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Air Refrigeration System by Using Vortex Tube

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Abstract

Vortex tube is a mechanical device with no moving parts in it. When compressed air is sent into it results in producing two air streams of extreme temperatures. This special characteristic of vortex tube is used for different purposes like heating and cooling. Vortex tube produces both cold and hot air from its both ends simultaneously. In this paper, the main focus on the cold end temperatures because of which refrigeration effect is produced. Four different vortex tubes with different dimensions, number of nozzles, orifice & Venturi are fabricated and their COP's are compared.

Keywords: Air Refrigeration system, Vortex tube, COP

1. INTRODUCTION

The vortex tube is a structurally simple device with no moving parts that is capable of separating a high-pressure flow into two lower pressure flows with different energies, usually manifested as a difference in temperatures. The vortex tube is relatively inefficient as a stand-alone cooling device but it may become an important component of a refrigeration system when employed as an alternative to the conventional expansion device. A cycle augmented with a vortex tube can offer several advantages including: efficient operation above the Joule-Thomson inversion curve, relative insensitivity to heat exchanger size, and the ability to operate with a lower pressure ratio. The extent to which these advantages are realized depends on the cycle configuration, the fluid properties, the operating conditions, and the behavior of the vortex tube.

The vortex tube has been subject of studies due to its enormous applications in engineering, such as to cool parts of machines, refrigeration, cool electric or electronic control cabinets, cooling of equipments in laboratories dealing with explosive chemicals, chill environmental chambers, cool foods, liquefaction of natural gas and cooling suits. Moreover, the lack of moving parts, electricity and others advantages make the device attractive for a number of special applications where simplicity, robustness, reliability and general safety are desired. Other important motivation for the study of vortex tube is concerned with the complexity of the energy separation phenomenon in the compressible and turbulent flow.

1.1 Working Principle

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 in vortex chamber, which subsequently spiral down the tube to right side (depends on the direction of spiral). The central core of the air is reversed by means of a conical valve, which control the pressure in the system. 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. The reversed air at low temperature moves through the washer to the cold section. Thus cold air is produced at the left side of vortex chamber. Hot air is produced at the right side through the conical valve..

2. LITERATURE

The vortex tube is well-suited for these applications because it is simple, compact, light, quiet, and does not use Freon or other refrigerants (CFCs/HCFCs). They are popular for their reliability (no moving parts), lack of maintenance and simple and inexpensive construction. There are two exits on the tube the hot exit is placed near the outer radius of the tube at the end away from the nozzles, and the cold exit at the center of the tube in the bottom of vortex chambers. Separating of compressed inlet gas into two different temperature streams (cold and hot) is referred as temperature separation effect that reported for the first time by Ranque in 1931 [1]; when he was studying processes in a dust separation cyclone. His design of the vortex tube was later improved by the German physicist Hilsch in 1947 [2], who arranged a diaphragm at the cold exit end of machine. He suggested that angular velocity gradients in the radial direction give rise due to frictional coupling between different layers of the highly rotating flow. Therefore, the transform of energy via shear work would occur from the inner layers to the outer ones. Other investigators have attributed the energy separation to work transfer via compression and expansion, although several variations of this theory are described in the literatures. Similarly, Harnett and Eckert [3] invoked the influence of turbulent eddies., J.

Prabakaran and S.Vaidyanathan [4] investigated the Effect of orifice and pressure of counter flow vortex tube was studied and the maximum temperature difference is obtained as 19.80 at 7 bar with orifice of 7 mm diameter. When the diameter of the orifice is 6 mm (0.5 D), it produces best cooling effect .When the diameter of the orifice is 7 mm (0.6 D), it produces best heating effect. When the orifice diameter is 5 mm, the energy separation is affected and temperature difference is decreased. It shows that the diameter of the orifice is an important factor for the energy separation. Karthik S et al [5] studied the results obtained by using PVC as the material provides similar outputs to that of the tests conducted by pioneer scientists such as Hilsch and Reynold. By increasing the mass flow rate, the temperature gap increases and hence produces a high COP. Mass flow rate can be adjusted by the valve position of the conical valve. Shrikrushna Nagane et al [6] studied the Increase of inlet pressure increases coefficient of performance, cooling effect and isentropic efficiency of the vortex tube. Rahul Patel Ramji Tripathi et al [7] studied the actual COP of system is improved by using the water cooled condenser instead of air cooled condenser.

