DESIGN AND ANALYSIS OF VORTEX TUBE WITH VARIOUS TYPES OF ORIFICE NOZZLES

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Abstract:
Refrigeration by vortex tube works on the principle of heat transfer between two layers moving opposite each other. Various experiments have been performed and have revealed two different approaches, one for attaining a high cold mass fraction and the other for achieving a cold end temperature. The geometry requirement is additional for the two approaches. The vortex tube is designed to overcome the disadvantage of a straight and divergent section hot tube to produce a high mass of cold air and low temperatures. An experimental study was conducted to determine the thoroughness of the behaviour. The nozzles material using ABS Plastic with different angles 30°,45° and 60° and the vortex tube with two different lengths (100 mm and 200mm), The design of the project was done with CAD and analysis using ANSYS 15.0 in addition to finding the most efficient nozzles and hot tube length, supported by experiments to identify energy-saving procedures which would apply to compressed air.
Keywords: vortex tube, ABS Plastic, CAD, ANSYS 15.0

1.0 INTRODUCTION

When he analyzed the processes in a dust-separated cyclone, the vortex pipe was created by a French physicist called Georges J. Ranque in 1931. Due to its obvious inefficiency, it was widely unpopular during gestation. The patent and the concept were abandoned for several years until 1947, when the tube design was changed by a German engineer Rudolf Hilsch. Since that time, many researchers have sought ways to optimize its efficiency. No single theory explaining the separation of the radial temperature until now operates. Hundreds of papers on temperature separation were published on the vortex space, the most important contribution to understanding the vortex tube Ranque–Hilsch. The principle of thermodynamic cycle vapor compression, whether for chilled and frozen cooling chambers, has historically been employed by cooling and climate control, to ambient air conditioning and many other applications. And it requires essential components like coolants, heat exchangers and compressors.In order to reduce the impacts of the application of these devices, the advancement of technical solutions for traditional cooling.

Vortex tubes:
A vortex tube is a device that involves the separation of air streams with different temperatures that Georges Ranque, a French physicist, has accidentally found during a proceeding. This enables vortex tubes to generate cold and hot air currents simultaneously through the airflow in the tube.

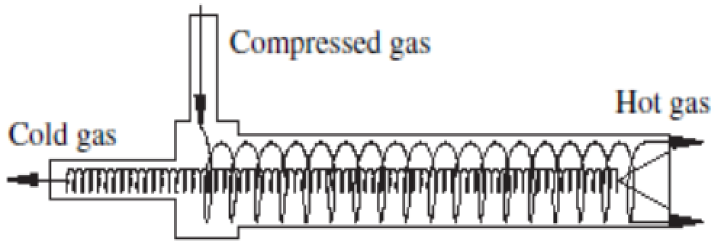

Figure 1: Schematic diagram of vortex tube

One or more information nozzles at high-speed submissions a compressed gas source with a high pressure, which causes a rotating vortex within the pipe after expansion. The air flows through the tube instead of through the central hole next to the compressor as the hole is much smaller in diameter than the tube.

Working of vortex tube:

A vortex tube is a thermal system that produces two streams from a single injection at a different temperature. The compressed gas is injected in the vortex tube tangentially and split into two components at lower and higher output temperatures than inlet gas.

- Compressed air passes through the bust as seen in the above figure. In this case, air is expanding and obtaining high speed due to its specific shape.
- In the chamber, a vortex flow is generated and air flows curving like motion through the hot side periphery. This flow of the valve is restricted. As the air pressure is increased by partial valve closing more than outside, the reverse axial flow from high pressure to low pressure area through the center of the heat-side occurs. The thermal transfers between the back-stream and forward stream take place during this process.
- • Thus, under inlet temperature the air flows through the center into the vortex tube, and air flows into the forward direction.
- The cold stream escapes to the cold side through the diaphragm hole while the heat stream passes through the valve opening. The volume of the cold air and its temperature can vary by controlling the opening of the valve.

Advantages of the vortex tube:

- Vortex tubes are very thin, producing both hot and cold air. It can be used in industries where both are required at the same time.
- Temperature as low as –50^{0}C can also be achieved without difficulty, so that it is very important to cool electronic components localized in industry.
- It is typically used in mining for body cooling.
- Use air as cold, so there is no issue with the leakage.
- Tubes Vortex in design are basic
- Control systems are avoided.
- It also has lower working costs when compressed air is readily available.
- Easy maintenance and no competent work are necessary.

Problem statement:

A vortex tube is a cooling system that can be used for air as an environmentally friendly working medium and thus for a vortex cooling system. The thermal separation flow was studied and preliminary tests indicated the ability to cools the vortex at an external surface temperature on the hot tube component of the vortex tube. A thermoelectric module is used in this project to isolate heat from the surface of the hot pipe, then to release it into the environment.

