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An Experimental Method on the Counter Flow Vortex Tube

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Abstract:
An experimental research has been performed to realize deep behavior of a vortex tube refrigeration system. A new design of the counter flow vortex tube has been adapted, re-machined and verified. The vortex tube is a synthetic produced cooling device, which runs as a refrigerating unit without disturbing the environment. It separates hot and cold air stream from a high pressure inlet air; this fundamental is called as temperature parting or energy separation process. The vortex tube efficiency depends on two following types of parameters, firstly pressurized inlet air, cold mass fraction and secondly geometric design constraints such as length of hot side, length to diameter ratio, diameter of nozzles, cone valve angle and mostly the material of vortex tube that impacts the efficiency. This paper shows the execution of new experimental methods of the above working parameters on the performance of Ranque-Hilsch vortex tube. The Aluminum, Mild steel (M.S) and Brass has been used for manufacturing of the vortex tube. In this experimental study the performance of vortex tube has been tested with compressed air at various pressures from 2-6 bars, which supplied through two tangential inlet nozzles. The L/D ratio of tube is kept constant.

Keywords: Counter Flow Vortex Tube, Energy separation, Ranque-Hilsch vortex tube

I. INTRODUCTION

A vortex tube is a device with idle non movable parts, which converts an incoming compressed air stream of consistent temperature and parts into two streams of nonhomogeneous temperatures, one warmer than the inlet and other cooler. By injecting pressurized air at room temperature circumferentially into a tube at intense velocity, a vortex tube produces low intensity and high intensity air streams. Temperature and airflow rates can be varied by adjusting valve on hot end of the tube. On one side, is the inlet chamber, where pressurized air is used at the input, and as output the discharged gases are thrown. Due to the friction formed, the flow moves toward the warm end. A little of the air expands to the central core and exits at the cold end. Ranque, an engineer, initial discovered this development of energy separation in 1931, once he was finding out method during a dirt separation cyclone. Later, Hilsch a German scientist performed the careful examination of the vortex impact and improved the planning of vortex tube. Intensive experimental and analytical studies of Ranque-Hilsch vortex tube began since then and continue even these days. Since the mechanism of energy separation in the vortex tube was a spectacular development, some works are revealed to clarify this development based on physical laws such as: conservation of mass and momentum, first and second laws of thermodynamics. Therefore, many completely different hypotheses have been reported to explain the energy separation development and maximum suited cooling impact. This paper shows experimental results of the temperature parting in vortex tubes, keeping the same length to diameter ratio at various nozzle diameters and keeping other geometrical parameters constant. It is through an experiment proved that the nozzle diameter greatly influences the separation performance and cooling potency. The foremost necessary purpose discovered during this paper is that there is an optimum nozzle diameter that offers the most effective performance of vortex tube.

II. LITERATURE REVIEW

The vortex tube was made-up quite accidentally in 1928; it has invariably been fascinated by several researchers. Many theories are advised to clarify the physics of vortex tube, however still it is to be explored totally. Analysis works which are according to understand vortex tube refrigerator throughout last three decades is classified into three major groups; theoretical, numerical and experimental studies. Among that majority of the analysis on vortex tube has been distributed on design aspects and dealing fluids. Several CFD studies have additionally been reported in literature on flow simulation of vortex tube. However, experimental studies are comparatively less obtainable in open literature. Succeeding section of this chapter presents a comprehensive report of the past analysis on numerous aspects of vortex tube

Fulton [1] explained that the energy separation is because of the free and compelled vortex flow generated within the system. He expressed that “Fresh gas before it has traveled so much within the tube succeeds in forming a nearly free vortex within which the angular rate or revolutions is low at the boundary and really high toward the middle. However, friction between the layers of gas undertakes to scale back all the gas to an equivalent angular rate, as during a solid body.” throughout the inner friction method between the peripheral and central layers, the outer gas successively gains additional K.E. than it loses internal energy and this results in a better gas temperature within the periphery; the inner gas loses K.E. so the gas temperature is lower.

