Fabrication and Performance Analysis of a Vortex Tube Refrigeration system

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Abstract - *Vortex tube is a simple, small &lightweight mechanical device that separates a gas into hot and cold streams. It has no moving parts. It has many advantages over conventional cooling system. It is an intriguing device that separates an incoming high-pressure fluid stream into a two low-pressure streams. Work Interaction during expansion process causes a temperature decrease in one of the two exit streams i.e. in cold side, while the other one experiences a temperature increases i.e. hot side. The overall expansion process in a vortex tube therefore approaches isentropic rather than isenthalpic expansion, the internal flow separation is achieved without any moving parts, resulting in robust inexpensive designs. Commercially available vortex tubes are almost exclusively used for spot cooling in industrial applications and use compressed air as the working fluid. The compressed air is injected tangentially into a chamber with high degree of swirl. On the other hand because of the valve only the outer periphery part is allowed to escape, where as the inner part is forced into the inner vortex with a small diameter within the outer vortex. In this work we made vortex tube made of UPVC material to study the effect of length and diameter on the performance of the refrigeration system, how different parameters are change with the inlet pressure and at different openings of control valve is also investigated. The results are drawn for the vortex tube with better performance. The material used for the construction of the vortex tube is PVC.*

Key Words: Non-conventional refrigeration, vortex tube, PVC Refrigeration, compressed air application, Refrigeration.

1. INTRODUCTION

Vortex tube is a simple device that is used to produce cooling effect. It has no moving parts. The vortex tube utilizes ambient air compressed to high pressure. The compressed air entering the vortex tube splits into two air streams at slightly above atmospheric pressure; one is hot and other is cold. It has been observed that when the compressed gas is injected into the tube tangentially at a high velocity, it starts rotating and moving to the hot end, i.e. the other end from the injection. A small portion of the flow escapes from the gap between the control plug and the tube with higher temperature than at the injection point, which in the literature is referred to as the hot stream. The other part of the flow is then forced back by the control plug and moves to the cold end through the central region of the tube.

This central flow is then exhausted from the central exit near the injection point, at a lower temperature than at the injection, and forms the cold stream. Thus, the injected flow is divided into two flows with different temperatures, and this phenomenon is well known as the temperature separation in a vortex tube. This cold air can be used for various applications. Similarly the hot air can also be used to serve some purposes. The volume and temperatures of these streams are adjustable with a valve built into a hot air exhaust. Cold airflow and cold air temperature are easily controlled by adjusting the slotted valve in the hot air outlet. Opening the valve reduces the cold airflow and the cold air temperature.

Closing the valve increases the cold air flow and cold air temperature. The percentage of air directed to the cold outlet of the vortex tube is called the “cold fraction”. In most applications, a cold fraction of 80% produces a combination of cold flow rate and temperature drop that maximize refrigeration, or Btu/hr output of a vortex tube. While low cold fractions (less than 50%) produce lowest cold air flow rate sacrificed to achieve that.

2. Working Principle

Compressed air is supplied to the vortex tube and passes through nozzles that are tangent to an internal counter bore. These nozzles set the air in a vortex motion. This spinning stream of air turns 90 degrees and passes down the hot tube in the form of a spinning shell, similar to a tornado. A valve at one end the tube allows some of the warmed air to escape. What does not escape, heads back down the tube as a second vortex inside the low pressure area of the larger vortex. Angular momentum has been lost from the inner vortex. The energy that is lost shows up as heat in the outer vortex. Thus the outer vortex becomes warm and the inner vortex is cooled. The working principle is illustrated in the following figure.

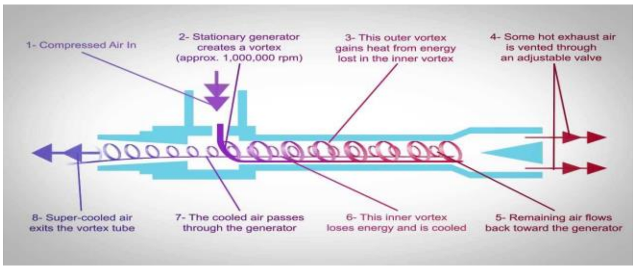

Fig -1: Working of vortex tube Refrigeration system

2. Design of Vortex tube

The material used for fabrication of hot and cold sides of vortex tube refrigeration system is un-plasticised poly vinyl chloride commercially known as UPVC. UPVC is basically inert to most inorganic bases, acids, saline solutions and paraffin/ aliphatic hydrocarbons. The unique molecular structure grants a low coefficient of thermal conductivity, it offers superior heat retention reducing heat loss through piping walls. Low permeability to oxygen and reduced water absorption. The material has excellent mechanical characteristics and good impact strength. These properties make the UPVC suitable for high service pressure (up to 16 bar at 20°C). UPVC is light weight when compared to metals. It is easy to work with UPVC compared to that of metals.

