DESIGN AND PERFORMANCE EVALUATION OF A ALUMINUM VORTEX TUBE

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Abstract
Refrigeration plays an important role in developing countries, primarily for the preservation of food, medicine, and for air conditioning. Conventional refrigeration systems are using Freon as refrigerant. And is the potential cause for depleting Ozone layer, extensive research is going on alternate refrigeration systems.
Vortex tube is a non – conventional cooling device, having no moving parts which will produce cold air and hot air from the source of compressed air without effecting the environment. When a high pressure air is tangentially injected into the vortex chamber, a strong vortex flow will be created which will be split into two air streams. The present work mainly focuses on Design and fabricating the vortex tube of Aluminum material. After fabricating, the performance of the Vortex tube is evaluated for different diameters of orifice and inlet pressures. Cooling effect, Heating effect and COP are selected as performance measures
Index Terms: Vortex Flow, Orifice, Tangential Nozzle, Vortex Chamber

1. INTRODUCTION

The vortex tube, also known as the Ranque-Hilsch vortex tube (RHVT) 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 1931 by George Ranque[1,2], a French physics student, while experimenting with a vortex-type pump that he had developed, and then he noticed warm air exhausting from one end, and cold air from the other. Ranque soon forgot about his pump and started a small firm to exploit the commercial potential for this strange device that produced hot and cold air with no moving parts. However, it soon failed and the vortex tube slipped into obscurity until 1945 when Rudolph Hilsch, a German physicist, published a widely read scientific paper on the device.

Much earlier, the great nineteenth century physicist, James Clerk Maxwell[4], postulated that since heat involves the movement of molecules, we might someday be able to get hot and cold air from the same device with the help of a "friendly little demon" who would sort out and separate the hot and cold molecules of air.

2. Important definitions

In this section, a few important terms commonly used in vortex tube work are defined.

2.1. Coefficient of performance (COP):

To find the coefficient of performance (COP) defined as a ratio of cooling rate to energy used in cooling, the same principle of adiabatic expansion of ideal gas is employed and the equation becomes

$$COP = Q_C/W$$

$$COP = \frac{Cooling\ effect}{Work\ input}$$

and

$$C.O.P = \eta ab.\ \eta ac.\ [(Pa/Pi)(\gamma-1)/\gamma]$$

where ηab, ηac , Pi, Pa and γ are the adiabatic efficiency, air compressor efficiency, inlet pressure, atmosphere pressure
and specific heat ratio, respectively.

2.2. Adiabatic efficiency (η_{ab})

To calculate the cooling efficiency of the vortex tube, the principle of adiabatic expansion of ideal gas is used. As the air flows into the vortex tube, the expansion in isentropic process occurs. This can be written as follows: (ηab)

$$\frac{\text{actual cooling gained in vortex tube}}{\text{Cooling possible with adiabatic expansion}}$$

and

$$\eta ab = [\Delta Th/(\Delta Th + \Delta Tc)] * (\Delta Tc/\Delta T'c)$$

in which ηab is the adiabatic efficiency and ΔTh is the temperature raise of Hot air tube and ΔTc is the temperature drop of Cold air tube and ΔT'c Static temperature drop due to expansion, respectively.

2.3. Cold orifice diameter (β)

Cold orifice diameter ratio (β) is defined as the ratio of cold orifice diameter (d) to vortex tube diameter (D).

$$\beta=d/D.$$

2.4. Cold air temperature drop(ΔTc)

Cold air temperature drop or temperature reduction is defined as the difference in temperature between entry air temperature and cold air temperature:

$\Delta Tc = Ti - Tc$.

in which Ti is the entry air temperature and Tc is the cold air temperature.

3. Review of the vortex tube

Vortex flows or swirl flows have been of considerable interest over the past decades because of their use in industrial applications. Vortex (or high swirl) can also produce a hot and a cold stream via a vortex tube. The vortex tube has been used in industrial applications for cooling and heating processes because they are simple, compact, light and quiet (in operation) devices [6–7]. Several researchers put a lot of efforts to explain for the phenomena occurring during the energy separation inside the vortex tube. Research studies about these phenomena were formed mainly into two groups. The first one performed the experimental work (geometrical and thermo-physical parameters) and then through the value of their results attempted to explain the phenomena. The second performed the studies in qualitative, analytical and numerical ways in order to help in the analysis of the mechanisms present in the vortex tube

4. Applications of Vortex Tube

Vortex flows or swirl flows have been of considerable interest over the past decades because of their use in industrial applications, such as furnaces, gas-turbine combustors, dust collectors, Cutting Tools and Shrink Fitting Cooling Of Gas Turbine Rotor Blades and Vortex Tube For Carbon Dioxide Separations. The following applications as drafted below.

