Computational Fluid Dynamics Modeling & Thermal Analysis of Flow Measurement in a Ranque – Hilsch Vortex Tube

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Abstract— Ranque - Hilsch Vortex Tube (RHVT) is a devise that generates the cold and hot air streams coetaneous with compressed air as a working fluid without any moving part. The Flow separation of hot and cold air mainly depends on factors viz., nozzle number, nozzle shape, length and diameter of vortex tube, control valve, inlet pressure, diaphragm hole size, mass flow rate etc.,. The mechanism behind the highly complex flow pattern can be explained with the help of computational Fluid dynamics modeling and the results of the Analysis is successfully explained in the present work. Among the various methods to analyze the flow measurements i.e., Artificial Neural Network (ANN), taguchi method, etc., Computational Fluid dynamics method is used in this paper. The vortex tube of various lengths and L/D ratio are considered for this analysis. The change in pressure and temperature of hot and cold end of the vortex tube is calculated and the efficiency and cooling capacity is tried to increase with these change in parameters. The cooling capacity of vortex can further be improved by changing other parameters.

Key words: Fluid Dynamics Modeling, Thermal Analysis, Hilsch Vortex Tube

I. INTRODUCTION

Vortex tube is a mechanical device that separates the single compressed air flow into cold and hot streams. It consists of a nozzle, vortex chamber, separating cold plate, when works, the compressed gaseous fluid expands in nozzle, and tangentially enter through diaphragm whose design helps to form a whirl which separates the low density hot at the outer and high density cold air at the middle of the tube. It has huge application in the industries. Over the years different theories have attempted to explain this effect without achieving any universal arrangements. It is a small and compact device with no moving parts, no electricity or chemicals, small and light weight, low cost protection free, direct cold air, temperature modifiable. Hence, the vortex tube has application in heating gas, cooling gas, cleaning gas, ventilation gas, and separating gas mixtures liquefying natural gas, consistency and lower apparatus cost are the main factors and the operating efficiency become less important.

These are of two types 1) Counter flow vortex tube 2) Uni-flow vortex tube. Among which counter flow type is accepted mostly in industries. In this type the hot air that exists from the distant side of the tube is controlled by the cone valve. The cold air exist through orifice next to inlets, shown in figure 1. This type of vortex tube is used in application where space and apparatus coast are of high importance.

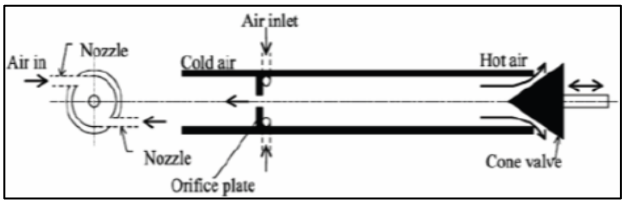


Fig. 1: Counter Flow Vortex Tube

The mechanism of Uni –flow tube is like to the counter flow tube a radial temperature separation tube is still induced inside, but its efficiency is less as compared to counter flow tubes. Although the vortex tube effect was known for decades and exhaustive experiment and correlative investigations had been carried out, the mechanism producing the temperature separation phenomenon as a gas or vapour passes through a vortex tube is not fully understood yet several dissimilar explanation for temperature effects in the vortex tube have been offered

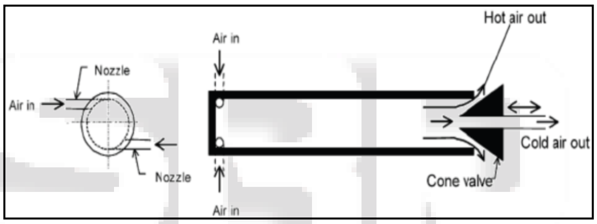


Fig. 2: Uni-Flow Vortex Tube

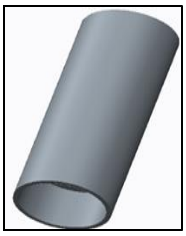
II. LITERATURE REVIEW

[1]The CFD analysis is carried out by changing the L/D ratio on the temperature parting in counter flow ranque hilsch vortex tube with six straight nozzles. He also studied the physical performance of the flow fluid in vortex tube. Cfd analysis is employed to achieve the highest temperature separation and finest length to diameter (L/D) ratio. The temperature separation phenomenon in the vortex tube has been found. He proposed that the best performance was found when the ratio of vortex tube length to diameter was 9.3. Moreover by increasing the cold mass fraction reduction the cold temperature differences and efficiency. Warapom improved the vortex cooling capacity by reducing hot tube surface temperature. He employed a thermoelectric module is employed to extract heat from hot tube surface and then release it to atmosphere. And this increases the cooling capacity and the efficiency increase when thermoelectric module is used to remove heat from hot tube surface of the vortex tube and electricity is generated as by-product. Mahyar kargaran, experimentally investigated the effect of orifice diameter and the tube length on the vortex tube performance. Suraj investigated the performance of the vortex tube by changing the working parameters. The chlorinated Poly Vinyl chloride (CPVC) material has been used for trade of the vortex tube as it has lower conductivity then metals and less fluid contact losses. In his study he conducted an

