

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

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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 need is to have a tube to produce a higher mass of cold air coming out at low temperatures. For this purpose, converging type of vortex tube is experimented with, and the results are promising. The results show an increase in cold mass fraction and cold end temperature. 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.

Key words: Vortex tube, ABS Plastic, CAD, ANSYS 15.0

1. INTRODUCTION

The Vortex Tube may be used for both spot cooling and process cooling in industrial settings, and it does so efficiently and affordably in both cases. Compressed air is fed into the Vortex Tube and then allowed to spin at speeds of up to 1,000,000 RPM. The air is guided to the Vortex Tube's heated end, where a portion of it is released via a control valve. The remaining air is directed back through the Vortex Tube and vented as cold air at the opposite end. The temperature of air entering a Vortex Tube can be reduced by 115 degrees Fahrenheit (46 degrees Celsius) and increased by 200 degrees Fahrenheit (93 degrees Celsius). Vortex Tube is a simple device for producing cold. It was invented by G.J. Ranque in 1931. It was further developed by German Prof. Hilsch, many people thought it was a breach of the second law of thermodynamics when it was first revealed that the system using compressed air discharged hot and cold streams simultaneously at its two ends. Eckert later provided a theoretical justification for its behavior. Many papers and research projects have been written about the tube since then, but commercial adoption has been sluggish. In today's world, an estimated one million vortex tubes are in use commercially. When pressurised gas is injected tangentially

into a tube at a high velocity, the gas begins to rotate and travel towards the hot end. In the scientific literature, the hot stream refers to the tiny amount of flow that escapes through the gap between the control plug and the tube at a greater temperature than the injection point. The other half of the flow is redirected back into the tube by the control plug and continues on to the cold end via the tube's interior. When the central flow leaves the central exit at the injection point at a cooler temperature than it was injected, a cold stream is generated. The resulting temperature separation in a vortex tube, also known as the Ranque effect, causes the injected flow to be divided into two streams with different temperatures. The vortex tube was created in 1933 by French physicist Georges J. Ranque. When compressed gas is tangentially introduced into the tube, it generates two streams of flow, one cooler than the other. At the opposite end of the tube was an exhaust for the heated stream. The input and outlet were used for the cold and warm streams, respectively. Ranque says the separating action of the vortex tube is driven by alternating periods of expansion and compression. In 1947, German scientist Rudolf Hilsch reported on his successful attempts to improve the performance of a tube in a prestigious journal. Due to the many people who have contributed to our understanding of the vortex tube, it has been variously referred to as the Ranque Vortex Tube (RVT), the Hilsch Vortex Tube (HVT), and the Maxwell-Demon Vortex Tube (MDVT). For consistency, though, we will refer to it from here on out as RHVT (Ranque-Hilsch Vortex Tube). Researchers have been looking into the vortex tube ever since it was first proposed, with the hopes of improving the system's performance, learning more about the flow structure inside the tube, and discovering what causes the Ranque effect. Several hypotheses have been proposed to account for the observation of temperature gradients inside a vortex tube. For instance, the pressure gradient inside the tube offers a simple explanation for the temperature difference. Higher pressures in the tube's periphery and lower pressures in its centre produce warmer and cooler temperatures, respectively, due to compression and expansion. Another possible cause of the temperature difference is the transfer of energy from the inside to the exterior flow. Since the inner flow is assumed to have a greater angular velocity than the flow at the periphery, the angular momentum of the inner flow is converted to kinetic energy and transferred to the outer vortex as the rotating flow moves radially.

1.1: Vortex tube

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 allows for simultaneous production of cold and hot air

currents in the tube as a result of the vortex effect. 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.

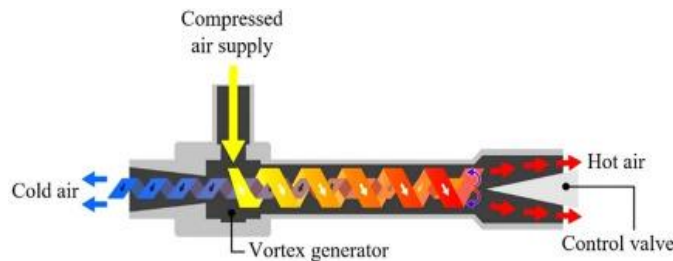


Figure 1.1: Vortex tube

1.1.1: Working of vortex tube

A vortex tube is a type of thermal device that splits a single thermal injection into two lower- and higher-temperature streams. Compressed gas is injected tangentially into a vortex tube, where it is heated and then separated into two streams with lower and higher temperatures, respectively, than the incoming 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 diaphragm hole lets the cold air escape to the chilly side, while the valve aperture lets the hot air through. By adjusting the valve's opening, one may control both the flow rate and temperature of the cold air.

