EXPERIMENTAL STUDY ON THE THERMAL PERFORMANCE OF THE VORTEX TUBE WITH VARIOUS TYPES OF ORIFICE NOZZLES AND ORIFICE NUMBERS

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Abstract: The Vortex Tube is a non-conventional cooling device that will produce cold air and hot air from the source of compressed air without affecting the environment. When a high-pressure air is tangentially injected into the vortex chamber a strong vortex flow will be created which will be split into two air streams. It can be used for any type of spot cooling application. The performance of the vortex tube depends on geometrical and thermophysical parameters. An experimental investigation has been performed to realize the thorough behaviour of a vortex tube system. The nozzles material using ABS Plastic with different angles s 1°,1.5° and 2° and the vortex tube with two different lengths (100 mm and 200mm), to identify the most effective nozzle size and hot tube length, followed by the conducting of experiments to determine the energy-saving procedures that can be applied to and affect the compressed air this project design was using CAD and analysis is done by using ANSYS 15.0.

Keywords: vortex tube, ABS Plastic, CAD, ANSYS 15.0

1.0 Introduction:

The vortex tube was invented by a French physicist named Georges J. Ranque in 1931 when he was studying processes in a dust separated cyclone. It was highly unpopular during its conception because of its apparent inefficiency. The patent and idea were abandoned for several years until 1947, when a German engineer Rudolf Hilsch modified the design of the tube. Since then, many researchers have tried to find ways to optimize its efficiency. [6] Until today, there is no single theory that explains the radial temperature separation. Hundreds of papers have been published about the temperature separation in the vortex tube, with the greatest contribution being to the understanding of the Ranque–Hilsch vortex tube.

Vortex tubes:

A vortex tube is a device involving the phenomenon of separation of air currents with different temperatures that was discovered accidentally by Georges Ranque, a French physicist, while conducting an experiment. As a result, vortex tubes can produce currents of cool and hot air simultaneously through the compressed air flow in the pipe.

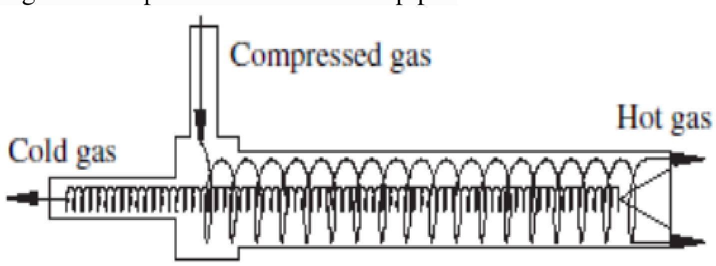


Figure:1.1 Schematic diagram of vortex tube

A source of compressed gas enters tangentially with high pressure through one or more inlet nozzles at high velocity which after expansion causes spinning vortex inside the tube. The air flows through the tube rather than pass through the central orifice located next to the nozzles because the orifice is of much smaller diameter than the tube.

Working of vortex tube:

The vortex tube creates two vortices forced and free. The free vortex fluid particle is moves towards the center of vortex and the angular velocity is fast at the center. In forced vortex particle velocity is directly proportional to the radius of the center vortex and is slower at that placed. In vortex tube outer vortex is free and the inner vortex is forced. [5] The rotational motion of the forced vortex is controlled by free vortex. The turbulence of both the hot and cold air streams causes the layers to be locked together in a single, rotational mass. The inner air stream flows through the hollow core of the outer air stream at a slower velocity than the outer air stream

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.

2.0 Literature Review:

Kun Chang et.al.[1] had focused on divergence angle of hot tube, length of divergent hot tube and number of nozzle intake. Experimental results present that 4^{o} is the optimal angle for obtaining highest refrigeration performance. He suggested that performance of vortex tube can be improved by using divergent hot tube.

H. Pourariaet al Zangooee [2] in this study numerical investigation has been carried out to study the effect of using divergent tube and to find optimum angle of divergence. Energy separation effect inside the tube was modelled using standard k-ε model.

M.H. Saidi et al. [3] conducted experiments to investigate the effect of geometrical parameters on the operational characteristics of vortex tube, vortex tubes with different tube sizes. He concluded that for $L/D \leq 20$ energy separation decreases leading to decrease in cold air temperature difference and efficiency decreases as well

Schubauer et al [4]Vortex generators are applied on wind turbine blades with the major goal to detain or stop the separation of the flow and to reduce roughness sensitivity of the blade. They are usually placed in a span wise array on the suction side of the blade and have the benefit that they can be join as a post-production fix to blades that do not perform as anticipate.