Objectives:

- To study the Thermal Performance of The Vortex Tube

- The Rectangular nozzles using ABS Plastic material and to find the Nozzle performance of the different angles
- The Rectangular nozzles design is done by AUTO CADD
- The Nozzle analysis is done by using CFD with using Compressor Air

2.0 REVIEW OF LITERATURE

Burak Markal et.al [1] Investigation of the thermal energy separation effects in a counter flux vortex tube by designing new cold end geometry known as 'helical swirl flow generator'. **Smith Eiamsa-arda et.al [2]** An analysis of the temperature separation experiments in the vortex tube. He investigated two main parameters, firstly, the geometric properties of a vortex tube (i.e., the hot-cold tube diameter and length, cold-orifice diameter, hot tube form, the number of inlet balls, the inlet shape nozzles, the cone valve shape. **Xiangji Guo a et.al [3]** Studies Various methods for the flow field, such as qualitative visualizations and intrusive probe measures, laser-non-intrusive measurements and numerical simulations, were utilized for identifying variations in the flow structure of vortex tube, which he concluded was proven to be an effective means of studying the flow field of vortex tube by numerical simulations. **Junior Lagrandeur et.al [4]** Focused on perfect gas models designed to predict the results of anti-flow vortex tubes. It includes analytical and thermodynamic models, model heat exchangers, pressure gradient models, impulse transfer models with inward rotating particles and models based on unstable phenomena, as is the case with a vortex failure. **Sudhakar Subudhi a et.al [5]** His previous studies that the best fit correlation between the optimal geometrical and operational performance of the system is cold temperature drop, cold mass fraction, performance coefficient and thermal efficiency.**Hitesh R. Thakare n et.al [6]** In their analysis is intended to advance the theoretical and numerical work carried out by different researchers CFD. Analysis of different studies of optimization process using techniques such as the Artificial Neural Network (ANN), Taguchi process. **Ratnesh Sahu et.al [7]** His research on compressor efficiency for different cooling systems concludes that Vortex tube also includes the second law of thermodynamics, showing energy deterioration from higher type and amount to lower type and effectiveness. **Sarkar et.al [8]** His work has been on energetic analyzes and comparisons of three natural vapor compression cooling cycles using vortex tube for expansion devices, including ammonia, propane and iso butane. **B.D.Wankhade et.a [9]** This is a very low vortex tube performance and three advanced modifying sections of the vortex tube such as input of the nozzle, nozzle, and new component, known as the diffuser, provide higher performance to increase performance. **E. Torrella1 et.al [10]** It investigates and shows the air vortex cooling tube energy efficiency under changes in air inlet properties, an impact of a vortex tube air inlet pressure, an analyses of temperature variations in the resulting cold stream and a cooling capability where the cold flow fraction varies. The air intake temperatures range under suitable coating fractions in the vortex tube.

3.0 METHODOLOGY

The experiment is performed with two various vortex tubes with angles of difference of 1°,1.5°,2°. Pressures vary from 2 to 6 bar and various angle valves are utilized. The compressed air is supplied to the pressure controller by the air reservoir from the compressor. To change air pressure coming from the air compressor, the pressure control is used. The air is supplied to the Rota Meter 1 after pressure regulator to calculate flow rate in the vortex tube at intakes. This air is then divided into two so it can be supplied to the inlet surfaces of the vortex. It is possible to change the conic valve of the cold air fraction of the tube that comes out of the vortex tube.

Construction of vortex tube:

Two design characteristics are usually associated with a vortex tube, namely maximum temperature changes. Vortex tube design for small amounts of air at very low temperature and maximum cooling effect, vortex tubing design for large quantity of energy at moderate temperatures. The vortex hot chamber size of internal diameter of 8 mm & outer diameter is 12mm is selected with a length of 100 mm,200 mm & 3 types of nozzles are taken with different nozzles at different sizes for high efficiency of the vortex tube. The conical valve made of nylon plastic it was provided on the right-hand side of the vortex tube to regulate the flow. A cold chamber is connected in the left side of the vortex tube with 22mm length & 26mm diameter.

Design Parameters:

The flow of air depends on the inlets of the nozzle. By designing of various nozzles with constant area by using analysis software ANSYS R15.0 we found that four inlet nozzles have given the best performance for our project. It is also designed in the AutoCAD software & it is manufactured with the help of 3-D printing technique by layer-by-layer method.

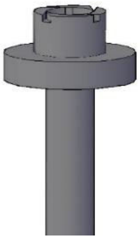

Figure 2: model of rectangular nozzle with angle

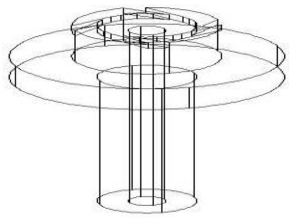

Figure 3: Model of rectangular nozzle without angle (wire frame)

Figure 4: 3D printed rectangular nozzle with angle

Table 1 specifications of rectangular nozzle

Length of the nozzle	43mm
width of the nozzle inlet	1.75mm
height of the nozzle inlet	1.75mm
Width of the nozzle outlet	1.75mm
Height of the nozzle outlet	1.5mm
bore diameter of the nozzle	4 mm
Slope angle from inlet to outlet	1.5 degrees
Material used	ABS plastic
area of the nozzle	2.18mm^2*4

Materials:

ABS plastic: ABS stands for Acrylonitrile Butadiene Styrene. ABS is a thermoplastic and amorphous polymer that is resistant to damage. Three monomers are formed by ABS: Acrylonitrile, Butadiene and Styrene.

Boundary Conditions:

The pressure and temperature data obtained from the experiments are supplied as input for the analysis. The boundary conditions given to simulate the vortex tube phenomenon at different regions are as follows.