4.1 Air Suits

The Air suits (Fig. 1a) these suits are used by the operators entering vessels, tanks and pits where it is dangerous due to the concentration of toxic vapors, fumes or dust. It is commonly used by the workers working in the coal mines and foundries. It is not always economical to condition the hot place like foundry where the heat load is considerably large. The only economical way is to air-condition the operators working near the hot places.

4.2 Vortex Tube Based Refrigeration

The Vortex Tube Based Refrigeration (Fig. 1b) Refrigeration of food and medicine is an extensive problem. Fishing communities living on the coast line are also dependent on cold storage facilities for storing a day's catch. Usually conventional cold storage rooms are expensive for a local fisherman to afford. Conventional refrigerators are expensive to buy for an average person. Another important problem is transport of medicines, specifically vaccines from one place to another. Several vaccines require storage at low temperatures. Thus the distance a medicine can be delivered via road is very limited. Thus many remote areas do not receive vaccines at local hospitals.

4.3 Sub-Zero Spot Cooling Using Compressed Air

The Sub-Zero Spot Cooling Using Compressed Air (Fig. 1c) Vortex tubes our founding technology. More than 40 years ago, we pioneered the application of the vortex tube principle to solve industrial cooling problems. Over the years, thousands of companies of all sizes have used vortex tubes on their equipment to spot cool a part or process, thermal test components, speed set solders or hot melt adhesives, and so much more.

a

b

c

Fig.1. Basic operation of vortex tubes :(a)Air suits of Vortex tube and (b) the Vortex tube refrigerator (c) the Vortex tube Cooling System for a drill bit.

5. *Literature review of Vortex Tube*

The vortex tube was first discovered by **Ranque [1,2],** a metallurgist and physicist who was granted a French patent for the device in 1932, and a United States patent in 1934. The initial reaction of the scientific and engineering communities to his invention was disbelief and apathy. Since the vortex tube was thermodynamically highly inefficient, it was abandoned for several years.

Interest in the device was revived by **Hilsch [3],** a German engineer, who reported an account of his own comprehensive experimental and theoretical studies aimed at improving the efficiency of the vortex tube. He systematically examined the effect of the inlet pressure and the geometrical parameters of the vortex tube on its performance and presented a possible explanation of the energy separation process. an experimental study was **made by Scheper [22]** who measured the velocity, pressure, and total and static temperature gradients in a Ranque–Hilsch vortex tube, using probes and visualization techniques. He concluded that the axial and radial velocity components were much smaller than the tangential velocity. His measurements indicated that the static temperature decreased in a radially outward direction. This result was contrary to most other observations that were made later.

K. Kiran kumar Rao et al [8] This paper presents experimental results by the different investigators on the effect of various geometrical parameters, like nozzles, orifice, conical needle modifications, and different material like metallic and non metallic and experiment, to improve cop, cooling performance of vortex tube under these conditions listed below. It is clear to that always the performance of vortex tube is directly proportional to inlet compressed air. Geometry for cold conical valves is improving at 45° valve and 90° a best result. The effect of the conical hot tube also influencing on cop. With the cooling of a hot tube are respectively, 5.5 to 8.8% and 4.7 to 9% higher than those of RHVT without the cooling (insulation only).

K. Kiran Kumar Rao et al [9] to study the effect of geometrical parameters on vortex tube made of two types of homogeneous wood to check the performance by using compressed air as a working fluid .The data was presented till date of the experimental work carried out by researchers for optimum performance of a vortex tube made of Rose wood and Sapota wood parameters such as the length of VT to its inlet diameter (L/ D) ratio as 24, use of different material in developing the vortex tube and its effect are discussed in detail.

