

Modeling and Investigation of Change in Working Parameters on the Performance of the Vortex Tube with CFD Analysis

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Abstract - Refrigeration plays an important role in developing countries, primarily for the preservation of food, Medicine, and for air conditioning. Conventional refrigeration systems are using Freon as refrigerant. As they are the main cause for depleting ozone layer, extensive research work is going on alternate refrigeration systems. Vortex tube is a non-conventional cooling device, having no moving parts which will produce cold air and hot air from the source of compressed air without affecting the environment. When An experimental investigation has been performed to realize thorough behaviour of a vortex tube refrigeration system. The simple counter flow vortex tube consist of long hollow cylinder with a tangential nozzle at one end for injecting the compressed air has been designed, manufactured and tested. The vortex tube is a without affecting environment. It has capability to separate hot and cold air stream from a high pressure inlet air without any external energy supply or chemical reaction; such phenomenon is called as temperature or energy separation process.

The vortex tube performance depends on two types of parameters, firstly air or working parameters such as inlet pressure of compressed air, cold mass fraction and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, cone valve angle and also material of vortex tube affects Coefficient of Performance (COP). This paper discusses the experimental investigation of effect of above working parameters on the performance of Ranque Hilsch vortex tube. The paper develops three dimensional flow domain using Computational Fluid Dynamics (CFD) and this CFD and experimental studies are conducted towards the optimization of RHVT.. The L/D ratio of hot side tube varied from 10-50.

Key Words: Vertex tube, optimization, COP, CFD, Geometric parameter.

1. INTRODUCTION

Background

The vortex tube was invented in 1933 by French physicist Georges J. Ranque. German physicist Rudolf Hilsch

improved the design and published a widely read paper in 1947 on the device, which he called a Wirbelrohr (literally, whirl pipe). The vortex tube was used to separate gas mixtures, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air in 1967 by Linderstrom-Lang. Vortex tubes also seem to work with liquids to some extent, as demonstrated by Hsueh and Swenson in a laboratory experiment where free body rotation occurs from the core and a thick boundary layer at the wall. Air is separated causing a cooler air stream coming out the exhaust hoping to chill as a refrigerator. In 1988 R.T. Balmer applied liquid water as the working medium. It was found that when the inlet pressure is high, for instance 20-50 bar, the heat energy separation process exists in incompressible (liquids) vortex flow as well. Note that this separation is only due to heating; there is no longer cooling observed since cooling requires compressibility of the working fluid. Vortex tube is a simple energy separating device which is compact, simple to produce and to operate. Although intensive research has been carried out in many countries over the years, the mechanism producing the temperature separation phenomenon as a gas or vapour passes through a Ranque-Hilsch vortex tube is not yet fully understood.

1.1 Problem statement

A vortex tube is a cooling device in which an air can be used as a working medium; thus, the vortex cooling system is environmentally friendly. Thermal separation flow studied and preliminary tests suggest that reducing the temperature of an external surface at the hot tube section of the vortex tube could increase the vortex cooling capacity. In this paper, a thermoelectric module is employed to extract heat from the hot tube surface and then release it to environment. In other words, a temperature difference is used to generate power by the thermoelectric generator as thermal energy harvester. A test rig is designed and constructed, in the laboratory, for the experiment on the vortex cooling system incorporating the thermoelectric module. Test parameters are the cold fraction from 0 to 1 and an inlet air pressure of 1.5 bars. The results show that the cooling capacity and efficiency increase when the thermoelectric module is used to extract heat from the hot tube surface of the vortex tube and electricity is generated as by product. The cooling capacity and efficiency of the vortex tube is increased by 4.3 % and 9.6 % respectively.