3. EXPERIMENTAL WORK

3.1 Construction details of vortex tube

The major components of a vortex tube are:

1. Vortex chamber
2. Hot end
3. Cold end
4. Air inlet
5. Hot end restriction

Where “d” is internal diameter of tube, then
Hot end length = 45*d
Cold end length = 10*d
Orifice diameter = d/2
Size of holes = d/8

Figure 1 Fabricated Vortex tubes

Figure 1 Vortex tube setup

The experimental setup of vortex tube air refrigeration system is same as Bell- Coleman cycle. The only change is heat exchanger is removed and vortex tube is added to the cycle

3.2Vortex tube air refrigeration cycle formulae

Heat absorbed by the air during constant pressure process

$$QA = mc\ cp\ (T1–T4)$$

Where mc = mass flow rate of air leaving cold end
Cp = specific heat at constant pressure (1.005 KJ/Kg K)
T1 = temperature of the air leaving the evaporator (cabin)
T4 = cold end temperature of vortex tube
Work energy supplied to compress the air is equal to power input to the compressor to compress the air (Pc)
Pc = power input to motor (Pm) X efficiency of the compressor
Where

$$P_m = \frac{(x).3600}{(t.EMC)}$$

Here
x= no. of flashes of energy meter
t= time taken for "x" flashes in seconds
EMC= energy meter constant = 1600 Imp/kWh
Efficiency of the compressor is taken as 50%
Coefficient of performance of the cycle
C.O.P = Heat absorbed / energy supplied
= mc cp (T1–T4) / Pc
Mass flow rate = (Density of Air) X (Cross-sectional area of pipe) X (Velocity of air)
Density of the air = 1.181 Kg/m3

4.EXPERIMENTAL WORK

4.1 Design and fabrication of Vortex tubes

4.1.1 Vortex tube (1)

Figure 3 Vortex tube (1)

Internal diameter = 1.35 cm
Number of holes = 2
Orifice diameter = d/2
Hot end restriction: Wooden piece with conical end

Table 1 Experimental values Vortex tube 1

Inlet Pressure (Kg/cm2)	Mass flow rate (kg/sec)	Cold end temperature	Hot end temperature	Temperature difference	Cold end temperature (cabin inlet) k	Temperature at exit of cabin (k)	Cooling effect (KW)	COP
6	3.91131	291.2	316.6	25.4	287.3	301.9	0.11285	0.03574
5	3.66775	293.3	314.4	21.1	288.6	302.4	0.10114	0.02986

4	3.16630	296.4	313.2	16.8	290.5	304.6	0.07882	0.02496
3	2.70783	299.8	312.6	12.8	291.8	305.8	0.07151	0.02264
2	2.17772	301.3	311.2	15.2	296.5	307.2	0.04505	0.01424

