Investigation of Vortex Tube by Changing Diffuser Angle

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Abstract

Vortex tube is a non-conventional device which is capable of separating hot and cold gas stream from an inlet gas stream with proper pressure energy. Number of researches has been carried out in order to identify the parameters which affect Vortex tube performance. The performance of the vortex tube depends on types of parameters, firstly inlet air 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 diffuser angle and also material of vortex tube affects Coefficient of Performance. The RHVT (Ranque Hilch Vortex tube) has been used for many appliances in different engineering applications. Because of its compact design and low maintenance requirements, it is very popular in cooling and heating processes. Despite its simple geometry, the mechanism that produces the temperature separation inside the tube is fairly complicated. There is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. In this paper we have experimentally studied the pressure vs. temperature graphs and result conclusions for different valve angles of diffuser and the material used is cast iron.

Keywords — *Cold-Hot Tube, Energy Separation mechanism, Ranque-Hilch Vortex Tube, Temperature Separation Tube.*

I. INTRODUCTION

The vortex tube has been firstly invented accidently by the scientist Ranque in 1928 and it is firstly experimentally studied by the scientist Hilch in 1942. Hence the vortex tube is also be known as the Ranque Hilch vortex tube (RHVT). The separation mechanism inside the vortex tube remains until today not completely understood since there is no theory so perfect which gives the satisfactory explanation of vortex tube.

II. WORKING

Compressed air at high pressure enters the vortex tube through tangential nozzle where the flow gets accelerated. Due to tangential entry, the air has high velocity and rotates at very high speed. Thus the air has whirling or vortex motion by using six slots CI spinner in vortex chamber. The end of the cold pipe, which built up with the vortex chamber, is fitted with a washer that has the half the diameter of the pipe. Washers with different diameter are also used to adjust the system. Thus cold air is produced at right end and hot air is produced at the left end of the vortex tube.

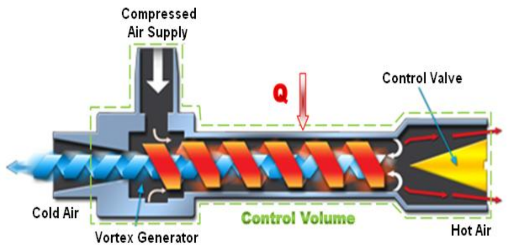

Fig. No. – 1 Vortex Tub

III. LITERATURE REVIEW

S. Rejin et al. [1] in the paper Experimental Analysis on Vortex Tube Refrigerator Using Different Conical valve Angles, this paper describes the experimental investigation on vortex tube refrigerator with different conical valve angle at the hot side and the effect of cold orifice diameter at cold side on the performance of vortex tube refrigerator. The experiment was started from the design and manufacturing stage of a vortex tube refrigerator. Finally he has observed from the study that as the cone angle decreases from 45° to 10° there will be a temperature difference of 3.5°C without altering the inlet conditions. It gives strong evidence that apart from the effect of pressure, orifice diameter, nozzle diameter, the hot end area, the hot end valve angle have much significance in temperature reduction process.

Upendra S. Gupta et al. [2] various sources producing waste heat and pressure energy are reviewed in this paper and application of a vortex tube setup to generate temperature difference from these waste energy sources according to input pressure is analysed. Most of the major heat and pressure energy sources provide energy in ranges that can be easily harnessed using newer technologies like vortex tube setups. Major technical problem with current energy recovery modes is varying pressures and temperatures of gases used as working agent. This paper aims to study various sources of waste heat and pressure energy and analyse the effectiveness of a counter flow vortex tube applied to recover waste energy.This study attempts to improve waste heat recovery technologies.

Rajarshi Kar et al. [3] in her paper she has given classifications of the vortex tube. Mainly there are two types of vortex tube. Both of these are currently in use in the industry. The more popular is the counter-flow vortex tube. On the other hand, the uniflow vortex tube does not have its cold air orifice next to the inlet. The RHVT has been used for many decades in various engineering applications. Because of its compact design and little maintenance requirements, it is very popular in heating and cooling processes.

H. M. Skye et al. [4] this paper presents a comparison between the performance predicted by a computational fluid dynamic (CFD) model and experimental measurements taken using a commercially available vortex tube. Specifically, the measured exit temperatures into and out of the vortex tube are compared with the CFD model. The data and the model are both verified using global mass and energy balances .Vortex tubes are typically used for their cooling capability in processes such as welding, brazing, solidifying polymers, and controlling air climate .While somewhat inefficient as a cooling device, vortex tubes can be useful in certain situations as they are small, simple to make and repair, and require no electrical or chemical power input.

