# REVIEW PAPER ON EXPERIMENTAL ANALYSIS OF VORTEX TUBE

**Sayali Darekar[1], Makarand Date[1], Shubham Chaudhari[1], Mangesh Dudhare[1], V.S. Bagade[2]**

*[1]Dept. of Mechanical Engineering, Finolex Academy of Management and Technology, Ratnagiri, Maharashtra, India.*

*[2]Assistant Professor, Dept. of Mechanical Engineering, Finolex Academy of Management and Technology, Ratnagiri, Maharashtra, India.*

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**Abstract -** *A vortex tube is a simple device which splits a high pressure gas stream into a cold and hot stream without any chemical reactions or external energy supply. It is a mechanical device without any moving parts. The splitting of flow into regions of low and high temperature range is referred to as the temperature separation effect. The performance of vortex tube depends on two basic parameters, first is the working parameter such as inlet pressure of compressed air, and the other one is geometric parameters such as number of nozzles , diameter of nozzle, cone valve angle, length of hot side tube, cold orifice diameter, and as well as material of vortex tube. Vortex tube has interesting functions and several industrial applications, and, as a refrigerator, it is used as a spot cooling device in industry.*

***Key Words***: Vortex Tube, nozzle, material, cone valve angle

## 1. INTRODUCTION

Refrigeration is the practical application of thermodynamics where heat is transferred from low temperature region to high temperature region through refrigerant which is the working fluid. But the refrigerants used causes environmental problems such as ozone depletion and global warming which have gave us a way to think about non-conventional systems. Vortex tube is one of the non conventional systems where air can be used as working fluid to achieve refrigeration. Vortex tube is a simple device without moving mechanical parts, which converts high pressure gas stream into two separate flows of different temperatures (cold and hot). Vortex tube consists of compressor, pressure gauge, control valve, thermocouple and temperature indicator. Compressed air from the compressor enters into the vortex tube tangentially. Due to tangential entry of compressed air into vortex tube swirling flow takes place in vortex chamber. The compressed air expands in vortex tube and divides into cold and hot stream. The cold air leaves the cold end orifice which is near inlet nozzle and hot air discharges at far end of the tube i.e. hot end. Thermocouples measure temperature at cold end and hot end. Vortex tube has many advantages such as no moving parts, no chemicals or electricity, low cost, light weight, maintenance free, durable, temperature adjustable. Vortex tube are commercially used for low temperature applications such as cool electronic parts, testing of thermal sensors, to set solders, cooling of electric or electronic control cabinets, cooling of cutting tools. Other industrial application of vortex tube includes fast starting up the steam power station, nuclear reactors, gas separation and liquefaction of natural gas.

## 2. LITERATURE REVIEW

N.F.Aljuwayhel *et al*[1] studied the parametric and internal study of vortex tube by using a CFD model. Computational fluid dynamics (CFD) model is used to investigate the energy separation mechanism and flow phenomena for which a counter-flow vortex tube is used. Results of the model are compared with the experimental data obtained from a laboratory vortex tube. Work transfer caused by torque produced by viscous shear acting on rotating control surface which separates cold and hot flow region and that exhibits energy separation as shown in Fig.1. Streamlines that separate these regions calculate the heat and work transfers through control surface. The opposite flow of net heat transfer from hot region to cold region whereas the work transfer flows from cold region to hot region tends to reduce temperature separation effect. The vortex tube's unique behavior is a result of work transfer by the viscous shear of the two low pressure streams which can be predicted by comparing the numerical model with the experimental data constrained with real time operating conditions. As the length of the vortex tube increases thus the magnitude of energy separation increases but only up to the critical length, however a further increase in the length does not improve the energy separation. As the diameter of the vortex tube increases the magnitude of angular velocities decreases and therefore the magnitude of energy separation decreases.

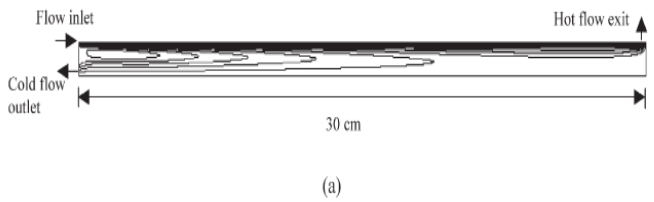
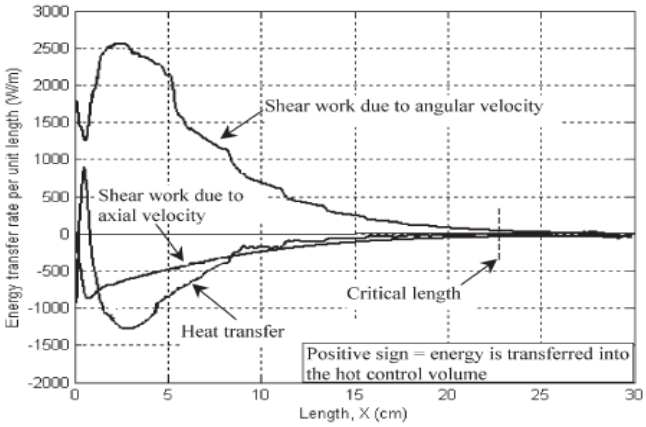