11.2 Problem Formulation

Theoretical explanation is given by various papers in different way. They have tried to explain as how does the pumping of heat from compressed air temp to high temperature takes place in absence of a mechanical device. When compressed air is passing through the nozzle in the vortex chamber inside the chamber high velocity swirl motion is created. The air moves as a free vortex from the nozzle plane towards the valve end. As it near the valve, the kinetic energy is converted into the pressure energy giving a point of stagnation. But the stagnation pressure is higher than the pressure in the nozzle plane; thereby the reversal in flow takes place. This reversed flow comes in contact with forward moving free vortex, which causes the reversed vortex flow to rotate with it. Heat exchange takes place between these two flows

The problem identification, objective and hypothesis has been prepared in previous sections now to devise the problem the parabolic leaf spring taken into consideration

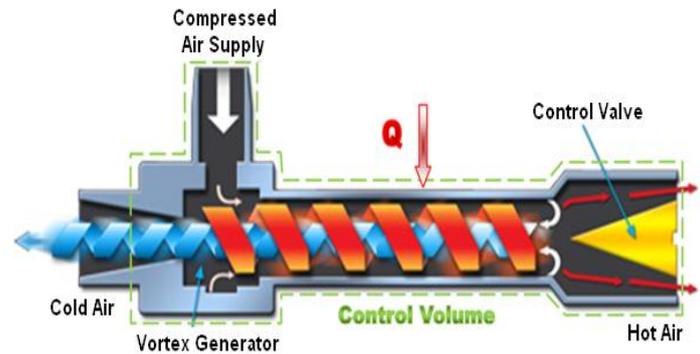


Figure .1.1

Since the energy is proportional to the square of the velocity, the cold air stream loses its energy by heat transfer. This allows energy to flow from the inner air stream to the outer air stream as heat creating a cold inner air stream.

3 Components of the Vortex Tube

Main body



Figure 3.1 (a) Main Body

It is connecting part of hot tube and cold tube. Length of main body 60mm and diameter is 29mm. The inlet is connected over the main body. The material of this part is PVC and mild steel.

Cold tube:



Figure 3.2 (b) Cold Tube

It is a smaller than hot tube. Diameter of this tube is 29mm and length is 80mm. Material of this tube is mild steel or PVC.

Hot tube:

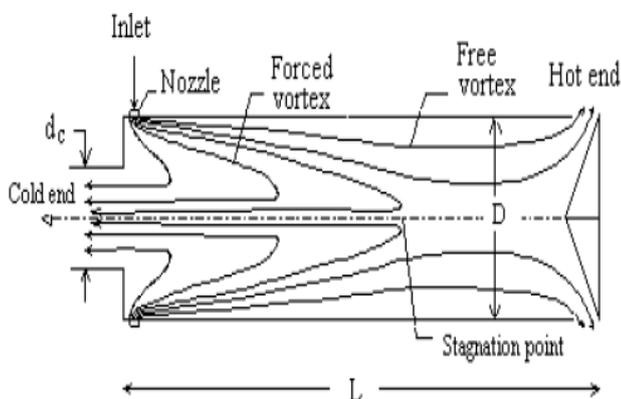




Figure 3.3 (c) Hot Tube

It is main part of the vortex tube. Material of this tube is mild steel or PVC .Diameter of this tube is 29mm and length is 105mm.At the one end of this tube control valve is placed.

Control valve:



Figure 3.4 (d) Control Valve

The function of the control valve is to control the hot air discharge. Cold effect of this vortex tube is depends on the opening of the control valve. Material of this valve is M.S or wood. The angle of control valve is up to 45 degree.

Inlet tube:

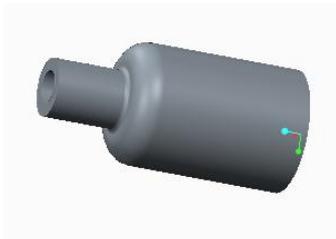


Figure 3.5 (e) Inlet Tube

Inlet tube is fitted into main body at the centre. Pipe from compressor connected to inlet tube. Compressed air enters into main body through inlet tube.

Diaphragm:

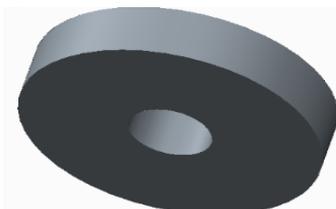


Figure 3.6 (f) Diaphragm

It is the thin part of the vortex tube. Material of the diaphragm is M.S. The 8mm diameter hole is drill on canter of diaphragm plate. Thickness of this diaphragm is 6mm.

Nozzle:

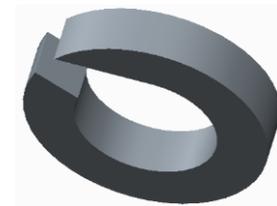


Figure 3.7 (g) Nozzle

Nozzle is used for passing the high velocity air as a input of the vortex tube. The diameter of the nozzle is 9mm. A tangential cut is given to the nozzle by using a hacksaw blade.