Heishichlro Takahama et al. [5] In his paper he has given the measurements of swirling flows in the vortex chambers several cross-sections at different axial distances, and radial, tangential, and axial velocity components were calculated. Typical-resultant values are given. The intensity of the swirl decreases in the direction of the flow in straight chambers, but increases in divergent chambers with relatively large divergent angles. In order to obtain a high energy-separation performance in straight chambers, it is necessary t h a tL a lOO flo (L = the chamber length, Do = the inner diameter of the chamber): the shorter the chamber length, the lower the performance. The efficiency of energy-separation in divergent chambers was higher than that in straight chambers of the same length.

Sumit Choudhary et al. [6] this paper describes the experimental study on vortex tube made up of CPVC material which is cheaper and lighter than conventionally used metals. This paper also depicts the numerical simulation of the same by using CFD. This paper reveals investigations to understand the heat transfer characteristics in a vortex tube with respect to various parameters. He has given the number of applications in his paper that the vortex tube is applied easily where there is ready availability of compressed air. Due to no moving parts and maintenance free utilization it could be used where safety matters much. It could be replacement for refrigerants as it is absolutely eco-friendly.

Suraj S Raut et al. [7] this paper discusses the experimental investigation of effect of above working parameters on the performance of Ranque-Hilsch vortex tube. The Chlorinated Poly Vinyl Chloride (CPVC) material has been used for manufacturing of the vortex tube as it has lower thermal conductivity than metals and less fluid friction losses. In this experimental study the performance of vortex tube has been tested with compressed air at various pressures from 5-10 bar, which supplied through two tangential inlet nozzles. The L/D ratio of hot side tube varied from 10-50 and cold mass fraction varied from 0.20 – 0.80. He described that Performance of vortex tube 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).

A.S. Gadhave et al. [8] 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 and testing of the vortex tube as it has better less fluid friction losses and thermal efficiency. In his experimental study the performance of vortex tube has studied with compressed air at different pressures from 2-8 bars, 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. An experimental study has been conducted to determine the effect of working parameters such as inlet air pressure, Cold mass fraction and length of hot side tube on the performance of Ranque-Hilsch vortex tube. In his 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.

B. sreenivasa Kumar Reddy et al. [9] in this paper he has given the alternative method for refrigeration to prevent ozone layer depletion. To run the system he has taken some power from the vehicle engine shaft which is diverted by a pulley arrangement to run an air compressor. The high pressure created in the air compressor is used as inlet to a vortex tube which is placed inside the vehicle cabin. The cold air from the vortex tube is used to cool the vehicle cabin and the hot air is exhausted to atmosphere. His project work has successfully developed air cooling for a passenger car based on Vortex Tube Refrigeration

System, which overcomes the major problems such as global warming and ozone depletion. Cooling conditions met by the Vortex Refrigeration System is healthier than the comfort conditions met by the VCRS system, because air is free from chemicals but refrigerant is a gas which is a chemical mixture.

D. Saha et al. [10] in this paper he has investigated the efficiency of the Ranque–Hilsch Vortex Tube (RHVT) to separate water droplets from nearly saturated humidified N2 gas. With respect to the injected water (1% in mass fraction), water vapour enrichment around 15% is found at the hot exit of the RHVT where the temperature is higher than at the inlet. Measurement at the cold exit where the temperature is lower than the inlet shows an oversaturated condition, i.e., the estimated relative humidity is ~200%. Therefore, we measured the separation efficiency by removing the droplets as condensate from the cold side. We found that the water separation efficiency at the cold side with respect to total amount of water injected is ~10% and with respect to the amount of water present at the cold side flow is ~20% respectively, for cold fractions 0.3–0.7. The condensate separation efficiency increases up to 40% by taking into account of the maximum condensable water from the oversaturated cold stream.