Gurol Onal et al [10] has presented in this experimental study, performance of a counter flow RHVT The inner diameter of the vortex tube used was D=9 mm and the ratio of the tube’s length to diameter was L/D=12. The experimental system was a thermodynamic open system. Flow was controlled by a valve on the hot outlet side, where the valve was changed from a nearly closed position to its nearly open position. Fraction of cold flow (ξ) = 0.1-0.9, was determined under 300 and 350 K Pa pressurized air. All with threads cut on its inner surface was investigated experimentally.

Vennos [11] measured the velocity, total temperature, and total and static pressures inside a standard vortex tube and reported the existence of substantial radial velocity.

Hartnett and Eckert [12,13] measured the velocity, total temperature, and total and static pressure distributions inside a uni-flow vortex tube. They used the experimental values of static temperature and pressure to estimate the values of density and hence, the mass and energy flow at different cross sections in the tube. The results agreed fairly well with the overall mass and energy flow in the tube.

Guillaume and Jolly [14]demonstrated that two vortex tubes placed in a charged configuration or placed in series by connecting the cold discharge of one stage into the inlet of the following stage. From their results, it was found that for similar inlet temperatures, a two-stage vortex tube could be produced a higher temperature reduction than one of the vortex tubes operating independently.

Manohar and Chetan [15] used a vortex tube for separating methane and nitrogen from a mixture and found that there was partial gas separation leading to a higher concentration of methane at one exit in comparison to the inlet and a lower concentration at the other exit.

Eiamsa-ard S and Promvonge P et al [16,17] this paper presents an overview of the phenomena occurring inside the vortex tube during the temperature/energy separation on both the counter flow and parallel flow types. The paper also reviews the experiments and the calculations presented in previous studies on temperature separation in the vortex tube. The experiment consisted of two important parameters, the first is the geometrical characteristics of the vortex tube (for example, the diameter and length of the hot and cold tubes, the diameter of the cold orifice, shape of the hot (divergent) tube, number of inlet nozzles, shape of the inlet nozzles, and shape of the cone valve. The second is focused on the thermo-physical parameters such as inlet gas pressure, cold mass fraction, moisture of inlet gas, and type of gas (air, oxygen, helium, and methane). For each parameter, the temperature separation mechanism and the flow-field inside the vortex tubes is explored by measuring the pressure, velocity, and temperature fields.

Saidi and Valipour [18] presented on the classification of the parameters affecting vortex tube operation. In their work, the thermo-physical parameters such as inlet gas pressure, type of gas and cold gas mass ratio, moisture of inlet gas, and the geometry parameters ,i.e., diameter and length of main tube diameter of outlet orifice, shape of entrance nozzle were designated and studied.

Tejshree Bornare et al [19] investigate the effect of geometrical parameters i.e. diameter and length of main tube, diameter of out let orifice, shape of entrance nozzle. Thermo-physical parameters are inlet gas pressure, type of gas, cold gas mass ratio and moisture of inlet gas.

Prabhakaran j et al [20,21] measure the performance of the vortex tube was evaluated by conducting the experiment by replacing the cylindrical hot tube with a conical hot tube at various inlet pressures. it was found that the vortex tube with conical hot tube gives the better performance than cylindrical hot tubes. There is an increase in COP about 25%-30%

Martynovskii and Alekseev [23] studied experimentally the effect of various design parameters of vortex tubes.

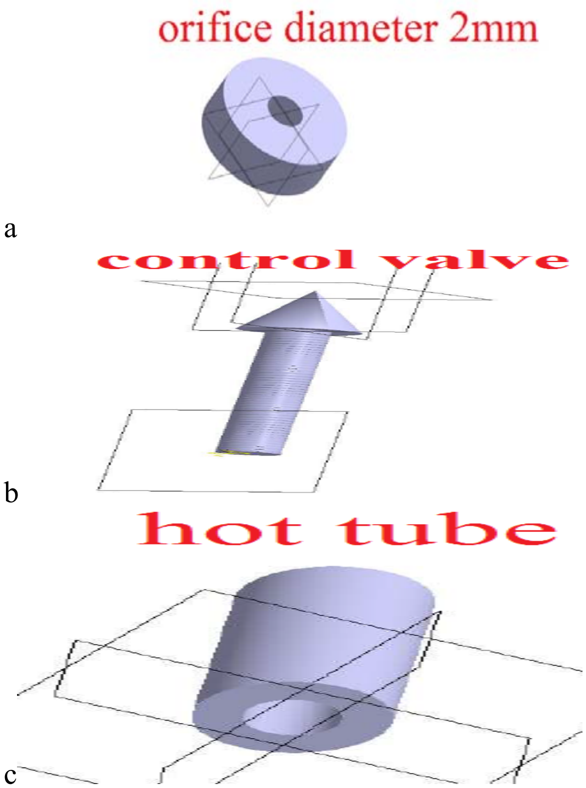
6. Design and Modeling of Vortex Tube

The setup is design and modeled using the CAD &CATIA V5 R21 modeling package – Then CATIA modeling is converted to STEP file (stp) format processing by the solver package.

Various steps in modeling to be carried out in CATIA are discussed below.

Select the new part from CATIA V5 R21
Select the RIGHT HAND SKETCH, give circle diameter and length
Select the work bench.
Draw the helix curve with the work bench
Select the point in corner
Take cut towards the flute length
Select the slot tool, follow the profile of helix
Select the cut out of helix angle
Select the centre plane, for shank part
Draw sketch of shank in the plane
Select the revolve action with reference of centre axis
Select the sketch for slot
Select the fillet radius, for fillet radius
Select the mid plane , to draw the cone angle
Select the pocket tool for full cut
Select the sketch, draw the for neck

Select the revolve command to cut out the neck

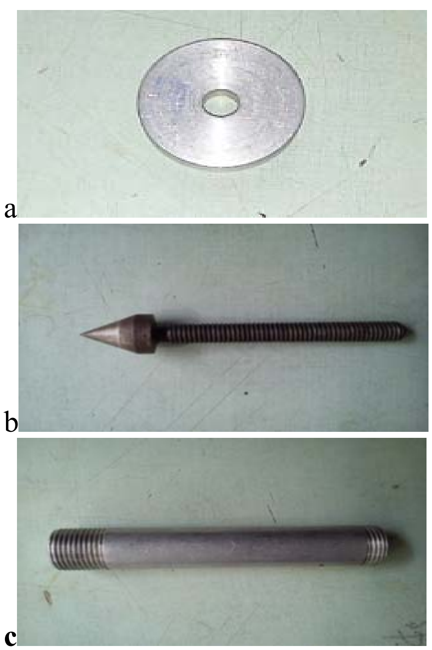


a

b

c

Fig.2. Basic design and modeling of vortex tube parameters:(a)diameter orifice and (b) the control valve (c) the hot tube



a

b

c

Fig.3. Fabrication of Aluminum vortex tube parameters:(a)diameter orifices and (b) the control valve (c) the hot tube.

we are using the CAD&CATIA V5 R21 and to designed and modelling of vortex tube parameters or parts like main body, hot tube, cold tube, inlet nozzle, control valve, hot end tube and orifice diameter s 4,5,6,7,8 mm respectively. A diaphragm is the most important part to be manufactured in the vortex tube. The diameter orifice (Fig. 2a,3a) it is manufacturing, modeling and designed by using aluminum material. The thickness is 9mm and the outer diameter is 25mm and hole of 8mm is made at the center.

A control valve is major part to be fabricated in the vortex tube. The control valve (Fig.2b,3b) it is fabricated, modeling and drafting by using mild steel material. The importance of control valve lies in building up a pressure, which causes flow through a diaphragm. There will be a stagnation zone should not disturb the flow pattern in chamber extension. Hence the hot tube is inserted between the extension and the valve.

A hot tube is the main part to be fabricated in the vortex tube. The hot tube (Fig. 2c,3c) it is fabricated, modeling and design by using aluminum material. the length of hot tube is 135mm and the through hole 12.5 diameter is made external threads of 1.5mm pitch are made on either side to length of 20mm.

7. Observations and Calculations

The experimental investigation was conducted to find the effect of different orifice diameters and inlet pressures on the performance of vortex tube. After conducting the experiment the observations are noted as given below:

For different Orifice diameter (d) at different input pressure by using aluminum material.

