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Design and Computation of COP of Vortex Tube

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Abstract— Vortex tube is a mechanical device operating as a refrigerating machine without any moving parts, by separating a compressed gas stream into a low total temperature region and a high one .A vortex tube is a device capable of production of both higher and lower temperatures simultaneous at both ends of the tube. The vortex tube's construction is such that it is made up of a hollow tube of either metallic or fibre components having a nozzle for letting in of compressed air and a diaphragm or a orifice for controlling the flow rate of air. When compressed air passes through a nozzle into the diaphragm of the vortex tube, the air forms a spiral shaped vortex, that causes the heating up of air, and when this air returns back, it cools down rapidly, producing a cooling effect. As the mass flow rates changes, the temperature gap between the atmospheric air and air through the cold end varies. In this paper, the calculations for flow rates are measured and the designs are similar to what was taken by Hilsch, Reynold and Albohrn.

Keywords— Vortex Tube, cooling, mass flow rate , temperature gap, compressed gas ,refrigeration ,nozzle, diaphragm

1. INRODUCTION

Vortex tube was first experimentally tested in the year 1933 by George Ranque while observing a thermal division in a cyclone separator . This primary design was altered in the year 1947 by Hilsch. In the subsequent years, more modifications was achieved by higher performance of the vortex tubes and to study various parameters concerning the tube design and output, for example Kassner and Knoemschild performed a study based on the assumption that the effect was due to a adiabatic expansion, which lead to a low temperature in the

low pressure area near the axis of the tube. . Even after various tests and analysis, no theory provides a proper explanation for the vortex mechanism undergoing in the tube.

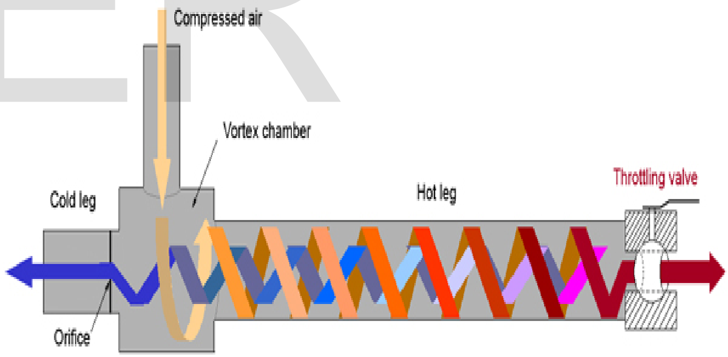


FIG. 1. DIAGRAM OF A VORTEX TUBE

A Vortex tube consists of a cylindrical tube with a nozzle, a diaphragm (cylindrical plate with a central hole) and a control valve. Compressed air is kept tangential through the nozzle which is kept tangential to the tube.

The Vortex Tube is now being used commercially for various applications such as food preservation and cooling in mines as the apparatus is very simple and compact and it doesn't require any interaction of heat and work with the environment for its operation.

2. LITERATURE REVIEW

After initial experiments, a lot of researchers tried a lot of modifications on the vortex tube to increase its performance. It is found from the previous scientist's records that each and every one of them used various L/D ratios and each one of them was a result of hit and trial method. The list is given below regarding the modifications and customisations:-

TABLE I. PREVIOUS REVIEWS

SCIENTIST	L *(inch)*	D *(inch)*	Nozzle dia *(inch)*	year	Cold end orifice dia *(d_c)*	$d_r=d_c/D$
TAKAHAMA	317	2	0. 5	1980	–	–
REYNOLDS	48	3	0. 12	1985	127	0. 42
AHLBORN	24	1	–	1997	0. 328	0. 33
C. RAO	8	0. 63	0. 12	2005	0. 16	0. 25
NINMBALKAR	10	0. 75	0. 162	2011	0. 38	0. 50

It is clearly evident from the above table that the various ratio parameters used in the construction of the vortex tube for different authors have no relation with each other. Each person has his own combinations of the ratio parameters.

