# Vortex Tube Performance Study for Forced Cooling Applications

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## Abstract

In a field of advanced manufacturing technology heat removal has gained prime concern of researchers. Vortex tube has emerged as simplified, robust and easy manufacturing solution to it. Air cooling phenomenon achieved by Vortex tube has spread its usefulness across prime application. Both conventional as well as non-conventional materials are found useful in manufacturing of vortex tube. Absence of moving parts leads to maintenance free service is an additional advantage. Improved thermal conductivity and cost effectiveness are positive aspects of UPVC vortex tube.

## 1. Introduction

Vortex tube is a device that separates compressed air into two streams simultaneously, one current of air hotter than the inlet temperature and one cooler, made even more remarkable by the absence of moving parts. Compressed air is introduced into a tube open at both ends through tangential inlets positioned about quarter of the tube's length away from one end. A strongly swirling flow, vortex flow, results and the air proceeds along the tube. The outer regions of the flow are found to be warmer than the inlet air, while air towards the centre of the tube found to be cooler.

But till date energy transfer mechanism in vortex tube is not explained properly. Some pioneers have tried to their own way to explain the magic but the explanations are not supported by experimental results. The reason for the difficulty in this work is the turbulence in the tube. There are certain parameters which contribute to the performance of the vortex tube. These parameters are investigated by the pioneers in this field who had conducted numerous experiments.

## 2. Literature Review

Various treatments were offered in order to predict the temperature at either ends considering various parameters. But literature review shows that no theory is perfect which will give satisfactory explanation of vortex tube phenomenon. Though Ranque reported the phenomenon, but the first who submitted the systematic result was Hilsch That's why the tube is also popularly ideas Ranque - Hilsch tube.

In the theoretical study by Deissler and Perlmutler made analysis of velocity, temperature and pressure distribution in the turbulent vortex tube with radial and axial flow, for calculations they divided the vortex flow into core and annular region each with bilateral uniform axial mass velocity. They try to present the mathematical model using Navior-Stoke equation. The equation obtained isapplicable to arbitrary mass velocity distribution. They concluded that dimension less tangential velocity and temperature distribution are function of the ratio of axial flow out of the core of vortex to total mass flow, the Ratio of core radius to radius of vortex, turbulent radial flow number. According to Deissler and Perlmutter the compressible fluid in the core region does the shear work on the fluid in the outer region with resultant total temperature separation. In the region of high total temperature the dissipation was found to produce most of the heating of the fluid element. The decrease of total temperature of the element as it moves in the core region was principally due to the kinetic and pressure energy terms, both of which are negative in the region. That is the turbulent shear work done, on or by the 'fluid element is the affecting factor for the total temperature separation.

HesnichiroTakahama presented paper on the study of vortex tube, in which he tried to investigate the relation between the profile of the velocity and the temperature of the air flowing in the vortex chamber and the dimension of the main tube, nozzle, cold end orifice. He obtained the date for designing a standard type of vortex tube with high energy separation. He presented the formulae for the profile of the velocity, temperature and the energy of the air in the standard vortex chamber considering the air flow in the annular region as wall let; Heshichiro Takahamaz used quite bigger tube for his experimentation than the conventional one. He used the nozzle bush with two openings (sometime 4 or 8) to obtained higher swirl of the air in the main tube; Cold side and hot side orifice were used along with flow straightened rectifiers. The length of the tube was 50 times the diameter of the tube He concluded that the high efficiencies are obtained when Mach number is within 0.5to1, orifice diameter to tube diameter ratio of D.20.The nozzle opening area, tube cross sectional area and cold end orifice areas are interrelated in order to give high efficient energy separation. The formulae presented by Takahama do not include factors such that radial velocity component or turbulent velocity component, convenient to predict the performance and the efficiency of the standard vortex tube under any working condition.

Experimental investigation of energy separation in the vortex tube carried out by K Stefan, M Durst, F Huang, DSeher, which presents hot and cold air temperature leaving the vortex tube. Thepaper gives the information regarding the temperature variation along the wall of the main tube surface. They try to locate stagnation points of the flow at the axis of the vortex tube. They provide the treatment of dimensional analysis in order to predict the cold side exit air temperature. According to the paper the Gortler vortex produced by the tangential velocity on the inside wall of the vortex tube is major driving force for the energy separation. They present hot and cold air temperature at inlet pressure against air mass ratio. The temperature profile of the gas was noted by placing temperature probe along the length of the tube. The emphasize was given to establish relation between temperature and the mass fraction. The tube dimensions like nozzle diameter, orifice diameter length were not considered in the formulation of the temperature. The vortex tube used in the experimentation was 20 times long than its diameter; the hot side orifice was omitted in the experimentation.

