Praduman Kumar Yadav, 2022, 10:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

Vortex Tube with CFD Analysis Using FEM Method

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Abstract- In the study effort the Vortex tube and the inherent phenomena of swirl production are investigated and understood. It is a mechanical device with no moving components. The splitting of the flow into low- and high-temperature zones is called the temperature separation effect. The output of the vortex tube is determined by two main parameters: one is the working parameter, for example, intake pressure for compressed air; the other is geometric parameters, such as nozzle number, nozzle diameter, cone valve angle, hot side tube length, hot opening diameter and vortex tube material. The Vortex tube has fascinating functionalities and many industrial applications and is employed as a cooling unit in industry as a refrigerator."The purpose of this study is to illustrate the working principles of vortex tubes, energy separation phenomena, geometric factors that influence vortex tube performance, and the analytical effect of CFD. This paper includes equations and boundary criteria for examining the vortex tube. Hypertension, viscosity, turbulence, temperature gradient, and secondary circulation are all examples of temperature separation. Furthermore, studies have shown that CFD analysis assesses various kinds of nozzle profiles as well as the number of nozzles. CFD analysis was performed to establish the highest warm-gas temperature and the lowest cold-gas temperature using different shapes and dimensions of the hot end valve. The boundary conditions of the necessary vortex flow have been modified."

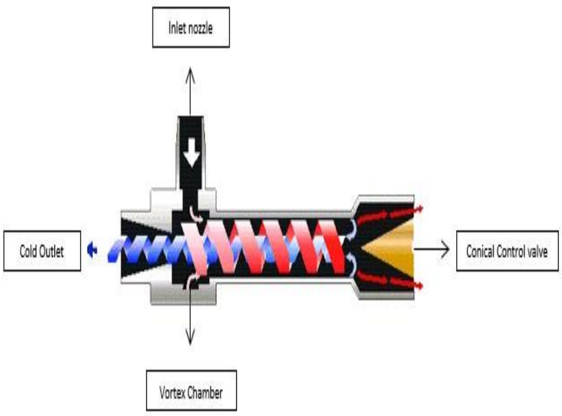
Keywords- CFD analysis, FEM etc.

I. INTRODUCTION

In 1932 Ranque invented the Vortex tube. It acts as a device able to separate compressed air supplied by various mass fractions into cold and hot streams. This process is known as the separation of energy (temperature). An axial tube having a vortex chamber, a cold gas outlet and the hot gas outlet comprises one or more of the tangential entrance nozzles.

Air without dehumidification from dust between 5 and 6 Bars is tangentially fed via the intake nozzles into the vortex chamber. The air expands via the jacks and reaches a high angular velocity, resulting in a high swirling flow, and with the conical control valve, the gas travels towards the heating outlet (shown in figure 1a).

A part of the gas flowing in the heating outlet reverses its course and proceeds to the cold outlet. It travels in the axial direction of the tube to the cold outlet.



(a) General model of Vortex tube.

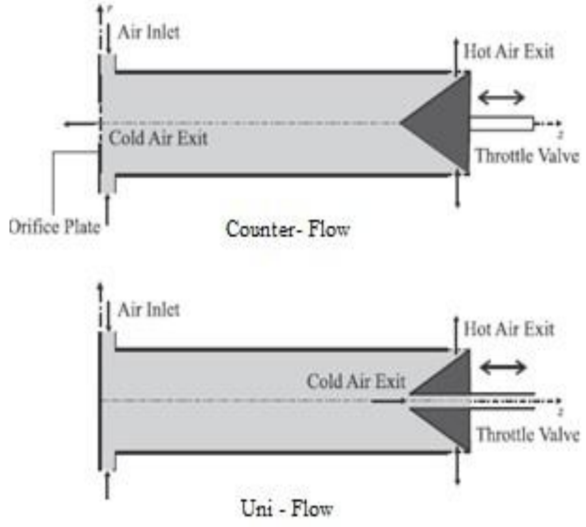


Fig 1. The Vortex tube: Schematic diagram [21].