**Fig-1(a)**: CFD results for the 30 cm vortex tube model showing the streamlines predicted by the numerical model




(b)

**Fig-1(b):** CFD results for the 30 cm vortex tube model showing the rate of heat and work transfer per unit length along the control surface separating the hot and cold control volumes[1].

Y.T.Wu *et al*[2] in this paper modified vortex tube to improve the energy separation and efficiency by three innovative technologies. Initially to reduce the flow loss a new nozzle with equal gradient of Mach number and a new intake flow passage of nozzles with equal flow velocity were designed. Later to improve the performance of vortex tube by reducing friction loss of air flow energy at end of hot end of vortex tube a new kind of diffuser was designed. The performance of vortex tube would remarkably increased by these modifications. The installed new nozzle gives cooling effect about 2.2°C lower than the nozzle with normal rectangle and even 5°C lower than that of the nozzle with Archimedes' spiral. A diffuser designed was installed between the outlet of vortex tube and hot valve in order to reduce the peripheral speed to zero within very short pipe as well as to reduce the ratio of length to diameter which results into cooling effect of the vortex tube which is up to 5°C lower by using a diffuser. The developed vortex tube is superior to the conventional vortex tube but also superior to that made in other country as shown in Fig.2.

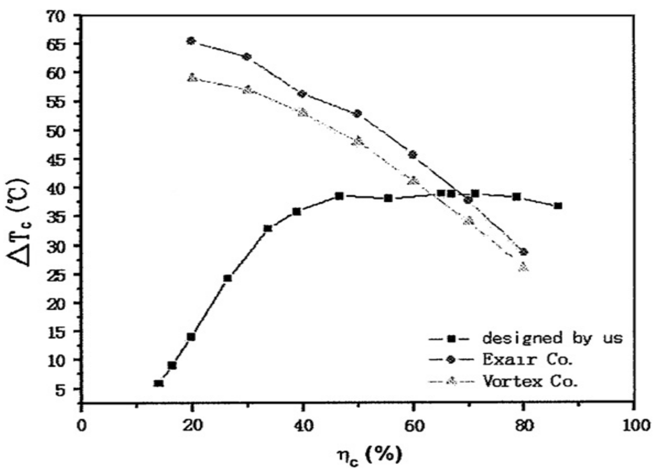



**Fig -2**: Comparison between different problems in $\Delta T_c$.[2]

Rahim Shamsoddini and Alireza Hossein Nezhad [3] put forth a three-dimensional numerical fluid dynamic model to study effects of the number of nozzles on the flow and power of cooling of a vortex tube. By keeping constant inlet flow conditions the number of nozzles are varied (2, 3, 4, 6 and 8). Experimentation results into increase in power with increase in number of nozzle but eventually decrease in temperature of cold outlet. Using axisymmetric model it is not possible to study quantitative and qualitative effect of nozzles number on the flow field and power cooling and cold outlet temperature but it is possible using full three dimensional numerical models. The best results were obtained by 8 number of nozzle with 8.7% increase in cooling power. Limitation on using large number nozzle is because of the small diameter of vortex tube. The comparison between Aljuwayhel work and present axisymmetric work is given as shown in Fig.3.