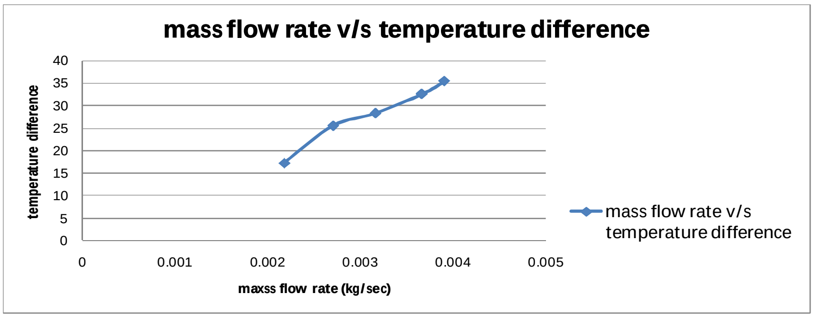

Figure 4 Mass flow rate Vs Temperature Difference

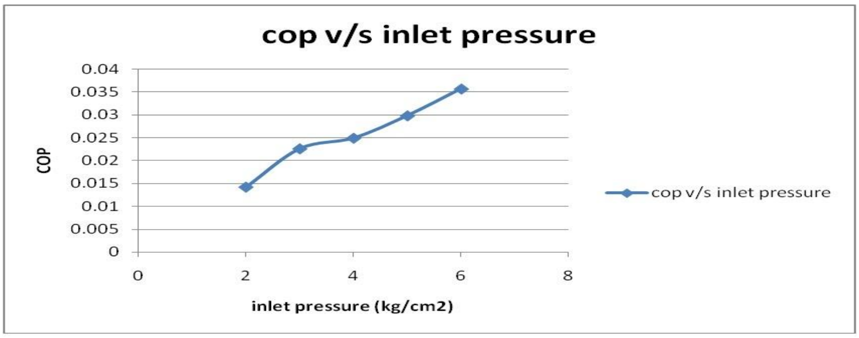

Figure 5 COP Vs Inlet Pressure

4.1.2 Vortex Tube (2)

Internal diameter = 1.35 cm
Number of holes = 4
Orifice diameter = d/2
Hot end restriction: Wooden piece with conical end.

Figure 6 Vortex Tube (2)

Table 2 Experimental values Vortex tube 2

Inlet Pressure (Kg/cm2)	Mass flow rate (kg/sec)	Cold end temperature	Hot end temperature	Temperature difference	Cold end temperature (cabin inlet) k	Temperature at exit of cabin (k)	Cooling effect (KW)	COP
6	3.91131	287.3	322.8	35.5	291.2	305.3	0.02156	0.02897

5	3.66775	288.6	321.2	32.6	293.3	306.6	0.01774	0.02384
4	3.16630	290.5	318.8	28.3	296.4	307.8	0.01391	0.01869
3	2.70783	291.8	317.3	25.5	299.8	308.4	0.00937	0.01259
2	2.17772	296.5	313.6	17.1	301.3	309.6	0.00729	0.0097

