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Fabrication and Experimental Analysis of Vortex Tube by Varying the Geometry and Material

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Abstract: *Refrigeration is plays vital role in human life and it has become prominent to human habitat, primarily for the preservation of food grains, medicine also for large quantity storing of Chemicals, Industrial cooling, and air conditioning. In Conventional refrigeration systems Freon is used as refrigerant. As they are the main cause of pollution, depleting of ozone layer, cause health hazard. To avoid this damage extensive research work is going on alternate refrigeration systems. Vortex tube (VT) is non-conventional cooling equipment, without moving parts which are capable of separating hot air stream and cold air stream form an inlet air stream with desired pressure without affecting the environment. This device suits for vital applications due to its light weight, simple and more importantly it is compact.*

Keywords: *Vortex tube, geometrical parameters, orifice diameter, tube length, Experimentation, COP, Ranque-Hilsch vortex tube*.

I. Introduction

The vortex tube is a small thermal static tube that which separates in to two streams when compressed

Gas flow is send one stream colder than the inlet flow while the other stream is hotter than the inlet flow. The vortex tube does not have any moving parts and the separation occurs due to vortex generation without requiring any external mechanical work or heat transfer. The separation mechanism inside the vortex tube remains until today not completely understood.

The vortex tube was first discovered by Ranque [1, 2] who was granted a French patent for the device in 1932, and a United States patent in 1934. Ranque encountered the vortex tube phenomenon while he was experimentally working with vortex tube pump in 1928. In 1945, Rudolf Hilsch [3] conducted an experiment on vortex tube that focused on the thermal performance with different inlet pressure and different geometrical parameters. The separation mechanism inside the vortex tube remains until today not completely understood Eiamsa-ard et al [4]. Lewins .J et al [5] proposed that despite its small capacity, the Ranque-Hilsch vortex tube (RHVT) is very useful for certain thermal management applications because of its simplicity, high durability, compactness, light weight, robustness, reliability, low maintenance cost and safety. By Mohammad O et al [6] investigates the effect of nozzle's orientation, numbers and symmetric/asymmetric arrangements on the energy separation. Also the study reports COP calculation for the effect of inlet pressure and vortex stopper location. By experimentally Mahyar Kargaran et al [7] obtained optimum values for cold orifice diameter to the VT inlet diameter (d/D) and the length of VT to its inlet diameter (L/D) for this experiment proposed. R. Madhu Kumar et al [8] were found that the vortex tube with a conical angle of about 2.5˚ surpassed the cylinder tube by 25%~30% in COP. The conical vortex tube reaches the same or more performance than the normal tube but with a smaller length .A study was made by Dr.Ing.Ramzi Raphael [9] on the effect of on the performance of Uni–flow vortex tube by varying the cone valve diameter (dc= 14, 12,10,8, and 6mm) using two nozzles with varying the pressure of the inlet air within the ranges 2-6 bar. By S. Eiamsa-ard et al [10] conducted experiment on the hot tube is directly cooled by cooling water jacket, the mean cold air temperature reduction and cooling efficiency of the RHVT with the cooling of a hot tube are respectively, 5.5 to 8.8% and 4.7 to 9% higher than those of the RHVT without the cooling. Hemant V. Darokar et al [11] proposed that different parameters of vortex tube by inlet pressure 2 to 5bar in step of 1bar with conical valves (30°, 45°, 60°, 90°) on the performance study maximum COP and isentropic efficiency found. Jaykumar D. Golhar et al [12] observed that experimental results of the energy separation in vortex tubes for different nozzle diameters keeping all other geometrical parameters constant greatly influences the separation performance and cooling efficiency. By Experimentation O.M. Kshirsagar et al [13] proposed the effect of various parameters like inlet pressure of air, number of nozzles, cold orifice diameter and hot end valve angle on the performance of vortex tube. Gurol Onal et al [14] in their experiment studied, performance of a tube (RHVT) with threads cut on its inner surface was investigated