"As the flow travels to the cold outlet, the heat energy in the flow reversal is transferred to the flow's perimeter. The peripheral flow becomes warmer as the input gas and the core flow area become colder than the inlet gas. The peripheral flow is blocked by the ring gap between the tube wall and the conical valve at the hot outlet.

The cold exit is where the core flow exits. The relative mass flow rate of hot and cold gases is controlled by a conical valve on the hot outlet. The Ranque effect is the name for these energy separation phenomena. The vortex tube can produce a temperature of 127 °C with a heat flow and a cold air flow of -46 °C with a heat flow.

1. Applications of Vortex Tube:

Vortex is lightweight, compact and devoid of moving parts. It has no maintenance problems, because it does not utilize electricity or chemical substances. It is inexpensive compared to other cooling equipment, and unlike other localized cooling equipment, no coolant is required. She's resistant to wear since she's constructed of steel. Corrosion and oxidation are also resistant.

The temperature is changeable, since both the cone valve and the generators may be changed by altering the user's geometric adjustment. It provides immediate chilly air, most essential. But it takes expensive compressed air to generate the immediate chilly air. Another key point to notice is that there is little efficiency in this separating process. However it is much overpowered by the benefits of the use of the vortex tube.

II. LITERATURE REVIEW

K.K.Arun et.al. (2014) The future of sustainable development is innovative methods that minimize the effect of production on the environment. The growing desire for a more eco-friendly populace makes sustainability increasingly essential in today's society. Vortex tube is a sustainable spot-cooling gadget that requires no coolant or power. Vortex tubes are free of maintenance and no maintenance is needed. This study optimizes the cooling temperature parameter of the tube. Different CFD analysis vortex tube of different length.

The CFD study provides the optimal cold end (dc) diameter, the length to diameter ratio (L/D) and optimal parameters to achieve the lowest cold gas temperature. The significance of this study is in showing the vortex tube as an alternative and sustainable spot cooling technique for machining operations. The efficiency of vortex tube with various profiles, length and diameter ratios is analyzed using the CFD tool".

Prof. Uday V. Aswalekar et.al. (2014) The Ranque's Hilsch (Ranque's Hilsch) The Vortex tube is a mechanical device that creates a localized cooling effect by separating pressurized air into hot and cold streams. "It is used in a variety of applications because to its simplicity, sturdiness, and ease of maintenance. Its design is still based on empirical connections and rules of thumb from experiments. Because of the complexities of the stream, it is difficult to capture the whole flow and energy separation properties of vortex tubes.

The objective of the numerical analysis of the vortex tube is to reveal previously unknown features. An L/d ratio 10 vortex tube with two straight, circular intersecting nozzles is used in this study. Solid Works 2010 is used to create a three-dimensional cavity model. The flow, press distribution, and temperature distribution along the length of the vortex tube are all evaluated using ANSYS FLUENT 13.0. The route lines for vortex tubes fit the theoretically stated course.

Abu Bakar IZHARa et.al. (2014)ANSYS CFX simulation code is used to model vortex-inductive vibrations of a cylinder in this study. The cylinder is regarded as a rigid body and the employment of a one-degree freedom spring damper system results in cross displacements. Air as a fluid is used for both 2-D and 3-D analyses. The number of Reynolds, which covers laminar and turbulent flow regimes, is variable between 40 and 16000 roughly. For validation use are made of the experimental findings (Khalak and Williamson 1997) and other researchers. Comparable outcomes are achieved.

Nilotpala Bej et.al. (2014) Ranque-Hilsch vortex tube (RHVT) is a simple tool which divides a compressed input gas stream into a cold and hot output stream without an additional energy source. The hot gas stream coming from the first stage vortex tube is provided in RHVT type of hot cascade at the entrance of the second stage vortex tube and thus produces a more heated effect.

