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EXPERIMENTAL PERFORMANCE ANALYSIS OF VORTEX TUBE FOR VARIOUS PARAMETERS

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Abstract: *The vortex tube (also called the Ranque-Hilsch vortex tube) is a mechanical device containing an entrance of nozzle with a central orifice, a vortex tube and a cone-shaped valve. A source of compressed gas (e.g. air) at high pressure enters the vortex tube tangentially through the inlet nozzle at high velocity. The expanding air inside the tube creates a rapidly spinning vortex. Once this vortex is set up in the tube, the air near the axis cools down while the air at periphery heats up in comparison with the inlet temperature. This phenomenon is known as temperature separation effect (also called the Ranque-Hilsch effect).In this study, three Ranque-Hilsch vortex tubes were used, which have 26.4 mm, 21.2mm, and 14.8 mm inside diameter and length/diameter ratio was 20, 30, and 40respectively. Their performances were examined as one of the classical RHVT and other was cold cascade type RHVT. Performance analysis was according to temperature difference between the inlet and the cold outlet (ΔTcold). The ΔTcold values of cold cascade type Ranque-Hilsch vortex tubes were greater than the ΔTcold values of classical RHVT, which were determined experimentally. The total inlet energy, total outlet energy, total lost energy and energy efficiency of cold stream were investigated by using experimental data. In both the classical RHVT and cold cascade type RHVT, it was found that as fraction of cold flow increases the total energy increases. It was also found that, the cold cascade type RHVT more energy efficiency of cold outlet than the classical RHVT. Excess ΔTcold value of cold cascade type Ranque-Hilsch vortex tube causes the excess energy efficiency of cold outlet. The range of operating conditions covered; Pressure: - 5 bar to 7 bar; cold fraction: - 0.2to 1. In order to investigate the effect of materials, vortex tubes of steel, aluminium and PVC are fabricated and tested.*

Keywords: Vortex tube of steel, Vertex tube of Aluminium and PVC, Compressed air, Ranque-Hilsch effect, Classical RHTV, cold cascade RHVT etc

INTRODUCTION

The vortex tube also known as Hilsch or Ranque tube is as impel device having no moving parts, whichproduceshotandcoldairstreamssimultaneouslyatits twoendsfromasourceofcompressed air. It consists of along tube having at tangential nozzle near one end and a conical valve at the other end, as shown schematically in Figure1.

A diaphragm called cold orifice, with a suitable sized hole in its centre is placed immediately to the left of the tangential inlet nozzle. The compressed air is the introduced into the tube through this nozzle. The tangential flow imparts whirling or vortex motion to the inlet air, which subsequently spirals down the tube to the right of the inlet nozzle. Conical valve at right end of the tube confines the exiting air to regions near the outer wall and restricts it to the central portion of the tube from making a direct exit. The central part of the air flow sin reverse direction and makes exit from the left end of the tube with size able temperature drop, thus creating a cold stream. The outer part of the air near the wall of the tube escapes through the right end of the tube and is found to have temperature higher than that of inlet air.

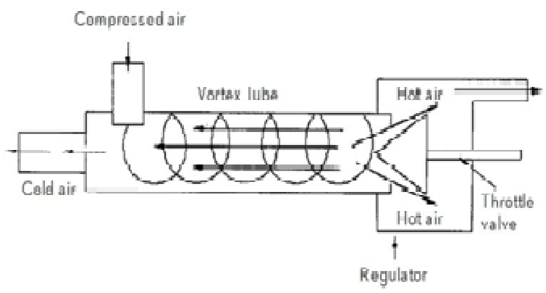


Figure 1 Schematic diagram of Vortex Tube

OBJECTIVES OF PRESENT WORK

In this work, an attempt was made to fabricate and test a counter flow vortex tube using UPVC, Aluminium & mild steel pipe. The performance of vortex tube was evaluated at different working parameters and geometry parameters.

a) Design of vortex tube using UPVC, Aluminium & mild steel pipe & UPVC pipe fittings.
b) Fabrication of three vortex tubes of different sizes.
c) Experimentation for various operating conditions.

d) Analysis of cascading of vortex tubes.
e) Thermodynamic analysis of experimental data.
f) Result and discussion on the above trials.