experimentally (pitch is 1 and 2 mm with inner diameter D=9 and L/D =12. Fraction of cold flow (ξ) = 0.1-0.9, was determined under 300 and 350 k Pa pressurized air. [15] Mohammad Sadegh Valipour et al proposed series of experiments has been carried out to investigate the influence of uniform curvature of main tube on the performance of the vortex tube. [16] Mohammad O. Hamdan et al in their experiment presented data that insulation has minimal effect on the vortex tube performance. The same inlet pressure tests show that energy separation increases as number of inlet nozzle increases. Gulyaev et al [17] recommends a minimum length of 13 times more than that of the diameter. Soni and Thompson [18] deduced an L/D greater than 45 for efficient working. Singh P.K and et al [19] states that the effect of nozzle design is more important than the cold orifice design in getting higher temperature drops. Balmer et al [20] has demonstrated that the heat separation, which occurs inside the Ranque–Hilsch vortex tube is not limited to compressible gases and can be applied for non compressible fluids as well. Dincer et al. [21] investigated the effect of control valve tip angle on performance of Ranque-Hilsch vortex tube using different inlet pressures. Behera et al. [22] showed from solutions obtained using computational fluid dynamics that this secondary flow could be related to the cold end cross-sectional area. It was concluded that a secondary flow would occur when the cold end cross-sectional area was small. Dincer et al [23] carried out energy analysis of the vortex tube with regard to nozzle cross sectional area and suggested that the variation of the energy efficiency increased with increasing pressure and cold fraction. Kun Chang et.al [24] performed experimentation with hot divergent tube and found that the Energy separation performance of vortex tube can be improved by using a divergent hot tube. Rahim Shamsoddini et al [25] observed on Effect of number of nozzles on the flow and power of cooling of a vortex tube using a three-dimensional numerical fluid dynamic model. It is observed that as the number of nozzles is increased, power of cooling increases significantly while cold outlet temperature decreases moderately. Nimbalkar et al [26] and Muller presented the results of a series of experiments focusing on various geometries of the ‘‘cold end side” for different inlet pressures and cold fractions. Wirachman Wisnoea,*et al [27] proposed that present analysis of sound produced from a Vortex Tube by the help of microphone was used to record the sound produced close to the hot tube with Different swirl generator nozzles were tested and presented. [28] H. Pourariaa*, et al proposed that the effect of using divergent tube and to find optimum angle of divergence. The existence of heat and work transfer inside the tube was investigated using the present results. Numerical results indicate that an increase in divergent tube angle results in an increase in cooling performance of vortex tube.[29] Ritesh Kumar Chaurasiya et al was proposed made to fabricate and test a simple vortex tube. The effect of change in length and diameter of vortex tube i.e. (L/D) ratio is investigated and presented in this paper. [30] H. Khazaeia et al that the hot outlet size and its shape do not affect the energy distribution in the vortex tube, and a very small diameter will decrease the temperature separation. [31] Yunpeng Xue et al proposed that critical review of current explanations on the working concept of a vortex tube. Hypotheses of pressure, viscosity, turbulence, temperature, secondary circulation and acoustic streaming are discussed in the paper, and presumably, future research will benefit from this discussion.[32] Xingwei Liu,et al proposed that the study to predict the energy separation and flow behavior within a vortex tube by three-dimensional computational fluid dynamic model is established.

This paper presents Fabrication and experimental analysis of vortex tube with different inlet pressures, different geometrical parameters, like nozzles, orifice dimensions, L / D ratio and for different material

The Fabrication and experimental investigation in this paper is carried out on

1.Stainless Steel Nozzle, Diaphragm Dia (inner, outer) = 7mm, 18mm, length=13mm, Hot pipe, length =840mm, Dia (inner) =15mm cold pipe length=80mm, Dia (inner) =15mm

2. Aluminium Alloy Nozzle, Diaphragm Dia (inner, outer) = 7mm, 18mm, length=13mm Hot pipe, length =840mm, Dia (inner) =15mm cold pipe, length=80mm, Dia (inner) = 15mm

