A Review of Vortex Tube Refrigeration System

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Abstract: - In developing countries refrigeration plays an important role, firstly for food preservation, storage of medicines, and as air conditioning in homes, offices, etc. Freon is used as a refrigerant in conventional refrigerators. Freon is a harmful chemical to the environment and helps depleting of ozone layer. And hence scientists are trying to find alternative methods of refrigeration. Vortex tube is a cooling device which is non-conventional and since it has no moving parts it is much more efficient. A vortex tube has a hot end and a cold end from which hot air and cold air is produced respectively with compressed air as its source. And due to this it has no harmful effect on the environment. When high pressure air is entered tangentially inside the vortex chamber a vortex flow is generated which is split into two flows, one is hot air flow and the other is the cold air flow. Considering the harmful effects on the environment due to conventional refrigeration methods there is a need to find such non-conventional techniques for the betterment of the environment.

Key Words: —*Vortex, Swirl, Refrigeration.*

I. Introduction

The vortex tube was invented by G.J Ranque in 1932. He managed to get two kinds of air flows at different temperature and air pressure. In 1945 a scientist named Rudolf Hilsch took Ranque's vortex tube design and improved it further and published his work in a scientific paper. Rudolf Hilsch work was very well accepted and the energy separation phenomena became a topic of interest at that time. Rudolf Hilsch managed to get the temperature difference but was unable to explain the physical phenomena behind this effect. Much later this device was called the "Ranque-Hilsch Vortex Tube". A vortex tube consists of more than one inlet nozzle from which dust free compressed air enters the vortex chamber, and as the air enters the vortex chamber the velocity of air increases and forms a swirl like motion. The pressure of the compressed air is usually 4-5 bar and changes accordingly depending upon the size of the vortex tube. However as the gas proceeds towards the hot end side of the tube there is a conical shaped pressure valve which controls the pressure of the air. As the conical control valve is pushed towards the hot air coming towards the hot side of the tube a portion of it is reversed and starts to flow towards the cold end side of the vortex tube.

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As the reversed flow starts to flow towards the cold end of the tube the air loses its thermal energy and cools down hence giving cold air at the other end of the tube. This phenomenon is known as Ranque Effect.

II. Working Of Vortex Tube

Firstly compressed air is passed inside the vortex tube through the nozzle and here the air expands and acquires high velocity due to shape of the nozzle. Then a vortex flow is created inside the vortex chamber where the air flows spirally in motion along the hot end side of the vortex tube. The speed of the air usually reaches almost 100000 rpm. There is control valve situated at the end of the hot end side of the tube, its main purpose is to resist the flow the air. When the high velocity air hits the control valve it slows the air down and increases the pressure on the hot end side of the vortex tube. Due to this a reverse axial flow is generated from the hot end side and moves through the core from high pressure region to low pressure region. During this process there is energy transfer between the peripheral flow and the axial flow and therefore air flow from the core gets cooled down below the inlet temperature of the air and while the peripheral flow gets hotter as it moves forward. The cold is let out from the hole on the cold side while the hot is let out through the control valve. By controlling the control valve we can adjust the quantity of air flow and temperature on the cold end side.

III. LITERATURE REVIEW

Literature review is to understand different effect of various parameters like inlet air pressure, length of the hot end side, length of the cold end side, number of nozzles, etc. That can affect the performance of the vortex tube. An experimental study was conducted in which it was shown that the temperature at the core of the vortex tube is much higher than that of the peripheral end of the vortex tube.

Analyze design of a vortex tube for several inlet constant pressure for good geometrical optimization of the vortex tube. The main purpose is to design a small sized vortex tube that can create a temperature difference of at least 4-10C0 at the hot and cold ends of the vortex tube.

IV. DESIGN CRITERIA

Tube Length:

The length of the vortex tube affects performance significantly. An efficient tube of either design should be many times longer than its diameter. Optimum L/D is a function of geometrical and operating parameters. The magnitude of the energy separation increases as the length of the vortex tube increases to a critical length, however a further increase of the vortex tube length beyond the critical length does not improve the energy separation.

Tube Diameter:

In general, smaller diameter vortex tubes provide more temperature separation than larger diameter ones.

