Experimental Investigation and Modification of Ranque Hilsch Vortex Tube

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Abstract— The technology is proliferating and making our environment unwell for existence, by emission of hazardous elements that affect the ozone layer that causes green house effect and affect human comfort. The vortex tube methods serve the purpose efficiently without any harm to the environment. The dissertation introduces the concept of vortex tube that is useful in many applications like refrigeration, used in CNC machines, airplanes etc, The paper includes the working principle of vortex tube with a new component is introduced in the experimentation, the diffuser is installed between the vortex tube outlet and hot valve and analyzing the change in the cooling effect by comparing the vortex tube without diffuser. The other parameter is changing the tube cross sectional area by making the tube conical throughout the length and analyzing the cooling effect with the cylindrical vortex tube.

Keywords: Energy separation, Vortex flow, Ranque-Hilsch vortex tube, cooling effect, instant cooling

I. INTRODUCTION

Conventional refrigeration systems are widely used for obtaining lower temperatures but they are ineffective when instant cooling is required to cool down high temperature material surfaces, CCTV, space suits, or any smaller area. These systems are bulky and work only for stationary cooling purposes.For this reason there has to be an alternative system that can provide cooling effect as well as can be transportive. In 1933 Ranque firstly described the Vortex tube and was examined experimentally by Hilsch , therefore is it commonly known as Ranque-Hilsch Vortex Tube. It is a simple device consisting of no moving parts and the main components are nozzle, diaphragm, chamber, cylindrical tube, cone valve, hot air outlet, cold air outlet; sometimes diffuser is also installed between the cylindrical tube outlet and the hot valve.

The main working depends upon the air being injected inside the vortex tube. Mainly air is tangentially injected that produces air swirls inside the chamber, just like a tornado and due to pressure differences the main air stream gets separated in to hot air and cold air. Separation of air stream is caused either due to pressure differences, air density differences, or because of entropy it is still the question unanswered and is under further research. For the experimental investigation the assumption i.e. pressure differences causes the air separation is assumed. The hot air is released back in to the surroundings from the hot air outlet present at the right hand side of the vortex tube and cold air exists from the opposite side of the hot air outlet. Working principle with the suitable diagram is being explained in the other section.Vortex tube has many advantages; it has less cost, less maintenance, durability, less electricity consumption, clean working media.

II. LITERATURE REVIEW

O.M. Kshirsagar, et al., explained the working principle of vortex tube, some modifications are done to understand the effect of inlet pressure of air, number of nozzles, hot valve angle on the performance of vortex tube.

N. Li, et al., pointed the factors that accelerate the separation of compressed air. Paper deals with the study to investigate the cause of separation.

Y.T. Wu, et al., has covered efficiency of the tube has been calculated by modifying the general parameters of the vortex tube, like shape of nozzles, a diffuser is installed to enhance the refrigerating effect.

C.H. Marquesa, et al., The KE and RANS model is explained and described. The investigation includes the numerical models to analyze geometrical optimization of the vortex tube.

S. Rejin, et al., includes the modification of hot plug by changing the geometry in to conical valve to increase the performance at cold side.

A.V. Khait, et al., the objective of the paper is the demonstration of the numerical model based on the proposed energy conservation equation.

M. Mohiuddin, explains the expansion process by isenthalpic approach, flow separation is gained without any internal moving parts, resulting in robust and inexpensive designs.

R.M. Kumar, et al., an experimental investigation has been done by changing the geometry of vortex tube from cylindrical to conical to enhance the COP.

N. Pormahmoud, et al., includes the L/D ratio of the vortex tube. The selection criteria of the design parameters are very well explained.

M.K. Dhanghar, et al., includes the investigation of the performance of counter flow tube by varying the geometrical parameters like length, diameter of hot end, number of nozzle to maximize the COP.

III. OBJECTIVE

The main objective of the experiment is to analyze the change in the cold temperature when the diffuser is installed between the hot valve and outlet of the vortex tube. In order to get instant cold air, the mass flow rate of the cold air should be high and can be easily obtained either by changing the cylindrical shaped vortex tube in to conical tube by varying the cone angle.