3. CPVC Length of the Hot pipe = 860mm, Dia of the hot pipe = 18mm, L/D ratio=47.7

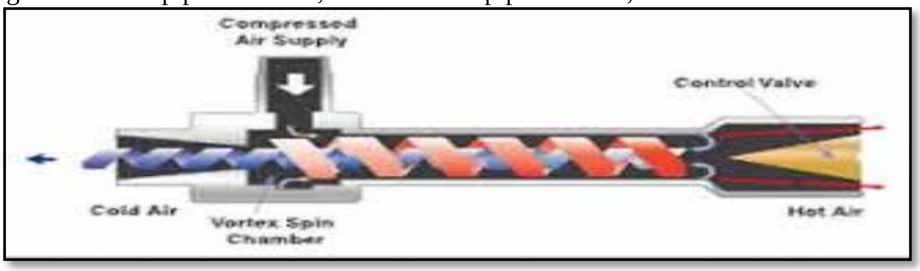

Figure. 1. Vortex tube schematic

There are two classifications of the vortex tube [6]. Both of these are currently in use in the industry. The more popular is the counter-flow vortex tube (Figure 2). The hot air that exits from the far side of the tube is controlled by the cone valve. The cold air exits through an orifice next to the inlet. On the other hand, the uni - flow vortex tube does not have its cold air orifice next to the inlet (Figure 3). Instead, the cold air comes out through a concentrically located annular exit in the cold valve. This type of vortex tube is used in applications where space and equipment cost are of high importance

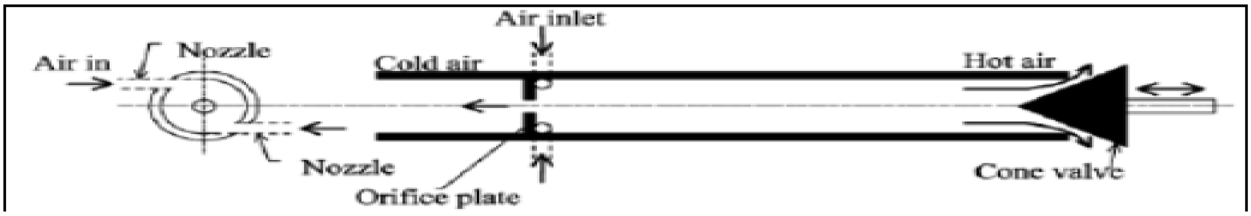

Figure. 2. Counter-flow vortex tube

The mechanism for the uni -flow tube is similar to the counter-flow tube. A radial temperature separation is still induced inside, but the efficiency of the uni -flow tube is generally less than that of the counter-flow tube.

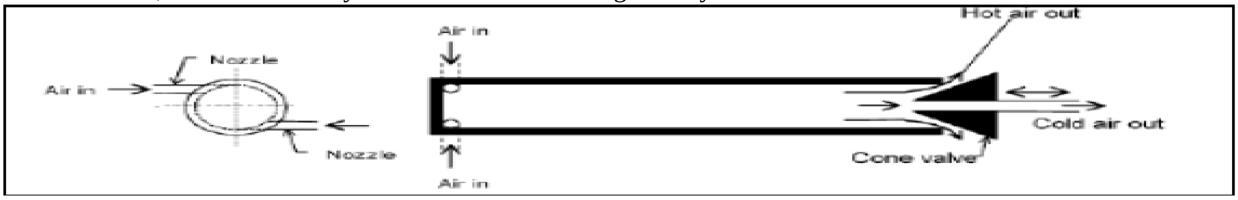

Figure. 3. Uni-flow vortex tube

2.1. VORTEX TUBE EXPERIMENTAL ANALASYS: (STAINLESS STEEL MADE)

Length of the hot pipe = 840 mm, cold end=80mm dia of the hot pipe = 18 mm L/D ratio=46.7

Sl. No	dia of the nozzle (mm)	dia of the diaphragm (mm)	Pressure (kg/cm^2)	Cold Temp ^{0}C	Hot Temp ^{0}C	difference
1	8	10	2	30	32	2
2	8	10	4	29	32	3
3	8	10	6	27	31	4
4	8	10	8	30	32	2
5	8	10	10	28	31	3
6	8	10	12	28	32	10

Figure . 2.1.1 Tabular column showing temperature difference on stainless steel made