Fluid	:	Compressed Air
Pressure	:	4 bar
Temperature	:	29 degree centigrade
Flow	:	Turbulent Model (k – ε model)

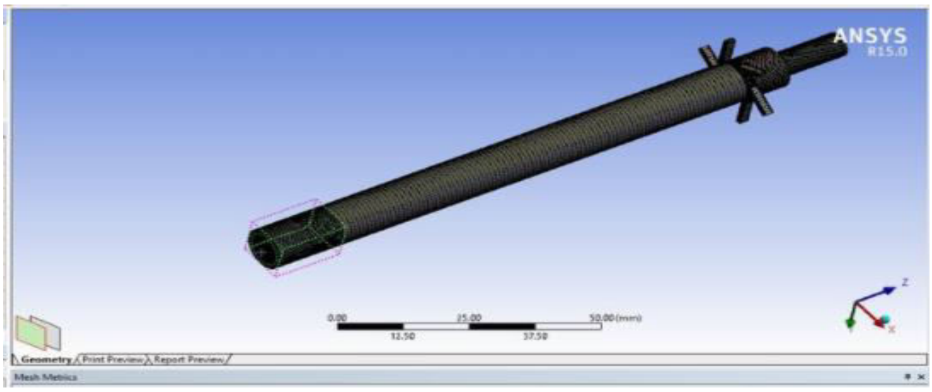

Figure 5: Mesh Model of Vortex Tub

4.0 SIMULATION & EXPERIMENTATION

The analysis of flow in a vortex tube can be done with the help of ANSYS R.15 package to study the flow distribution and some parameters like pressure (P) temperature (T), velocity (V),Etc, and its behavior for different l/d ratios of vortex tube.

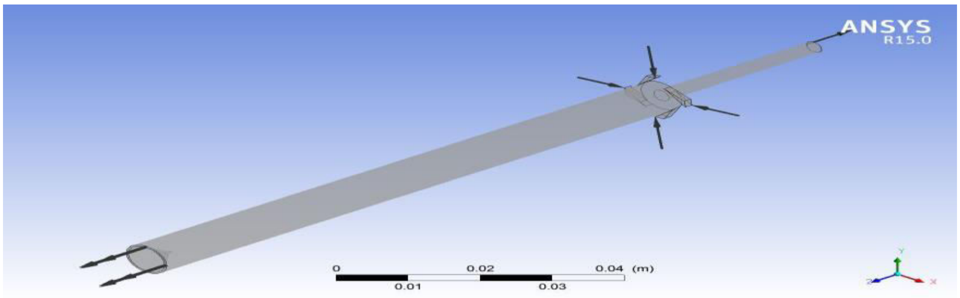

Figure 6: Design model on Ansys workbench for simulation

Results for Rectangular nozzle without angle at 100 mm length:

For the given boundary conditions, the results for Velocity, temperature, and pressure taken and they are as follows

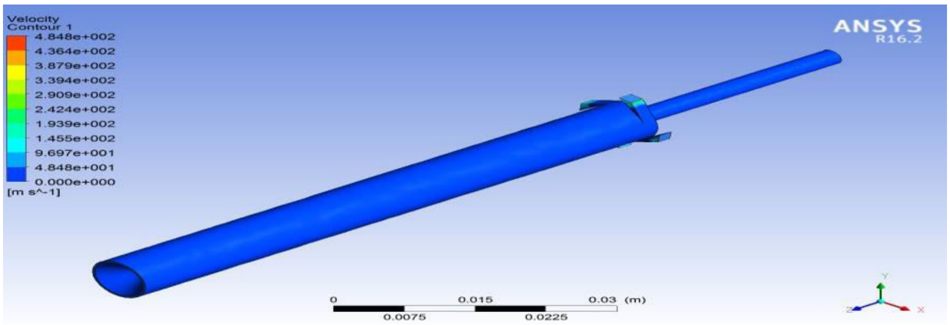

Figure 7: contour for velocity of rectangular nozzle without angle(l=100mm)

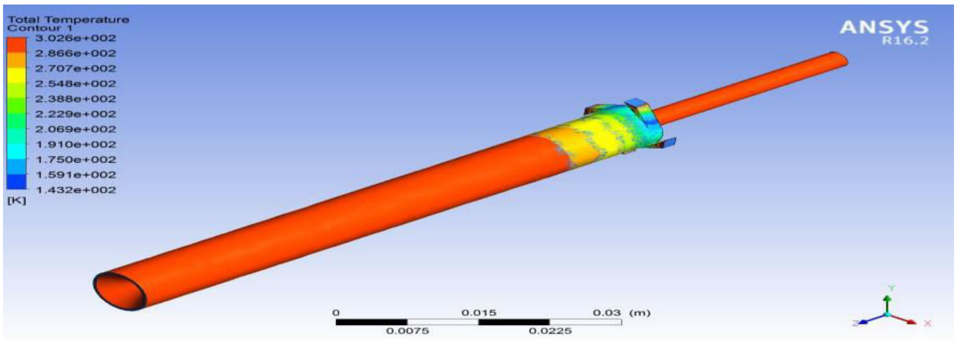

Figure 8: contour for total temperature of rectangular nozzle without angle(l=100mm)

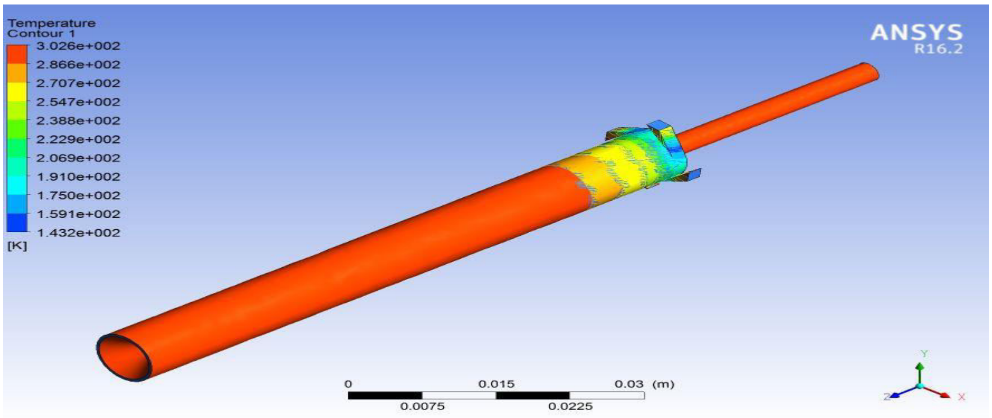

Figure 9: contour for temperature of rectangular nozzle without angle(l=100mm)