Xue Y. et al. [2] has reported a comprehensive review on energy separation within the vortex tube. In the exploration of the temperature separation during a vortex tube, various factors are thought of like pressure gradient, viscosity, flow structure within the tube and acoustic streaming. The temperature drops of a vortex tube are often thought of because the combination effects like sharp enlargement close to the entrance, energy transferred outward due to the inner friction and turbulence, secondary flow and static gradient.

Lewins J. and Bejan A. [3] suggested that the angular velocity gradients in the radial direction give rise to frictional coupling between different layers of the rotating flow resulting in a migration of energy via shear work from the inner layers to the outer layers.

Saidi M. S. and Yazdi N. [4] had used a thermodynamic model to investigate vortex tube energy separation. An equation has been derived for the rate of entropy generation. This equation is used to model the irreversibility term.

Piralishvili S. A. and Fuzeeva A. A. [5] had derived regression equation for scheming the relative cooling of a gas by its physics parameters. However, this equation was obtained with no account for the pure mathematics of a vortex tube and therefore the differential pressure in it. As a result, these quantities were held constant within the experiment. To derive an additional general regression equation with account for all decisive parameters, it is necessary to perform extra experimental investigations.

III. PROBLEM STATEMENT

An experimental study has been conducted to judge the result of operating parameters like cold mass flow rate (μ_c), cold and hot temperature difference ($\Delta T_c, \Delta T_h$), Isentropic Efficiency (η_{is}) and Coefficient of Performance (C.O.P). In this work, the counter flow vortex tube has been designed, manufactured and tested. Different parameters were evaluated like comparing the vortex tube by different materials such as Brass, Mild Steel and Aluminum and also changing the diaphragm diameter. The L/D ratio is kept constant.

IV. DESIGN AND CONSTRUCTIONAL DETAILS OF VORTEX TUBE

Geometric Parameters:

Tube length:

It is suggested to have an economical design tube length should be persistently longer than its diameter. The length of the vortex tube affects performance considerably. Optimum L/D may be a function of geometrical and operational parameters. The magnitude of the energy separation will increase because the length of the vortex tube will increase to a critical length. However, an extra increase of the vortex tube length beyond the critical length does not improve the energy separation.

Tube diameter:

In general smaller diameter vortex tubes offer additional temperature separation than larger diameter ones. a really tiny diameter vortex tube results in low diffusion of K.E. that also means that low temperature separation. a really massive tube diameter would end in lower overall tangential velocities each within the core and within the boundary region that may turn out low diffusion of mean K.E. and additionally low temperature.

Number of nozzles:

For maximum temperature drop the inlet nozzles ought to be designed in order that the flow is tangentially moving into vortex tube. The rise of the amount of inlet nozzles ends up in higher temperature separation. The inlet nozzle location should be as close as attainable to the orifice to yield high tangential velocities close to the orifice.

Tube geometry:

Tapered vortex tube contributes separation method in vortex tubes used for gas separation. In divergent vortex tubes, there exists associate degree best cone-shaped angle and this angle is extremely tiny (3°). Rounding off the tube entrance improves the performance of the RHVT.

Cold orifice:

Using a tiny cold opening (Dc/D= 0.2, 0.3, and 0.4) yields higher backpressure whereas an oversized cold opening (Dc/D= 0.6, 0.7, 0.8, and 0.9) permits high tangential velocities into the cold tube, leading to lower thermal/energy separation within the tube. Dimensionless cold opening diameter should be within the range of 0.4 to 0.6 for optimum results.

Hot flow control valve:

The hot-end plug isn't a important part in vortex tube. Optimum worth for the angle of the conelike control valve (α) is about 45°.