IV. EXPERIMENTAL SETUP

The following section includes geometrical aspects and the experimental setup of vortex tube.

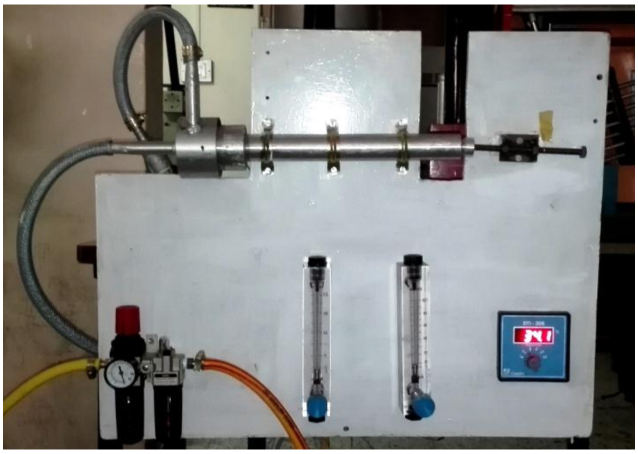

Fig. 1 Experimental Setup

The components used in the setup are as follows:

Compressor(2 stage reciprocating)	:	Pressure up to 20 bars
Tank	:	Capacity of 165 liters
FRL unit	:	Pressure up to 8 bars
Pressure Gauge	:	Pressure up to 10 bars
Temperature Indicator	:	-50^{0}C to 200^{0}C
Rotameter	:	0-100 LPM 0-200 LPM

4.1 Geometrical Aspects

The following are the CAD models of vortex tube with diffuser installed between the hot plug and the outlet of the vortex tube and the vortex tube with conical geometry according to the below mentioned geometrical aspects.

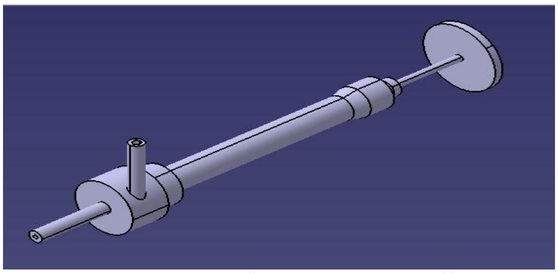

Fig. 2 CAD Model of Vortex Tube with Diffuser

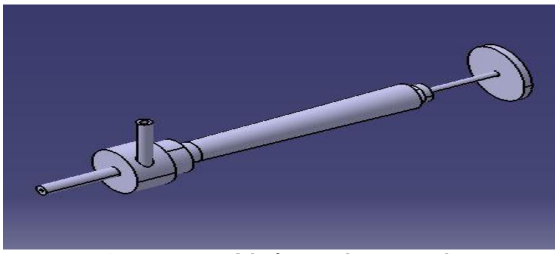

Fig. 3 CAD Model of Conical Vortex Tube

Length (L)	:	300 mm
Diameter (D_0)	:	20 mm
Nozzle Diameter (N_{Di})	:	10 mm
Diffuser Diameter	:	1.5D, 1.7D, 1.9D
Cone Angle for Conical Tubes	:	2^0,3^0,4^0
Hot plug Angle	:	60^0
L/D Ratio	:	15.5