This article provides the findings of an exergy analysis for second stage RHVT for various fractions in cold, using the standard keć turbulence model. The findings obtained from numerical simulations are favourable for the application of the RHVT cascade model for the experimental measures available.

SarathSasi et.al. (2014) The most essential good feature in the refrigeration industry, which is connected with nearly any analyses or even advances, is their green mother nature, which satisfies your fundamental requirements without damaging the environment. These businesses and people are now working together to ensure environmental security. The goal of this article is to improve the effectiveness of just one green technique for commercial cooling, known as vortex tube, and to refresh process requirements such as location cooling, solder cooling, inexpensive slitting, extrusion cooling, and so on.

Using these commonly used cooling methods, the fuel works with fluids that either degrade the ozone layer or contribute to increasing global temperatures in accordance with CO2. Many features have previously been included in attempts to achieve optimum production using knowledge of this vortex tube. I'm looking at a vortex tube for the purpose of constructing the most cost-effective tube possible. To that end, I created an optimal vortex tube and conducted experimental research on the vortex tube by changing various variable numbers, turbo materials, various cone angles, and various mass fractions.

Waraporn Rattanongphisata et.al. (2014)A vortex Tube is a cooling device where an air may also be utilized as an ecologically beneficial working medium. Studies of thermal separation flow and early testing indicate the potential to improve vortex cooling capacities by lowering the temperature of an external surface at a hot tube part. A thermoelectric module is used here to extract heat and release it into the environment from the surface of the hot tube.

In other words, the thermoelectric generator as thermal energy harvester uses a tempering difference. The experimental plant on the vortex cooling system, which includes the thermoelectric module, is developed and built in a laboratory. Cold fraction from 0 to 1 and air inlet pressure of 1.5 bars constitutes the test conditions.

The findings indicate that when the thermoelectric module extracts heat from the hot tube surface of the vortex tube and electricity is produced as per product, the cooling capacity and effectiveness are increased. The cooling power of the vortex tube and its efficiency improved by 4.3% and 9.6% respectively.

Anatoliy Khait et.al. (2013)"Numerical simulations utilising various Turbulence Models visualise the air flow in the Ranque-Hilsch vortex tube. During calculations: k-β, k-μ realisable, k-μ RNG, SST and SAS-SST, the following turbulence models were utilised. It was discovered that the presence of massive secondary vortex structures in the computational domain is only predictable in the SAS-SST turbulence model. Different experimental investigations indicate the presence of massive secondary vortex formations".

Sankar Ram T. et.al. (2013) The Ranque-Hilsch effect is a temperature distribution phenomenon that occurs in confined, constantly rotating gas flows. The basic counterflow vortex tube is a long hollow cylinder with a compressed air injection tangential nozzle on one end. The flight within the vortex tube of a spring-formed vortex track may be described as rotating air.

The peripheral flow is directed towards the heat end by a heat end plug, while the axial flow, which is forced back by the connection, is directed in the opposite direction to the cold end.

Zahari Taha et.al. (2013) We have grown more aware of the need to reduce environmental impacts over the last 10 years. The manufacturing industry aims to minimize environmental impacts via greater features, less processing power and less coolant uses for new materials. The main objective of this study is to assess the effect on energy consumption and quality of surface ruggedness of the vortex cooling tube from Ranque–Hilsch while utilizing the carbide-recording tool used to manufacture softer steel. The machining parameters involved in the experiment are cutting speed, feed rate and cutting depth.

The cutting speed is 160 m/min and the feed rate and cutting depth vary. The feeding rate must be 0.10, 0.18 and 0.28 mm/rev, and the cutting depth shall be between 1.0 and 4.0 mm. Infraround thermometers are used to monitor the cutting temperature throughout the machining process and a power and harmonics analyzer is utilized to measure power usage. The machined components are measured using a robust surface testing equipment. Results show that Ranque–Hilsch vortex cooling reduces the cutting temperature, but under environmental conditions power consumption and surface ruggedness is more than 0.28 mm/rev.