Calculation of Geometrical Parameters:

Cold and Hot temperature difference:

Cold temperature distinction or cooling is defined because the distinction in temperature between entry air flow temperature and cold air flow temperature:

$$\Delta T_c = T_i - T_c.$$
$$\Delta T_h = T_h - T_i.$$

Cold mass fraction:

The cold flow mass ratio (cold mass fraction) is the most significant parameter indicating the vortex tube performance and also the temperature/energy separation within the RHVT. The performance of the RHVTs is evaluated based on the cold mass fraction. Cold mass fraction is defined because the ratio of cold air mass flow rate to water atmosphere flow rate:

$$\mu = mc/mi$$

Isentropic efficiency:

To calculate the cooling efficiency of vortex tube, the principle of adiabatic expansion of ideal gas is used. As the air flows into the vortex tube, the expansion in isentropic process occurs. This can be written as follows:

$$\eta_{is} = \frac{Ti - Tc}{Ti\left[1 - \left(\frac{Patm}{Pin}\right)^{\frac{(\gamma-1)}{\gamma}}\right]}$$

Coefficient of Performance:

The coefficient of performance (COP) is defined as the ratio of cooling rate to energy used in cooling, the same principle of isentropic expansion of ideal gas is employed and equation becomes:

$$COP = Qc/w$$

Takahama has projected the subsequent correlations for optimized RHVT for larger temperature difference, given as;

$D_{in}/D \leq 0.2$……………….(i)

$D_c^2/ND_{in}^2 \leq 2.3$…………(ii)

$D_c < D - 2D_{in}$……………(iii)

Experiments are performed under following conditions:

- Inlet pressures range : 02 bar – 06 bar
- Cold mass fraction : 0 – 1
- L/D Ratio by varying diameter : 10
- Number of inlet nozzle : 1
- Working substance : Air

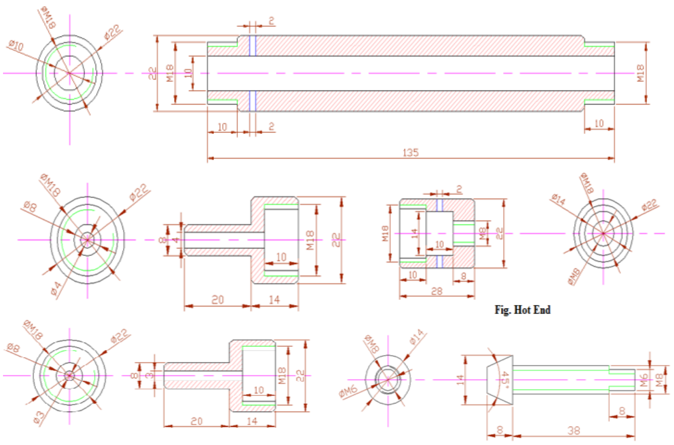

Figure .1: Detail Design of Vortex Tube

V. EXPERIMENTAL SETUP

The vortex tube experimental setup consists of a two stage reciprocal compressor and a receiver as a supply of compressed gas, control valve, a counter-flow vortex tube and measuring instruments as shown in Figure.2. Compressed air from the receiver of compressor is equipped through a hand operated control valve to manage the pressure at the inlet to the vortex tube. The pressure at the inlet to the vortex tube and at cold end is measured with the assistance of a calibrated pressure gauge indicator. The temperature of the new air and temperature of the cold air coming out of the vortex tube is measured with the RTD placed instantly on the downstream of the cone formed valve, and downstream of the cold passage settled next to the inlet respectively. The temperature of the air is additionally measured at the inlet to the vortex tube to calculate the temperature drop or temperature rise of the cold and hot air respectively. The mass flow rates of the inlet air and cold air discharges are measured by calibrated passage flow meters. The pressure difference across the opening is measured by a U-tube pressure gauge.

Component selection:

Temperature indicator:

To measure the temperature at supply, cold end opening and hot end temperature indicator with T- sort thermometer is employed with range -30°C to 80°C.
Filter Pressure Regulation unit(FRL):

To extract moisture content in supply air FRL unit is employed that conjointly controls the pressure and flow.
Compressor:

A two stage, two cylinder reciprocal compressor is utilized to get the continuous supply of compressed gas at the order of 2-10 bars.

Anemometer:

To measure the air flow rate at supply nozzle and cold end. Anemometer is selected of maximum measuring range of velocity 45 m/s.

