An Efficient Vortex Tube With Max C.O.P

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1.1 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, 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.[3]

Much earlier, the great nineteenth century physicist, James Clerk Maxwell 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.[4]

Thus, the vortex tube has been variously known as the "Ranque Vortex Tube", the "Hilsch Tube", the "Ranque-Hilsch Tube", and "Maxwell's Demon". By any name, it has in recent years gained acceptance as a simple, reliable and low cost answer to a wide variety of industrial spot cooling problems.

When high-pressure gas is tangentially injected into the vortex chamber via the inlet nozzle, a swirling flow is created inside the vortex chamber. In the vortex chamber, part of the gas exists via the cold exhaust directly, and another part called as free vortex swirls to the hot end, where it reverses by the control valve creating a forced vortex moving from the hot end to the cold end. Heat transfer takes place between the free end and the forced vortices there by producing two streams, one hot stream and the other is cold stream at its ends.[9]

1.2 COMPONENTS OF VORTEX TUBE:

The systematic diameter gram of vortex tube is shown in the figure.

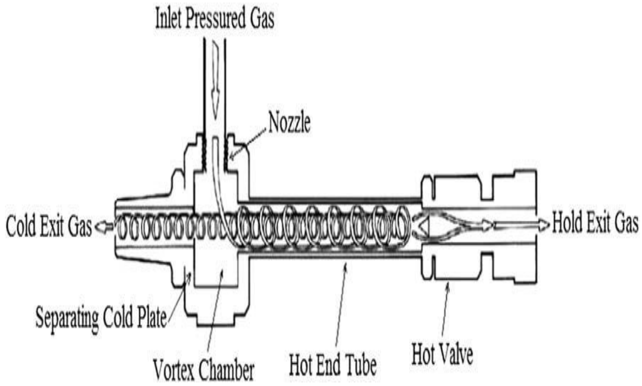

Fig:1.2 Vortex Tube.

It consists of the following parts.

1. Nozzle.
2. Diaphragms.
3. Control valve.
4. Hot air side.
5. Cold air side

The actual diameter gram of vortex tube is shown below.

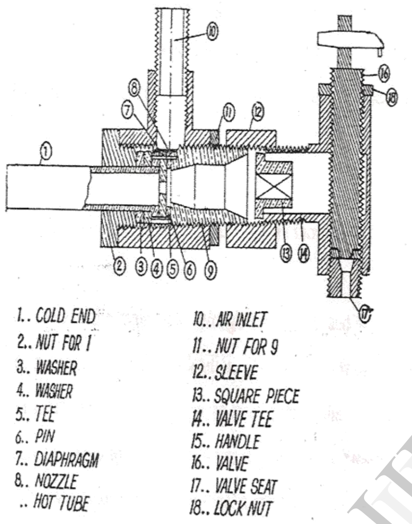

Fig: 1.2.1 Sectional view of Vortex Tube.

1.3 WORKING OF VORTEX TUBE:

A compressed air is passed through the nozzle as shown in figure. Here 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 motion along the periphery of the hot side. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm.

The control valve restricts this flow. When the pressure of the air near the valve is made more than the outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region. During this process, energy transfer takes place between reversed stream and forward stream and therefore air stream through the core gets cooled below the inlet temperature of the air in the vortex tube while the air stream in forward direction gets heated. The cold stream is escaped through the diaphragms hole into the cold side, while hot stream is passed through the opening of the control valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied.[6]

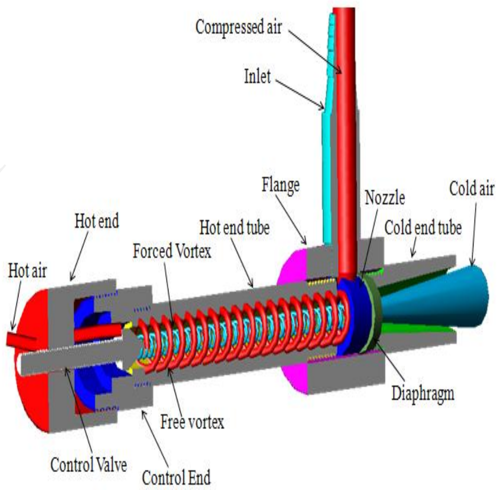

Fig:1.3 3D Sectional view of Vortex tube.