V. EXPERIMENTATION

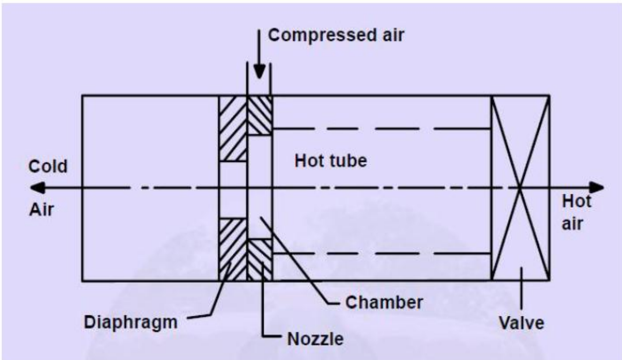

Fig. 4 Schematic of Vortex Tube

The above diagram shows the schematic of vortex tube. Diaphragm, nozzle, vortex chamber, valve, tube, outlets are the basic components. Nozzles can be converging or diverging type and are designed to achieve higher velocity and minimum inlet losses.Chamber is the portion that connects nozzle with the tube and provides tangential entry of the high velocity air stream to the vortex tube and facilitates the formation of air swirls.

Diaphragm is a cylindrical piece of small thickness and having a small hole of specific diameter at the center. Air stream traveling through the core of the hot side is emitted through the diaphragm hole. Cold side is a cylindrical portion through which cold air is passed.

Vortex tube has two outlets present at the opposite ends. Hot air outlet is situated at the right side of the vortex tube near the hot plug/control valve. After the formation of air swirls in the chamber the air get separated into two air streams, the hot air exists from the right side outlet i.e. hot air outlet. Due to the generation of back pressure the separated cold air exists from the outlet opposite to hot air outlet and is named as cold air outlet.

Valve obstructs the flow of air through hot side and it also controls the quantity of hot air through vortex tube.

3.2 Working of Vortex Tube

The main working principle of vortex tube is separation of injected air stream into two air stream, hot air and cold air respectively. Once the compressed air of specific pressure is injected tangentially into the vortex tube through the spiral nozzle the air stream attains higher velocity and forms swirls just like a tornado in the vortex chamber present just behind the nozzle.

Energy or entropy differences is the main cause of the air stream separation, the peripheral of the tube is surrounded by the hot air whereas, cold air is present at the center of the vortex tube. When the pressure near the valve is higher than the outside pressure it leads to back flow of the stream that causes heat transfer between the hot and cold air stream. The cold air is escaped from the outlet present near the diaphragm and hot air is escaped from the outlet present near the control valve/hot plug.

Control valve/hot plug is conical in shape and is helpful to provide minimum cold air temperature by maintaining the pressure directed by to and fro movement of the valve. By installing the diffuser between the outlet of the vortex tube and the hot plug the cold air temperature can further be minimized to obtain large refrigerating effect.

VI. DATA REDUCTION

The *cold flow mass ratio* is the most important parameter used for indicating the vortex tube performance. The cold mass fraction is the ratio of mass of cold air that is released through the cold end of the tube to the total mass of the input compressed air. It is represented as follows:

$$E = \frac{m_c}{m_i} = \frac{T_i - T_h}{T_c - T_h} \quad (1)$$

Where, m_c represents the mass flow rate of the cold stream released, m_i represents the inlet or total mass flow rate of the pressurized air at the inlet.
Therefore E varies in the range of 0-1.
Cold air temperature difference or temperature reduction is defined as the difference between inlet flow temperature and cold air temperature:

$$\Delta T_c = T_i - T_c \quad (2)$$

Where T_i is the inlet flow temperature and T_C is the cold air temperature. Similarly, hot air temperature difference is defined as:

$$\Delta T_h = T_h - T_i \quad (3)$$

The refrigerating / cooling effect produced by the cold air of vortex tube is given as:

$$Q_c = m_c c_p (T_i - T_c) \quad (4)$$

Since cooling and heating streams are obtained simultaneously the heating effect produced by the vortex tube is given as:

$$Q_h = m_h c_p (T_h - T_i) \quad (5)$$

The coefficient of performance (COP) is normally defined as the cooling power Qc gained by the system divided by the work power P input. So the COP can be expressed as:

$$COP = \frac{Q_c}{P} \quad (6)$$

Or,

$$COP = \frac{E c_p (T_i - T_c)}{\left(\frac{\Upsilon - 1}{\Upsilon}\right) R T_i \left(\left(\frac{P_i}{P_{atm}}\right)^{\left(\frac{\Upsilon - 1}{\Upsilon}\right)} - 1 \right)} \quad (7)$$

Here the cooling power can be calculated according to the cooling capacity of the cold exhaust gas.
The Carnot COP is the maximum efficiency for all the heat engines.
The COPs for Carnot cycles are:

$$COP = \frac{T_i}{T_i - T_c} \quad (8)$$

VII. RESULTS AND DISCUSSION

The graphs below are plotted between COP and injected pressure P_i for vortex tube with cylindrical and conical geometry, and between cold temperature T_C, and injected pressure P_i for vortex tube with diffuser.