DESIGN PROCEDURE

The parameters investigated in the study, to understand their inter-relationships and their effect on the performance of the vortex tube are:

a) Diameter of vortex tube
b) Nozzle diameter
c) Cold orifice diameter
d) Length of the tube
e) Area at the hot end.

In the present investigation, a nozzle area to Inlet tube area ratio of 0.145 ± 0.035 for achieving maximum efficiency has been considered, as suggested by Soni and Thomson. The same researchers also mentioned that the length of the vortex tube should be 45- 55 times the tube diameter. Keeping these suggestions in view, a vortex tube of size 10 miner diameter of UPVC was selected. The vortex tube was 450 mm long pipe. Materials were selected based on easy availability, ease of working, and insulating capability which is necessary for achieving the adiabatic conditions assumed. UPVC has high chemical resistance across its operating temperature range. To obtain optimum design and to perform experiment on vortex tube different diameters of UPVC pipes are selected.

Table-1: Design Parameters of equipment constructed

Tube Inner Diameter	10mm	(d)
Cold Plate Orifice Diameter	5mm	(0.5d)
Inlet Nozzle Diameter	1 mm	(0.1d)
No. of Inlet Nozzle	4	(depending on flow rate of air)
Length: Hot End	450 mm	(45d-55d)
Length: Cold End	20 mm	(experimental
Pressure Range	1 bar -6	(experimental

EXPERIMENTAL SETUP

To study the effect of various parameters such as mass flow rates of cold and hot air, cold orifice area and hot end area on the performance of the vortex tube, an experimental set up was prepared as per design described earlier. The temperature of air at cold and hot ends was measured with digital thermometer with an accuracy of ± 1^0C. Air flow rotameter are provided for measuring mass flow rate of air. The pressures were measured by pressure gauges. All the instruments were calibrated before the measurements were actually recorded. The different parts of experimental set-up are as below:

a) Compressor
b) Various types of Vortex Tubes
c) Inlet air flow Rotameter
d) Cold stream air flow Rotameter
e) Thermocouples with digital temperature indicator
f) Clamps for mounting Various Vortex Tube
g) M.S. frame

Fig-2: Photograph of experimental setup.

TEST PROCEDURE

The various parameters, which affect the performance of the vortex tube, were divided into following input and output variables:

Input variables: Area of cold orifice, Effective Area of Hot End, Inlet Pressure, Inlet Mass Flow Rate

Output variables: Temperature of cold air, cold fraction, and Temperature of hot air. Tests are conducted on experimental setup for various vortex tubes. The steps by steps procedures of each test are as below

a) Mount the different diameters vortex tube using clamps provided.
b) Provide connection of inlet air hose pipe to 1^{st} vortex tube on which experiment is to perform.
c) ConnectPT-100temperaturesensorstocoldendandhotendrespectivelyto1^{st} vortex tube on which experiment is to perform.
d) Check connections.
e) Start the main power supply and check for all electrical supply and display units.
f) Start compressor and Allow compressor to build pressure up to 7 bar.
g) Adjust flow rate using flow control valve.
h) Adjust mass flow rate of hot air escaping through hot end using conical valve provided.
i) Note inlet temp, inlet mass flow rate, cold end mass flow rate, inlet temp, cold stream temp, hot stream temp for different cold fraction by adjusting position of conical valve.
j) Repeat the above procedure for another remaining vortex tubes.