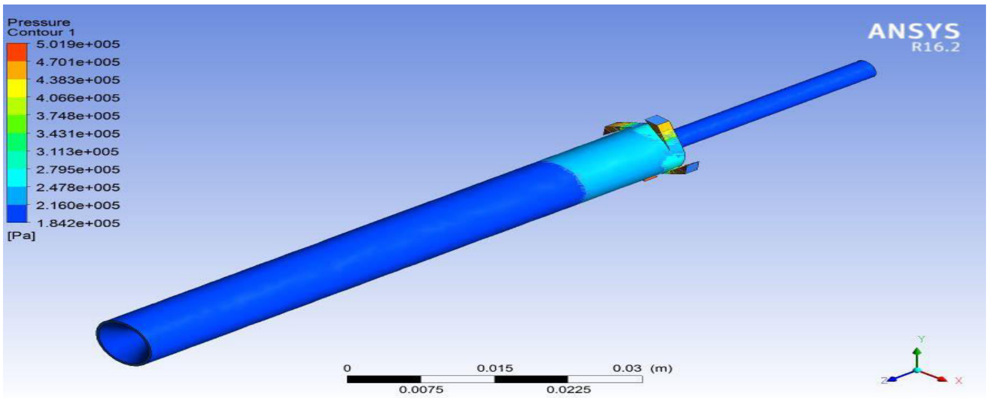

Figure 10: contour for pressure of rectangular nozzle without angle(l=100mm)

Results for Rectangular nozzle without angle at 200 mm length:

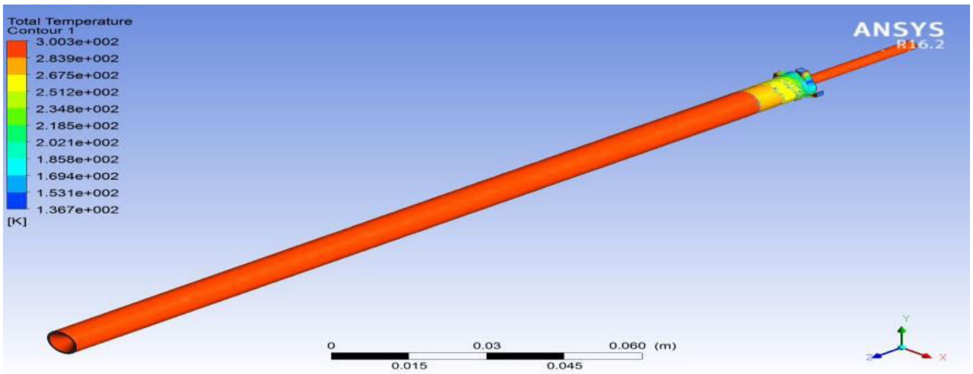

Figure 11: contour for total temperature of rectangular nozzle without angle(l=200mm)

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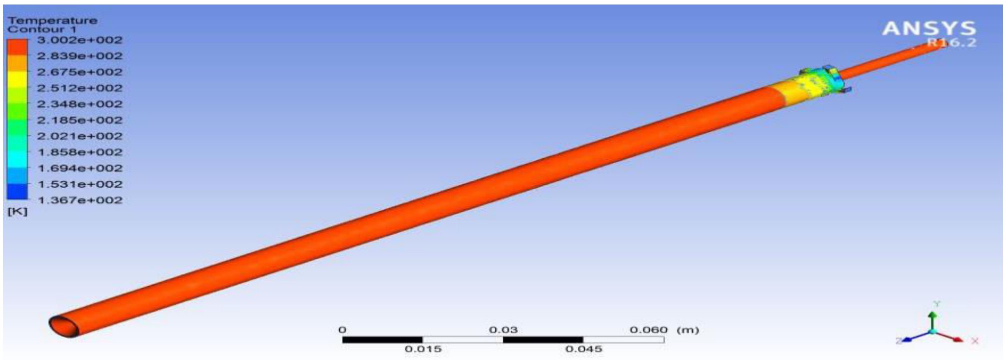

Figure 12: contour for temperature of rectangular nozzle without angle(l=200mm)