The chamber of the vortex tube is made up of UPVC, it is in cylindrical shape concentric with the cold and hot side tubes. The chamber consists of a coupling which contains tangential nozzles. It also consists of a provision for inlet air supply to vortex tube. In the chamber the pressure energy of the compressed air is converted into kinetic energy.

The control valve or control plug is in conical shape. It abstracts flow of air through hot side. Cold air flow and temperature are easily controlled by adjusting the control valve in the hot air outlet. Opening the valve reduces the cold airflow and the cold air temperature. Closing the valve increases the cold airflow and the cold air temperature. Since wood has properties like light weight, good thermal resistance, and it can be easily machined, we use teak wooden piece for control valve.

The material used for diaphragm is ACRYLITE Poly methyl methacrylate (PMMA), also known acrylic or acrylic glass as well as by the trade names Plexiglas, Acrylite, Lucite, and Perspex among several others, is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. The same material can be utilised as a casting resin, in inks and coatings, and has many other uses.

The nozzles are of converging or diverging or converging-diverging type as per design. An efficient nozzle is designed to have higher velocity, greater mass flow, and minimum inlet losses. Chamber is portion of nozzle in the same plane of nozzles and facilities the tangential entry of high velocity of air stream into hot side. Generally the nozzles are not of circular form but they are gradually converted into spiral form

2.1 DESIGN PARAMETERS

Table -1: Design parameters for vortex tube

Tube inner diameter	20.32mm	d
Cold plate orifice diameter	8.1mm	0.4d
Inlet nozzles diameter	3mm	Depending on the air flow rate
No. of inlet nozzles	5	Depending on the air flow rate
Hot end length	920mm	45d
Cold end length	50mm	As required
Pressure range	0-8bar	Experimental setup

2.2 Fabrication result

Fig -2: Vortex tube with nozzle setup

3. EXPERIMENTAL SETUP

We used ESKAY SKTC 300 two stage air compressor for the supply of the compressed air to the vortex tube.

Fig -3: Two stage air compressor

Table -2: specifications of air compressor

Type	Reciprocating
Stage	Two Stage
Cylinder	Two cylinder
LP cylinder bore	70mm
HP cylinder bore	50mm
Stroke length	85mm
Motor Rating	3HP
Motor Speed	1420 rpm
Compressor Speed	925 rpm
Belt size	A68
Type of lubrication	Splash
Type of cooling	Air cooled

3.1 TESTING PROCEDURE

i. First of all we need to check the compressor storage tank and remove previously stored air if presented.
ii. Now connect the vortex tube and the air compressor with the help of nylon tube.
iii. Give all the necessary connection and check them thoroughly.
iv. Switch on the air compressor till the required pressure is stored in the storage tank of the compressor.
v. The temperatures and the amount of cold air and hot air produced depend on the position of the control valve, so adjust the control valve at the position where maximum cold and hot temperatures produced.
vi. Repeat the experiment with different pressures and different positions of the control valve.

3.2 Assumptions

i. 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
ii. Assuming no losses i.e, inlet mass flow rate of the air is equal to mass flow rate of the cold air + mass flow rate of hot air.
iii. Neglecting friction between the internal surface of the vortex tube and outer vortex of air.
iv. Neglecting friction in the supply pipe of vortex tube.