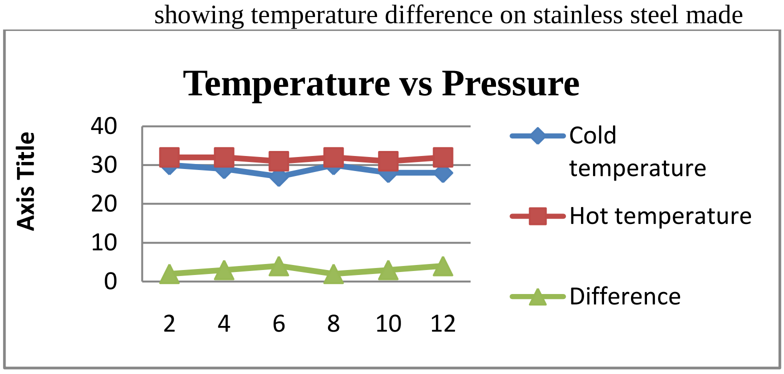

Figure. 2.1.2Graph showing temperature difference on stainless steel made

2.2 VORTEX TUBE EXPERIMENTAL ANALASYS: (STAINLESS STEEL MADE)

Length of the Hot pipe = 840mm, cold end pipe =310 mm, Dia of the hot pipe = 15mm L/D ratio= 840/15 = 56

Sl. No	dia of the nozzle (mm)	dia of the diaphragm (mm)	Pressure (kg/cm^2)	Cold Temp ^{0}C	Hot Temp ^{0}C	difference
1	8	8	2	28	30	2
2	8	8	4	27	31	4
3	8	6	6	28	30	2
4	8	6	8	26	31	5
5	8	6	10	22	32	10
6	8	6	12	20	30	10

Figure. 2.2.1 Tabular column showing temperature difference on stainless steel made

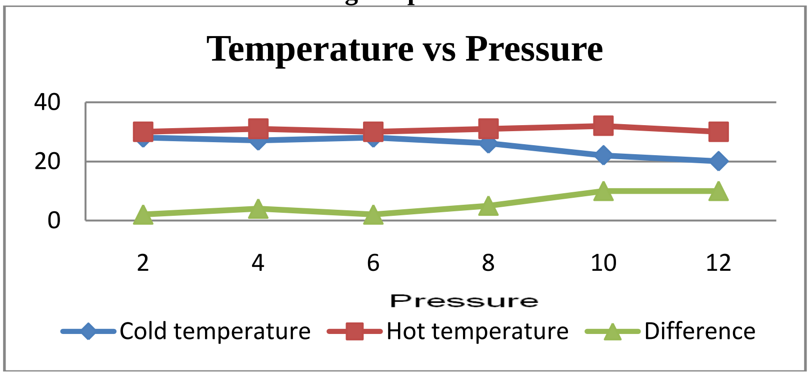

Figure. 2.2.2 Graph showing temperature difference on stainless steel made

2.3 PHOTOGRAPHS STAINLESS STEEL

Fig: 2.3.1 conical needle, Adapter, Hot chamber   Fig: 2.3.2 cold chamber, Nozzle, Diaphragm

Figure. 2.3.3 Vortex tube Nozzle, Diaphragm   Dia(inner, outer)=7mm,18mm,length=13mm
Fig: 2.3.4 Experimental view of vortex tube   Hot chamber, Dia inner, outer=40mm, 45mm
Fig: 2.3.5 Experimental view of vortex tube   Hot pipe, length =840mm, Dia (inner) = 15mm
Figure. 2.3.6 Experimental view of vortex tube   cold pipe, length =80mm, Dia (inner)=15mm

Fig: 2.3.7 Experimental view of vortex tube stainless steel.