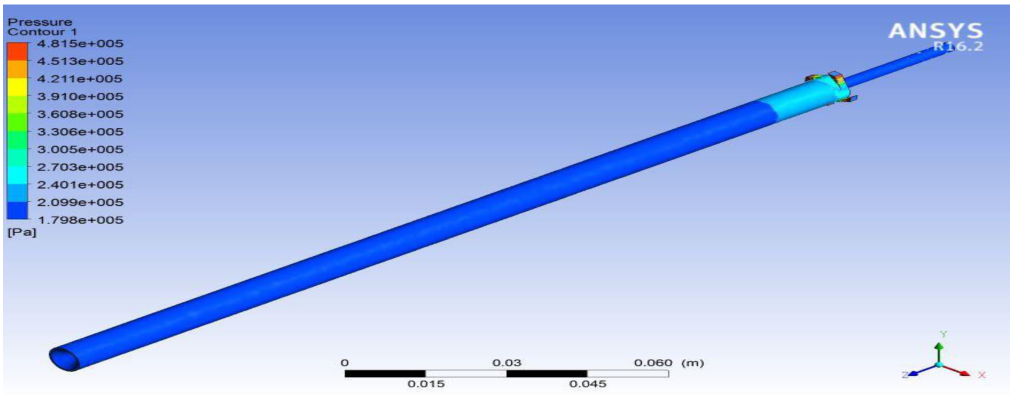

Figure 13: contour for pressure of rectangular nozzle without angle(l=200mm)

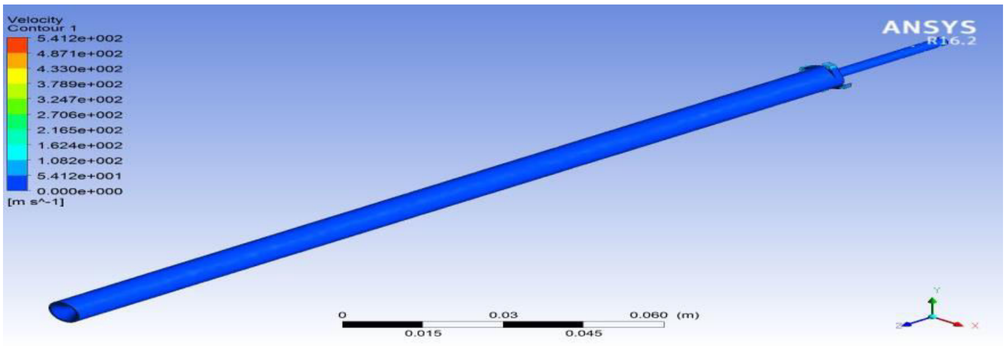

Figure 14: contour for velocity of rectangular nozzle without angle=200mm)

Results for Rectangular nozzle with angle at 100 mm length:

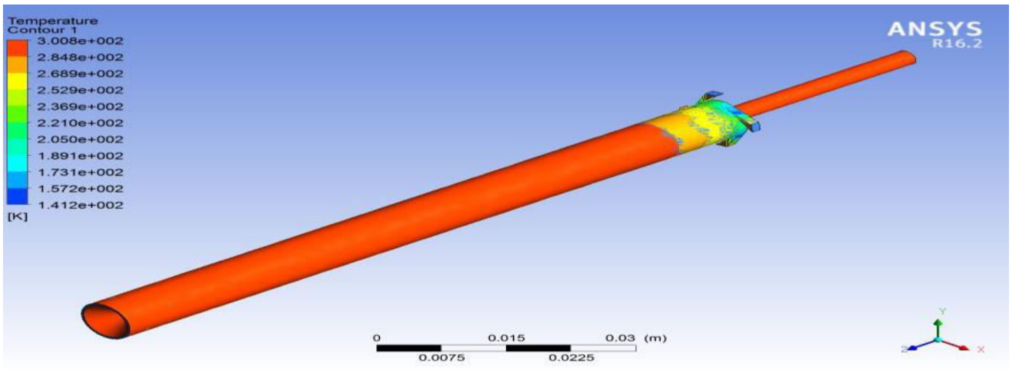

Figure 15: contour for temperature of rectangular nozzle with angle(l=100mm)

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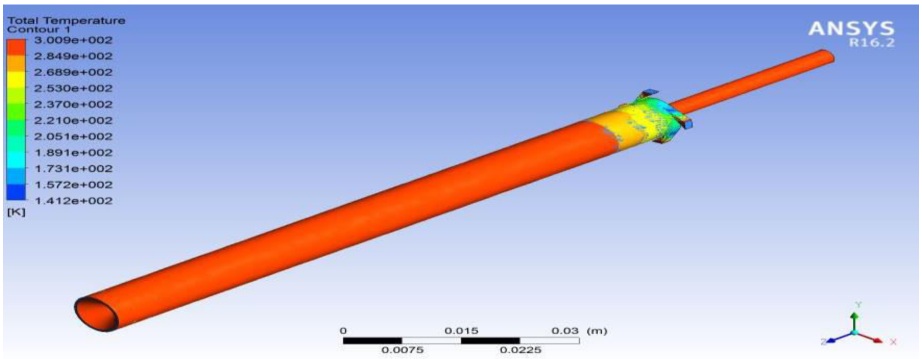

Figure 16: contour for total temperature of rectangular nozzle with angle(l=100mm)

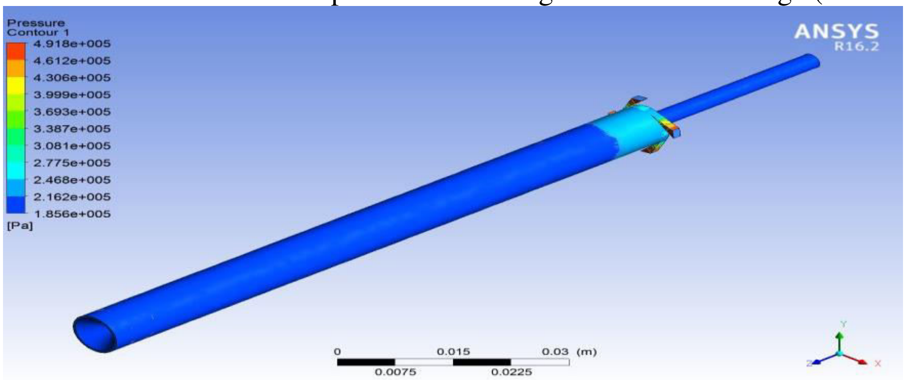

Figure 17: contour for pressure of rectangular nozzle with angle(l=100mm)