Type and Number of Nozzles:

The inlet nozzle location should be as close as possible to the orifice to yield high tangential velocities near the orifice. For maximum temperature drop the inlet nozzles should be designed so that the flow be tangentially into vortex tube. For maximum temperature drop the inlet nozzles should be designed so that the flow be tangentially into vortex tube

Cold End Diameter:

Using a small cold orifice yields higher energy separation while a large cold orifice results lower energy separation in the tube. Coaxial orifices have greater temperature separation in compared to the other orifice configurations such as eccentric orifices, diaphragm nozzles, and diaphragms with cross sections other than cylindrical configurations.

A. Construction

Vortex Tube Assembly (Sectional View):

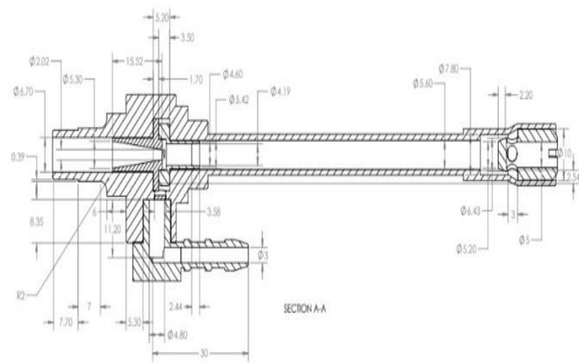


Fig.1.Sectional view of Vortex Tube

Control Valve:

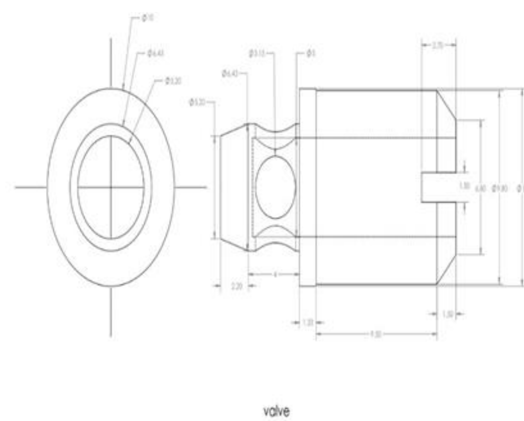


Fig.2. Control Valve

Nozzle:

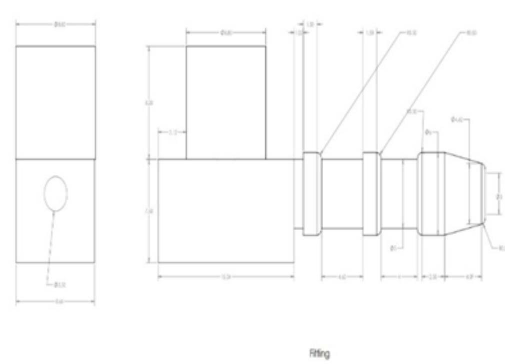


Fig.3. Nozzle

Vortex Generator:

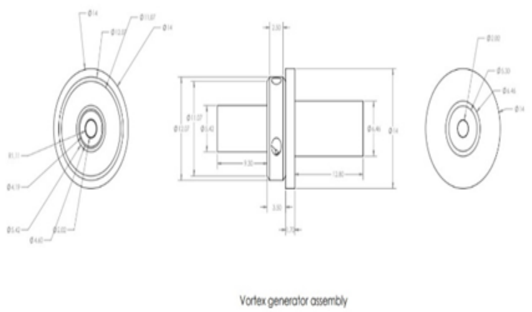
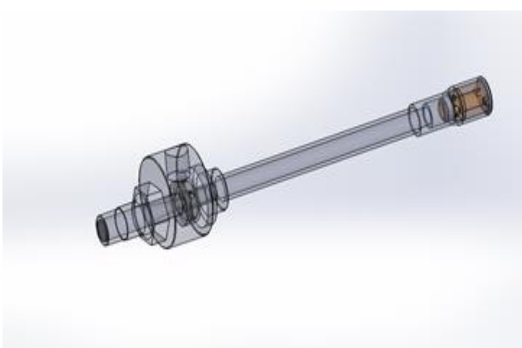


Fig.4. Vortex Generator assembly

V. Analysis



The above model has designed in SOLIDWORKS software. In that we have designed al l the parts separately then we assembled in the assembling file. By this analysis we trying to prove that cooling effect of the vortex tube is high when the inlet pressure is high and the opening on the hot end side is small. And the performance of the vortex tube is depended on the inlet pressure given at the nozzle.