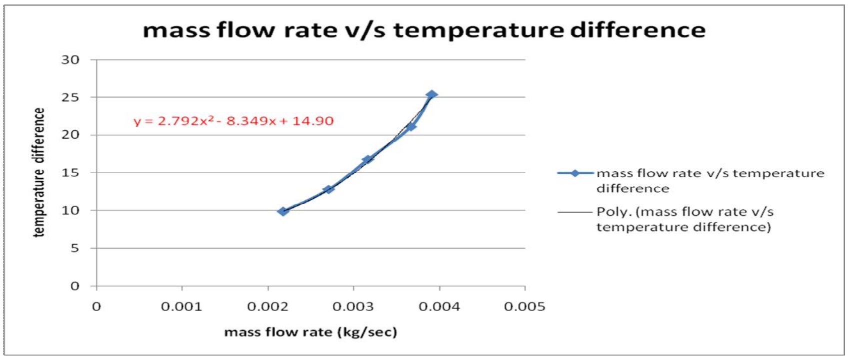

Figure 7 Mass flow rate Vs Temperature Difference

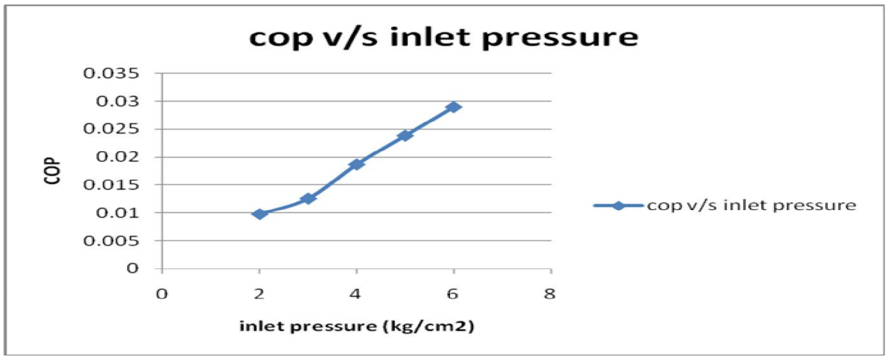

Figure 8 COP Vs Inlet Pressure

4.1.3 Vortex Tube (3)

Internal diameter (d) = 19 mm
Number of holes = 2
Orifice diameter = d/2
Hot end restriction: Wooden piece with conical end.

Figure 9 Vortex Tube (3)

Table 3 Experimental values Vortex tube3

Inlet Pressure (Kg/cm2)	Mass flow rate (kg/sec)	Cold end temperature	Hot end temperature	Temperature difference	Cold end temperature (cabin inlet) k	Temperature at exit of cabin (k)	Cooling effect (KW)	COP
6	3.91131	293.9	321.9	28	293.9	305.6	0.02601	0.03495
5	3.6677	295.6	319.8	24.2	295.6	306.5	0.0214	0.02879

	5						2	
4	3.16630	296.9	316.8	19.9	296.9	307.1	0.01742	0.02341
3	2.70783	300.8	314.1	13.3	300.8	308.4	0.01200	0.01612
2	2.17772	303.3	311.3	8.3	303.3	309.3	0.00721	0.010123

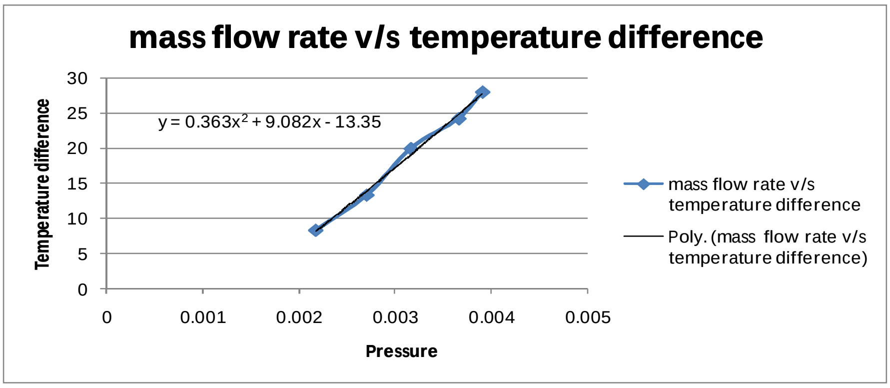

Figure 10 Mass flow rate Vs Temperature Difference

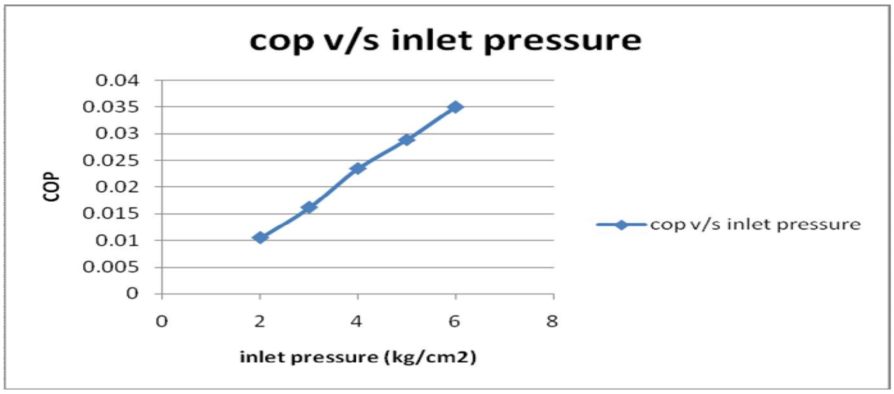

Figure 11 COP Vs Inlet Pressure

4.1.4 Vortex Tube (4)

Internal diameter = 19 mm
Number of holes = 4
Venturi with diameter reduction from d to d/2
Hot end restriction: Wooden piece with conical end.