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 -500°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.

Applications of vortex tube

- The extremely small size of vortex tubes means that they can generate both hot and cold air. It could be useful in areas that need both of those things.
- It is easy to achieve temperatures as low as -500°C , making it ideal for the industrial spot cooling of electronic components.
- It is commonly used for body cooling of the workers in mines.

1.2: 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 cool 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. LITERATURE REVIEW

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] Experiments involving the separation of temperatures in a vortex tube are analysed. He studied two primary factors: first, the hot-cold tube diameter and length, cold-orifice diameter, hot-tube form, number of intake balls, inlet shape nozzles, and cone valve shape that define a vortex tube. The second is related to thermo-physical variables including the intake gas pressure, cold mass fraction, inlet gas moisture, and gas type (air, oxygen, helium, and methane). Quantitative, theoretical, analytical, and numerical details of the sample are dissected using the finite-volume approach.

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. The study has shown that the COP improvement through a vortex tube as an expansion unit depends on coolant species, operating conditions and cycle configurations. The expansion system of the vortex tube is an optimized improvement in the CYC2 COP of 12.2, followed by propane (11,5% for CYC2), while ammonia produces a significant improvement in the range of studies.

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. vortex generator which is positioned near the tube inlet and allows the compressed gas to reach the vortex tube at various angles. In its third form, the vortex tube is cooled directly through the cooling jacket and concludes that it has been seen more effective to produce vortex tube with improvement to the intake of the nozzle and the addition of the diffuser.

E. Torrella1 et.al [10] It studies the effects of varying air intake characteristics, air inlet pressure, the temperature of the resulting cold stream, and the fraction of cold flow on the cooling capacity of an air vortex cooling tube. In the vortex tube, air intake temperatures fall within a functional coating fraction range.

3. DESIGN AND ANALYSIS SOFTWARES

Ansys was established in 1970 and formally established as a company in 1994. Ansys' main focus is on providing software and support for engineers conducting simulations. Aerospace, defence, automotive, biomedical, and other industrial sectors all make use of the company's products. Bloomberg Businessweek and FORTUNE magazine, among others, have named Ansys, a provider of engineering simulation software, as one of the most inventive firms in the world. Ansys provides a unified environment for all phases of product creation, from initial ideation to final testing and validation, by harnessing the processing power of modern desktop computers. Multi-physics applications, including heat transfer, fluid mechanics, statics, solid mechanics, etc. are simulated using the company's simulation platform solutions. Ansys is the industry standard for finite element analysis (FEA), a modelling and simulation technique that has gained popularity over the years (and notably with the arrival of powerful computers) in dealing with a wide range of challenging engineering problems. Ansys's widespread acceptance in both academic and industrial contexts can be attributed to the software's multi-physics capabilities, rich documentation, and the availability of training institutions that provide both online and in-person Ansys courses. Because of the many benefits that can be gained from using Ansys software. Ansys's Workbench is its basis. The

simulation workflow is linked together by the Ansys Workbench environment. It keeps tabs on the interconnections between the various data sets involved in the project. The project diagram illustrates how changes in an upstream cell need updates in downstream cells.

3.1: Introduction to FEA

The first step is to describe FEA and see why it has become so popular, and then dive into the specifics of Ansys software. Analytical methods, experimental methods, and numerical methods are the three primary approaches to solving difficult engineering problems. Although problems can be solved precisely using analytical techniques, this is restricted to extremely simple geometries. Although experiments are often reliable, their high cost makes them impractical in most situations. As a versatile and all-encompassing numerical methodology, finite element analysis (FEA) offers reliable engineering solutions to a wide variety of engineering challenges. In FEA, the area of interest is broken down into a series of smaller, simpler domains known as "finite elements," which is the major distinguishing feature. higher of these finite elements means higher precision in the model and analysis. Mathematically speaking, the finite element method is a technique for solving differential equations. Derivatives, whether ordinary or partial, make any equation a differential equation. They can also be linear, partial, or just plain old. From a technical standpoint, differential equations are crucial because they are the language in which physical laws are stated. The purpose of finite element analysis is to convert a system's differential equations into a set of linear equations that can be solved effectively.