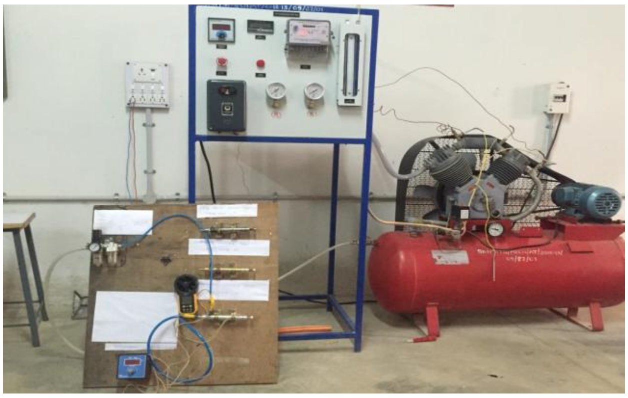

Figure .2. Detailed Experimental Setup

VI. RESULT AND DISCUSION

Performace Charts:

1. **Pressure Vs Cold Mass Fraction**

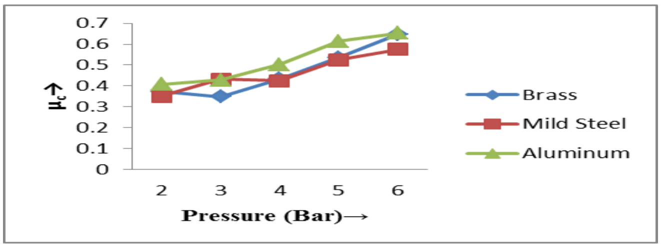

Figure .3: For Diaphragm (3mm)

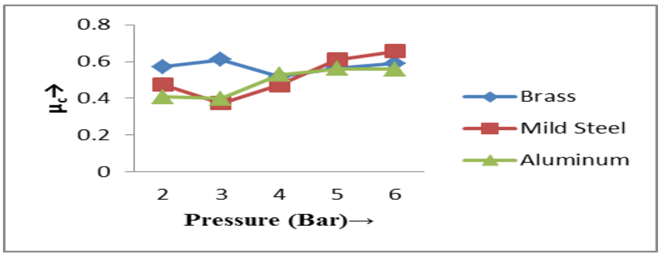

Figure. 4: For Diaphragm (4mm)

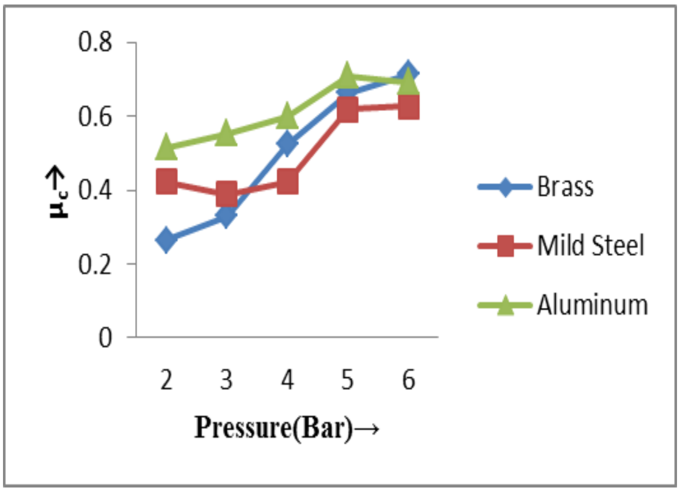

Figure.5: For Diaphragm (5mm)

2. Pressure Vs Isentropic Efficiency (η_{is})

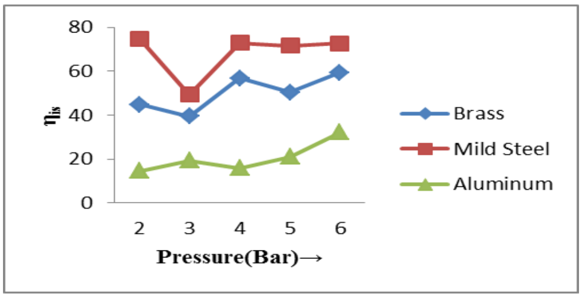

Figure 6: For Diaphragm (3mm)