RESULT

1.1 Analysis of cold side for different dimensions of UPVC pipe

a) Performance Curves of Vortex Tube (Dia. 26.4mm)

It is found that temperature difference increases with cold fraction reaches a peak value and then decreases suddenly. The temperature difference is lowest for 100 % cold fraction for all cases. The temperature difference also varies with length of vortex tube, increases with decreasing length. The maximum value of temperature difference occurs for 80-90% cold fraction for all cases

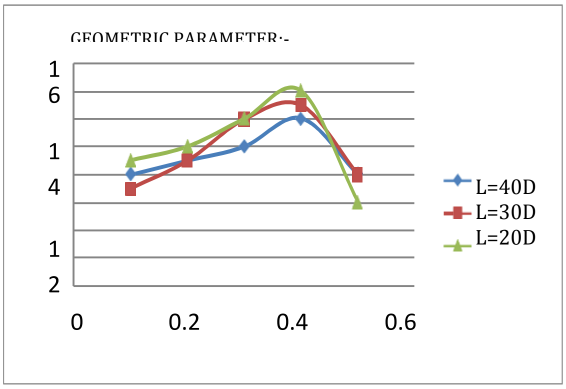


Chart-1: Effect of Length of tube on temp.difference (ΔTc) (D = 26.4 mm, P= 7 bar)

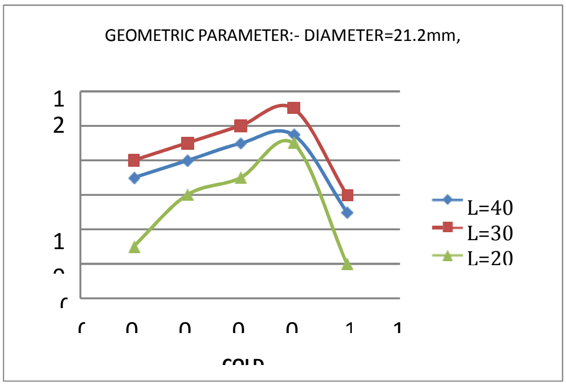


Chart-2: Effect of Length of tube on temp.difference (ΔTc) (D = 26.4 mm, P= 5bar)

b) Performance Curves of Vortex Tube (Dia. 21.2mm)

Chart 3&Chart 4 describes variation of temperature difference, (Inlet temperature- cold end temperature) for different cold fractions at inlet pressure of 7 bar & 5 bar respectively. It is found that temperature difference increases with cold fraction reaches a peak value and then decreases suddenly. The temperature difference is lowest for 100 % cold fraction for all cases. The temperature difference also varies with length of vortex tube, increases with increasing length. The maximum value of temperature difference occurs for 80-90% cold fraction for all cases.

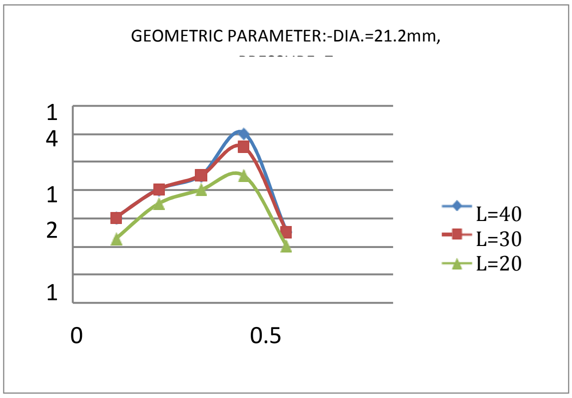


Chart-3: Effect of Length of tube on temp.difference (ΔTc) (D = 21.2 mm, P=7bar)

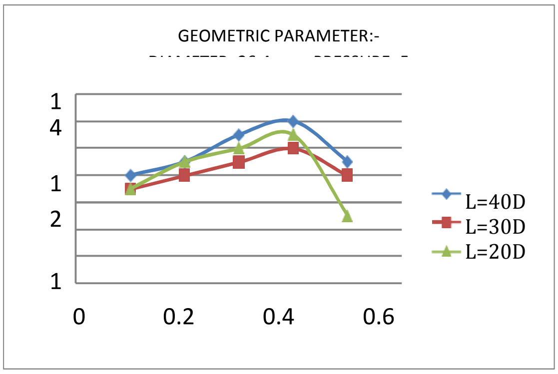
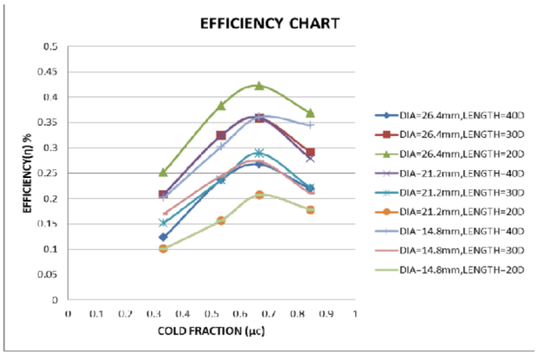