4. Experimental Observations

Table -3: Results for 1/4 valve opening

Inlet pressure in bar	Inlet air temp in ^{0}C	Cold side air temp in ^{0}C	Hot side air temp in ^{0}C	Refrigeration effect in Watts	C.O.P
8	29	21	44	114.21	0.04185
7	29	20	42	132.25	0.05086
6	29	17	43	216.46	0.08396
5	29	12	46	124.18	0.04861
4	29	16	45	119.54	0.05118
3	29	15	42	111.71	0.0410
2	29	18	41	112.87	0.05531

Table -4: Results for ½ valve opening

Inlet pressure in bar	Inlet air temp in ^{0}C	Cold side air temp in ^{0}C	Hot side air temp in ^{0}C	Refrigeration effect in Watts	C.O.P
8	29	22	42	100.56	0.1436
7	29	20	40	145.47	0.1325
6	29	14	43	277.05	0.9815
5	29	13	37	273.68	0.04132
4	29	15	46	129.75	0.05371
3	29	16	41	104.03	0.04826
2	29	19	39	51.31	0.04325

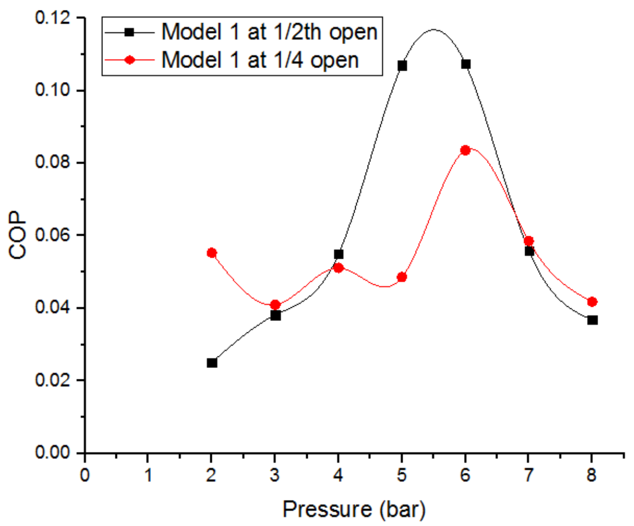

Chart -1: Variation of pressure with COP at different openings of control valve

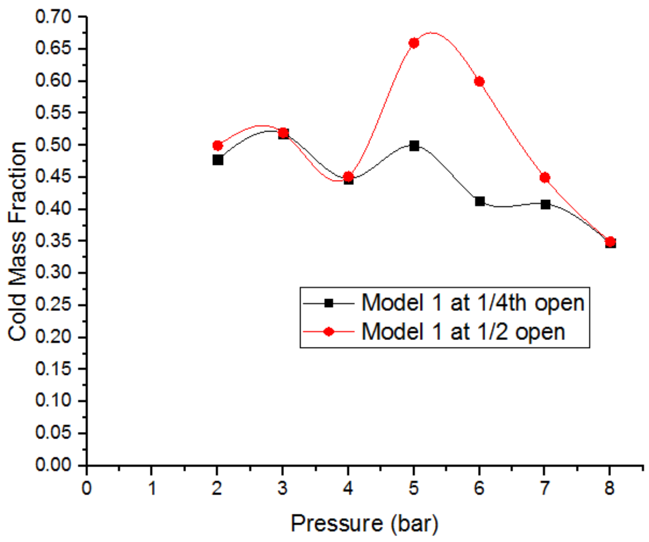

Chart -2: Variation of pressure with cold mass fraction at different openings of control valve

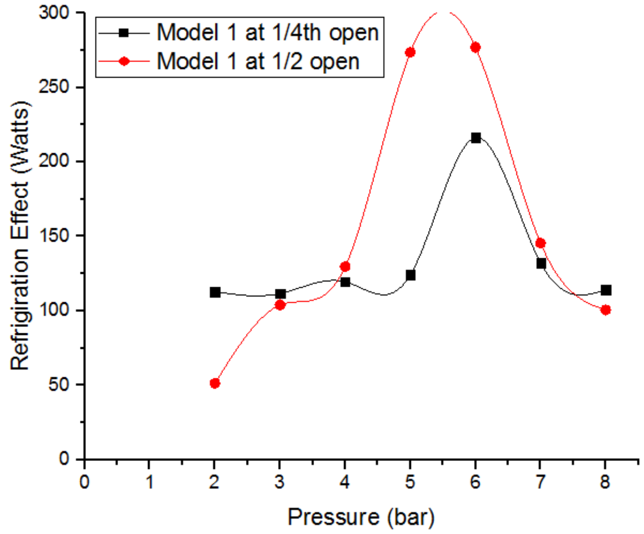

Chart -3: Variation of pressure with refrigeration effect at different openings of control valve