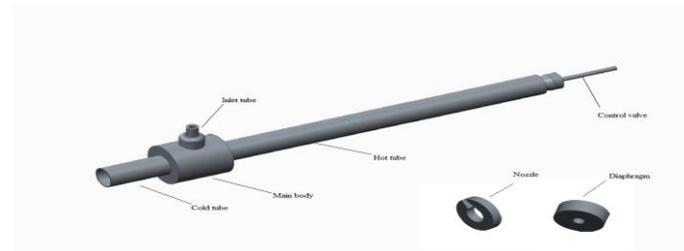


Figure 3.8 (h) Creo-Parametric Model of Vortex tube

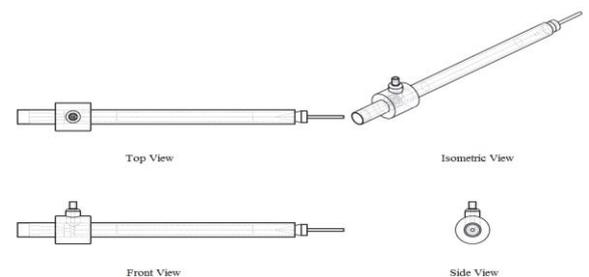


Figure 3.9 (i) Different Views of Vortex Tube



Figure 3.10 (j) Drafting of Vortex Tubes

4. Computational Fluid Dynamics

Computational Fluid Dynamics, Computational – mathematical analysis, computing Fluid Dynamics - the dynamics of things that flow CFD - a computational technology that enables one to study the dynamics of things that flow. CFD is concerned with numerical solution of differential equations governing transport of mass, momentum and energy in moving fluid. Using CFD, one can build a computational model on which physics can be applied for getting the results. The CFD software gives one the power to model things, mesh them, give proper boundary conditions and simulate them with real world condition to obtain results. Using CFD a model can be developed which can breed to give results such that the model could be developed into an object which could be of some use in our life.

4.1 The Benefits of CFD

There are three reasons to use CFD software: insight, foresight, and efficiency.

4.2 Insight

Think of an object which is difficult to produce practically and do some experiment on it. CFD provides the break through. Using the CFD software, one can easily design the object and use the boundary conditions to get output. The simulation thus helps in getting results much easily than constructing the real object.

4.3 Foresight

In CFD first we make the model then use certain boundary conditions to get the output. Thus using CFD we can give some real world condition say as pressure or temperature and simulate things to get the output. Many variations can be adopted till an optimal result is reached. All of this can be done before physical prototyping and testing.

4.4 Efficiency

The analysis gives better idea of, how the object works. So necessary changes could be brought about to facilitate better production of the product. Thus CFD helps to design better and faster bringing about improvement in each step.

4.5 The CFD Process

In the past decades many modeling and simulation software have been developed like PHONICS, FLUENT, SRAT-CD, CFX, FLOW -3D and COMPACT. Generally this software's are based on finite volume method. FLUENT is one of the major software which has helped a lot in modeling fluid and heat transfer problems.

5. Observation.

5.1 Model No. 1

Nozzle diameter (D n) =13 mm

No of inlet = 1

Diaphragm diameter= 7mm

Length of tube (L) =377mm

Diameter of tube (D) = 24mm

Sr. No	Pressure (bar)	Inlet temp. (ti)	Hot end temp (th)	Cold end Temp. (tc)	Temp. Diff. (th-tc)
1	6.5 – 3	28.5	33	16.9	16.1
2	5 – 3	28.3	32.2	17.2	15
3	4.5 – 3	28	31	18	13

Observation for Model No. 1

5.2 Model no. 2

Nozzle diameter (D n) =13 mm

No of inlet = 1

Diaphragm diameter= 7mm

Length of tube (L) =348mm

Diameter of tube (D) = 24mm

Sr. no	Pressure (bar)	Inlet temp. (ti)	Hot end temp. (th)	Cold end Temp. (tc)	Temp. Difference (th-tc)
1	6.5 – 3	28.5	30.7	18.6	12.1
2	5 – 3	28.3	30	19.1	10.9
3	4.5	28	29.8	20.5	9.3