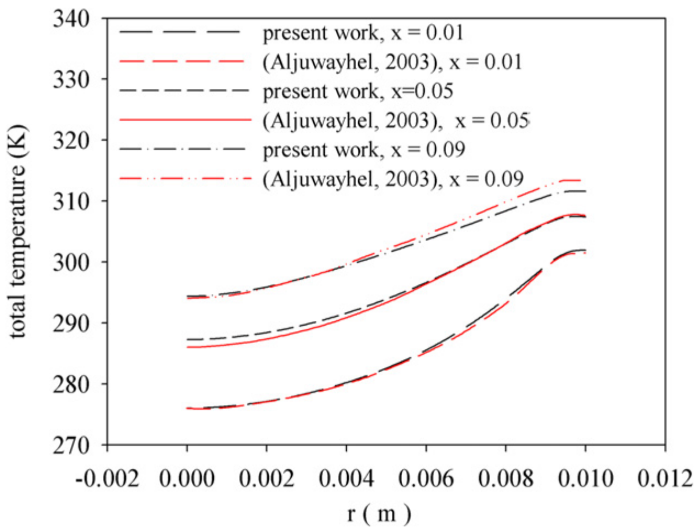



**Fig -3:** Comparison of the variation of total temperature versus radial distance at different axial locations from the inlet on the plane crossing longitudinally vortex tube and including its axis between Aljuwayhel work and present axisymmetric work.[3]

Orhan Aydın and Muzaffer Baki[4]put forth their experimental study performing experiments in tubes with inner diameter of 18mm made of aluminum/stainless steel. The constructional (or geometrical) parameters are tested and tried to be optimized: the length of the vortex tube, the diameter of the inlet nozzle and the angle of the control valve. Six different vortex tubes having various lengths are used: 250, 350, 450, 550, 650 and 750mm. The diameter of the cold end is 5mm, while that of the hot end is kept at 6mm. Three different values are used for the diameter of the inlet nozzle introducing the pressurized working fluid into the vortex tube: 5, 6 and 7mm. The inlet pressure is adjustable from 2 to 5bar. The effect of the angle of the control valve is also investigated in the range from 451 to 601. In addition, three different working fluids are comparatively tested in the experiments, which include: air, oxygen and nitrogen. The above parameters and the gases are examined for simultaneously varying the gas inlet pressures and cold fractions. To analyse the working parameters of the counter flow vortex tube various experiments were carried out. For different inlet pressures at which the working fluid is supplied into the vortex tube, whereby the magnitude of the thermal energy separation, the length of the pipe, the diameter of the inlet nozzle were the crucial parameters for the performance that were examined and optimized, i.e. the mass flow rate of the inlet flow and the angle of the control valve. It can be concluded by the experiments show that the higher the inlet pressure, the greater the temperature difference of the outlet streams. This paper also shows us that the cold fraction is an important parameter which influences the performance of the energy separation in the vortex tube. Fig.4 shows the comparison between three different gases: air, oxygen and nitrogen which concludes that higher temperature difference is obtained by using nitrogen due to its smaller molecular weight.

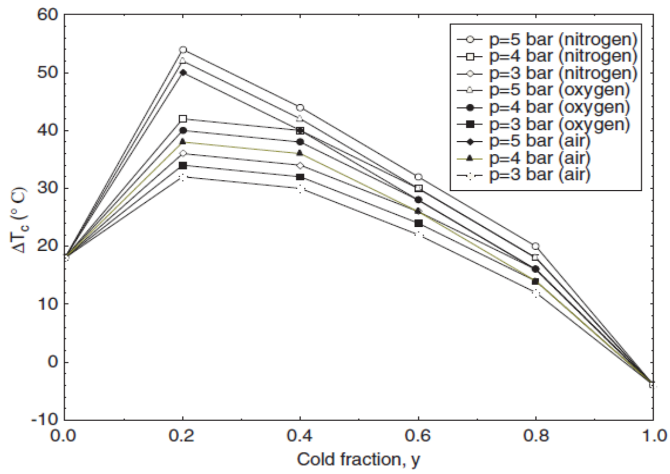



**Fig-4**: Comparison of the thermal performance of different gases.[4]

Sachin U Nimbalkar and Michael R Muller[5] investigated that the Energy separation and Energy flux separation efficiencies help recover the parametric characteristics of a Vortex tube. Their study found out that for maximum energy separation there is an optimum orifice end diameter. Their study also found that the maximum value of energy separation was always reachable at a 60% cold fraction irrespective of the orifice diameter and the inlet pressure. The experimental results indicate that the maximum energy separation is achieved by an optimum diameter of cold-end orifice. The observation made by them for 60% cold fraction, the effect of cold end orifice diameter is negligible and above 60% cold fraction it becomes prominent. Their results also show that the maximum value of performance factor was always reachable at a 60% cold fraction irrespective of the orifice diameter and the inlet pressure as shown in Fig.5. The pressure drop across hot fraction control valve controls the flow structure inside the vortex tube. When hot fraction increases (or decrease in cold fraction), axial stagnation point moves towards the hot end, and due to the stretching of the central recirculating core, radial stagnation point moves towards the axis of the tube. On the contrary, when the hot fraction decreases, axial stagnation point moves towards the cold end, and radial stagnation point travels to the wall of the tube. But for the ideal separation of cold and hot air streams, there are fixed critical locations for the axial and the radial stagnation points. The cold end orifice diameter appears to be characteristics by secondary circulation flows confirmed by their study and could be a performance degrading mechanism.