Another explanation was given by Tim Cockerill which is based on his experimental observation is discussed. According to him, Air enters the tube tangentially and forms a free vortex. The vortex travels along with the wall due to centrifugal action. The air almost seizes to rotate in the lube as a result of obstruction of the valve. The pressure near the valve is more than the pressure outside the orifice at the other end: hence a reversed axial flow starts. This reversed flow comes in contact with the peripheral vortex i.e. free vortex. The free vortex forces the axial stream to rotate as it rotates at very high speed. Thus an axial stream forms a forced vortex. Energy required to form the forced vortex of the axial stream is supplied by the outer free vortex. However, the flow of the energy is in the opposite direction but it's too small as compared with the energy transferred from the inner core to the outer periphery. The energy transferred from the inner core to the outer periphery is explained as "The turbulent mixing in the centrifugal Gelds results in pumping of energy from low pressure region of the axis to the high pressure region of the periphery. This energy is transferred towards the wall in the form of momentum. This radial outflow of energy is due to turbulent mixing is much more than that of the inward flow of energy due to formation of forced vortex. There is a net transfer of energy radially outwards and towards the valve. Thus, peripheral layer emerges as hot stream while axial layer as cold stream. For the insulated lube the energy carried away by the hot stream is equal to the energy rejected by the cold stream

Boye K Ahlborn and Jeffery Gordon state in their paper on the vortex tube ‘the vortex tube as classical thermodynamic refrigeration cycle that the phenomenon of the energy separation can be looked upon as the classical cooling cycle and can be analyzed with the help of thermal and fluid dynamic principal and with some analytical modelling, one can estimate the principal temperature, pressure and velocity profiles. This enables to qualify the thermodynamic performance of the vortex tube chiller and to analyze its characteristic with same approach applied to conventional chiller. Internal dissipation, in the form of fluid friction, far exceeds the irreversibility associated with the finite rate of heat exchange. The flow field inside the vortex tube is highly strained. It also contains the radial acceleration of the order of $10^5$ g. This portends vortex tube application to problems where differential buoyancy in this pseudo gravitational field can be exploited.

Secondary circulation of the compressible working fluid was considered. This secondary circulation helps to explain vortex tube phenomenon as the classical thermodynamic cycle having thermodynamic processes as heat rejection, adiabatic compression and expansion and energy absorption. Thus predicting that energy separation is outcome of the several phenomenons inside the tube.

From the literature review, the energy transfer mechanism can be summarized as follows. The energy transfer mechanism i.e. heat transfer is not a result of single phenomenon; rather it is result of several phenomenon happening inside the tube. These phenomenon are adiabatic compression, friction between peripheral layer and the walls of the tube and adiabatic expansion, and conservation of angular momentum. The compressed air entering the nozzle starts swirling after entering the pipe forming a free vortex, at region near the inlets, the compressed air gets divided into two regions, one axial and another peripheral. The angular velocity of the particles at the axial regions is more than that of the particles at the peripheral. Due to this, the temperature of the particles near the axial region decreases as the more amount of pressure energy is get converted into velocity along with temperature drops. Thus, the initially energy separation occurs.

The angular velocities of the axial particles and peripheral particles are different and former being greater in magnitude. Now, the centrifugal force acting on the particles at axial region is greater than that on the peripheral particles. Thus, to conserve the momentum, the axial particles should apply some pressure on the peripheral particles increasing the temperature of the peripheral particles; this compression is assumed to be adiabatic one.

As the free vortex precedes along the tube the friction between the peripheral particles and the walls of tube increases for some length. This continues as centrifugal force acting on it and force applied by the axial particles are significant. The temperature of the peripheral particles again increases due to friction. As the free vortex proceeds, the partially closed valve obstructs if and the vortex breaks resulting in stagnation of the air in front of the valve. This stagnated air is driven back in the tube due to less pressure in the axial region forming another vortex, forced vortex. The energy to rotate the inner forced vortex is supplied by the free vortex. This process is assumed to be adiabatic hence this is adiabatic expansion process. As the gas expands it loses its temperature and the process continues along the length of the hot pipe. Forced vortex is supplied by the free vortex. This process is assumed to be adiabatic hence this is adiabatic expansion process. As the gas expands it loses its temperature and the process continues along the length of the hot pipe.

Further as forced vortex travels along the pipe, the heal transfer from forced vortex to free vortex occurs. Roughly this can be explained as follows. There is centrifugal force acting on the forced vortex too. The energy to rotate this vortex is supplied by the outer vortex. During this process, again the forced inner vortex compresses the outer vortex increasing the temperature of outer vortex further more. This energy transfer dominates the former energy.

3.**References**

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