Table 7.2 Observation for Model No. 2

5.3 Model no. 3

Nozzle diameter (D n) =13 mm

No of inlet = 1

Diaphragm diameter= 7mm

Length of tube (L) =319mm

Diameter of tube (D) = 24mm

Sr. no.	Press ure (bar)	Inlet temp. (ti)	Hot end temp. (th)	Cold end Temp. (tc)	Temp. Difference (th-tc)
1	6.5 -	28.5	30.3	19.8	10.5
2	5 - 3	28.3	29.9	20.2	9.7
3	4.5 -	28	29.5	20.6	8.9

Table 7.3 Observation for Model No. 3

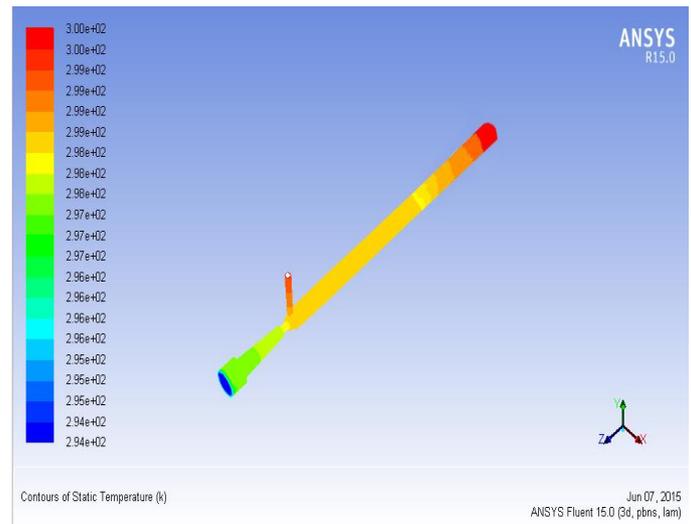


Figure 6.2 CFD Result

Cold side temperature = 294 K

Hot side temperature = 300 K

Inlet temperature = 297 K

6. RESULTS AND DISCUSSION

6.1 Practical Result

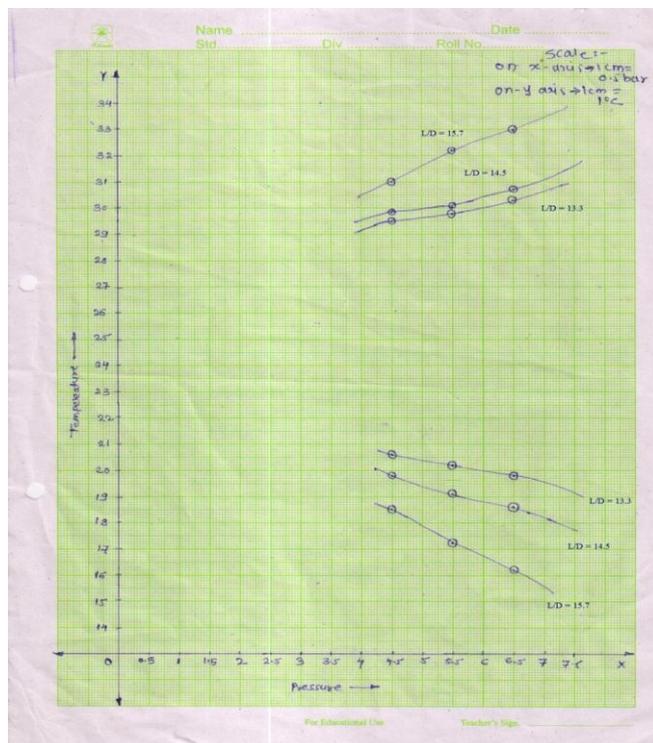


Figure 6.1 Pressure Vs Temperature

6.2 Ansys Result

7. CONCLUSION

The study was conducted with a simple, in house fabricated vortex tube with the aim for obtaining correct thermodynamic results. The equipment designed was for the best results i.e. Least temperatures, but for more accurate results. Nevertheless the equipment worked as desired and the readings were obtained. Vortex tube is used for utilizing the waste compressed air which is produced in various industrial applications. For this tube if we use a separate compressor then the complete process is not so efficient, just because of low COP.

From the graph, it is conclude that at high pressure we get more temperature difference. As pressure decreases temperature difference also decreases.

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