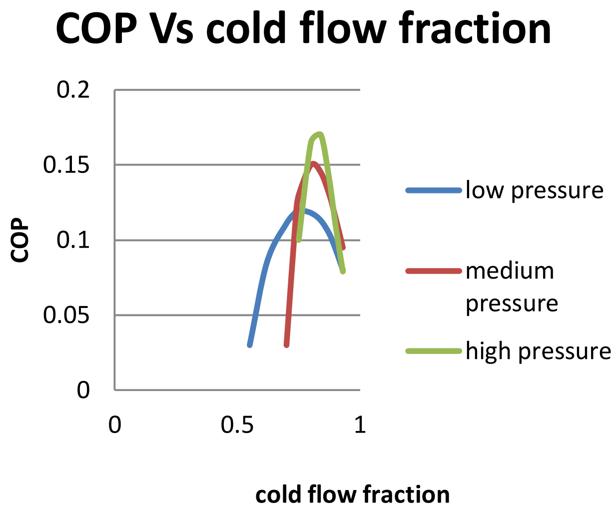


FIG. 2. COP DATA FROM PIONEER SCIENTISTS

According to previous standards, maximum COP obtained was 0.17 . But now, with improvement in materials and standards, the COP is increased upto 2.

3. ASSUMPTIONS

The following assumptions were made for the ease of calculation:-

1. The entire system is insulated and the process are adiabatic.
2. The outlet pressures are equal to atmospheric pressures.
3. The cold end diaphragm and hot end conical valve does not absorb any heat.
4. The flow is turbulent.

4. DESIGN PROCEDURE

The main aim of this setup is the production of a Vortex path of air. Since the nozzle is tangential, air entering through it gets a swirling motion inside the cylinder. The air acquires a high velocity and travel towards the valve (in the end of the hot side) as a spiral vortex. When the swirling flow reaches the end, it is resisted by the partially opened valve. Due to the conversion of kinetic energy, the pressure of the air near the valve increases and a reversed axial flow through the low pressure case.

By controlling the opening of the valve, the proportion of cold air and hot air and their temperatures can be varied.

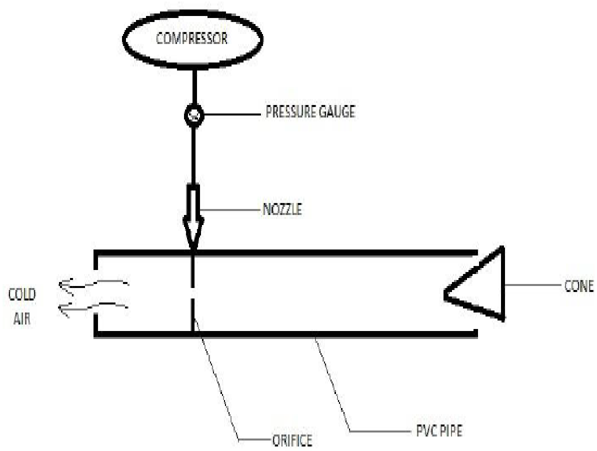
some of the restrictions followed were:-

1. For obtaining the maximum temperature difference at cold end, the ratio L/D should be maintained in the range of 30 ≤ L/D ≤ 60.

hence, considering the length to be 113.03cm and diameter to be 2.05cm, we get the L/D ratio to be in the range.

2. Decreasing conical valve angle have positive effect on performance of vortex tube but not so much difference is observed in the temperature reduction. Therefore it is better to use conical valve with smaller angle in order to improve the performance of vortex tube.

3. The following schematics is followed-



5. PERFORMANCE PARAMETERS

Performance are divided into input and output variables:

INPUT VARIABLES :

1. Area of cold orifice
2. Inlet pressure

OUTPUT VARIABLES :

1. Temperature of hot air
2. Temperature of cold air

6. DESIGN PARAMETERS

The primary material used is PVC pipe for the vortex tube refrigerator. the cone valve used is of a wooden material.

In the current investigation, the design parameters used are provided in the table below.

Tube inner diameter	**2.057 cm**	**d**
Cold plate orifice diameter	**1.028 cm**	**0.5d**
Inlet nozzle diameter	**0.3 cm**	**6.75d**
No. Of nozzle inlet	**5**	**Depending on air flow rate**
Hot end length	**92.71 cm**	**45d**
Cold end length	**20.32 cm**	**10d**
Pressure range	**0-2 bar**	**Experimental setup**

The total length of the vortex tube made from the PVC pipe was found out to be 113.03cm; having the length of the hot side to be 92.71cm and that of cold side to be 20.32cm.