3.2: Ansys Software

The standard approach to solving engineering challenges entails three steps: modelling the issue at hand, developing a solution, and analysing the outcomes. Like many other FEA programmes, Ansys consists of a pre-processor, a solution processor, and a post-processor, all of which are processors. The Ansys pre-processor facilitates the creation of geometry, the definition of materials, and the generation of element mesh. The Ansys processor lets users apply loads and get answers to their difficulties. Ansys's post-processor provides a graphical interface for exploring and listing results in tabular or printed representations.

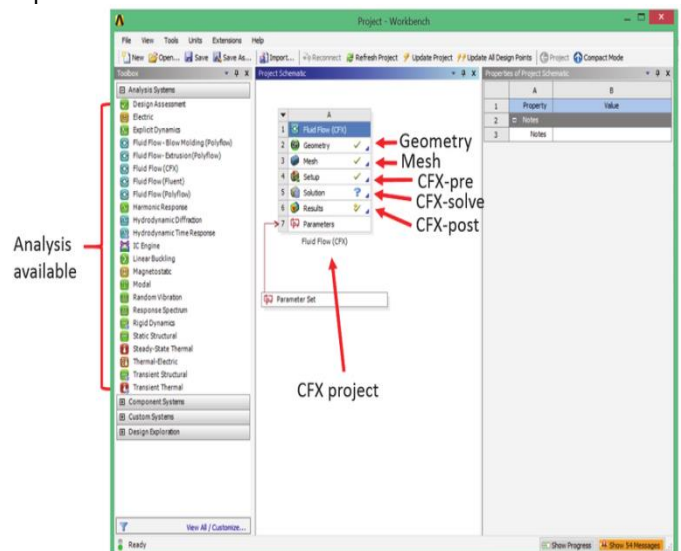


Figure 3.1: Ansys software interface

4. EXPERIMENTAL DESIGN AND SETUP

The experiment will be performed with two various vortex tubes with angles of difference of $1^\circ, 1.5^\circ, 2^\circ$. 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.

4.1: Construction of vortex tube

A vortex tube is defined by its highest temperature variations and its unique construction. The maximum cooling effect can be achieved with a little volume of air in a vortex tube, while a considerable amount of energy can be stored in a tubing design operating at moderate temperatures. Forward-moving swirl air and axial air flow both had their heat transfer rates improved by taking use of these two factors. The analysis analyzes parameters for recognizing their interaction & impact on the efficiency of the vortex tube

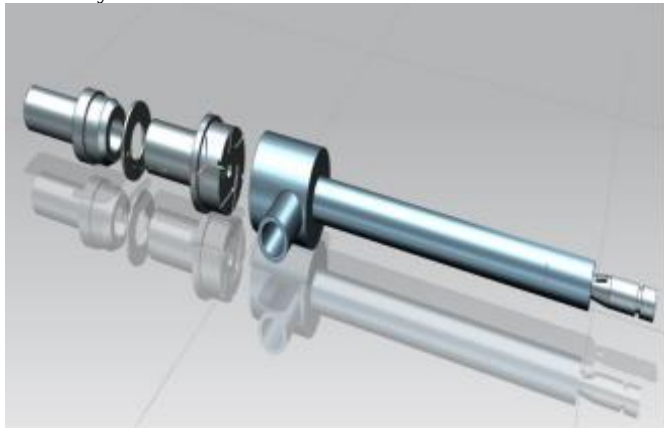


Figure 4.1: Model of our Vortex Tube

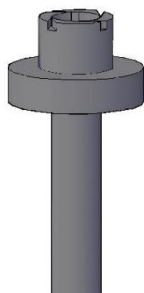


Figure 4.2: model of rectangular nozzle with angle



Figure 4.3: 3D printed rectangular nozzle with angle

4.2: Boundary Conditions

The analysis makes use of the pressure and temperature readings acquired in the experiments. In order to model the vortex tube phenomena in various settings, the following boundary conditions are provided.