Table 1

Summary of experimental studies on vortex tubes (Aluminium Orifice dia: 8mm)

S. No	P_i, bar	(T_c)^{0}C	(T_h) ^{0}C	$\Delta T = T_h - T_c$ ^{0}C	ΔT_c, ^{0}C	ΔT_h, ^{0}C	µ	$\eta_{Adiabatic}$	COP
1	**7**	**9**	**51**	42	18	24	0.57	0.89	0.23
2	6	10	50	40	17	23	0.57	0.90	0.24
3	5	12	48	36	15	21	0.58	0.88	0.25
4	**4**	12	47	35	15	20	0.57	0.97	**0.29**

Table 2
Summary of experimental studies on vortex tubes (Aluminium Orifice Dia: 4 mm)

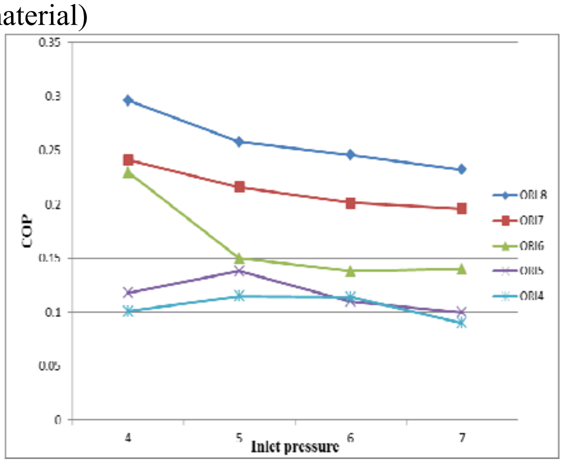
S. No	P_i, bar	$(T_c)^0C$	$(T_h)\ ^0C$	$\Delta T = T_h - T_c\ ^0C$	$\Delta T_c,\ ^0C$	$\Delta T_h,\ ^0C$	µ	$\eta_{Adiabatic}$	COP
1	**7**	12	36	24	15	9	0.37	0.49	**0.09**
2	6	14	34	20	13	7	0.35	0.42	0.11
3	5	15	33	18	12	6	0.33	0.40	0.11
4	4	16	31	15	11	4	0.26	0.33	0.10

8. Specifications Of The Air Compressor Used:

Compressor H.P = 7.5
No of cylinders = 3
Diameter of two L.P cylinders = 2 x 0.0936m
H.P cylinders = 0.07 m
Stroke length = 0.076 m
Number of stages = 2
Coefficient of discharge = 0.8
Working pressure = 15.525 bar
Orifice diameter = 0.025 m

9. RESULTS AND DISCUSSION

Fig.4. Inlet pressure vs COP (From Aluminum material)



Inlet pressure vs. COP

The above graph shows the effect of orifice diameter and pressure on the COP.

As the inlet pressure increases, the COP is decreased.

At 7 bar pressure COP is minimum as 0.9 with orifice diameter 4mm.
At 4 bar pressure COP is maximum as 0.29 with orifice diameter 8mm

Aluminum material : After evaluating the performance of vortex tube by varying the orifice diameters and inlet pressures it was found that the vortex tube with 8mm diameter orifice and at a pressure of 7 bar gives the best performance. As shown [Table1].

10. CONCLUSION

The well suited diameter orifice (8mm)at pressure 7 bar for getting superlative cooling effect (9^{0C}) from Aluminum material.

The felicitous orifice diameter (8mm) at pressure 7 bar for getting utmost heating effect (51^{0C}) from Aluminum material.

The convenient diameter orifice(4mm)at pressure 7 bar for getting poor Co-efficient of performance (0.09) from aluminum material.

The adaptable diameter orifice (4mm) at pressure 7 bar is gives supreme Co-efficient of performance(0.2964) from Aluminum material.

11. FUTURE SCOPE

The vortex tube's ability to separate two phase gas mixtures based on density may enable high performance, multi-stage cryogenic refrigeration systems. The vortex tube has the potential to improve the performance of cryogenic refrigeration system.
The vortex tube has potential uses in automobiles for air conditioning and spot cooling/heating purposes.
There is scope for using the vortex tube as a dust trap.

We can increase number of inlet air entries.