3.3. VORTEX TUBE EXPERIMENTAL ANALASYS: (ALUMINIUM ALLOY MADE)

Length of the Hot pipe = 840mm ,cold end pipe =340 mm , dia of the hot pipe = 15mm
L/D ratio=840/15 = 56

Sl. No	Dia of The Nozzle (Mm)	Dia of The Diaphragm (mm)	Pressure (kg/cm^2)	Cold Temp ^{0}C	Hot Temp ^{0}C	difference
1	8	8	2	30	32	2
2	8	8	4	30	34	4
3	8	6	6	30	33	3
4	8	6	8	34	30	4
5	8	6	10	29	34	5
6	8	6	12	28	36	8

Fig :3.3.1 Tabular column showing temperature difference on Aluminum Alloy made

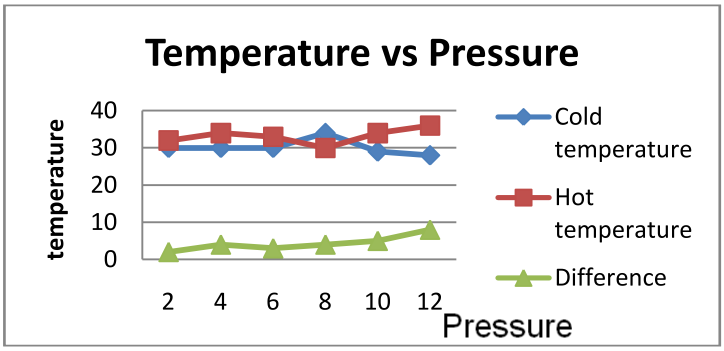

Figure. 3.3.2 Graph showing temperature difference on Aluminum alloy made

3.4 VORTEX TUBE EXPERIMENTAL ANALASYS: (ALUMINIUM ALLOY MADE)

Length of the Hot pipe = 840mm cold end pipe =80mm
Dia of the hot pipe = 15mm L/D ratio=840/15 = 56

Sl. No	Dia of The Nozzle (Mm)	Dia of The Diaphragm (mm)	Pressure (Kg/Cm^2)	Cold Temp ^{0}C	Hot Temp ^{0}C	difference
1	8	8	2	31	32	1
2	8	8	4	30	33	3
3	8	6	6	30	32	2
4	8	6	8	30	34	4
5	8	6	10	28	34	6
6	8	6	12	28	36	4

Fig: 3.4.1. Tabular column temperature difference on aluminum alloy made

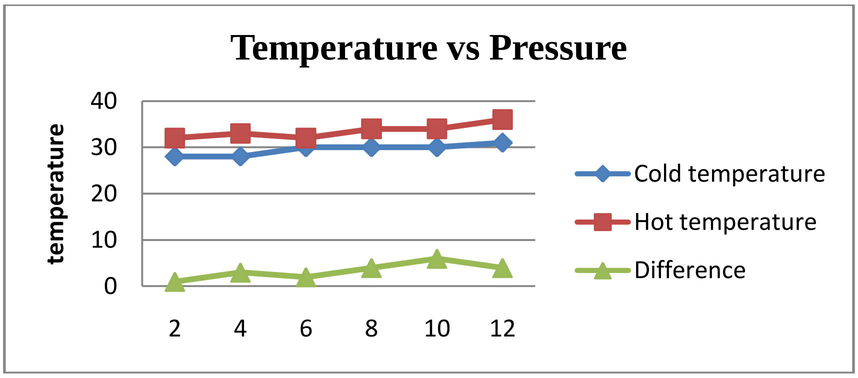

Figure. 3.4.2 Graph Showing Temperature difference on Aluminum Alloy Made

3.5 PHOTOGRAPHS ALUMINIUM ALLOY



Fig: 3.5.1 Vortex tube cold and Hot chamber, Nozzle, Diaphragm, Adapter
Fig: 3.5.2 Vortex tube cold chamber Dia (inner, outer) =15mm, 45mm
Figure. 3.5.3 Vortex tube Hot chamber Dia (inner, outer) =40mm,45mm



Figure. 3.5.4 Vortex tube Nozzle, Diaphragm Dia (inner, outer) = 7mm, 18mm,length =13mm
Fig: 3.5.5 Experimental view of vortex tube Hot pipe, length=840mm, Dia (inner) =15mm
Figure. 3.5.6 Experimental view of vortex tube cold pipe length =80mm, Dia (inner)=15mm