A. Engineering Database

Gases:

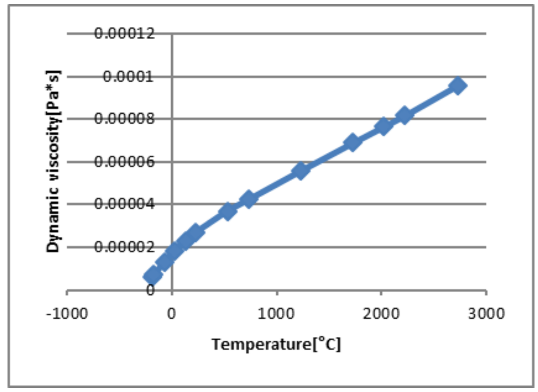
Air

Path: Gases Pre-Defined

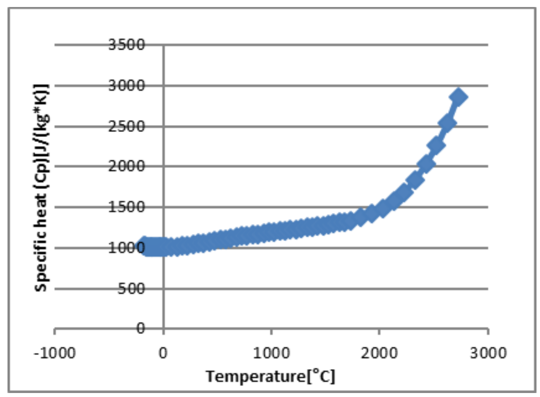
Specific heat ratio (Cp/Cv): 1.5

Molecular mass: 0.031 kg/mol

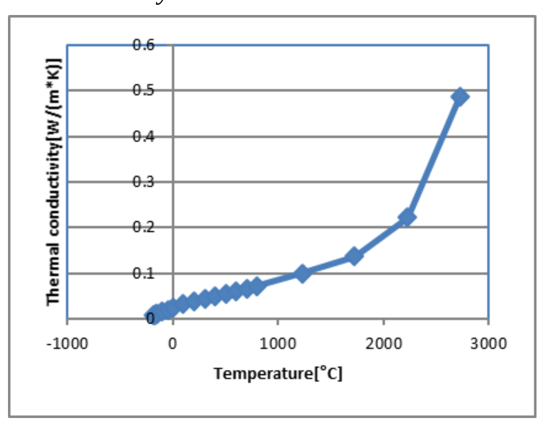
Dynamic Viscosity:



Specific Heat (Cp):



Thermal Conductivity:



B. Boundary Conditions

Table.1. Inlet Velocity 1

Type	Inlet Velocity
Faces	Face<1>@LID5-1
Coordinate system	Face Coordinate System
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face Velocity normal to face: 13.000 m/s Fully developed flow: Yes
Thermodynamic parameters	Approximate pressure: 5.80 bar Temperature: 20.00 °C

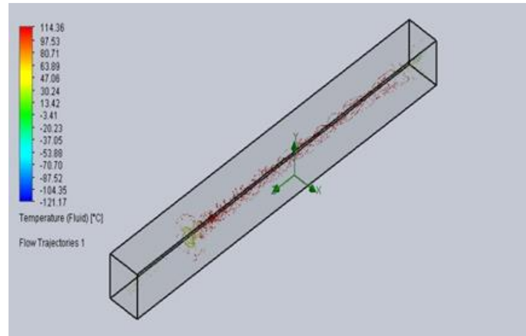
Table.2. Environment Pressure 1

Type	Environment Pressure
Faces	Face<2>@LID2-1
Coordinate system	Face Coordinate System
Reference axis	X
Thermodynamic parameters	Environment pressure: 1.01 bar Temperature: 20.00 °C
Turbulence parameters	
Boundary layer parameters	Boundary layer type: Turbulent

Table.3. Environment Pressure 2

Type	Environment Pressure
Faces	Face<4>@LID3-1
Coordinate system	Face Coordinate System
Reference axis	X
Thermodynamic parameters	Environment pressure: 1.01 bar Temperature: 20.00 °C
Turbulence parameters	
Boundary layer parameters	Boundary layer type: Turbulent