K. Kiran Kumar Rao et al. [11] in his experiment he has studied the variation of temperature at hot end and cold end with respect to pressure variation and valve position variation. He has obtained best results in his paper when the length (L) 290 mm. diameter of the hot tube (D) 12mm and L/D ratio with 24 of both Rose wood and Sapodilla wood. After analysis the material of Sapodilla wood the minimum and maximum temperature has been obtained 240C and 310C at a pressure of 12kg/cm2 after analysis the material of Rose wood the minimum and maximum temperature has been obtained 220C and 280C at a pressure of 12kg/cm2. It is clear to that always the performance of vortex tube is directly proportional to inlet compressed air. The surface finish of the nozzle and the hot tube plays a great role in the performance of the vortex tube, good surface finish leads to the better performance so care to be taken while fabrication of the parts to obtain to get good surface finish.

Mahyar Kargaran et al. [12] an experimental study has been made to offer optimum values for cold orifice diameter to the VT inlet diameter (d / D) and the length of VT to its inlet diameter for this experiment. The results show that temperature difference is maximized for a specific orifice diameter .In this regard, d / D = 8 / 25 =32 and= 769 / 25 = 30.76. As far as cooling capacity and hot temperature difference are concerned, the study indicates that the aforementioned ratios are same for them .It means that for orifice d=8mm and hot tube length =769mm we can reach the maximum proficiency of a vortex tube for the current study. As for μ value, at μ≈ .6 we witness the maximum of cold temperature difference and cooling capacity, while for hot temperature difference μ is about 7.

Rahul B Patel et al. [13] in this paper the Experimental study on energy separation in the vortex tub. Also studied governing of geometrical parameters on the performance characteristics of the vortex tube are investigated by the ANSYS CFX 12.0. The result is that the optimum value of L/D is determined. The L/D ratio for best performance is 30. Number of nozzle hole is also determined. The six number of hole gives maximum temperature difference. The cold air temperature difference increases by increasing the inlet pressure, meanwhile there is an optimum efficiency at a specific inlet pressure. The optimum cold end diameter (dc) and the length to diameter (L/D) ratios and optimum parameters for obtaining the maximum hot gas temperature and minimum cold gas temperature are obtained through CFD analysis.

Prabhakaran j.et al. [14] In this work they have investigate the effect of three controllable input variables such as diameter of the orifices, diameter of the nozzles and inlet pressure over the temperature difference in the cold side as output using Response Surface Methodology . It is found that the inlet pressure and diameter of nozzle are significant factors that affect the performance of vortex tube. The maximum temperature difference of 26.50C is obtained in cold end side on the other hand 19.80 C is obtained in hot end side. When the inlet pressure increases, the temperature difference in cold end and hot end is increased. When the inlet pressure increases, the Carnot COP is decreased.

A.V. Khait, et al. [15] this paper briefly explains about semi-empirical turbulence model for numerical simulation of swirled compressible flows in Ranque Hilsch vortex tube this paper presents a three-dimensional numerical model of swirled compressible flow in the Ranque Hilsch vortex tube. The modification of the energy conservation equation used in Reynolds Averaged Naviere Stokes (RANS) numerical simulations. While the additional turbulent heat transfer mechanism caused by gas compressibility is taken into account in the proposed equation, it is not applied in standard RANS models. The data were obtained both by standard and proposed energy conservation equations using the k - ε turbulence model. The application of the proposed energy conservation equation was shown to increase the accuracy of static and total temperature distribution prediction. The objective of this paper is the demonstration of the applicability of the new numerical model based on the proposed energy conservation equation after the calibration of empirical coefficients.

IV.EXPERIMENTATION

Experimentations were performed at various operating conditions. Initially compressor was put on to get the compressed air at desired pressure continuously from the receiver. The FRL unit is used to control the inlet pressure. After setting the supply air pressure, measured the reading at supply pressure for both Rotameter and multiply by multiplication factor for inlet Rotameter reading from calibration chart, cold end Rotameter already calibrate at atmospheric condition, no need to multiply by multiplication factor, from this we obtain exact cold mass fraction. Desired cold mass fraction is obtained with the help of hot end valve. Two minutes were allowed to stabilize the flow and temperature to reach on steady state. The inlet temperature (It) is noted before pneumatic connector, from this compressed air supplied double inlet nozzle of vortex tube. After setting of cold mass fraction from fully closed to fully open, the temperature at cold end (Tc) and hot end (Th) are noted. Based on the recorded data the performance of system is calculated in terms of coefficient of performance (COP) and isentropic efficiency of system for air and geometric parameters

An experimental set-up is developed to carry out the experiments of two nozzle vortex tubes using air as the working fluid. Three different configuration vortex tubes have been developed and tested. Each vortex tube is tested at various operating condition with air as working substance. A series of experiments are performed to evaluate the performance of the system and to optimize the geometrical parameters. Experiments are performed under two parts, in first part experiment carried out using different diameters of cold orifice i.e.3, 4 and 5 mm to optimize cold orifice and in second part, experiments are carried out on optimized cold orifice by varying different geometric parameters such as diameter and single or double inlet nozzles for optimizing L/D ratio.