7. CALCULATION

density of air $\rho_a = P_a/(RT_a)$

$$= \frac{1.01325 \times 105}{287 \times 300} = 1.176 \text{ kg/m}^3$$

flow rate $v_a = cd\ a\ (2gh_a)^{1/2}$

$h_a = (h_w\ \rho_w)/\rho_a = (8.4 \times 10^{-2} \times 10^3) / 1.176$
$= 71.428$ m of air

therefore
$v_a = 0.6 \times \{\pi \times (0.012)^2\}/4 \times [2 \times 9.81 \times 71.428]^{1/2}$
$= 2.539 \times 10^{-3}\ m^3/s$

flow rate at NTP, $v_{ntp} = (va\ T_o)/T_a$;

T_o = normal temperature=273 K
T_a= ambient temperature = 300K

$v_{ntp}= \{2.539 \times 10^{-3} \times 273\} / 300$
$= 2.275 \times 10^{-3}\ m^3/s$

mass flow rate at NTP = $v_{ntp}\ \rho_a$

$= 2.275 \times 10^{-3} \times 1.176 = 2.67 \times 10^{-3}$ kg/s

refrigeration effect = $\dot{m}\ Cp\ \Delta T$
where $\dot{m}$= mass flow rate

$= 2.67 \times 10^{-3} \times 1.005 \times (300 - 297)$
$= 5.3667$ W

Work done = $\frac{3600}{E} \times \frac{2}{t} \times 10^3$ W

where E= energy meter constant for compressor used
t = time taken for 2 seconds for the energy disc to rotate

hence
work done = $(3600/1000) \times (2/35.81) \times 10^3$
= 201.06 W

Coefficient of performance (COP)
= Refrigeration effect/ work done
= 5.3667 / 201.06
= 0.026

TABLE II. VARIATION OF MASS FLOW

Valve position	Mass flow rate (Kg/s)	Refrigeration effect (W)	COP
Full closed	2.67×10^{-3}	5.03	0.02
¾	2×10^{-3}	4.623	0.023
½	1.335×10^{-3}	3.354	0.016
1/4	6.675×10^{-4}	1.475	0.007

TABLE III. TEMPERATURE VS COP

TEMPERATURE DIFFERENCE ΔT (°C)	COP
3	0.026
4	0.047
5	0.061
6	0.093

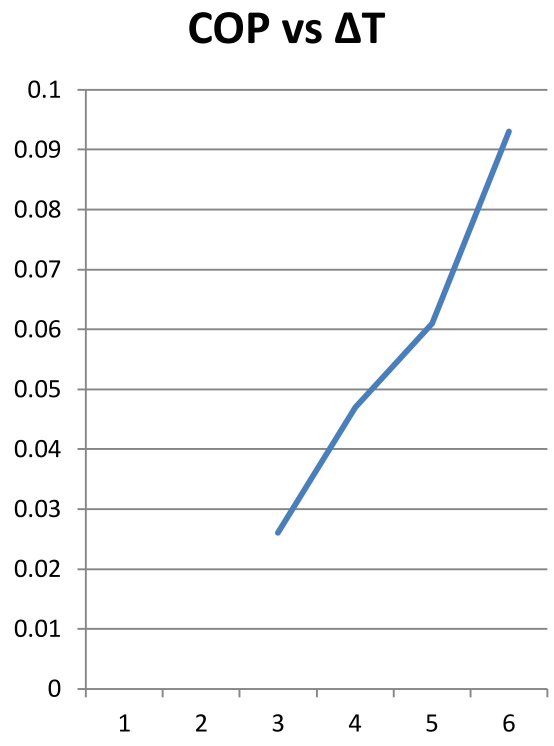


FIG. 3. GRAPH OF CALCULATED COP VS TEMPERATURE DIFFERENCE

8. RESULT and INFERENCE

1. 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.

2. By increasing the mass flow rate, the temperature gap increases and hence produces a high COP.

3. Mass flow rate can be adjusted by the valve position of the conical valve.

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