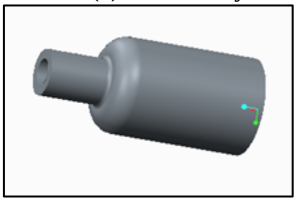
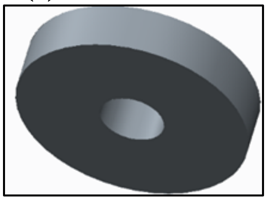
experimental study with compresses air at various pressure from 5-10 bar, which is supplied with help two tangential inlet nozzles.

III. MODELING & MODEL

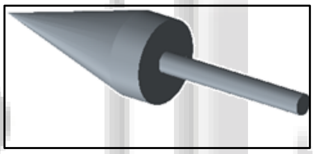
Performance of a Ranque – Hilsch vortex tube is mainly depends on the design parameters, geometrical parameters, mass flow, reservoir conditions, gas properties, internal flow parameters and other factors.

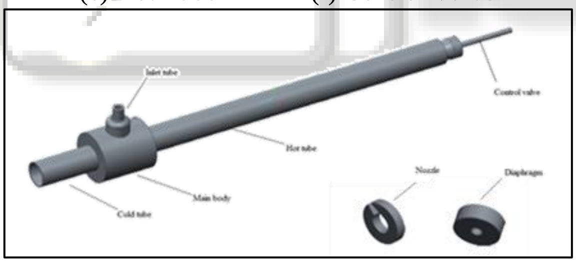
(a) Main Body (b) Cold Tube

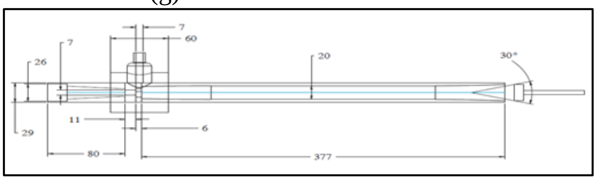
(c) Inlet Tube (d) Diaphragm

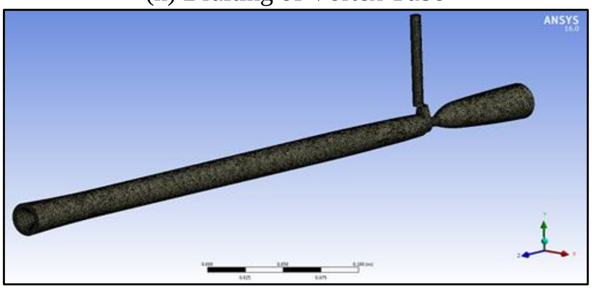
(e) Hot Tube (f) Control Valve



(g) Assembled Vortex Tube



(h) Drafting of Vortex Tube



(i) Messed Model of Vortex Tube

Fig. 3:

Geometric parameters affecting the performance of the vortex tube are the tube length affect the magnitude of energy separation by increasing the tube length to the critical length. In general smaller diameter vortex tube provides additional temperature separation. A very small diameter vortex tube leads to low diffusion of kinetic energy which also earning slow temperature separation. For maximum temperature drop the inlet nozzles should be designed so that the flow is tangential. Even by increasing number of inlets nozzles leads to higher temperature separation.

Parameter		Specification
Length of tube	:	319 , 348 , 377
Diameter of tube	:	29
Diameter of cold end	:	29
Diameter of inlet nozzle	:	9
Cone angle of hot valve	:	45^0
Number of nozzle	:	1

Table 3:

The modeling the vortex tube is completed with the help of the CREO parametric and the analysis for the CFD is performed with the help of Ansys software. The different length of hot tube are 377 mm, 348 mm , 319 mm. The observation made during trail with consideration of leakage losses and environment conditions.

Nozzle Diameter	=	13 mm
No. of Inlets	=	1
Diaphragm diameter	=	7 mm
Diameter of tube (D)	=	24 mm

Table 4:

The results obtained for the computational analysis of the vortex tube is further explained and demonstrated in the further sections of the papers.

IV. RESULT & DISCUSSION

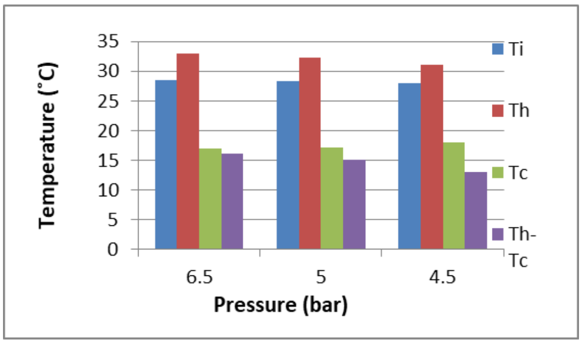
By changing the Length and the diameter of the tube the analysis result is shown of the following models.