We can increase number of inlet air entries.

Experiments are also possible with varying the length of Cold ends and Hot ends.

We can try different types of fluids like carbon dioxide, hydrogen as inlet element.

Same Vortex tube as we have manufactured can be tested by using water as cooling agent.

Also the vortex tube may be used for flame propagation in furnaces, jet propulsion, etc.

REFERENCES

1. Ranque GJ. Experiments on expansion in a vortex with simultaneous exhaust of hot air and cold air. J Phys Radium (Paris) 1933;4:112–4 S-115, June. Also translated as General Electric Co., Schenectady Works Library 1947; T.F. 3294.
2. Ranque GJ. Method and apparatus for obtaining from a fluid under pressure two outputs of fluid at different temperatures. US patent 1:952,281, 1934.
3. Hilsch R. The use of expansion of gases in a centrifugal field as a cooling process. Rev Sci Instrum 1947;18(2):108–13.
4. Maxwell Boltzmann distribution, http://www.answers.com/topic/maxwell boltzmann-distribution;http://www.google.com/maxwellsdemon
5. Experimental Investigation and Optimization of Vortex Tube with Regard to Nozzle Diameter AN PAWAR
6. http://arizonavortex.com/vortextubes.htm S
7. Colgate SA, Buchler JR. Coherent transport of angular momentum-the Ranque–Hilsch tube a paradigm, astrophysical turbulence and convection. Ann NY A cad Sci 2000;898:105–12.
8. Rao KKK, Reddy BVM, Ramesh A, Dennes MT. Experimental analysis of vortex tube made of homogeneous wood. International Journal of Engineering Research & Technology (IJERT). 2016 April: 5(4).
9. Önal G, Dincer K. Experimental Study of Performance of a Counter Flow Ranque-Hilsch Vortex Tube with Inner Threaded Body. In Proceedings of World Academy of Science, Engineering and Technology 2013 Aug 1 (No. 80, p. 744). World Academy of Science, Engineering and Technology (WASET).
10. Vennos SLN. An experimental investigation of the gaseous vortex. PhD thesis. Rensselaer Polytechnic Institute, 1968.
11. Hartnett JP, Eckert ERG. Experimental study of the velocity and temperature distribution in a high-velocity vortex-type flow. Heat Transfer and Fluid Mechanics Institute, Stanford University Press;1956. p. 135–50.
12. Hartnett JP, Eckert ERG. Experimental study of the velocity and temperature distribution in a high-velocity vortex-type flow. Trans ASME J Heat Transfer 1957;79:751–8.
13. Guillaume DW, Jolly JL. Demonstrating the achievement of the lower temperatures with two-stage vortex tubes. Rev Sci Instrum 2001;72(8):3446–8.
14. Manohar R, Chetan R. Enrichment of methane concentration via separation of gases using vortex tubes. J Energy Eng 2002;128(1):1–12.
15. Eiamsa-ard S, Promvonge P. Numerical prediction ofvortex flow and thermal separation in a subsonic vortex tube. J Zhejiang Univ SCI Int Appl Phys Eng J 2006;7(8):1406–15.
16. Eiamsa-ard S, Promvonge P. Numerical investigation of the thermal separation in a Ranque–Hilsch vortex tube. Int J Heat Mass Transfer 2007;50(5–6):821–32.
17. Saidi MH, Valipour MS. Experimental modeling of vortex tube refrigerator. Appl Therm Eng 2003; 23:1971–80.
18. Tejashree bornare (IJMET) vortex tube Refrigeration system based on compressed air.
19. Prabhakaran j Effect of diameter of orifice and nozzle on the performance of counter flow vortex tube, IJEST journal,2010.
20. Prabhakaran j Effect of orifice and pressure of counter flow vortex tube, IJEST journal,2010.
21. Martin RW, Zilm KW. Variable temperature system using vortex tube cooling and fibber optic temperature measurement for low temperature magic angle spinning NMR. J Magn Reson 2004;168(2):202–9.*
22. Scheper GW. The vortex tube; internal flow data and a heat transfer theory. JASRE Refrig Eng1951;59:9859. PprabhakaranTICLE IN PRE of counter flow vortex tube IJST vol.s.No.4(Apr.2010)