C. Flow Stimulation Images



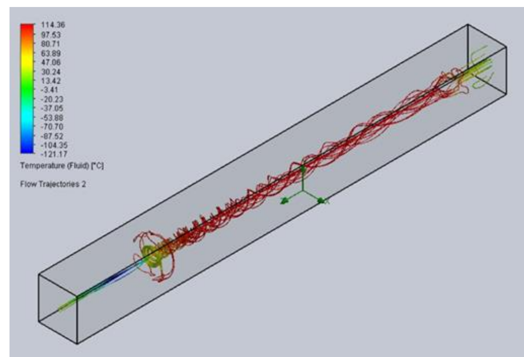


Fig.5. Flow Stimulation (spheres)

VI. RESULTS

A. Temperature at Different Pressures

Sr. No	(bar)	Cold end(°c) (t_c)	Hot end(°c) (t_h)	($\delta t=t_h-t_c$) (°c)
1	7-6	3	37	33
2	6-5	7	45	38
3	5-4	8	51	40
4	4-3	12	57	43

B. Calculations

Inlet velocity =27.5m/s

Inlet area = π/4 d2 (inner diameter of inlet = 5mm)

=1.863*10-5 m 2

Discharge at inlet Q= area* velocity (m3 /s)

=27.5*1.863*10-5

=5.2477*10-4 m 3 /s

Density of inlet air ρ= P/RT (kg/m3)

=5.5*105 /267*195

=6.0110 kg/m3

Mass flow rate at inlet (ṁ) = Q* ρ (kg/s) = 5.2477*10-4*6.0110

=3.1543*10-3kg/s

Cold end Velocity v =14.49m/s

Area of cold end a =π/4 (id)2 (inner diameter of cold end d=6mm)

=2.82*10-5 m2

Discharge Qc = velocity* area (m3 /s)

= 14.49*2.82*10-5 =3.650*10-4 m3/s

Density of cold air ρ= P/RT (kg/m3)

=6.5*105 / (287) (277)

=7.176(kg/m3)

Mass flow rate of cold end (ṁc) = Q * ρ (kg/s)

3.650*10-4 *8.176

= 2.9919*10-3 (kg/s)

Cold flow mass ratio = mass flow at cold end / mass

Flow rate at inlet (ṁc/ ṁ) = 2.9919*10-3/4.2207*10

VII. Application

- Vortex tubes have a wide range of application in the industries as they produce cold and hot air simultaneously. So both cold and hot air has its uses in various industries.
- Vortex tubes are extremely small in size and can produce cold air as low as -400C0, so it is very much useful in spot cooling in electronics industries.
- They are also used as body cooling for workers working in mines.
- Commercial vortex tubes can produce temperatures of 130C0 on the hot end side and -120C0 on the cold end side. Without any moving parts, without any electricity and without the use of Freon, just with an inlet pressure on 6-7 bar.
- Vortex tubes are also used for cooling of cutting tools such as lathes machines and mill machines and also CNC machines too.

VIII. Future scope

Since there is always a room for improvement, the same goes with the vortex tube. We can come up with new ideas to improve the efficiency of the vortex tube or even increase the performance of the vortex tube. There are experiments done which say that geometrical modifications on the vortex tube can be the key in improving the performance of the vortex tube. Various geometrical modifications are listed below:

- We can increase number of inlet air entries.
- Guiding element inside the Vortex tube can be provided for guiding inlet air circumferentially towards hot end.
- Experiments are also possible with varying the length of Cold ends and Hot ends.
- Same Vortex tube as we have manufactured can be tested by using water as cooling agent. 5. We can try some modification in the geometry of convergent nozzle with the help of CFD analysis.

IX. Conclusion

The cooling effect of vortex tube is high when inlet pressure is high and when the hot end opening is small. It is clear that always the performance of vortex tube is directly proportional to inlet compressed air. Placing a tangential nozzle in cylinder is complicated job, this complication can be avoided by Vortex generator. Vortex generator doesn't need tangential nozzle. Compactness, environment friendly, no wear and tear makes vortex tube to find its application in many places.

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