2.METHODOLOGY

2.1 ASSUMPTIONS:

1. Mass flow rate of air entering into compressor is equal to *mass flow* rate of air entering in to the vortex tube maintaining at constant pressure in receiver tank.[2]

2. Assuming no losses i.e. inlet mass flow rate of air is equal to mass flow rate of cold air + mass flow rate of hot air. [5]

2.2 ADIABATIC EFFICIENCY OF AIR COMPRESSOR:

The coefficient of performance of the vortex tube is the product of adiabatic efficiency of the air compressor and adiabatic efficiency of the vortex tube and $[(P_a/P_i)^{(\gamma-1)/\gamma}]$, the adiabatic efficiency of the Air compressor is to be calculated first.[3]

2.3 SPECIFICATIONS OF THE AIR COMPRESSOR USED :

Compressor H.P = 3

No of cylinders = 2

Diameter of two L.P cylinders = 70 mm
H.P cylinders = 50 mm

Stroke length = 85 mm

Number of stages = 2

Coefficient of discharge = 0.62

Working pressure = 120 lbs

Orifice diameter = 20 mm

FOR CYLINDRICAL TUBE:

S.No	Pressure P_i, bar	Cold Temp (T_c), ^{0}C	Hot Temp (T_h), ^{0}C	Difference $\Delta T= T_h- T_c$ ^{0}C	Cold Temp Drop ΔT_c, ^{0}C	Hot Temp Drop ΔT_h, ^{0}C	Cold mass Fraction μ	Adiabatic Efficiency	COP
1	2	23	36	13	7	6	0.4615	0.6099	0.0798
2	3	21	38	17	9	8	0.4705	0.5294	0.0967
3	4	21	39	18	9	9	0.5	0.4622	0.1022
4	5	20	40	20	10	10	0.5	0.4550	0.1111
5	6	18	42	24	12	12	0.5	0.5020	0.1311

Table:2.1

2.2 AIR COMPRESSOR ADIABATIC EFFICIENCY CALCULATION:

CALCULATIONS:

P_1 atm pressure = 1 bar

P_2 delivery pressure = 6 bar

Energy input =

$$\frac{3600 \text{ x no.of revolutions of energy meter}}{\text{time taken in sec x 100 x0.8}}$$

$$= \frac{3600\text{x}10}{87.28\text{x}100\text{x}0.8}$$

= 5.156 kW

Theoretical volume V_1 =

$$\frac{Л \text{ x d x d x L x 2 x N}}{4 \text{ x } 60} =$$

$$\frac{Л \text{ x } 0.07 \text{ x } 0.07 \text{ x } 0.085 \text{ x } 2 \text{ x } 886}{4 \text{ x } 60}$$

$=0.0096 m^3/sec$

Adiabatic Work Done $= \frac{\gamma}{\gamma-1} P_1 V_1[(p_2/p_1)^{(\gamma-1/\gamma)}-1]$

$= 1.4 * 1*10^5 *0.0096 [(6/1)^{(0.4/1.4)} - 1]/0.4$

= 2239.02 J

Adiabatic Efficiency of a Compressor = (Adiabatic Work Done)/(Energy Input)
=2239.02/(5.156*1000)

Adiabatic Efficiency of a Compressor =0.4342 ≈ 43%

2.2SPECIMEN CALCULATIONS:

SPECIMEN CALCULATIONS FOR THE INLET PRESSURE OF AIR

Pi = 6 bar

OBSERVATIONS:

1. Atmospheric pressure P_a = 1 bar.
2. Inlet pressure of air P_i = 6 bar
3. Inlet temperature of air T_i = 30^0C
4. Cold air exit temperature T_c = 18^0C
5. Hot air exit temperature T_h = 42^0C

CALCULATIONS:

1. Cold drop temperature $\Delta T_c = T_i - T_c$

$\Delta T_c = 30 - 18 = 12^0C$

2. Hot raise temperature $\Delta T_h = T_h - T_i$

$\Delta T_h = 42 - 30 = 12^0C$

3. Temperature Drop at the two ends $\Delta T = T_h - T_c$

$\Delta T = 42 - 18 = 24^0C$

4. Cold mass fraction $\mu = \frac{\Delta T_h}{\Delta T_h + \Delta T_c}$

$\mu = \frac{12}{12+12} = 0.5$

5. Static Temperature Drop Due To Expansion

$\Delta T'_c = Ti - T'_c = T_i[1-(P_a/P_i)^{(\gamma-1)/\gamma}]$

$\Delta T'_c = 30[1-(1/6)^{\{1.4-1\}/1.4}]$

$= 12.01^0C$

6. Relative Temperature Drop (ΔT_{rel}) = $\Delta T_c/(\Delta T'_c)$

3 GRAPHS

After conducting the experiment we noted the tabulated results and the following graphs are plotted.

3.1 COLD END TEMPERATURE VARIATION AT DIFFERENT PRESSURES

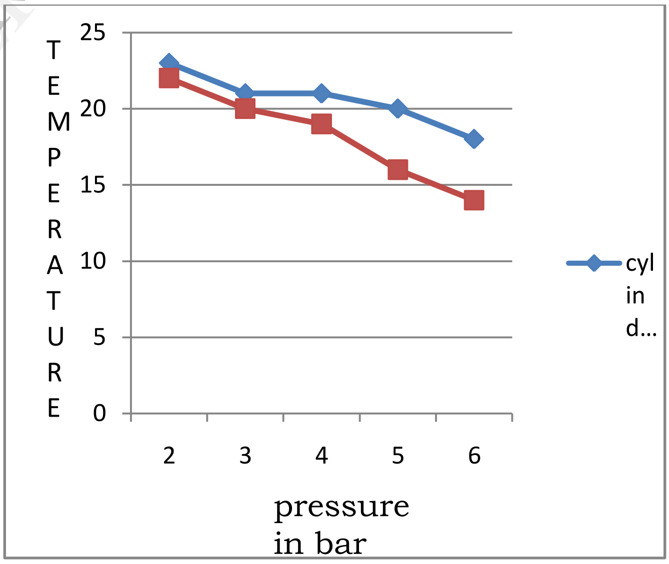

Fig..3.1 COLD END TEMPERATURE VARIATION AT DIFFERENT PRESSURES

From the above Fig. 6.3.1 it is clear that at any given pressure the temperature of the conical hot tube is better when compared to cylindrical hot tube and the temperature difference between them is proportional to pressure i.e., the temperature difference is increasing progressively with pressure.

3.2 HOT END TEMPERATURE VARIATION AT DIFFERENT PRESSURES

S.No	Pressure in Bar	COP of cylinder hot tube	COP of conical hot tube	% increase in COP of conical hot tube
1	2	0.0798	0.1085	35.96
2	3	0.0967	0.1289	33.29
3	4	0.1022	0.1196	17.25
4	5	0.1111	0.1330	19.71
5	6	0.1311	0.1540	17.46

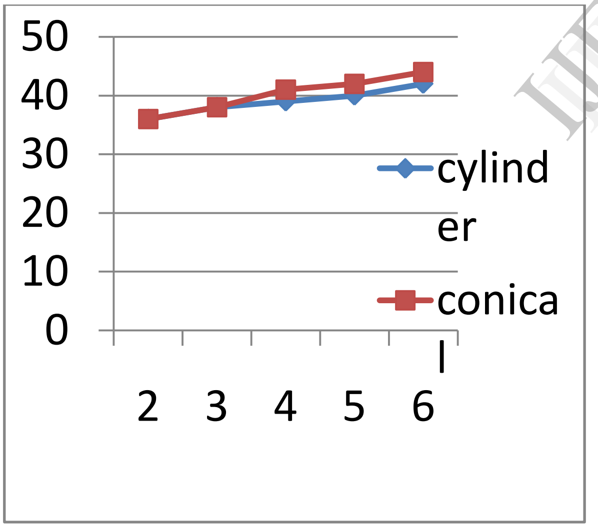

Fig.3.1 HOT END TEMPERATURE VARIATION AT DIFFERENTPRESSURES

From the above Fig. 6.3.1 the temperature of hot end for conical hot tube is more compared to cylindrical hot tube .from this we can say that temperature difference between them is proportional to pressure i.e., the temperature difference is increasing progressively with pressure.