Chart-4: Effect of Length of tube on temp.difference (ΔTc) (D = 21.2 mm, P=5bar)

c) Performance Curves of Vortex Tube (Diameter 14.8mm)

Chart5&Chart6 describes variation of temperature difference, (Inlet temperature- cold end temperature) for different cold fractions at inlet pressure of 7 bar & 5 bar respectively. It is found that temperature difference increases with cold fraction reaches a peak value and then decreases suddenly. The temperature difference is lowest for 100 % cold fraction for all cases. The



temperature difference also varies with length of vortex tube, increases with increasing length. The maximum value of temperature difference occurs for 80-90% cold fraction for all cases.

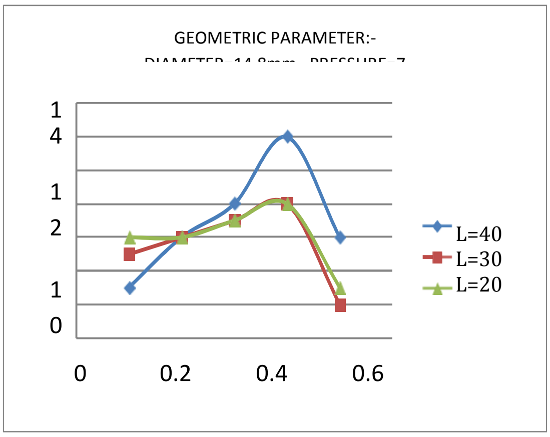


Chart-5: Effect of Length of tube on temp.difference (ΔTc) (D = 14.8 mm, P=7 bar)

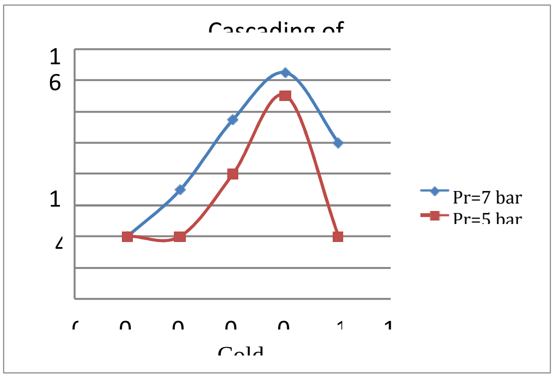


Chart-6: Effect of Length of tube on temp.difference (ΔTc) (D = 14.8 mm, P= 5 bar)

d) Adiabatic Efficiency of Vortex Tubes

Chart 7 describes variation of Adiabatic Efficiency for different cold fractions.

Chart-7: Adiabatic Efficiency Chart of All lengths and diameters Vortex Tub

By observing the above graphs we decided to cascade three vortex tubes as follows:

a) D=26.4mm,L=20D
b) D=21.2mm,L=40D
c) D=14.8mm, L=40D.

So, analysis and graphs of this configuration are as follows:

Operating Conditions: Inlet Pressure = 7 bar, Ambient temperature = 28⁰C

Table-2: Observations for cascaded configuration for pressure7 bar

Sr.	m	m	T	T	Δ	μ
1	5	5	2	1	1	1
2	5	4	2	1	1	0.
3	5	3	2	1	1	0.
4	5	2	2	2	7.	0.
5	5	1	2	2	3.	0.