Figure 12 Vortex Tube (4)

Table 4 Experimental values Vortex tube4

nlet Pressure (Kg/cm2)	Mass flow rate (kg/sec)	Cold end temperature	Hot end temperature	Temperature difference	Cold end temperature (cabin inlet) k	Temperature at exit of cabin (k)	Cooling effect (KW)	COP
6	3.91131	295.6	315.5	19.9	295.6	307.2	0.02093	0.02812

5	3.66775	298.1	315	16.9	298.1	308.1	0.01579	0.02121
4	3.16630	301.8	313.2	11.4	301.8	309.3	0.00990	0.01331
3	2.70783	303.9	312.3	8.4	303.9	310.4	0.00754	0.01013
2	2.17772	304.9	311.5	6.6	304.9	311.4	0.00649	0.00872

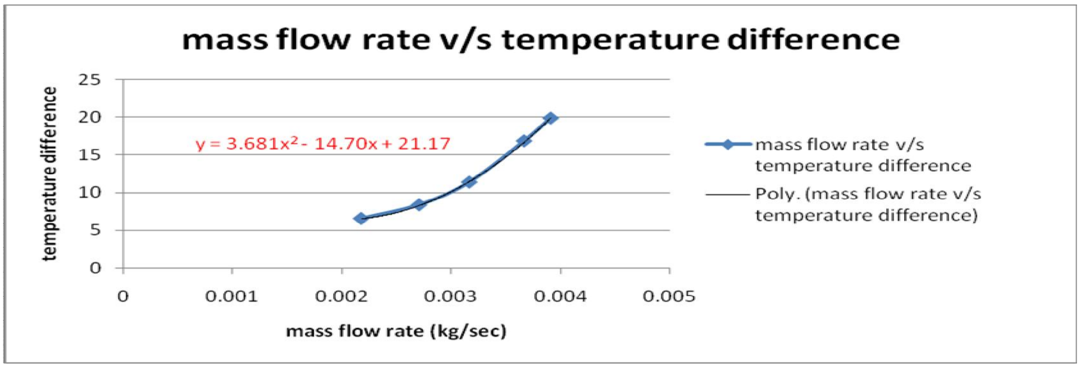

Figure 13 Mass flow rate Vs Temperature Difference

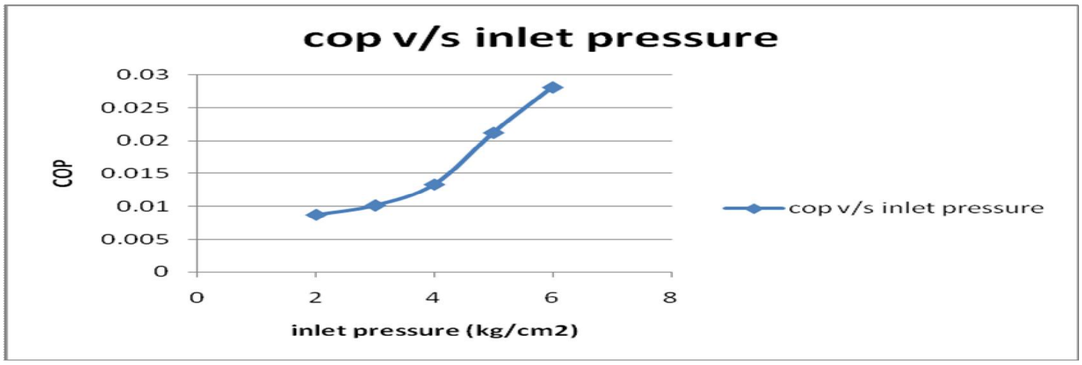

Figure 14 COP Vs Inlet Pressure

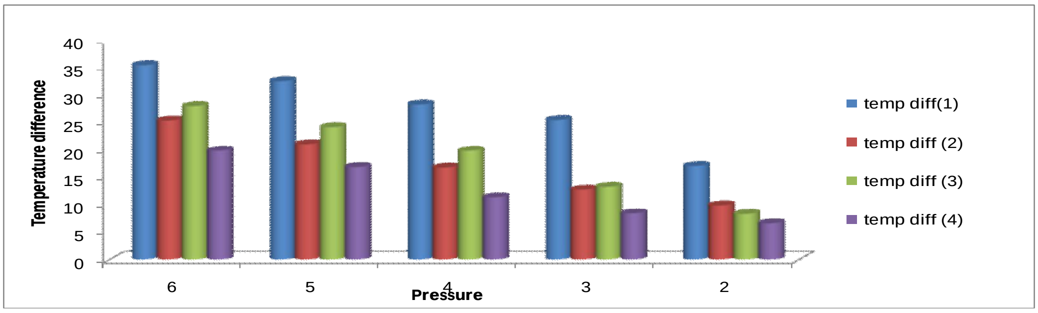

Figure 15 Temperature differences for 4 vortex tubes at different pressures.

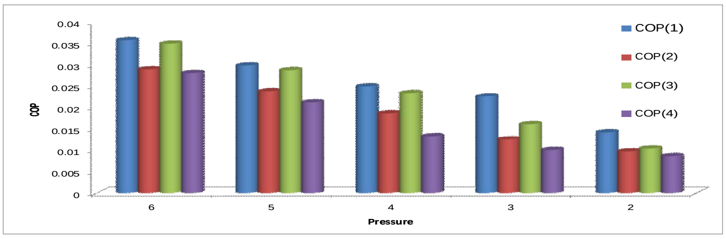

Figure 16 COP of 4 vortex tubes at different pressures.

5. CONCLUSION

The refrigeration effect is produced using vortex tube, from the calculations it is observed that for the same power input, COP of the vortex tube is high compared with cooling effect. It is also proved that as the as the inlet air pressure of the vortex tube increases, the cooling effect also increases. Out of the four fabricated vortex tubes, Vortex tube 1 (internal diameter = 1.35 cm and 2 holes with orifice) has higher COP and cooling effect than others.