S.Rejin et.al. (2012) This article covers the experimental research on the vortex tube fridge of the cold side and on the performances of the vortex tube fridge with a variable conical valve angle on the hot side. The project began with the design and manufacture of a vortex tube fridge. At the input compressed air was inserted at the pressure of 5bar. A maximum temperature decrease of 7°C was obtained for these specified intake circumstances. This result achieved a conical valve angle of 10° and a cold orifice diameter of 6mm in the working state.

The results of the test indicate a temperature fluctuation with different conical angles and a diameter of 6 mm at the lowest temperature. The test findings are compared and showed that comparable trends are seen in results with prior research.

Ratnesh Sahu et.al. (2012) At the current time, its ecolabel nature, which meets our fundamental requirements without harming nature, is the first and main characteristic of research or development. Environmental safety has now become a key element of common businesses and individuals. This article seeks to improve the effectiveness of a system known as a vortex tube used to cool industrially and to cool processes, including spot cooling, welding cooling, plastic slitting, extrusion cooling, food chilling etc. The cooling methods frequently utilised involve gas and liquids that either damage the ozone layer or contribute to global warming in the same way as CO_2. In order to get the greatest output from the C.O.P. and understanding of the vortex tube, efforts have been made to incorporate many factors.

The paper details the work and construction of a vortic tube with experimental findings for a number of physical, thermal and mechanical circumstances. The report contains comprehensive information. This article provides a summary of cooling and heating impact analysis, difference in temperature and C.O.P. with various working circumstances and building characteristics. The table of data with experimental values in this article also.

Mohammad O. Hamdan et.al. (2011) This study examines the effect of different operating circumstances on the vortex pipe's thermal performance. The results of the experiments indicate that the intake and cold fraction are the most important variables influencing the vortex pipe's performance. The results of the experiments indicate that insulation has minimal effect on the vortex tube's performance. The separation of energy increases as the number of intake pins increases, according to the same inlet pressure measurements".

III. RESEARCH METHODOLOGY

1. Introduction to FEM:

The FEM is a helpful tool for numerically achieving a wide range of construction issues. The method is sufficient to handle any complicated form or geometry for each material at different limitations and stacking circumstances. The all-inclusive technique for designers to implement parametric design concepts and to break down the optimal structure taking into consideration different structural situations (divergent types, materials, charges etc.).

The technique was introduced to analyses stress in a complex aircraft airframe structure. The method utilized for the building of aircraft machines is the so-called matrix control approach. Both practitioners and experts have taken importance in technology. The fundamental concept of a tiny component approach is that a body or system may be divided into small components using particular measurements known as "finite components." In a sequence of these components with a finite number of nodes or hubs, the initial structure is regarded.

2. General procedure of finite element method:

The Finite Element technique is a partial estimating method using tiny, restricted components. The limited structure or body is regarded as a collection of the parts with a limited number of joints known as the node focus or hub for the original body or structure. The base level of a restricted component may mimic a number of field variables since a continuum cannot detect a true field range of parameters such as shifting, stress, temperature, pressure or velocity. Initial models which devise abilities are used for estimating the impacts of the hub in the field. Evaluate the field circumstances referred to as "system conditions" informally by calculating the Nodal field variables.

When the nodal values are known, the approximate functions explain the field variable of all element assemblies.