Operating Conditions: - Inlet Pressure = 5 bar, Ambient temperature = 28⁰C

Table-3: Observations for cascaded configuration for pressure 5 bar

Sr.	m	m	T	T	Δ	μ
1	5	5	2	2	8	1
2	5	4	2	1	1	0
3	5	3	3	2	1	0
4	5	2	2	2	5	0
5	5	1	2	2	5	0

Chart 8 describes the temperature drop for selected cascading arrangement of 3 vortex tube. This configuration gives better results at inlet pressure of 7 bar

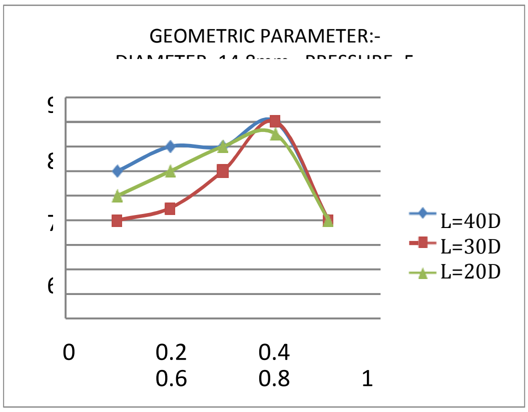


Chart-9: Graph of temperature difference vs cold fraction for selected config.

1.2 Analysis of cold side for different materials of vortex tube

Analysis is done using different materials of vortex tube i.e. aluminum, mild steel and polyvinyl chloride. Geometric parameters selected are diameter= 14.8 mm and Length= 20 D. From Chart 10 vortex tube made from aluminum gives better temperature drop than it can achieve in mild steel and polyvinyl chlorides pipe.

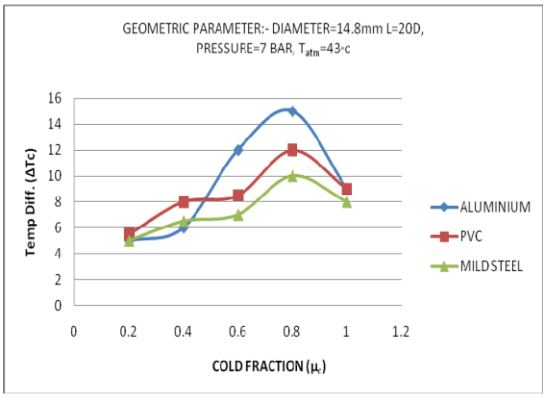


Chart-10: Graph of temperature difference vs cold fraction for different materials

CONCLUSION

1) The effect of various parameters, such as nozzle area, cold orifice area, hot end area and L/D ratio of the tube length to the tube diameter, on the performance of the vortex tube can be investigated.
2) There were experimentally tested variations of the cold air temperature Tc and hot air temperature Th with respect to the change of the hot end area for L/D = 20,30,40
3) Experimentally tested, the temperature differences between the inlet air and the cold exit air, ΔTc = Ti-Tc, as functions of the cold air mass ratio is defined as follows: μc = mc/mi, where mc is a mass flow rate of the cold air and mi is a total air mass flow rate, with the pressure of the inlet air as a parameter.
4) The cold stream temperature increases slightly with μc in the range of about μc = 30 ~ 50 %. And the temperature difference between the inlet stream and the cold one approaches its maximum value in the range of about μc = 65 ~ 85 %. Again further increase in μc cold stream temperature decreases.
5) The hot stream temperature decreases slightly with μh in the range of about μh = 30~65%.Andthetemperaturedifferencebetweent heinletstreamandthehot.One approaches its maximum value in the range of about μc = 10 ~ 30 %
Again further increase in μc cold stream temperature decreases.
6) The percentage change in temp of aluminum pipe over PVC pipe is increase by 25%.
7) The percentage change in temp of aluminium pipe over steel pipe is increase by 50%.
8) For a diameter of 14.6mm, the percentage change in temp of length 20D over 40D is decrease by42%.
9) For a diameter of 21.2mm, the percentage change in temp of length 20D over 40D is decrease by25%.
10) For a diameter of 26.4mm, the percentage change in temp of length 20D over 40D is decrease by19%.
11) The percentage change in temp of cascade pipe over single pipe is increase by 93%.

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