Length of the tube	377 mm
L/D ratio	15.7

A. *Model 1*

	Trial 1	Trail 2	Trail 3
Pressure(bar)	6.5	5	4.5
Inlet temperature (T_i)	28.5	28.3	28
Hot end Temperature (T_h)	33	32.2	31
Cold end Temperature (T_c)	16.9	17.2	18
Temperature difference (T_h - T_c)	16.1	15	13

Table 5:

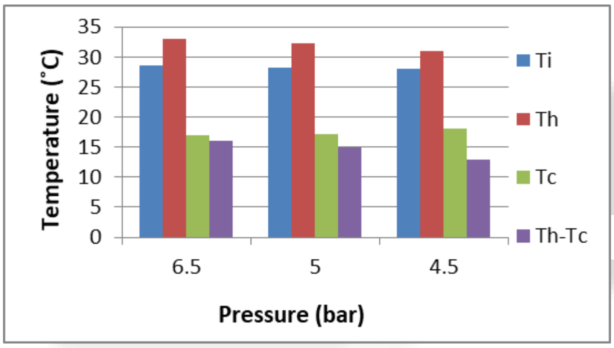


Graph 1:

B. Model 2

Length of the tube	348 mm		
L/D ratio	14.5 mm		
	Trial 1	Trail 2	Trail 3
Pressure(bar)	6.5	5	4.5
Inlet temperature (T_i)	28.5	28.3	28
Hot end Temperature (T_h)	30.7	30	29.8
Cold end Temperature (T_c)	18.6	19.1	20.5
Temperature difference (T_h - T_c)	12.1	10.9	9.3

Table 6:



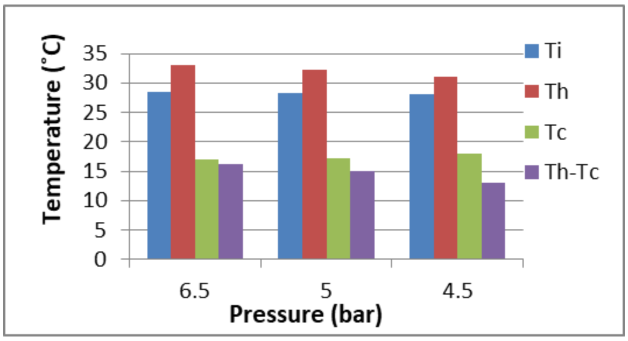
Graph 2:

C. Model 3

Length of the tube	377 mm
L/D ratio	13.3 mm

	Trial 1	Trail 2	Trail 3
Pressure(bar)	6.5	5	4.5
Inlet temperature (T_i)	28.5	28.3	28
Hot end Temperature (T_h)	30.3	29.9	29.5
Cold end Temperature (T_c)	19.8	20.2	20.6
Temperature difference (T_h - T_c)	10.5	9.7	8.9

Table 7:



Graph 3:

The boundary condition used in this work is Static pressure with temperature at inlet of vortex tube and static pressure at cold & hot end. The domain surface is used as wall with no slip condition. The above result shows the different boundary condition apply to the vortex tube software model formation, in this firstly CREO model GENRATETED and this model can be used in ANSYS Software. Then all the give data can be inserted in to the ANSYS software.

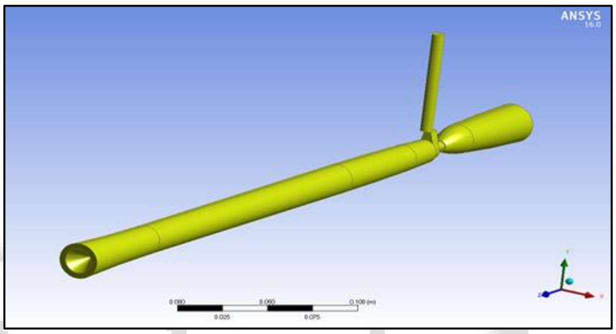


Fig. 4: Geometry

After applying boundary condition the whole geometry can be generated, this can be generated in solid in nature.

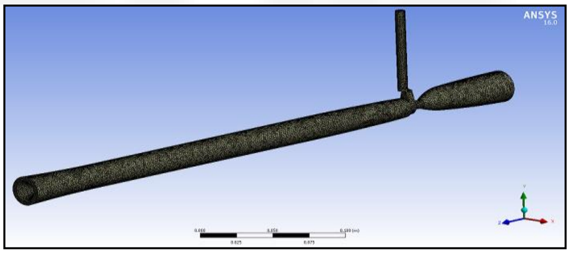


Fig. 5: Meshing

After geometry completed the Meshing can be done, in this the all the parts of vortex tube can be fixed exactly to each other. Then air will be supply to the inlet valve.