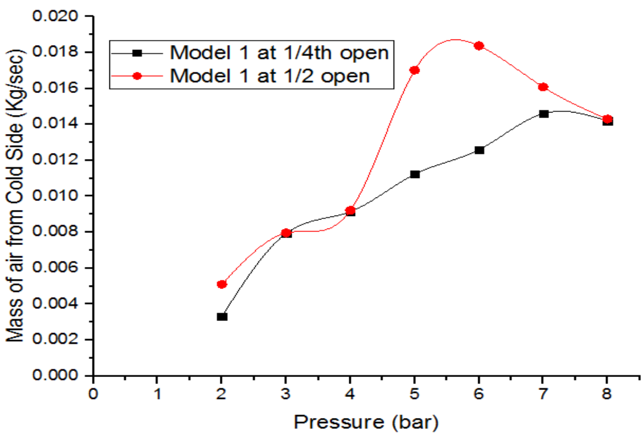

Chart -4: Variation of pressure with Mass of air from cold side for different openings of control valve.

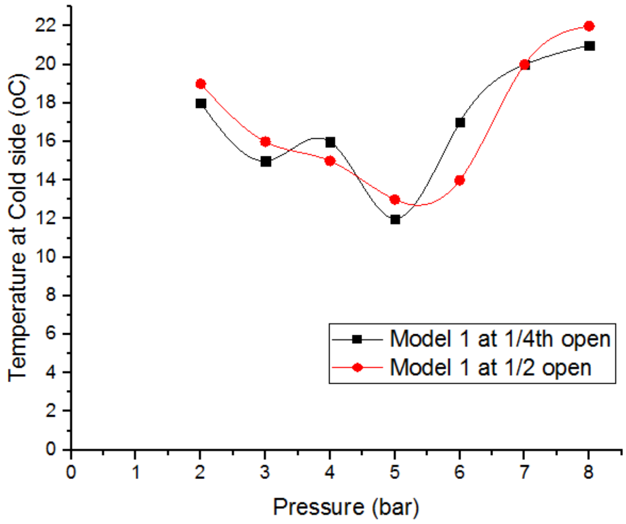

Chart -5: Variation of pressure with temperature at cold side of a vortex tube for different openings of control valve.

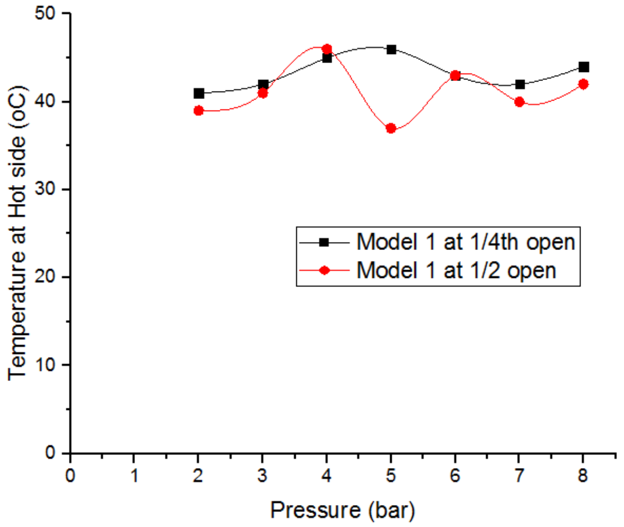

Chart -6: Variation of pressure with temperature at hot side of a vortex tube for different openings of control valve

5. Conclusion

- In my variable investigation shows that five nozzles with UPVC as vortex tube material have the best cooling effect.
- The maximum temperature difference of 17°C is obtained on cold side while 16° C is obtained on hot side of Vortex tube.
- The temperature drop increases with increase in inlet pressure up to 6bar.
- The optimum value of L/D ratio is in range of 45 as in this range ΔT_c and ΔT_h is maximum.
- The highest temperature drop is found between 0.45 -0.6 cold air mass fractions.
- At 6 bar Inlet pressure, 45 L/D ratio, ½ throttle valve opening and 0.6 Cold mass fractions give the best performance on vortex tube.
- The maximum COP(Coefficient of Performance) for the model 1 obtained at 6bar inlet pressure is 0.10745
- Even through the COP of the system is very low it is always acceptable to use the waste energy to generate useful form of energy.

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