3.0 Research Methodology

The experimental study is carried out with two different vortex tubes having divergence angle 1°,1.5°,2°. Pressure is changing from 2 to 6 bar and valves of different angle are used. Compressed air from the compressor is supplied to the pressure regulator through the air reservoir. Pressure regulator is used to adjust the pressure of compressed air coming from air reservoir. After pressure regulator air is supplied to the Rota meter 1 to measure the flow rate at inlet to the vortex tube. [7] This air is then split into two to feed it to the inlet nozzles of vortex tube. By adjusting the conical valve of the tube fraction of the cold air coming out of vortex tube can be regulated. The same set of procedure is followed for all tubes and with each orifice diameter and set of valves the readings are taken for all three orifice diameters.

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.

Table: 3.1 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

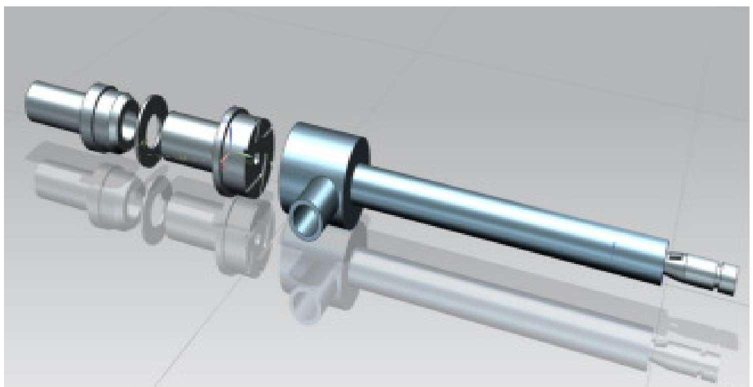


Figure:3.1 Model of our Vortex Tube

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)

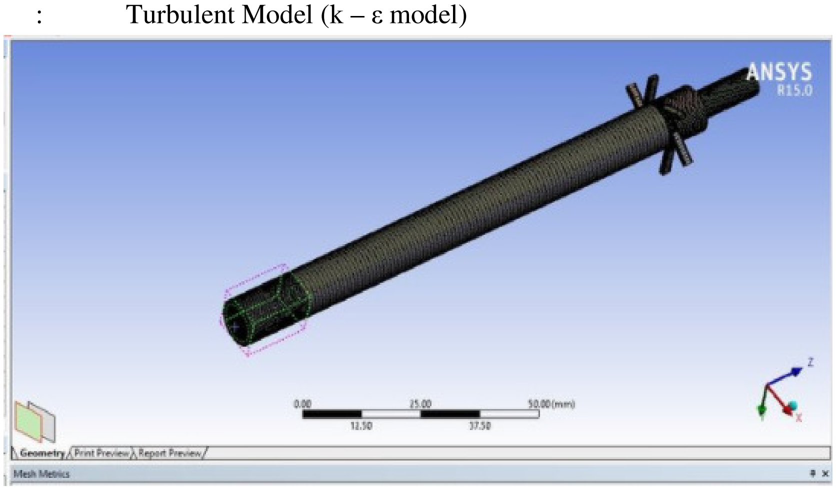


Figure: 3.2 Mesh Model of Vortex Tube

Experimental procedure:

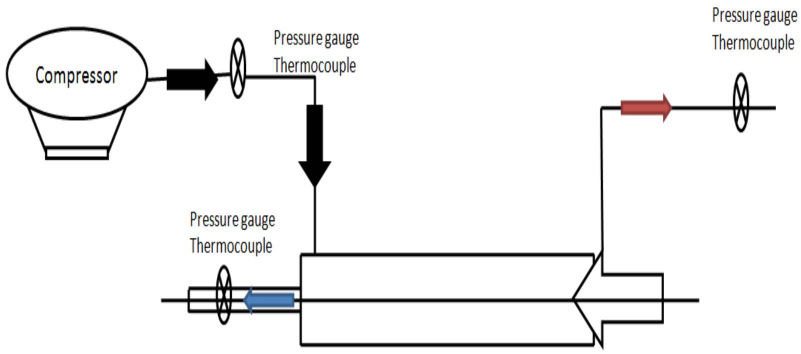


Figure: 3.3 Schematic diagram of experimental setup

Figure: 3.4 Experimental procedure

In this experiment compressed air from the compressor is given to the vortex tube through the pressure regulator, regulator regulates the flow by controlling the throttle valve for the required amount of pressure.