The basic continuum problems are arranged utilizing the finite component technology in a precise, well-ordered method. It may be stated as follows in the orderly system for structural solutions:

- **Step 1**: Description of the project procedure (domain). The first stage is in dividing the resulting area in subdivisions or elements in the process of the finite element.
- **Step 2**: For the proper interpolation form selected. Given that the dislocation of a complex structure (the area variable) cannot be anticipated in a specific load circumstances correctly, we presume that the unknown solution is to be estimated in a component. The desired outcome has to be simple and certain convergence needs to be fulfilled.
- **Step 3:** The beginning of rigidity matrices and loading of the component (feature matrices). The stiffness matrix [K(e)] and the weight vector P(e) of the element 'e' are the outcome of the alleged displacement utilizing both the balance and the appropriate variation precept.
- **Step 4**: Assembly of the balance element equations.
- Because the structure is made up of several end components, stiffness matrices and load vectors must be used to build each one,

$$[K]\varphi = P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

- **Step 5**: - Solution of system equation for nodal displacement values detection (subject variable). Standard equations for the balance have to be modified so that the limits of the issue are taken into account. Balance equations may be stated once the boundary conditions have been included. For linear problems, the 'α' function can be easily solved. In a series of phases, however, the solution may be adjusted for non-linear issues in the stiffness matrix [K] and β' or weight vector P.

- **Step 6**: - Strains and stresses are defined in detail. The basic equations of stable or structural mechanics in each node movement may be computed to compute detailed lines and stresses. The bracket phrases gradually conform to the general FEM in the previous phases.

IV. RESULTS AND DISCUSSION

1. Introduction:

This section will provide an outline of the project's experimental approach used to address the issues and gaps in the existing literature. Dimensional analyses, as well as the design of physical models and test rig setup, were given preliminary attention. The velocimetry methods of particle tracking velocimetry and particle streak velocimetry, which were developed depending on whether the experiment is conducted in the far-field or near-field of the vortex, are then given in more detail.

The testing methods for determining the impacts of approach flow geometry, free-surface profiles, critical air core diameter, velocity fields, and flow visualization are detailed. Finally, qualitative and quantitative observations on the anticipated relative uncertainty of experimental results are addressed.

We have done CFD ANALYSIS with different parameters

- At **tube length** or **L/D ratio- 10, 14,18** where tube diameter **D= 8mm, so** tube length will be respectively **80mm,112mm,144mm**.
- And at different **valve angle30^{0},45^{0},60^{0}**.

- And at different **inlet pressure 2 bar,3 bar,5 bar**.

And using above parameters we got different **cold exit and hot exit temperatures** which are mentioned in the table.

1. Study of Output Temperatures (IN K):

In this study we optimized the output data of temperatures from vortex tube as per variations in L/D ration with Pressure variations from 2 bar, 3 bar and 5 bar. Tables shows the temperatures in kelvin at various pressures are described below in tables.

Table 1. Temperatures at different pressure with 30^0 angle.

PRESSURE	VALVE ANGLE=30^0					
	L/D=10		L/D=14		L/D=18	
	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT
2 Bar	286	325	283	330	294	325
3 Bar	276	298	278	310	274	300
5 Bar	268	300	265	298	270	298

Table 2. Temperatures at different pressure with 45^0 angle.

PRESSURE	VALVE ANGLE=45^0					
	L/D=10		L/D=14		L/D=18	
	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT
2 Bar	288	325	292	330	296	328
3 Bar	276	298	278	310	274	300
5 Bar	268	300	265	298	269	298

Table 3. Temperatures at different pressure with 60^0 angle.

PRESSURE	VALVE ANGLE=60^0					
	L/D=10		L/D=14		L/D=18	
	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT	COLD EXIT	HOT EXIT
2 Bar	290	323	292	326	295	323
3 Bar	274	300	280	306	286	306
5 Bar	268	300	265	300	271	298

- The different value of **cold exit temperature (T8),** which we are going to use in refrigeration system to calculate.
- **Energy balance**
- **Exergy balance**
- **COP of RHVTC** system and **VCC** system
- **Exergy efficiency** of **RHVTC** system and **VCC** system.

"The various results are obtained from the analysis fluid flow in vortex tube is discussed inthis chapter. The temperature at the cold end and hot end is taken as output".