3.3 COP VARIATION AT DIFFERENT PRESSURES

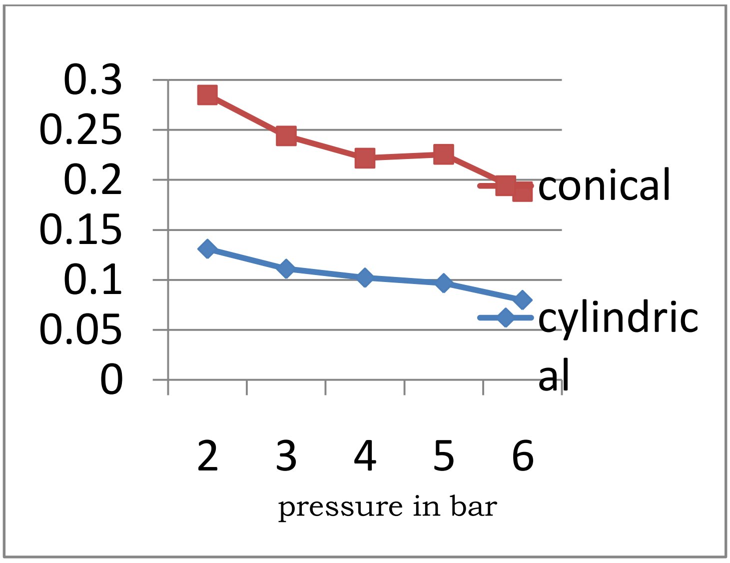

Fig..3.3 COP VARIATION AT DIFFERENT PRESSURES

The above Fig**.** 3.3 is plotted for pressure V/s COP. From the graph it is noted that the COP of the vortex tube with conical hot end is higher than the vortex tube with cylindrical hot tube.

From the above three graphs it is noted that the performance of the vortex tube with conical hot tube is better than the vortex tube with cylindrical hot tube.

4. RESULTS &DISCUSSIONS

RESULTS:

After evaluating the performance of vortex tube with cylindrical and conical hot tubes it was found that the vortex tube with conical hot tube gives the better performance than the cylindrical hot tube i.e. there is an increase in cop of about 25%-30%. The COP values obtained for cylindrical and conical hot tubes at various pressures are:

DISCUSSIONS:

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

The other parameters like orifice diameter, nozzle is kept unchanged. The highest COP is obtained at 6bar for taper tube and the value is 0.1540.

The lowest cold temperature for vortex tube with conical hot tube is 14˚C at 6 bar and with cylindrical hot tube is 18˚C at 6 bar.

The highest hot temperature for vortex tube with conical hot tube is 44˚C at 6 bar and with cylindrical hot tube is 42˚C at 6 bar.

Cold mass fraction obtained is better for the vortex tube with the conical hot tube than the cylindrical hot tube see table 6.2.3.1 & table 6.2.5.1

The maximum of 30˚C difference between hot and cold ends temperature for vortex tube with the conical hot tube and maximum of 24˚C difference between hot and cold ends temperature for vortex tube with the cylindrical tube is obtained.

REFERENCES

[1]. FikretKocabas , Modeling of heating and cooling performance of counter flow type vortex tube by using artificial neural network, Elsevier Journal, February 2010.

[2]. K. Dincer , Experimental investigation and exergy analysis of the performance of a counter flow Ranque-Hilsch vortex tube with regard to nozzle cross-section areas, Elsevier Journal, April 2010.

[3]. Prabakaran.J , Effect of Diameter of Orifice and Nozzle on the performance of Counter flow Vortex tube, IJEST Journal, 2010.

[4]. J. Prabakaran, Effect of orifice and pressure of counter flow vortex tube, IJST, April 2010.

[5]. Nader Pourmahmoud, The effect of L/D ratio on the Temperature separation in the Counter flow Vortex tube, IJRRAS Journal, January 2011.

[6]. ChengmingGao, Experimental study on the Ranque-Hilsch Vortex Ttube, PhD Thesis.

[7]. S.C Arora and S. Domkundwar, A course in refrigeration and air conditioning, DhanapatRai& Sons Publications.

[8]. www.ExAir.Com.

[10]. www.P.A. Hilton.com

[11]. www. Air Tx international.com

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