following conclusion has been drawn from the experimentation:

1. Coefficient of Performance of vortex tube increases with increase in cold mass fraction. It is found maximum for CMF 0.9. It shows good agreement with previous work.

2. For L/D 22.5 coefficient of performance increases with increase in inlet nozzle number. It is maximum at nozzle 4.

3. Conical valve angle has significant effect on COP. For valve angle 30^0 COP is maximum.

The literature shows that increase in number of nozzles improve the temperature separation and the performance of vortex tube. Hence above results satisfy the same. As the cold mass fraction increases coefficient of performance increases and reaches the maximum value upto certain value and then it decreases, but in above study it is found that as cold mass fraction increases coefficient of performance also increases, this can be due to effect of stagnation point on vortex tube. Hence study on higher L/D ratios is required in order to find out the better relations between cold mass fraction and coefficient of performance which can justify the above trends and also more studies can be done by using different working fluids to obtain better performance results

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