Experiments are performed under following conditions:

1. Inlet pressures range: 02 bar – 05bar
2. L/D Ratio diameter 13.5
3. Number of inlet nozzle: 2
4. Number of diffuser: 3
5. Angles of the diffuser: 200, 450, 600
6. Material of vortex tube: Cast iron.
7. Working substance: Compressed air.

Following are the observations we got while performing an experiment.

V. OBSERVATOINS

Pressure (bar)	Diffuser angle	Inlet temp.	Temp of cold air		Temp of hot air		Cold drop temp. 20°		Hot drop temp.20°	
			outside	inside	outside	inside	outside	inside	outside	inside
2	20°	29.9	25.6	27.5	31.5	33.1	4.3	2.4	1.6	3.2
3			24.4	27.1	33	34.3	5.5	2.7	3.1	4.4
4			23.3	23.3	33.7	34.7	6.6	3.1	3.8	4.8
5			23.1	26.1	34	35.4	6.8	3.8	4.1	5.5
Pressure (bar)	Diffuser angle	Inlet temp.	Temp of cold air		Temp of hot air		Cold drop temp. 45°		Hot drop temp.45°	
			outside	inside	outside	inside	outside	inside	outside	inside
2	45°	29.9	24.9	27	34	33.2	3.4	2.9	4.1	3.3
3			23.1	25.9	34.4	33.1	6.8	4	4.5	3.2
4			19.4	25.4	34.6	34.4	10.5	4.5	4.7	4.5
5			19.8	24.8	35.1	34.8	10.1	5.1	5.2	4.9
Pressure (bar)	Diffuser angle	Inlet temp.	Temp of cold air		Temp of hot air		Cold drop temp. 60°		Hot drop temp.60°	
			outside	inside	outside	inside	outside	inside	outside	inside
2	60°	29.9	26.5	27	33.3	33.3	3.4	2.9	3.4	3.4
3			23.5	26.2	33.5	33	6.4	3.7	3.6	3.1
4			22.5	24.8	34.5	32.8	7.4	5.1	4.6	2.9
5			20.1	23.3	35.5	32.2	9.8	6.6	5.6	2.3

Fig. No. – 2 Observations

VI.RESULT ANALYSIS

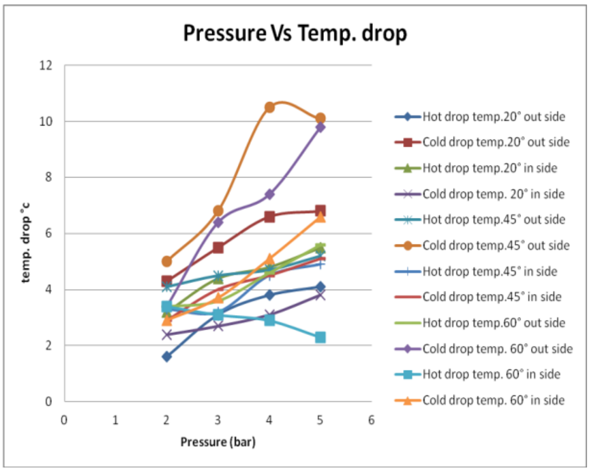

Fig. No. – 3 Result analysis

VII. CONCLUSION

The main outcome of this project is to examine the temperature drops by varying the diffuser taper angles. From experimentation testing on vortex tubes following conclusions are investigated.

➢ **For 20^0 diffuser angle**

- The pressure increases the temp drop for hot & cold air is also increases with equal proportion.
- Pressure increases the cold drop temp & hot drop temp gets increases simultaneously.

➢ **For 45^0 diffuser angle**

- Cold drop temp increases with large proportion as compared to hot drop change.
- Initially both cold drop and hot drop temperatures are almost same but as pressure increases both temp goes on increases.

➢ **For 60^0 diffuser angle**

- Initially both cold drop and hot drop temperatures are exactly same but as pressure increases both temp goes on increases
- For hot drop as the pressure increases the hot drop temp decreases & for cold drop as the pressure increases the cold drop increases with large proportion.

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