2. Results of the calculations:

As per study, we received the output results from analysis and then we arranged all results in a table for better comparison. Tables designed as per different refrigeration uses. **Energy Balance Output parameters**

Table 4. Energy Balance Output parameters with refrigerant 1234yf.

Refrigerant	Valve Angles		
1234yf	L/D=10	L/D=14	L/D=18
	30^0	45^0	60^0
Evaporator	43.96	157	43.96
Condenser	171.9	399.1	318.8
Heat Exchanger	5.652	11.1	5.652
Compressor	158.7	272.9	305.6
Rhvtc	326.8	334.8	344.9

Table 5. Energy Balance Output parameters with refrigerant 1234ze.

Refrigerant	Valve angle		
1234 ze	L/d=10	L/d=14	L/d=18
	30^0	45^0	60^0
Evaporator	157	43.96	157
Condenser	300.6	261.5	462.1
Heat exchanger	11.1	19.47	11.1
Compressor	174.4	248.3	335.8
Rhvtc	316.7	327.8	334.8

Table 6. Energy Balance Output parameters with refrigerant R32.

Refrigerant	Valve angle		
R32	L/d=10	L/d=14	L/d=18
	30^0	45^0	60^0
Evaporator	43.96	157	43.96
Condenser	171.9	217.4	318.8
Heat exchanger	19.47	25.32	19.47
Compressor	158.7	280.4	305.6
Rhvtc	309.7	354.6	327.8

Table 7. Energy Balance Output parameters with Isobutane.

Refrigerant	Valve angle		
Isobutane	L/d=10	L/d=14	L/d=18
	30^0	45^0	60^0
Evaporator	366.4	366.4	366.4
Condenser	539	653.9	727.4
Heat exchanger	36.22	36.22	36.22
Compressor	203.4	318.4	391.8
Rhvtc	296.6	314.7	314.7

3. Exergy Balance:

Exergy Balance Output parameters.

Table 8. Exergy Balance Output parameters with refrigerant 1234yf.

Refrigerant	Valve angle		
1234yf	L/d=10	L/d=14	L/d=18
	30^0	45^0	60^0
Evaporator	36.35	36.35	36.36
Condenser	140.2	222.1	274.5
Heat exchanger	14.29	14.29	14.29
Compressor	0.5863	0.5863	0.5863
Rhvtc	311.5	330.9	330.9
Throttling valve	54.23	54.23	54.23

V. CONCLUSION

The intake pressure is the required driving unit for energy separation in a vortex tube. The temperature difference of the output streams is the higher the input pressure. The effectiveness of the vortex tube also depends on the cold fraction. Energy separation and separation of energy flow efficiencies are suited to measure the distinctive characteristics of the vortex rod for the recovery of the parameters.

As the length of the vortex tube grows, but only up to the crucial length, the size of the separation does not rise further in length nevertheless. The magnitude of angular velocities diminishes as the diameter of the vortex tube rises and therefore the energy separation decreases.“The results indicate that the CFD model used in this study accurately predicts vortex behavior in the vortex tube. The data reveals while certain errors have occurred as a consequence of the model's inaccuracy and the use of exact limit conditions, these errors may be prevented by increasing the model's accuracy.

This proposed CFD model of the vortex tube was used to analyse the temperature change.

The Concluding points from project are:-

- A rapid expansion of air around the entry is primarily due to the decrease in temperature. Viscosity and turbulence between periphery and the core vortex are responsible for the temperature separation inside fluid. Another cause for the heat transmission from the core to the periphery is secondary circulation towards the cold end.
- Better outcome achieved when the fineness of the mesh is increased. For about 7986006 elements and 143451 nodes, maximum temperature decrease is achieved.
- Determined by L/D of 10, cold mass fraction of 0.3-0.4 and six box-numbers are the design criteria that indicate the aforementioned findings.
- We thus succeeded in achieving fluid (air) in the vortex tube design parameters and flow analyses”.

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