1) When the vortex tube is cylindrical, COP is 0.12324 at 6 bar P_i.
2) When the cone angle is kept at 2^0, COP is 0.15206 at 6 bar P_i.
3) When the cone angle is kept at 3^0, COP is 0.16768 at 6 bar P_i.
4) The COP lines are almost similar for cone angles 3^0 and 4^0.
5) When the diffuser is installed the cold temperature decreases abruptly, T_C decreases to 16.5^0C at 6 bar pressure, whereas T_C is 18^0C at 6 bar pressure without diffuser.
The cold temperature can be reduced by 2.5^0C by installing diffuser between the hot plug and outlet of the vortex tube.

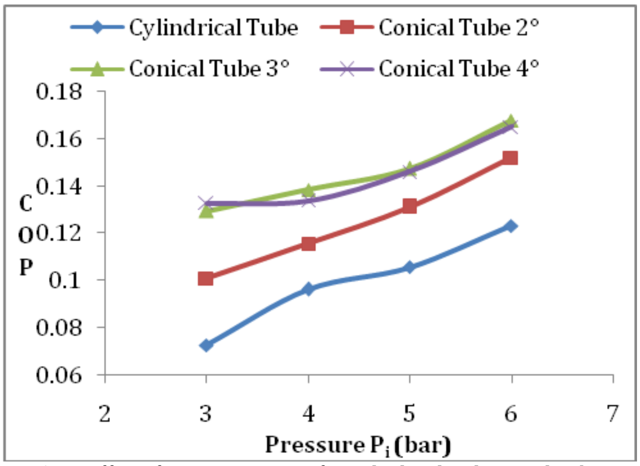

Fig. 5 Effect of Pressure on COP for Cylindrical and Conical Tubes

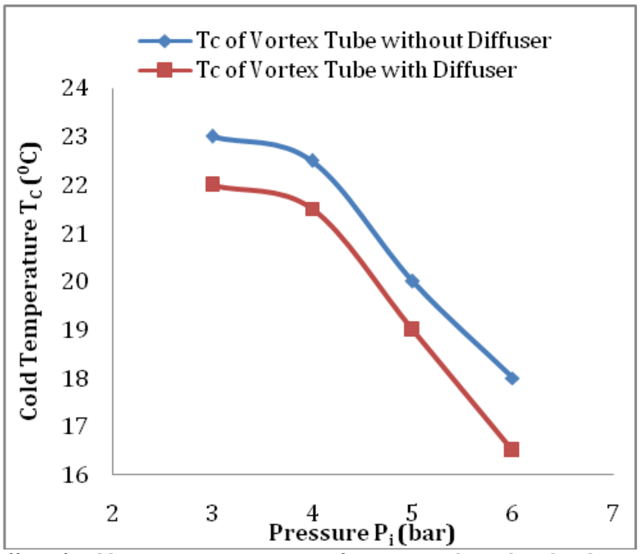

Fig. 6 Effect of Cold Temperature on Pressure for Vortex Tube with and without Diffuser

VIII. CONCLUSIONS

From the dissertation work the following conclusions are made:

1) When the diffuser is installed, T_C is reduced by 2.5^0C.
2) To increase refrigeration effect, COP should be high at higher pressure, with the conical geometry the COP value is 0.16768 at cone angle 3^0 at 6 bar pressure.
3) The results are almost similar when cone angle is kept at 4^0.

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