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An Experimental Modeling and Investigation of Change in Working Parameters on the Performance of Vortex Tube

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Abstract

An experimental investigation has been performed to realize thorough behavior of a vortex tube refrigeration system. The counter flow vortex tube has been designed, manufactured and tested. The vortex tube is a non-conventional cooling device, which operates as a refrigerating unit without affecting environment. It has capability to separate hot and cold air stream from a high pressure inlet air; such phenomenon is called as temperature or energy separation process. The vortex tube performance depends on two types of parameters, firstly air or working parameters such as inlet pressure of compressed air, cold mass fraction and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, cone valve angle and also material of vortex tube affects Coefficient of Performance (COP). This paper discusses the experimental investigation of effect of above working parameters on the performance of Ranque-Hilsch vortex tube. The Chlorinated Poly Vinyl Chloride (CPVC) material has been used for manufacturing of the vortex tube as it has lower thermal conductivity than metals and less fluid friction losses. In this experimental study the performance of vortex tube has been tested with compressed air at various pressures from 5-10 bar, which supplied through two tangential inlet nozzles. The L/D ratio of hot side tube varied from 10-50 and cold mass fraction varied from 0.20 – 0.80.

Keywords: Energy separation process, COP, Ranque-Hilsch vortex tube, CPVC.

1. Introduction

Vortex tube is a simple-compact device, which produces cooling at one end and heating at the other end simultaneously. The vortex tube was invented in 1933 by George Ranque [1] and later developed in 1947 by Rudolf Hilsch. In memory of their contribution the Vortex tube is also known as Ranque-Hilsch vortex tube (RHVT). Several different explanations for the temperature (energy) separation effects in the vortex tube have been offered. Hilsch (1947) firstly studied the mechanism of vortex tube and claimed that internal friction lead to the energy separation of vortex tube [2]. Fulton (1950) explained that the energy separation is due to the free and forced vortex flow generated inside the vortex tube, Lay (1959) attributed the friction effect and turbulence as the reason for the energy separation, Linderstrom-Lang (1971) assumed turbulent transfer of the thermal energy lead to the energy separation of vortex tube, Kurosaka (1982) proposed an acoustic streaming process[3], Stephan and Lin (1983) suggested that Gortler vortex produced by the tangential velocity on the inside wall of the vortex tube is the major driving force for the energy separation[4], A different theory was developed by Mischner and Bespalov (2002) they explained the energy separation mainly caused by entropy generation in vortex tube[5].

2. Problem Statement

An experimental study has been conducted to evaluate the effect of working parameters such as inlet air pressure (P_i), Cold mass fraction (μ) and length of hot side tube (L_h) on the performance of Ranque-Hilsch vortex tube. In this work, the counter flow vortex tube has been designed, manufactured and tested. Different parameters were evaluated like temperature reduction on cold side, temperature rise on hot side, refrigerating effect and isentropic efficiency. The performance of vortex tube has been tested with compressed air at various inlet pressures from 5-10 bar which supplied through two tangential inlet nozzles. The L/D ratio of hot side tube varied from 10-50 and cold mass fraction varied from 0.20 – 0.80.

3. Design and Constructional Details of Vortex Tube

The schematic diagram of counter-flow vortex tube is given in Fig.1, which has been designed and manufactured.

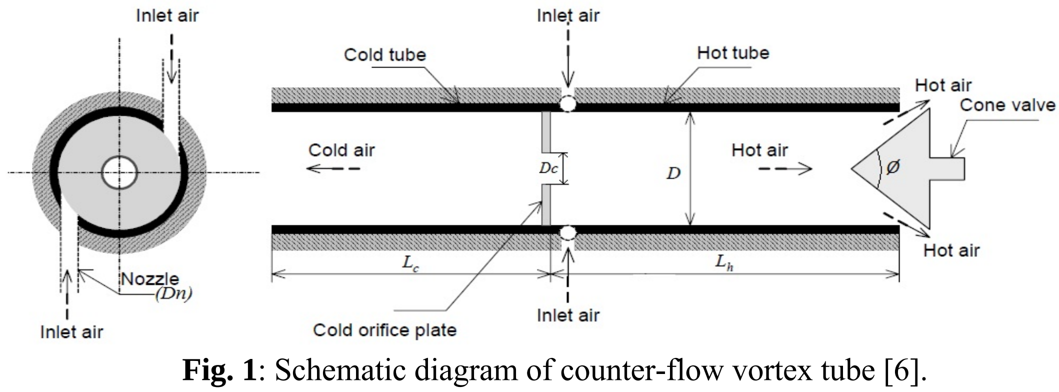

Fig. 1: Schematic diagram of counter-flow vortex tube [6].

Table.1 shows the detailed design parameters and their values employed in this study. The counter-flow vortex tube consists of inlet nozzles, vortex chamber, separating cold orifice plate, hot side cone valve, hot and cold end tubes.

The Chlorinated Poly Vinyl Chloride (CPVC) material has been used for manufacturing of the vortex tube as it has lower thermal conductivity than metals, good thermal insulating, less fluid friction losses, easy to machining and low overall cost. A conical valve made of nylon was provided on the right hand side of the tube to regulate the flow.

Table 1: Design parameters and their values.

Sr. No.	Design parameter	Dimension / Value
1	Diameter of vortex tube,D	24 mm
2	Orifice diameter,D_c	12 mm
3	Number of inlet nozzles,n	2
4	Diameter of nozzle,D_n	3.6 mm
5	Cone valve angle,Ø	30^0
6	D_c/D ratio	0.50
7	D_n/D ratio	0.15
8	Length of hot side tube,L_h	10D,20D,30D,40D,50D
9	Inlet pressure,P_i	5,6,7,8,9,10 bar
10	Cold mass fraction,µ	0.20,0.40,0.60,0.80

4. