INVESTIGATION OF VORTEX TUBE REFRIGERATION WITH NOVEL MATERIAL

[1] Dr. U. V. Kongre, [2]M. V. Dudhe, [3]A. N. Petkar, [4]V. S. Kamble [5]S. M. Kamble
[1] Associate professor Mechanical Engineering, [2,3,4,5] Student of Mechanical Engineering
[1,2,3,4,5] J.D.I.E.T. Yavatmal Maharashtra, India

Abstract : In this paper, we have constructed a vortex tube refrigeration system. Effects of inlet tangential nozzles, the tube diameter, and the diameter of the inlet nozzle on the temperature reduction in the tube were experimentally investigated. The general motivation of this thesis is to clarify the numerous assumptions and taking optimal data from various research papers in order to analyze the temperature difference obtained. Compared to previous studies, standard measurements and the fabrication techniques are improved to achieve accurate results.

This paper presents experimental results of the energy separation in vortex tubes for different nozzle diameters keeping all other geometrical parameters constant. It is experimentally evidenced that the nozzle diameter greatly influences the separation performance and cooling efficiency. The most important point revealed in this paper is that there is an optimum nozzle diameter that gives the best performance of vortex tube. An experimental investigation has been performed to realize thorough behavior of a vortex tube refrigeration system. The counter flow vortex tube has been designed, manufactured and tested. The vortex tube is a non-conventional cooling device, which operates as a refrigerating unit without affecting environment. It has capability to separate hot and cold air stream from a high pressure inlet air; such phenomenon is called as temperature or energy separation process. The vortex tube performance 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).

***IndexTerms* – Refrigeration, Nozzle, Temperature.**

I. INTRODUCTION

The vortex tube is a device which generates separated flows of cold and hot gases from a single compressed gas source. The vortex tube was invented quite by accident in 1933 by George Ranque and later developed by Hilsch (1947). In memory of their contribution the Vortex tube is also known as Ranque-Hilsch vortex tube (RHVT).It contains the parts: inlet nozzle, vortex chamber, cold-end orifice, hot-end control valve and tube.Compressible fluid is tangentially introduced into the vortex tube through the nozzles, due to the cylindrical structure of the tube and depending on its inlet pressure and speed, leads a circular movement inside the vortex tube at high speeds. A pressure difference between the tube walls is lower than the speed at the tube center, because of the effects of wall friction. As a result, fluid in the center region transfers energy to the fluid at the tube wall. The cooled fluid leaves the tube by moving against the main flow direction after a stagnation point, whereas the heated fluid leaves the tube in the main direction. The RHVT is widely used for both cooling and heating purpose.

Many researches had been carried out to find the reason of separation of air streams happening inside the tube. Mischer and Bespalov explained that energy separation takes place because of entropy generation, still the theory is unacceptable. Kassener and knoernschild in their work proposed that the pressure difference causes the separation of air streams also they have undergone the work that converts initially free vortex in to forced vortex, since then vortex tube has become a topic of research. Changes in the components of vortex tube has practiced and analyzed the results with the Ranque-Hilsch tube.

A diffuser was installed between the cone valve and the vortex tube outlet, experiments shows that the cold air temperature TC reduced tremendously and increases the refrigeration effect. The cylindrical tube geometry when converted to conical tube, the hot air temperature TH, and cold air temperature TC were quite high compared to conical tube. The results obtained were impressive by changing the aspect ratio (L/D), number of nozzles. Vortex tube has many advantages it is a simple device, no moving parts, no electricity or chemicals, small and light weight, low cost, less maintenance, instant cold air, durable because of material used (stainless steel, aluminum), clean work media. Vortex tube has following applications it is used in spaced suits, for spot cooling in welding, in CCTV camera. In future because of its advantages vortex tube can be the best replacement over conventional refrigeration system.