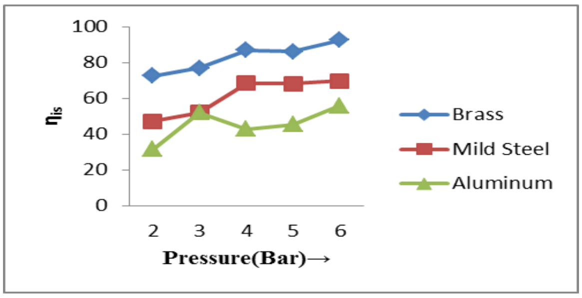

Figure 7: For Diaphragm (4mm)

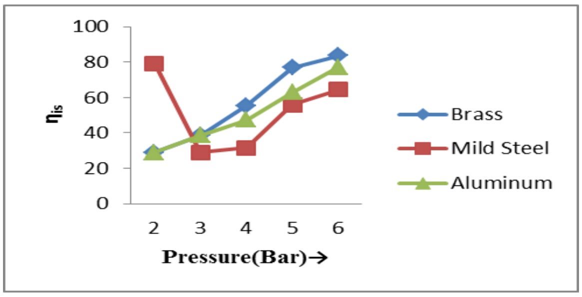

Figure 8: For Diaphragm (5mm)

3. Pressure Vs Cooling Capacity (Q_c)

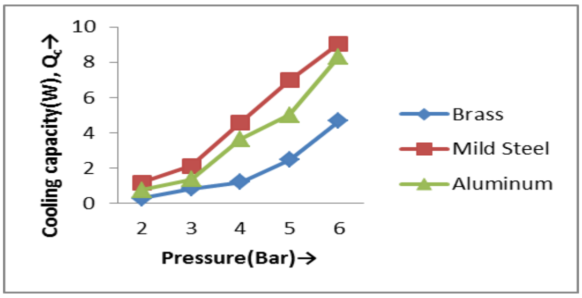

Figure 9: For Diaphragm (3mm)

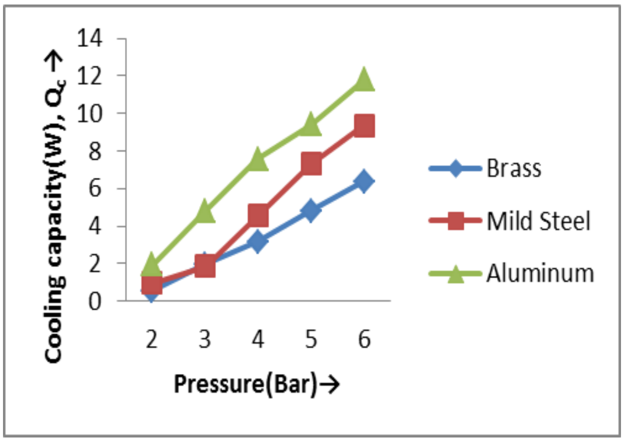

Figure 10: For Diaphragm (4mm)

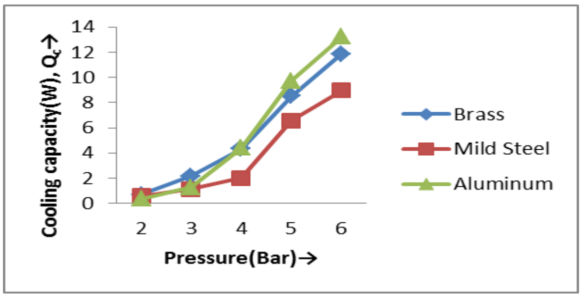

Figure 11: For Diaphragm (5mm)

4. Pressure Vs ΔT_c

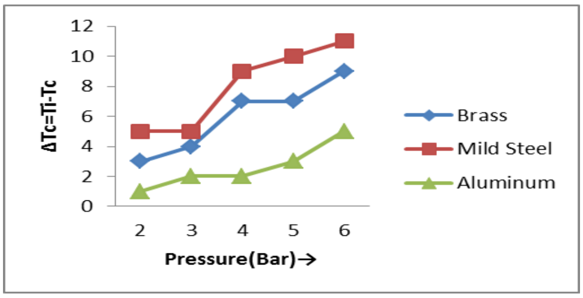

Figure 12: For Diaphragm (3mm)