Fig: 3.5.8 Experimental view of vortex tube Aluminium Alloy

3.6 CPVC

Length of the Hot pipe = 840mm Dia of the hot pipe = 18mm L/D ratio=47.7

Sl. No	Dia Of The Nozzle (mm)	Dia Of The Diaphragm (mm)	Pressure (Kg/Cm^2)	Cold Temp ^0C	Hot Temp ^0C	difference
1	8	6	2	31	33	2
2	8	6	4	30	32	2
3	8	6	6	28	35	7
4	8	6	8	26	32	6
5	8	6	10	24	35	9
6	8	6	12	20	34	14

Figure. 3.6.1 Tabular column showing the difference temperature analysis CPVC made

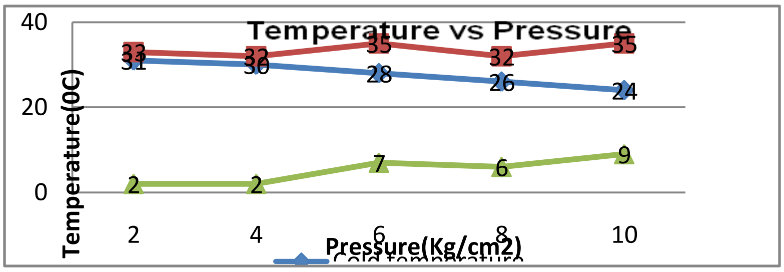

Figure. 3.6.2 Graph showing the temperature vs. pressure analysis CPVC made

Fig: 3.6.3 Vortex tube CPVC Hot pipe, length =840mm, Dia (inner) =15mm

Figure. 3.6.4 Vortex tube CPVC cold pipe , length =80mm,Dia(inner)=15mm

3.6 Applications of Vortex Tube

- Vortex Tube Based Refrigeration
- A Vortex Tube For Carbon Dioxide Separations
- Personal Air Conditioning
- Cutting Tools
- Shrink Fitting
- Cooling Of Gas Turbine Rotor Blades
- Laboratory Sample Cooler:
- Cooling Of Machine
- Cooling Electrical Cabinets
- Cooling Mould Tools
- Cooling Sewing Needles
- Cooling Of Hot Operations
- Cooling Workers
- Testing Thermostats
- Cooling CCTV Cameras
- Setting Hot Glue Operations
- Cool Soldering
- Air Suits

3.7 Advantages of Vortex Tube:

- Simple in constructions,
- No moving parts,
- No chemicals,
- Light weight,
- Low cost,
- Maintenance free,
- Instant cold air,
- Durable for its application.
- Therefore, if compactness, reliability and lower equipment

II. Conclusion:

The following conclusion has been drawn from the experimentation:
1. It is clear to that always the performance of vortex tube is directly proportional to inlet compressed air.
2. The cold mass fraction is an important parameter influencing the performance of the energy separation in the vortex tube
3. The effect of number of nozzle is very important for improve better cop.
4. At higher values of L /D ratio the performance of vortex tube is very good
5. Larger size diaphragms are well preferred to avail better performance.
6. In the test we found that the performance is directly proportional to pressure.
7. We found that, as pressure increases the temperature is proportionately changing i.e. decreasing at cold stream and increasing at hot steam.
8. By the experimental investigations on CPVC it is found that better performance and cold temperature were obtained than that of the Aluminum Alloy and Stainless steel material as it has good surface finish
8. By the experimental investigations on Aluminum Alloy the better performance Length of the Hot pipe = 840mm, cold end pipe =310 mm, Dia of the hot pipe = 15mm , L/D ratio= 840/15 = 56

Material.
9. The effect of nozzle design is more important than the cold orifice design in getting higher temperature drops.
10. The graph drawn shows the effect of increasing the inlet pressure with the temperature drop which shows an increase trend i.e. initially with increase in the inlet pressure the temperature drop increases linearly and after a certain pressure the temperature drop tends to becomes almost constant.
11. We also found that when cold pipe length is changing the cold performance also increased.
11. We also found that the ideal pressure at lowest temperature is around 12bar where we can see that the temperature obtained is lower than the other cases.

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