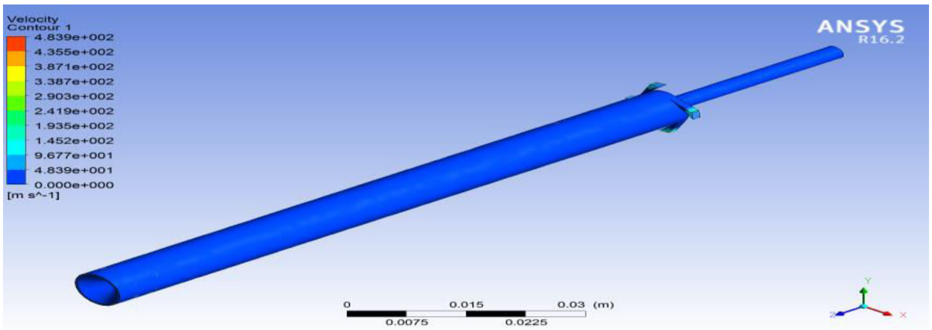

Figure 18: contour for velocity of rectangular nozzle with angle(l=100mm)

Results for Rectangular nozzle with angle at 200 mm length:

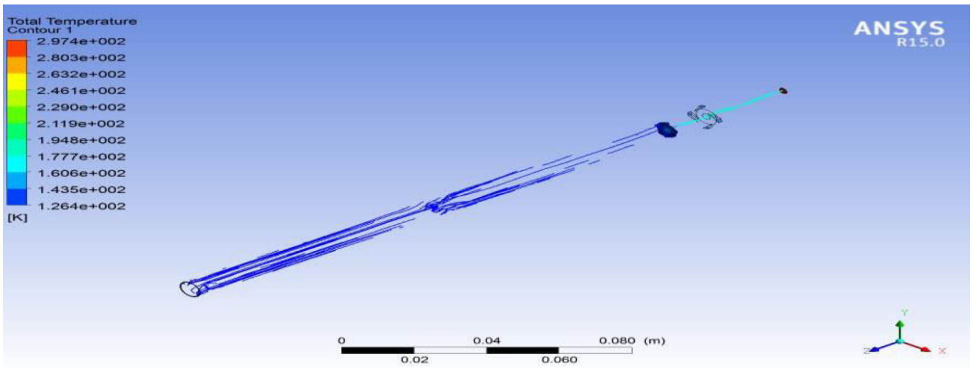

Figure 19: contour for total temperature of rectangular nozzle with angle(l=200mm)

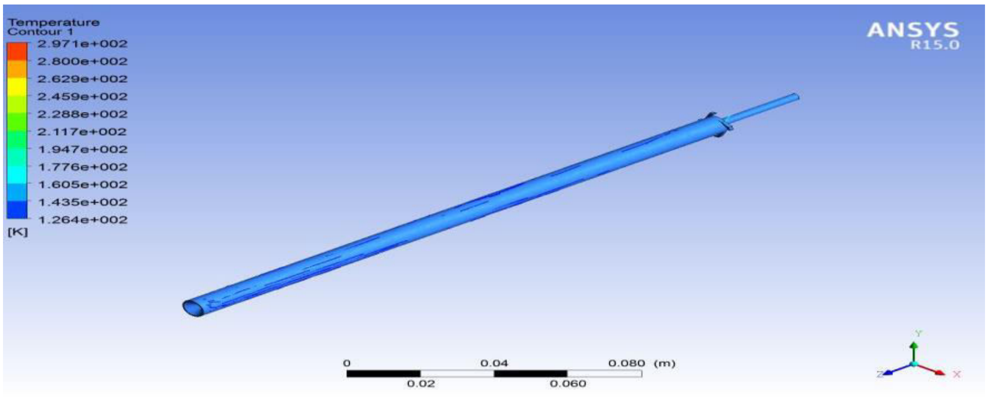

Figure 20: contour for temperature of rectangular nozzle with angle(l=200mm)

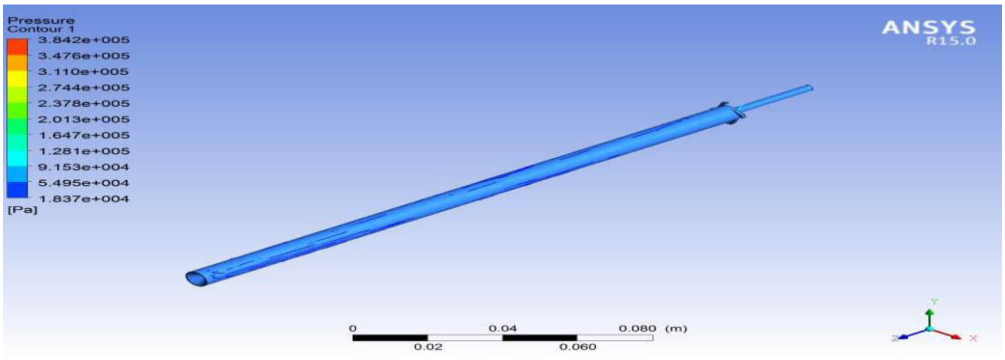

Figure 21: contour for pressure of rectangular nozzle with angle(l=200mm)