References

[1] G.J. Ranque, " Experiments on expansion in a vortex with simultaneous exhaust of hot air and cold air," J. Phys. Radium (Paris), vol. 4, pp. 112-115, 1993.
[2] R. Hilsch, "The use of expansion of gases in a centrifugal field as a cooling process," Rev. Sci. Instrum, vol. 18, pp. 108-113, 1947
[3] J. Harnett, E. Eckert, "Experimental study of the velocity and temperature distribution in a high velocity vortex-type flow," Trans. ASME , vol.79, pp. 751-758, 1957.
[4] J. Prabakaran, S. Vaidyanathan, "Effect of diameter of orifice and nozzle on the performance of counter flow vortex tube," Int. J. Eng. Sci. Tech', vol. 2 (4), pp. 704-707, 2010.
[5] Karthik S, "An Experimental Setup of Vortex Tube Refrigeration System', International Journal of Engineering Research & Technology," Vol.4 Issue 03.PP 263-265, 2015.
[6] Shrikrushna Nagane Sagar et al, "A Review on vortex tube refrigeration system', International Journal of Innovative Science, Engineering & Technology," Vol.2 Issue 9, 2015.
[7] Er. Rahul Patel and Er. Ramji Tripathi, "Performance Evaluation of Refrigeration System Based on Bell-coleman cycle," International Journal of Recent Scientific Research Vol. 6, Issue, 4, pp.3321-3327, 2015.

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