Fluid	:	Compressed Air
Pressure	:	4 bar
Temperature	:	29 degree centigrade
Flow	:	Turbulent Model ($k - \epsilon$ model)

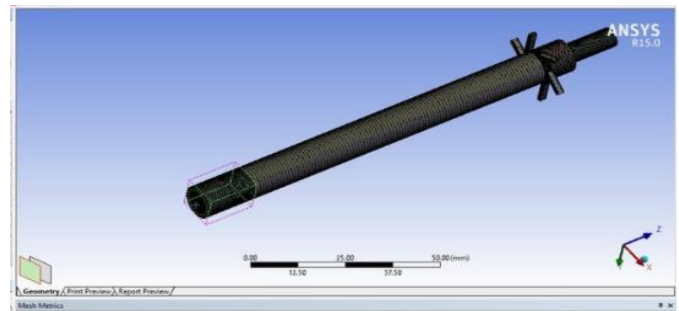


Figure 4.4: Mesh Model of Vortex Tub

5. DESIGN AND ANALYSIS

Considering the results of the numerical simulation and a careful parametric analysis of the most important design factors that have a significant impact on the thermal performance of the vortex tube, this section explains the mechanism of energy separation. Some of the factors that have been looked into are the mass percentage of hot gas, the orifice diameter, the length to diameter ratio, the tube diameter, and the supply pressure. The ANSYS R.15 software can be used to analyse the flow in a vortex tube and determine the distribution of the flow and the behaviour of the flow's parameters (such as pressure, temperature, velocity, and so on) for a range of l/d ratios. Following are some figures displaying the analysis section for various types of nozzles using the aforementioned values.

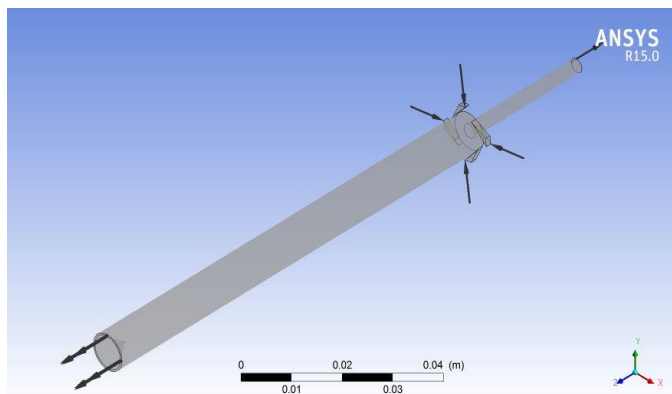


Figure 5.1: Design model on Ansys workbench for simulation

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

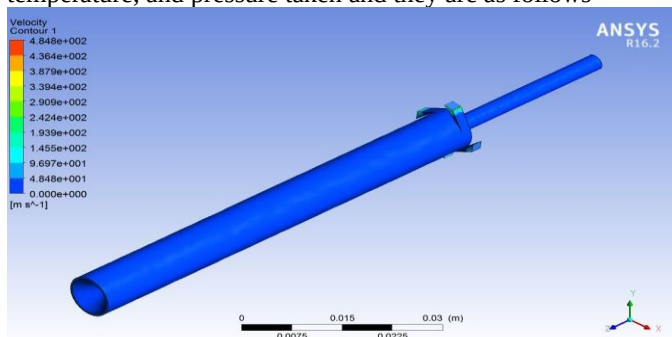


Figure 5.2: Contour for velocity of rectangular nozzle without angle

Table 5.1: Ansys results for temperature of cold fluid at 100 mm length of Vortex tube

Parameters	Rectangular Nozzle			
	Without angle	30° angle	45° angle	60° angle
Inlet pressure (kg/cm ²)	4	4	4	4
Inlet temperature (°C)	29	29	29	29
Cold outlet temperature (°C)	23	21	19	22

Table 5.2: Ansys results for temperature of cold fluid at 200 mm length of Vortex tube

Parameters	Rectangular Nozzle			
	Without angle	30° angle	45° angle	60° angle
Inlet pressure (kg/cm ²)	4	4	4	4
Inlet temperature (°C)	29	29	29	29
Cold outlet temperature (°C)	21	20	17	22