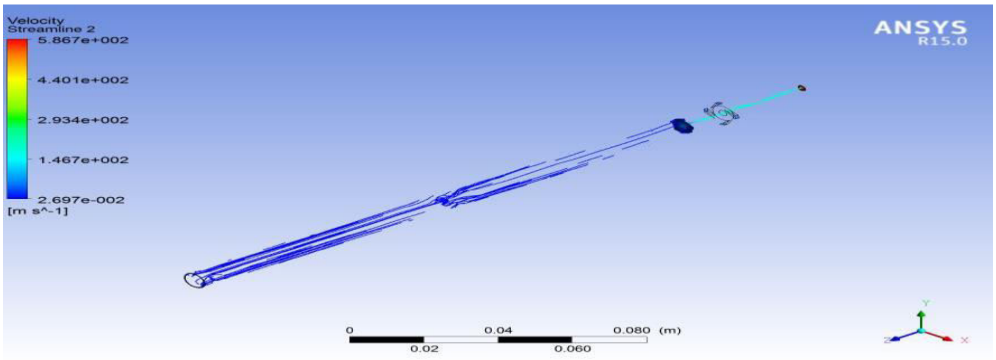

Figure 22: contour for velocity of rectangular nozzle with angle(l=200mm)

Experimental procedure:

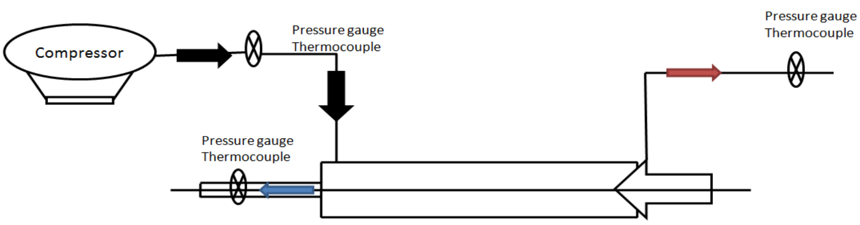

Figure 23: Schematic diagram of experimental setup

Compressor is a device which is used to produce high pressurized air for doing experiments on vortex tube. We will maintain this compressor at study state position with the pressure of 5kgf/cm^2. Regulator is operated by manually to regulate the fluid flow up to required pressure. Pressure gauges are used to calculate the pressure of fluids. Thermocouples are used to see the temperature at required positions. Nozzle is used to convert the pressure into velocity. Vortex chamber is a device hears the vortex flow will be created by mean of nozzle inlet and fluid velocity. Conical valve operated by manually to regulate the fluid flow at hot chamber.

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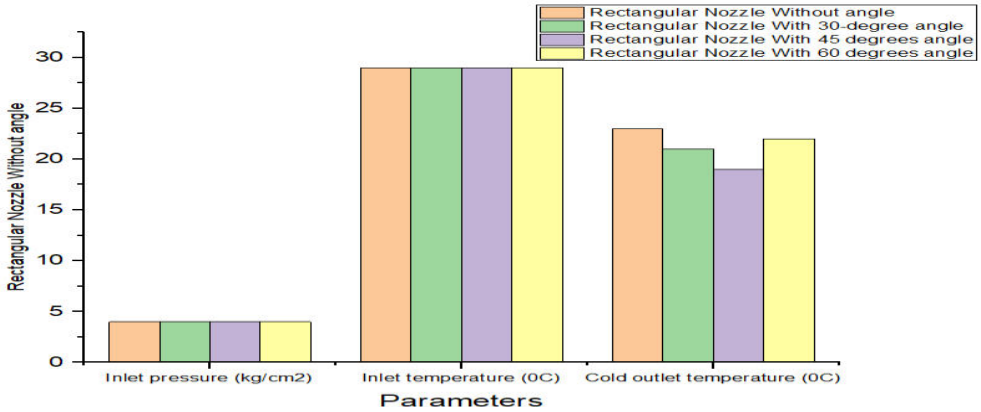
Table 2: Ansys results for temperature of cold fluid at 100 mm length of Vortex tube

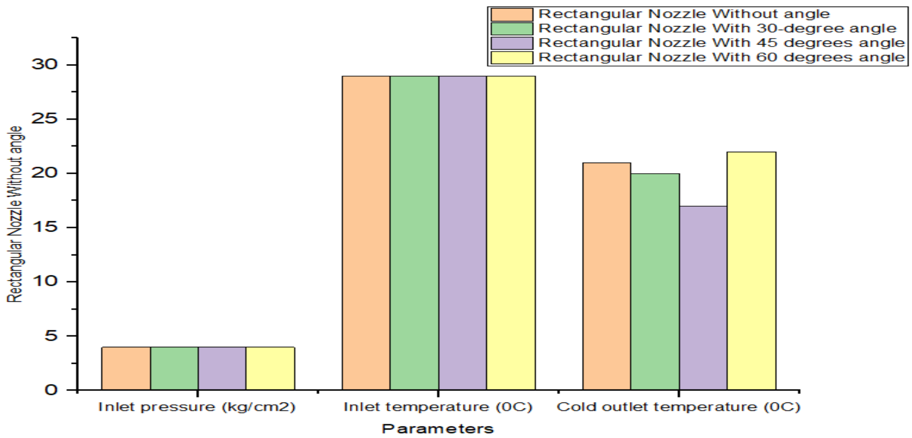
Parameters	Rectangular Nozzle Without angle	Rectangular Nozzle With 30-degree angle	Rectangular Nozzle With 45 degrees angle	Rectangular Nozzle With 60 degrees angle
Inlet pressure (kg/cm2)	4	4	4	4
Inlet temperature(^{0}C)	29	29	29	29
Cold outlet temperature (^{0}C)	23	21	19	22