Figure: 3.5 Fluid flow in vortex tube

Table: 3.2 Observations from Experimentation

Parameter	Nozzle without angle		Nozzle with angle	
Length of the tube (mm)	100	200	100	200
Pressure at inlet(p_1) in kg/cm2	4	4	4	4
Temperature at inlet(t_1) 0c	25.6	25	25.6	27.2
Pressure at cold outlet(p_2) kg/cm2	0.2	0.1	0.2	0.2
Temperature at cold outlet(t_2) 0c	21.6	21.6	21.8	19
Pressure at hot outlet(p_3) kg/cm2	0.8	0.86	1.12	1
Temperature at hot outlet(t_3) 0c	31.4	31.4	31.6	34
No of blinks/30sec	29.6	30.2	28.8	29.6

4.0 Results and discussions:

This section deals with an explanation of mechanism of energy separation which is based on the numerical simulation and a detailed parametric study of key design parameters which directly influence the vortex tube's thermal performance. The cold gas mass fraction, orifice diameter, length to diameter ratio, tube diameter, and supply pressure are some parameters which have been investigated. 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 behaviour for different l/d ratios of vortex tube. The following figures shows the analysis part for different types of nozzles for the above-mentioned parameters.

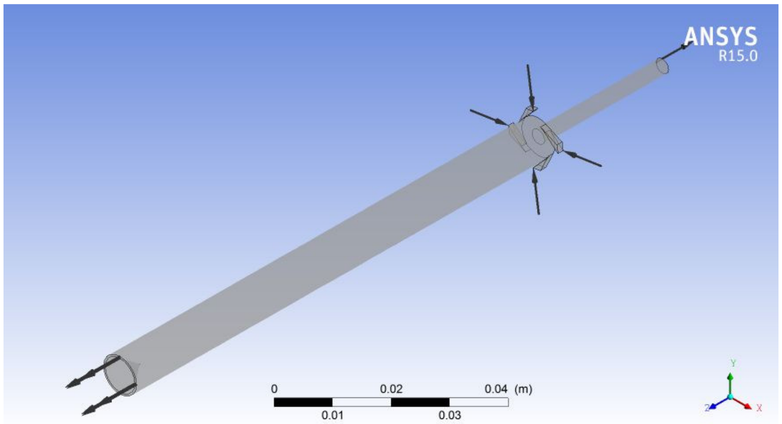


Figure: 4.1 Design model on Ansys workbench for simulation

Rectangular nozzle without angle at 100 mm length:

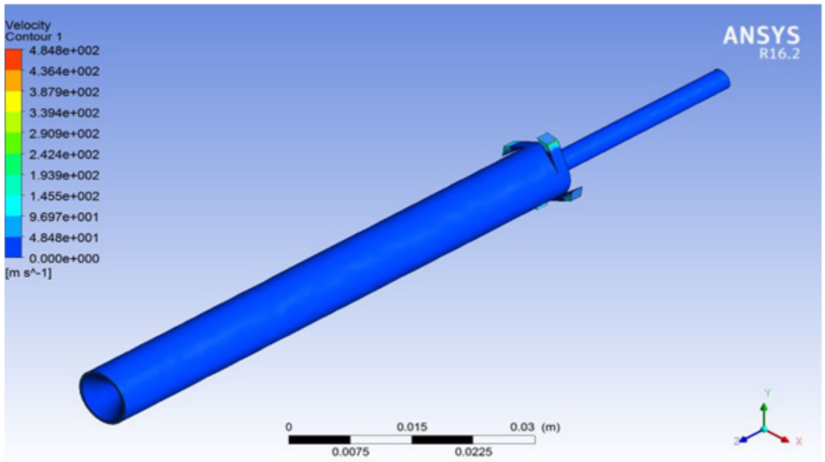


Figure: 4.2 contour for velocity

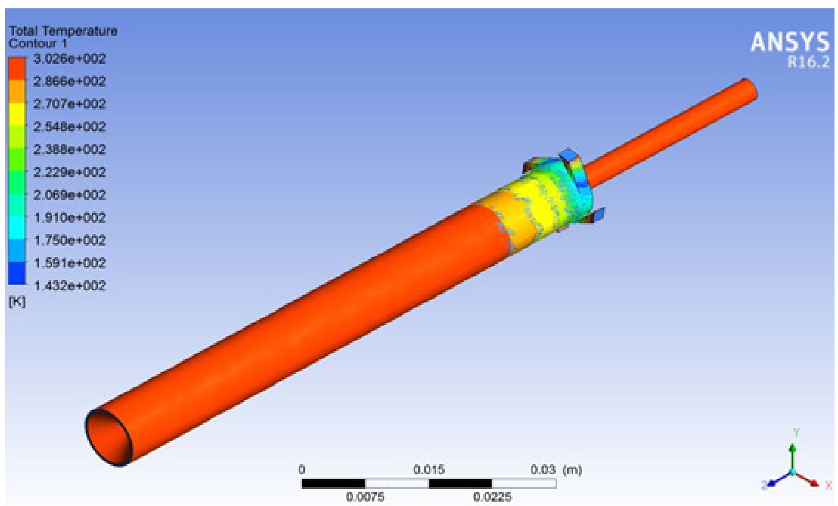


Figure: 4.3 contour for total temperature

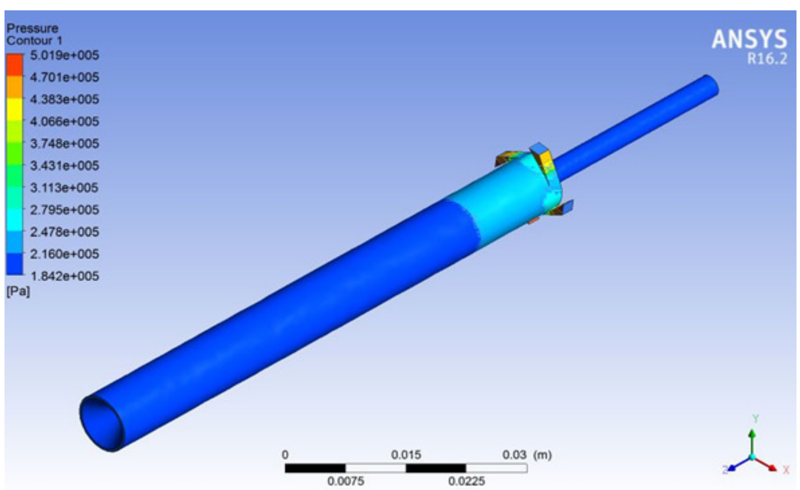


Figure: 4.4 contour for pressure

Results for Rectangular nozzle without angle at 200 mm length

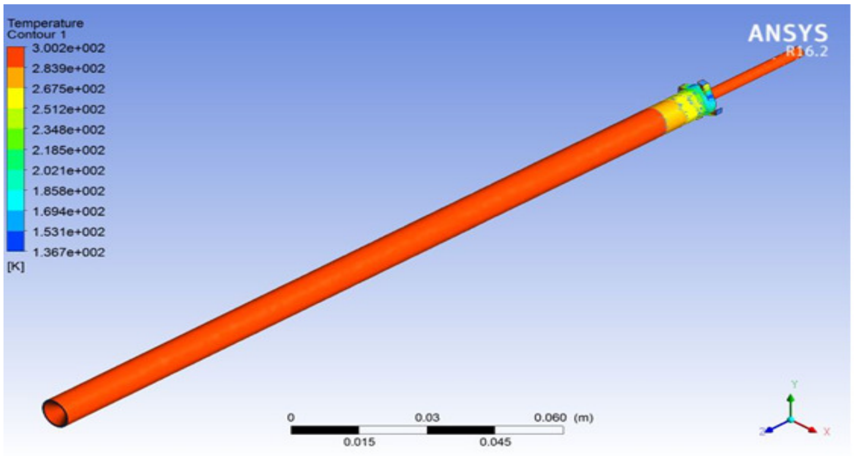


Figure: 4.5 contour for velocity

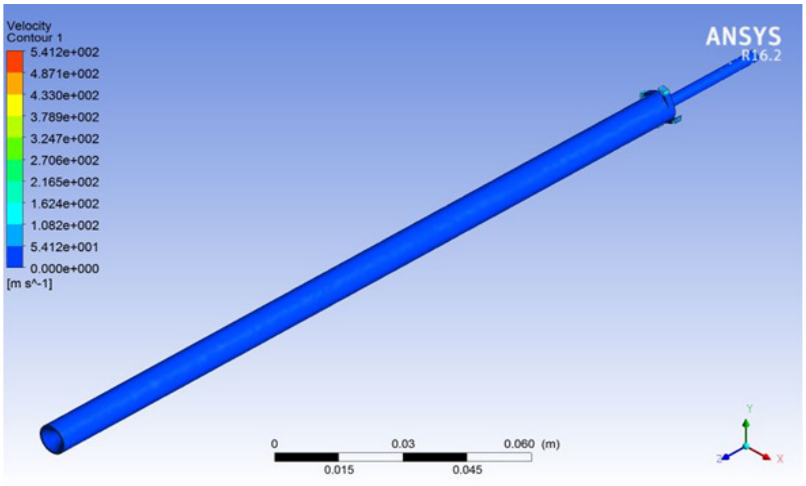


Figure: 4.6 contour for total temperature

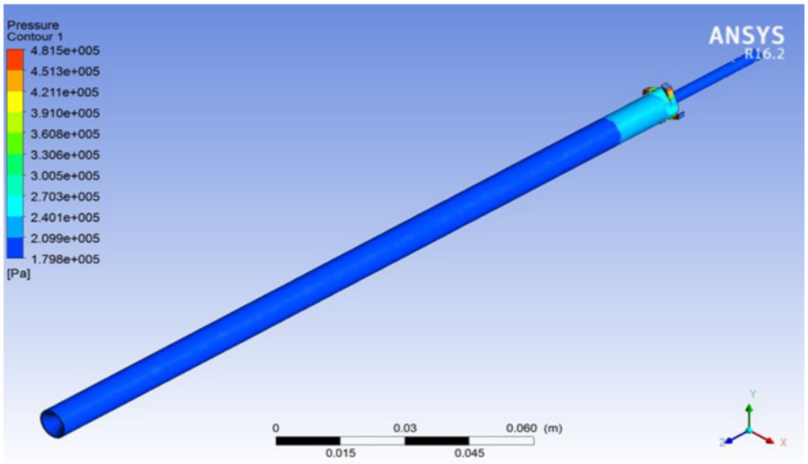


Figure: 4.7 contour for pressure

Table: 4.3 Ansys results table at rectangular nozzle 100- and 200-mm length of hot chamber

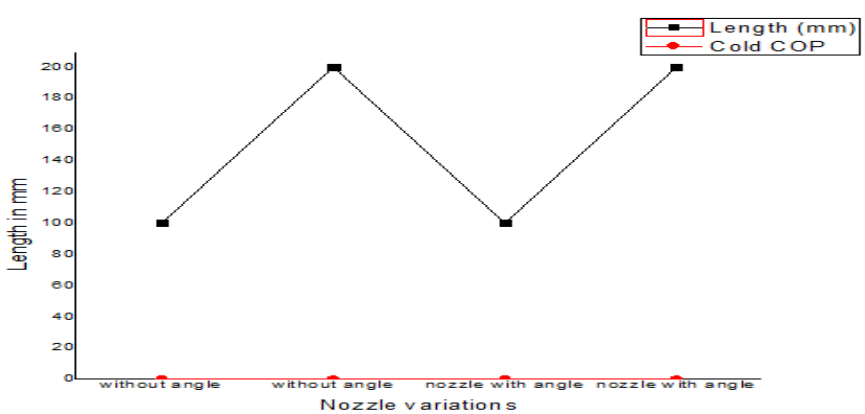
Parameters	**Without angle**	**1 degree angle**	**1.5-degree angle**	**2-degree angle**
Inlet pressure (kg/cm2)	4	4	4	4
Inlet temperature	29	29	29	29
Cold outlet temperature	21	20	17	22
Hot outlet temperature	40	45	49	47

Ansys results given that rectangular nozzle with angle 1.5^0 is giving the better performance for cold outlet temperature. So, the experiment is carried with rectangular nozzle without angle and with 1.5^0 angle.From the above analysis it can be concluded that the CFD model used in this study was quite effective to predict the vortex behaviour in a vortex tube. Although there have been some errors in the result but these errors can be eliminated by increasing the accuracy of the model and by applying exact boundary conditions. This proposed CFD model of the vortex tube can be used to analyse the change of temperature and velocity within a vortex tube in a very effective way

Theoretical Results:

Table: 4.4 Theoretical Results of Rectangular vertex nozzle

Nozzle	Length (mm)	Cold COP
Rectangular nozzle without angle	100	0.00253
	200	0.00377
Rectangular nozzle with angle	100	0.00421
	200	0.01533



Graph: 4.1 Theoretical Results of Rectangular vertex nozzle variations

Conclusion:

The study was conducted with investigation on 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.

- 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.

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