II. Working Principle

Compressed air is passed through the nozzle as shown in figure1.Then air expands and acquires high velocity due to particular shape of the nozzle. A vortex flow is created in the chamber and air travels in spiral like motion along the¬ periphery of the hot side. This flow is restricted by the valve. When the pressure of the air near valve is made more than outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region to low-pressure region. During this process, heat transfer takes place between reversed stream and forward stream. Therefore, air stream through the core gets cooled below the inlet temperature of the air in the vortex tube, while air stream in forward direction gets heated up. The cold stream is escaped through the back side cold part, while hot stream is passed through the opening of the valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied.

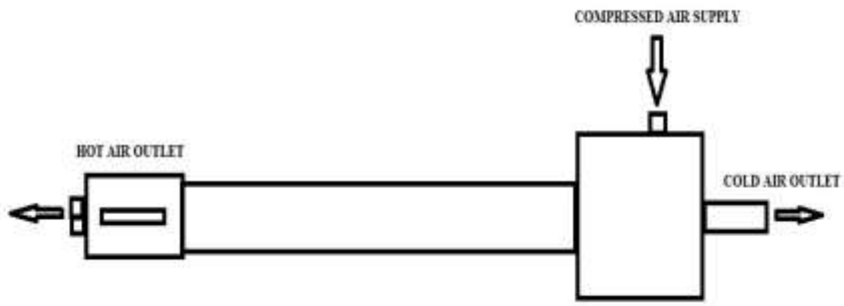


Fig 1 - Drafting of vortex tube.

III. Literature Review

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 **[4]**. 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 **[5]**. By experimentally Mahyar Kargaran et al **[6]** 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 alKun Chang et.al **[7]** 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

The research efforts taken by different researchers are discuss all the information in the table format. which contain name of literature, material, output parameter and investigation are as fallows.

Sr.No.	Name of researchers	Material	Output parameter	Investigation
1	Shankar ram T. & anish Raj k.	CPVC	Tube diameter 18 mm, tube length 810 mm no. Of nozzles 4, diameter of nozzles 2 mm, length of nozzles 2.5 mm, orifice diameter 4.5 to 5.8 mm	The design of nozzle affects the conversion of pressure to velocity. It doesn't have much contribution in the energy separation process. The area of nozzle is a constant for given tube size and number of nozzles depends on mass flow rate possible
2	Pongjet promvonge & Smith eiamsa-ard	Plexiglass	Tube diameter 16 mm, tube length 880 mm.	As the increase of the number of nozzle led to higher temperature separation in the vortex tube.
3	Sarath sasi. & serenity M	PVC and copper	Tube diameter 36 mm, tube length 110 mm, pressure 10 to 12 bar	pvc tube gives minimum temperature at the same mass fraction,also vortex tube with pvc as material is better than copper tube
4	Kiran Kumar rao	Mild steel , aluminium and copper	Diameter of nozzle 8 mm, diameter of orifice 6 mm, and L/D ratio is 22.	The best performance is obtained with the vortex tube which has 4 nozzles. The effect of number of nozzle is very important for improve better cop. 4. The secondary circulation zone is determined by controlling the vortex stopper location.
5	M .selek, S. Tasdemir	Gray Cast Iron	15 to 20 mm Diameter and 100mm length	The maximum performance of RHVT was found to be, for a diameter of sample ¼ 15 mm, cutting depth ¼ 3 mm and cutting speed ¼ 800 rpm

IV. SPECIFICATIONS:

4.1 DIMENSIONS AND PROPERTIES

Fig 3 – Nozzle

Fig 4 – Vortex Chamber

4.1.1 Nozzle :-

1. Dimensions :-
   - Nozzle angle (Φ) = 4^0
   - No of nozzles entry = 3
   - Diameter of convergent nozzle = 3mm
2. Properties :- Brass
   - The metal exhibits low friction.
   - Good machine-ability.
   - Excellent heat conductivity
   - Brass is easy to cast.
   - High thermal conductivity 109 W/mK .

4.1.2 Vortex Chamber :-

1. Properties :- Copper
   - Good machinability
   - Copper is a tough, ductile and malleable material.
   - The melting point for pure Copper is 1083ºC
   - Copper extremely suitable for tube forming, wire drawing, spinning and deep drawing.
   - Thermal conductivity of copper 385 W/mk .

Fig 5 - Cold Side Tube

Fig 6 – Hot Side Part

4.1.3 Cold Side Tube :-

1. Dimensions :-
   - Cold tube length = 30mm
   - Cold Orifice diameter = 3mm
2. Properties :- Mild Steel
   - Weldability: - AISI 1018 mild/low carbon steel can be instantly welded by all the conventional welding processes.

- Good machinability.
- Good heat treatment properties.
- High thermal conductivity.

4.1.4 Hot Side Tube :-

1. Dimensions :-
   - Hot tube length = 265mm
   - Diameter of hot tube = 12mm

2. Properties :- Brass
   - Good machinability
   - Brass is easy to cast.
   - Brass is a tough, ductile and malleable material.
   - High thermal conductivity 109W/mK.
   - Brass has a higher malleability than either bronze or zinc.

V. EXPERIMENTAL STRUCTURE.

5.1 EXPERIMENTAL SET UP

The layout of the experiment setup is given below.

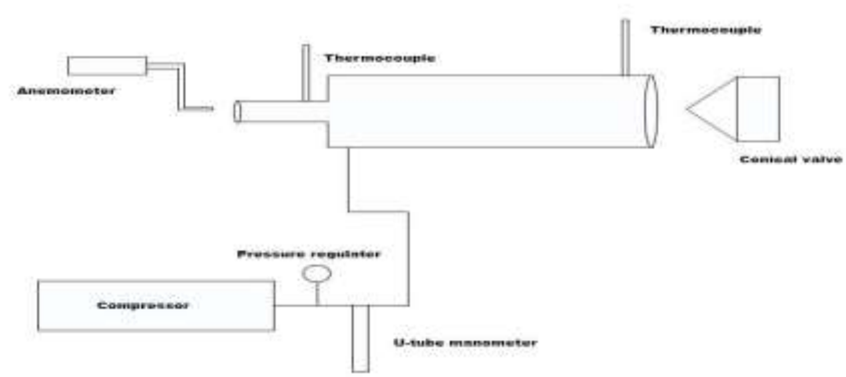


Fig 7- Experimental layout of vortex tube

The experiment set up consists of compressor, pressure regulator, U tube manometer, nozzles, vortex tube, thermometer, conical valve. The materials used for the construction of this new type of vortex tube is inexpensive and easily obtainable in the market. Our experiment is set up with reciprocating compressor which can deliver a pressure upto 10 bar. We use a vortex tube with 12 mm diameter and length 345mm and pressure regulator which regulates the flow in the range of 4 to 10 bar pressure, and two thermometers one at cold end side and one at hot end side. We are selected different materials for the different components which are as follows:

Sr. no.	Name of components	Material used
1	Vortex chamber	Copper
2	Cold side tube	Mild steel
3	Hot side tube	Brass
4	Nozzle	Brass

Table no 1 – Parts and Material

5.2 DIMENSIONS OF DESIGN PARAMETERS

Sr. No	Design parameters	Dimensions and numbers
1	Diameter of vortex tube, D	12mm
2	Cold Orifice diameter, Do	3mm
3	Length of vortex tube, L	345mm
4	Hot tube length, L_h	265mm
5	Cold tube length, L_c	30mm
6	L/D ratio	29mm
7	Diameter of convergent nozzle	3mm
8	Nozzle angle (Φ)	4^0
9	No of nozzles entry	3
10	Inlet pressure	4,5,6,7,10.
11	Conical controlling valve angle *(ϕ)*	45^0