Graph 1: Ansys results for temperature of cold fluid at 100 mm length of Vortex tube

Table 3: Ansys results for temperature of cold fluid at 200 mm length of Vortex tube

Parameters	Rectangular Nozzle Without angle	Rectangular Nozzle With 30-degree angle	Rectangular Nozzle With 45 degrees angle	Rectangular Nozzle With 60 degrees angle
Inlet pressure (kg/cm2)	4	4	4	4
Inlet temperature (^{0}C)	29	29	29	29
Cold outlet temperature (^{0}C)	21	20	17	22



Graph 2: Ansys results for temperature of cold fluid at 200 mm length of Vortex tube

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From these results it is observed that the results are better for the rectangular nozzle with 45^0 angles. So, the remaining calculations are taken for that and compared with that of the rectangular nozzle without angle for checking the variation. The calculations basing on the observations taken from Ansys results are as follows:

Table 4: Calculation of Mass flow rate from the velocity taken from Ansys results

Nozzle	Length in mm	Density ρ, Kg/m^3	Area, m^2	Velocity, m/s	Mass flow rate, Kg/s
Rectangular nozzle without angle	**100**	**1.225**	1.26E-05	48.4	0.000745
	200	**1.225**	1.26E-05	54.12	0.000833
Rectangular nozzle with angle	**100**	**1.225**	1.26E-05	48.39	0.000745
	200	**1.225**	1.26E-05	146.7	0.002259

Table 5: Calculation of the Cooling Effect from the mass flow rate calculated from Ansys data

Nozzle	Length in mm	Mass flow rate Kg/s	Specific Heat, KJ/Kg-K	Change in Temperature ΔT, K	Cooling effect
Rectangular nozzle without angle	**100**	**0.000745**	1.0045	6	0.0044923
	200	**0.000833**	1.0045	8	0.0066976
Rectangular nozzle with angle	**100**	**0.000745**	1.0045	10	0.0074856
	200	**0.002259**	1.0045	12	0.0272322

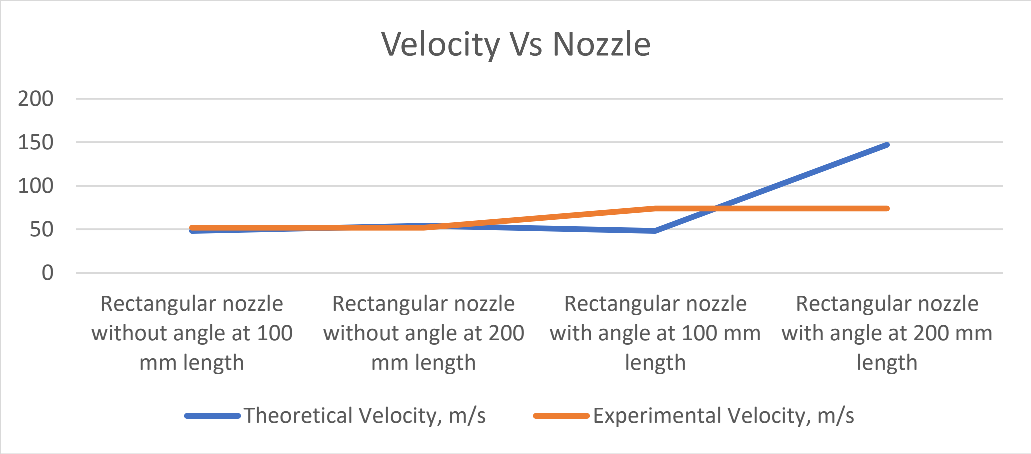
Analytical Results:

For the parameters velocity, mass flow rate, temperature drop, cooling effect and the COP in both theoretical and experimental

COMPARATIVE RESULTS:

Table: 6: Comparison of Velocity for theoretical and experimental

Nozzle	Theoretical Velocity, m/s	Experimental Velocity, m/s
Rectangular nozzle without angle at 100 mm length	48.4	51.61
Rectangular nozzle without angle at 200 mm length	54.12	51.929
Rectangular nozzle with angle at 100 mm length	48.39	74.19
Rectangular nozzle with angle at 200 mm length	146.7	74.19



Graph 3: Comparison of Velocity for theoretical and experimental

From the figure is observed that the velocity of the fluid is more at nozzle with 45^0 angles with 200 mm length hot chamber (vortex tube) and the experimental value is 74.19 m/s. In the velocity point of view, it is better to take rectangular nozzle with 45^0 angle at 200 mm length of the vortex tube.

CONCLUSION:

The study was conducted with investigation on vortex tube with the aim for obtaining correct thermodynamic results. The equipment was configured to make the most effective, i.e. lower temperatures, but for better results. However, the equipment was performing as required and the readings obtained. The Vortex tube is used for use in various industrial applications of waste compressed air generated. For this tube if we use a separate compressor then the complete process is not so efficient, just because of low COP.

- Finally, the energy separation depends upon the length of the tube and different types of nozzles.
- using of rectangular nozzle without angle at 200 mm length of the tube gives the better performance.
- COP as high as 0.0153 but small variation of 0.0135 in Theoretical and experimental COP of the vortex tube.

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