Table 5.3: Calculation of Mass flow rate from the velocity taken from Ansys results

Nozzle	Length (mm)	Density (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 5.4: Calculation of the Cooling Effect from the mass flow rate calculated from Ansys data

Nozzle	Length (mm)	Mass flow rate, (Kg/s)	Specific Heat, (KJ/Kg-K)	Tem. (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

Table 5.5: COP calculation from Ansys data

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

6. RESULTS AND DISCUSSIONS

Ansys results given that rectangular nozzle with angle 450 is giving the better performance for cold outlet temperature. So, the experiment is carried with rectangular nozzle without angle and with 450 angle. This study's CFD model was shown to be quite accurate when predicting vortex activity in a vortex tube, as shown by the above data. Improving the accuracy of the model and using precise boundary conditions can help rectify the inaccuracies that have crept into the outcome. In order to effectively examine the variation in temperature and velocity within a vortex tube, a computational fluid dynamics (CFD) model has been presented.

Table 6.1: Ansys results table at rectangular nozzle 100- and 200-mm length of hot chamber

Parameters	Without angle	30° angle	45° angle	60° angle
Inlet pressure (kg/cm ²)	4	4	4	4
Inlet temp.	29	29	29	29
Cold outlet temp.	21	20	17	22
Hot outlet temp.	40	45	49	47

Table 6.2: Theoretical Results of Rectangular nozzle

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

Table 6.3: Experimental Results of Rectangular nozzle COP of the cold fluid variations

Nozzle		Length (mm)	Cold COP
RECTANGULAR	without angle	100	0.00095
		200	0.00037
	with angle	100	0.00064
		200	0.00178

Table 6.4: Comparison of Velocity for theoretical and experimental

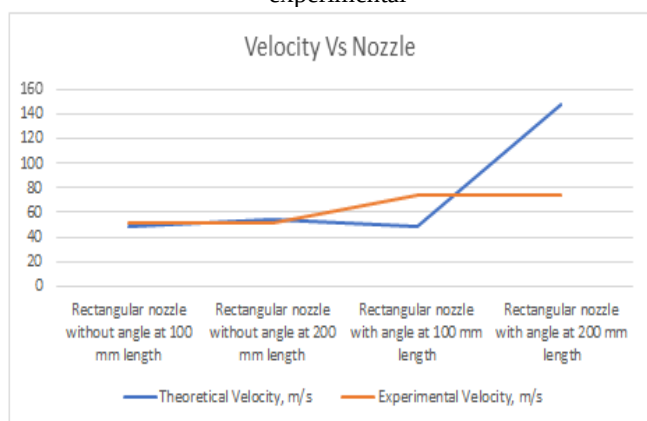


Figure 6.1: Comparison of Velocity for theoretical and experimental

From the above figure it is observed that the velocity of the fluid is more at nozzle with 450 angle 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 450 angle at 200 mm length of the vortex tube.

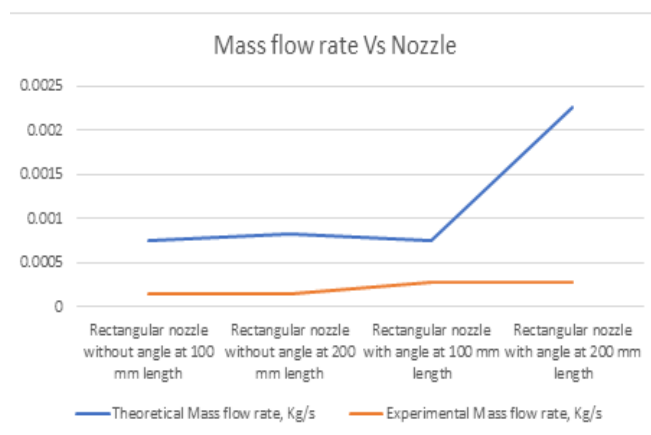


Figure 6.2: Comparison of Mass flow rate for theoretical and experimental

From the figure it is observed that the mass flow rate of the fluid is more at nozzle with 450 angle with 200 mm length hot chamber (vortex tube) and the experimental value is 0.000278 Kg/S. In the velocity point of view, it is better to take rectangular nozzle with 450 angle at 200 mm length of the vortex tube.