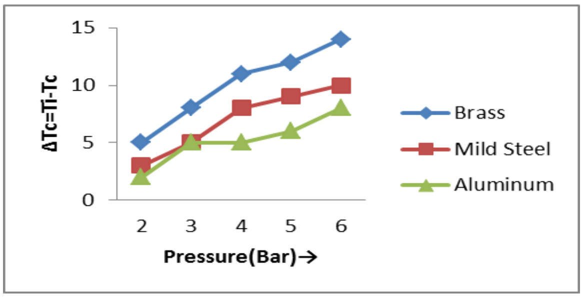

Figure 13: For Diaphragm (4mm)

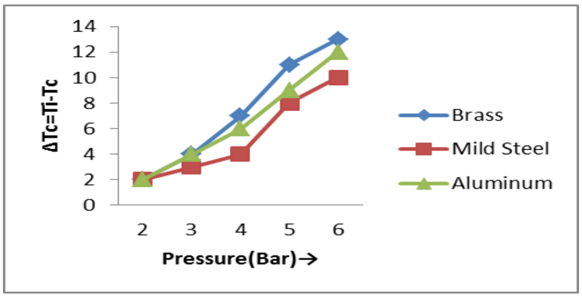

Figure 14: For Diaphragm (5mm)

5. Pressure Vs ΔT_h

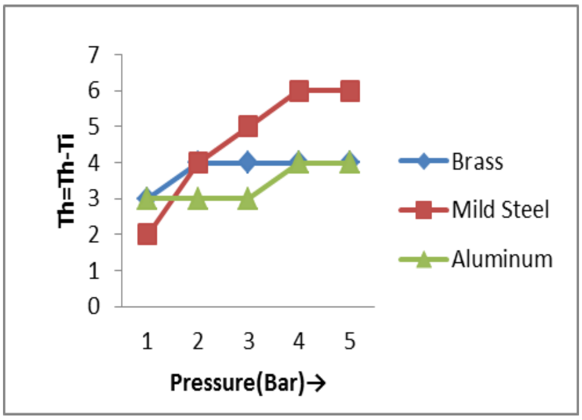

Fig 15: For Diaphragm (3mm)

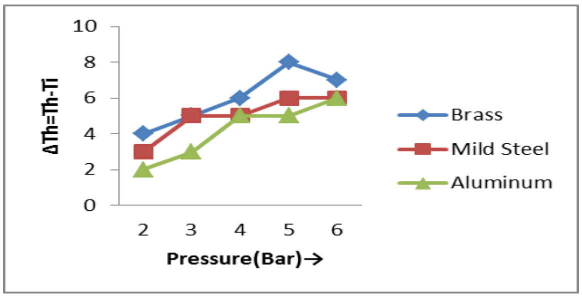

Figure 16: For Diaphragm (4mm)

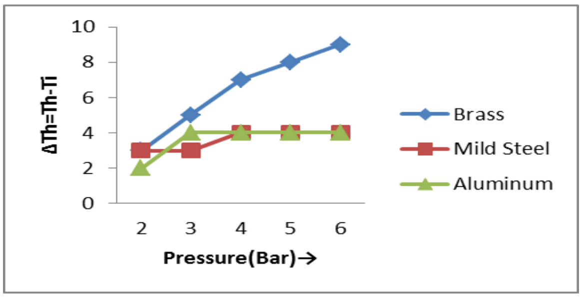

Figure 17: For Diaphragm (5mm)

VII. CONCLUSION

After the experimentation on the vortex tube with different nozzle diameters, it can be concluded that, nozzle diameter have great influence on the performance of vortex tubes. Cold temperature drop (Tc)max varies with the variation of nozzle diameter. But there is a unique nozzle diameter that gives the optimum performance for various geometrical parameters like nozzle angle (Φ), orifice diameter (Do), nozzle number (N), tube length (L) and physical parameter like pressure (P). For 3mm diaphragm, Mild Steel is most efficient and has high cooling capacity as well as maximum temperature difference of 11^{0}C above 5 bar pressure. Aluminum has highest cold mass fraction for 3mm. Brass of 4mm diaphragm shows the maximum temperature difference of 14^{0}C at 6 bar pressure.

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