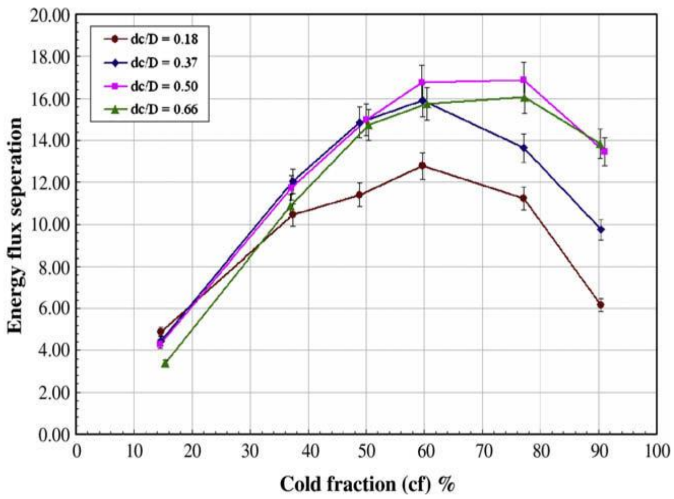



**Fig -5**: The effect of orifice diameter on the energy flux separation efficiency (mi = 0.45 kg/min). Error bars in the graph indicate 5% of experimental error [5].

Jeffery Lewins and Adrian Bejan[6] studied that the drop in pressure of a vortex tube while splitting up the high pressure stream by swirling more than accounts for this apparent breach of the Second Law of Thermodynamics, which limits the performance. Their study gives simple models, which include perfect gases, order-of-magnitude analysis for the vortex tube as a heat exchanger and the optimization of the vortex system as refrigerator by use of unit effectiveness of regenerative and refrigerative heat exchangers. Thus an estimate of the optimum refrigerative effect can be measured or calculated if the leading parameter of the tube and the temperature difference are established at equal cut. It is notable, to first order in the temperature DT/T0, that the first optimization calls for a load half way from zero to the maximum refrigerative effect available at a given cut, and the second optimization has this cut best at one-half, i.e. balanced hot and cold streams. The maximum cooling effect is twice to the second order in temperature by the optimization. Their study was also able to provide bounds for the temperature difference that could be established from a given pressure ratio and gas. Their optimizations achieved and analyzed do not depend upon any real time model and thus do not predict the actual performance but rather where it will be optimized, in cut and load. More exact results would seem to turn on more detailed theory which might well facilitated by computational fluid dynamics.

M.H. Saidi and M.R. Allaf Yazdi[7] put forth a thermodynamic model which has been used to investigate energy separation in vortex tube. A new approach has been used to optimize dimensions and operating conditions of vortex tube using exergy analysis. Exergy evaluation is done based on first and second law of thermodynamics. A conventional energy analysis only consider heat balance and cooling and heating effect but exergy analysis of irreversibility includes the losses due to heat transfer and separation effect as well as the pressure drop losses. Experimental data was taken for constant inlet pressure and varying tube length. Experiment Results show that with increasing tube length, temperature differences increase and exergy destruction decreases significantly as shown in Fig-6. It is clear that exergy destruction is minimized at y=0.7 which means the efficient working point of this vortex tube is at y=0.7.It also concludes that increasing nozzle diameter decreases exergy destruction and improve second law efficiency.