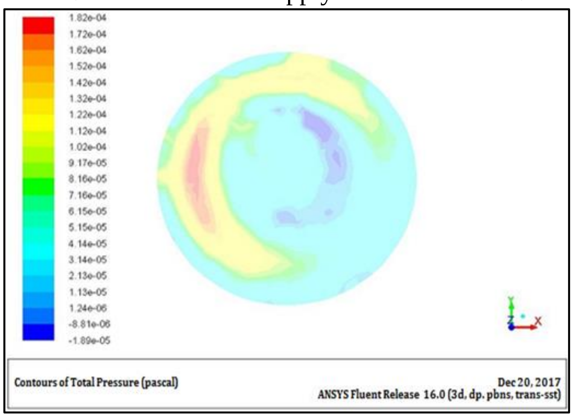


Fig. 6: Pressure at Cold End

The above result shows the pressure at cold end, in this there is colure column in left side and there is some value of pressure in Pascal. The light brown colure and light blue colure shows in above result, to match this colure to left hand side colure and value.

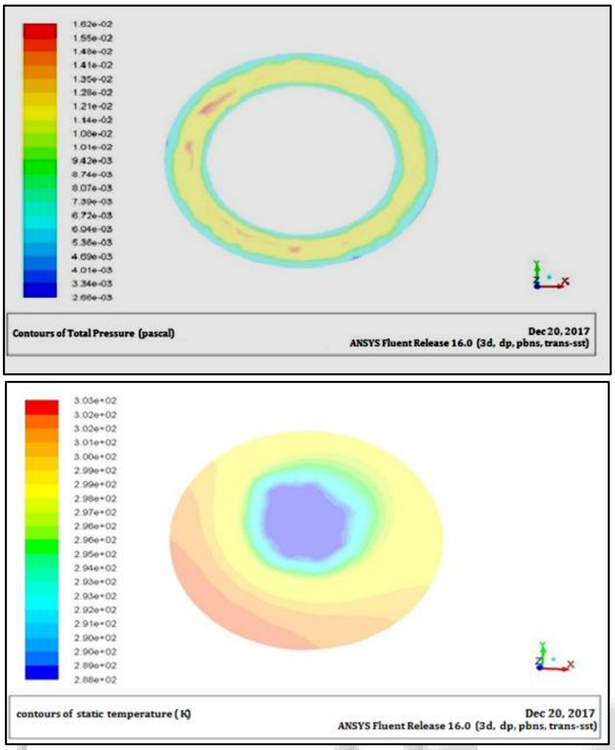


Fig. 7: Pressure at hot end Temperature at Cold End

In above result ,there is blue colure in middle to match this colure to left side value & colure ,the value are given in kelvin then the temperature in cold side should be 289.9 K

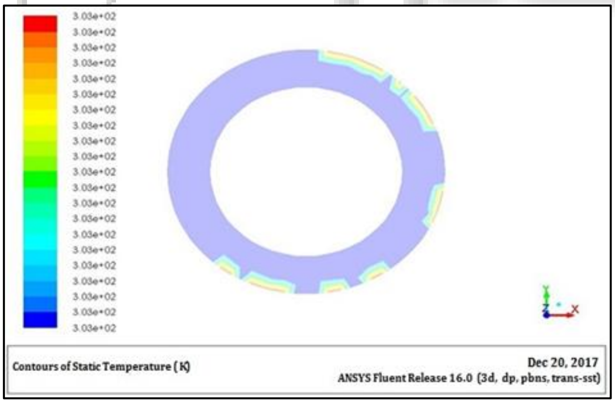


Fig. 8: Temperature at Hot End

In above result ,there is light blue colure in inner surface and outer side colure will be light brown, to match the light brown colure to the left side value, the value are given in Kelvin then the temperature in hot side should be 306 K

- Cold side temperature = 289.9 K
- Hot side temperature = 306 K
- Inlet temperature = 301.5 K
- Temperature Differences=16.1^{0}C

Temperature Differences	=	Hot side temperature	-	Cold side temperature
	=	306	-	289.9
Temperature Differences			=	16.1

V. 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.

1) Effect of Length of Tube to Diameter of Tube Ratio on Temperature Difference

The graphical result claims that the temperature difference increases as increase in L/D ratio then decreases thereafter. We get better result on 15.7 L/D ratio.

2) Effect different pressure on Temperature Difference

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

3) As hot side temperature increases, cold side temperature decreases.
   Maximum temperature difference obtained by CFD analysis is 16.1

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