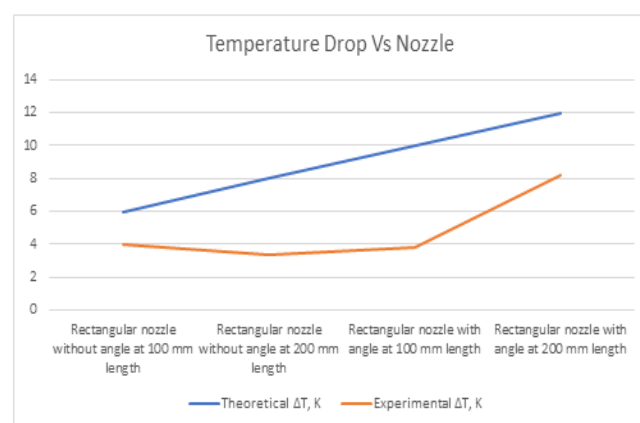


Figure 6.3: Comparison of Temperature drop for theoretical and experimental

From the above figure it is observed that the temperature drop of the fluid is more at nozzle with 450 angles with 200 mm length hot chamber (vortex tube) and the experimental value is 8.2 in K. In the velocity point of view, it is better to take rectangular nozzle with 450 angle at 200 mm length of the vortex tube.

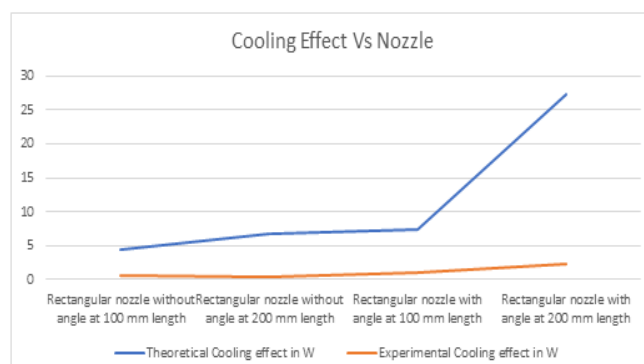


Figure 6.4: Comparison of Cooling effect for theoretical and experimental

From the above figure it is observed that the cooling effect of the fluid is more at nozzle with 450 angle with 200 mm length hot chamber (vortex tube) and the experimental value is 2.29 W. In the velocity point of view, it is better to take rectangular nozzle with 450 angle at 200 mm length of the vortex tube.

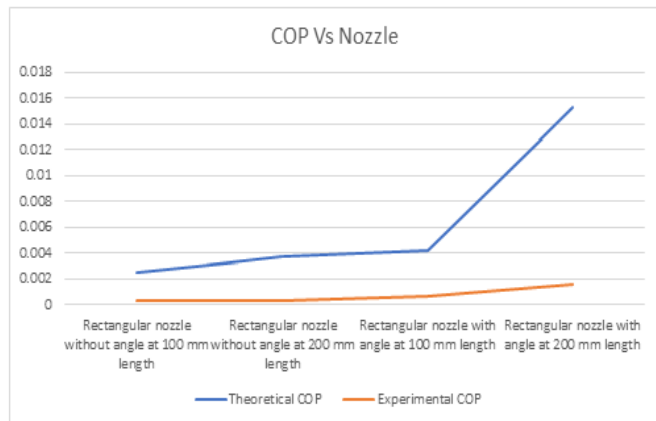


Figure 6.7: Comparison of COP for theoretical and experimental

From the above figure it is observed that the COP of the fluid is more at nozzle with 450 angle with 200 mm length hot chamber (vortex tube) and the experimental value is 0.00158. In the velocity point of view, it is better to take rectangular nozzle with 450 angle at 200 mm length of the vortex tube.

7. CONCLUSIONS

The study was conducted with investigation on vortex tube with the aim for obtaining correct thermodynamic results. The equipment was set up so that it would be as efficient as possible, allowing for lower temperatures but better outcomes. However, the results obtained and the operation of the apparatus were both satisfactory. Compressed air that has served its purpose in a variety of manufacturing processes can be recycled using a Vortex tube. When a separate compressor is used for this tube, the overall process is less efficient.

- 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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