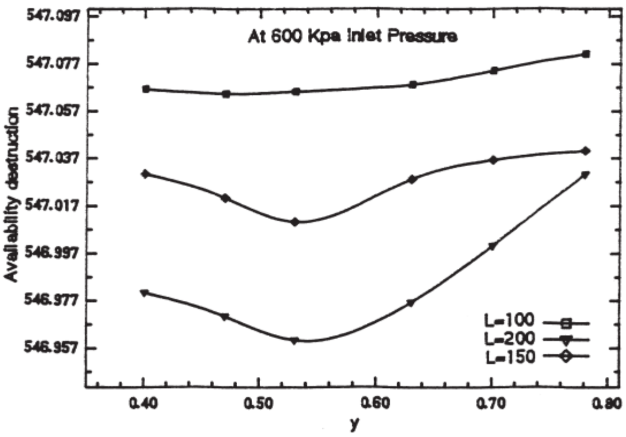



**Fig -6**: Variations of Exergy destruction versus tube length[7].

K. Stephan *et al* [8] studied the process of energy separation in vortex tube. It also gives useful information about location of stagnation point of the flow field at the axis of the vortex tube due to variation of the maximum wall temperature along the vortex tube surface. For experimentation to obtain temperature distribution along the surface of vortex tube there are 10 thermocouples distributed at equal interval of 25mm. While conducting test the pressure of the inlet air ($P_0$) and the cold air mass ratio (y) were varied. The experiment results effect of energy separation i.e. Without the outflow of the cold air, y = 0, the temperature measured at the center of the central orifice used for the exit of the cold air, is lower than the temperature of the inlet air, similarly without the outflow of the hot air, y = 1, the temperature of the vortex tube wall at the hot air exit end is higher than that of the inlet air. As the highest temperature of the tube wall is located near the far end of the tube, therefore, it is expected that the stagnation point on the axis of the vortex tube is also near the far end of the tube. For two inlet pressures $P_0$= 2 bar and 4 bar and y as parameter the temperature difference between wall and the inlet temperature tells us that the temperature of the vortex tube wall increases with an increase in the cold air mass ratio, y, except for y= 1 as well as increase in the value of y results in a relocation of the maximum temperature to the inlet end of the vortex tube.

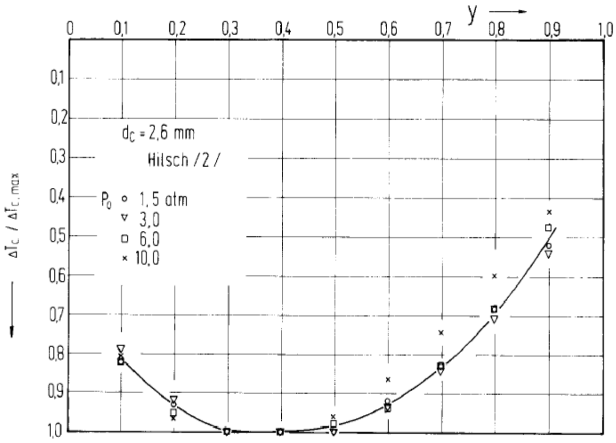



**Fig -7:** Similarity relation, equation (25), compared with experimental data of Hilsch [2][8].

A S Gadhave and Dr. S S Kore[9] has done an experimental study regarding working parameters such as inlet air pressure (Pi), Cold mass fraction (μ) and length of hot side tube (Lh).In this work they have designed, manufactured and tested counter flow vortex tube. Different parameters evaluated during experimentation were temperature reduction on cold side, temperature rise on hot side, refrigerating effect and isentropic efficiency. Experiment was performed on single inlet nozzle vortex tube, at various inlet pressures from 2 to 8 bars for three diameters of cold end orifice; 3 mm, 4 mm and 5 mm, considering L/D ratio for first case as 12.5, second case as 13.5 and for third case as 17.5.Thus from the experimentation they have concluded that the maximum temperature difference of 14°C and 17°C are obtained at cold and hot side respectively which tells us that temperature drop increases with increase in inlet pressure. The best results were obtained at 8 bar pressure 17.5 L/D ratio and 0.65 cold mass fraction.

## 3. CONCLUSIONS

For energy separation in a vortex tube the inlet pressure is the necessary driving unit. Higher the inlet pressure greater is the temperature difference of the outlet streams. The performance of the vortex tube is also influenced by the cold fraction. Energy separation and energy flux separation efficiencies are suitable for measuring the parameters to recover the characteristic properties of the vortex tube. As the length of the vortex tube increases thus the magnitude of energy separation increases but only up to the critical length, however a further increase in the length does not improve the energy separation. As the diameter of the vortex tube increases the magnitude of angular velocities decreases and therefore the magnitude of energy separation decreases. Performance degradation occurs due to secondary circulation flow which also appears to be characteristics of the cold end orifice diameter. The maximum energy separation can be achieved by an optimum diameter of cold-end orifice. The maximum value of performance factor is attainable at 60% of the cold fraction irrespective of the inlet pressure and orifice diameter. The power of cooling increases as the number of nozzles increases while the temperature at cold end decreases moderately. An increase of 8.7% can be observed in case of 8 nozzles over a system with 2 nozzles. The second law efficiency improves with increase in nozzle diameter while the exergy destruction decreases. The temperature and the variation of the temperature along the surface of the vortex tube helps locating the stagnation point along the axis of the vortex tube along the flow field.

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