Table no 2 – Dimension And Design Parameter

5.3 EXPERIMENTAL PROCEDURE

The very first thing that came is to start the compressor for generation of the desired pressurized air at required pressure range. Keep the compressor on still the pressure of air inside the compressor reaches up to the mark then open the outlet valve of compressor to pass the air to vortex tube. Before passing air into the vortex tube, one pressure regulator is mounted on the outlet pipeline through which a constant pressure of air is maintained and then passes it to the vortex tube. Now vortex tube is equipped with two digital thermometers one at cold side end and other is at hot side end. These thermometers are used to measure and show the temperature reading on both sides so that one can mark the maximum temperature drop which is getting from this vortex tube. To restrict the air at hot side end a closing valve is provided, the major and important function of the valve is to create a back flow which is the most important phenomenon which creates two air streams at different temperatures on two ends of the vortex tube. The same procedure is repeated for different pressure ranges.

Fig 8 – Experimental Set Up

VI. OBSERVATION TABLE AND GRAPH:

6.1 OBSERVATION TABLE

1) Data taken at 4 bar pressure.

SR. NO.	PRESSURE (P) bar	HOT TEMPERATURE (T_H) ºC	COLD TEMPERATURE (T_L) ºC	TEMPERATURE DIFFERENCE (T_D) ºC
1	4	32	24.9	7.1
2	4	32.3	25	7.3
3	4	32.4	25.1	7.3
4	4	32.5	24.8	7.7
5	4	32.7	24.6	7.8

2) Data taken at 5 bar pressure.

SR. NO.	PRESSURE (P) bar	HOT TEMPERATURE (T_H) ºC	COLD TEMPERATURE (T_L) ºC	TEMPERATURE DIFFERENCE (T_D) ºC
1	5	30.7	20.8	9.9
2	5	30.4	20.5	9.9
3	5	31	21.6	9.4
4	5	30.8	21.2	9.6
5	5	30.9	21	9.9

3) Data taken at 6 bar pressure.

SR. NO.	PRESSURE (bar)	HOT TEMPERATURE (T_H) ºC	COLD TEMPERATURE (T_L) ºC	TEMPERATURE DIFFERENCE (T_D) ºC
1	6	31.3	22	9.3
2	6	31.7	22.5	9.2
3	6	31.9	22.7	9.2
4	6	31.3	22.2	9.1
5	6	31.6	22	9.6

4) Data taken at 7 bar pressure

SR. NO.	PRESSURE (bar)	HOT TEMPERATURE (T_H) ºC	COLD TEMPERATURE (T_L) ºC	TEMPERATURE DIFFERENCE (T_D) ºC
1	7	30.5	22	8.5
2	7	31	22.8	8.2
3	7	31	22.2	8.8
4	7	30	22.1	7.9
5	7	31.5	21.8	9.7

5) Data taken at 10 bar pressure\

SR. NO.	PRESSURE (bar)	HOT TEMPERATURE (T_H) ºC	COLD TEMPERATURE (T_L) ºC	TEMPERATURE DIFFERENCE (T_D) ºC

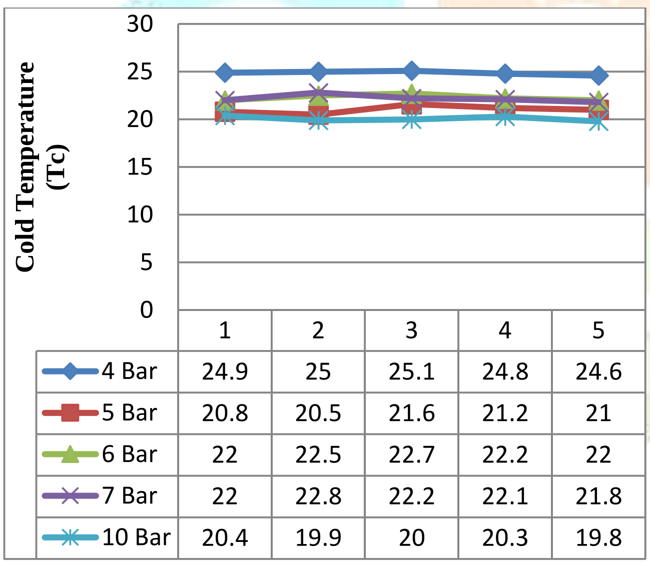
1	10	30	20.4	9.6
2	10	30.2	19.9	10.3
3	10	30.4	20	10.4
4	10	30.2	20.3	9.9
5	10	30.6	19.8	10.8

6) Average temperature drop

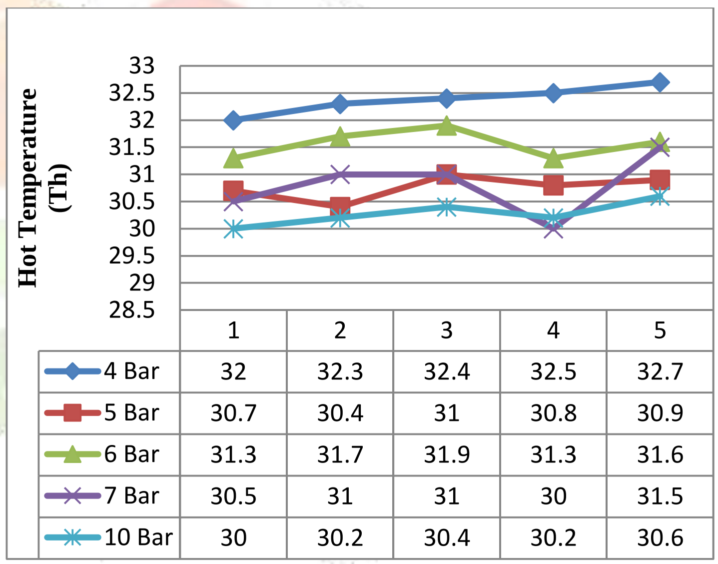
SR NO	PRESSURE P (bar)	TEMPERATURE DIFFERENCE (T_D) °C
1	4	7.35 °C
2	5	9.7 °C
3	6	9.2 °C
4	7	8.35 °C
5	10	10.05 °C

6.2 GRAPH

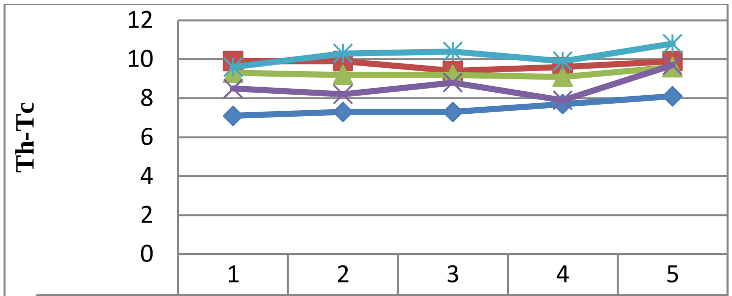
1. GRAPH OF COLD TEMPERATURE



2. GRAPH OF HOT TEMPERATURE



3. GRAPH OF TEMPERATURE DIFFERENCE



	1	2	3	4	5
4 Bar	7.1	7.3	7.3	7.7	8.1
5 Bar	9.9	9.9	9.4	9.6	9.9
6 Bar	9.3	9.2	9.2	9.1	9.6
7 Bar	8.5	8.2	8.8	7.9	9.7
10 Bar	9.6	10.3	10.4	9.9	10.8

VII. CONCLUSION

In this for the fabrication of vortex tube combination of material is used such as copper, brass, mild steel, etc. and by doing the actual performance on such vortex tube various results are obtained with that are reveled in this paper. From these results it is conclude that the maximum temperature difference of 10^0c is obtained at the pressure of 10 bar and with the help of obtained experimental data the graphs are plotted by considering hot temperature, cold temperature and temperature difference.

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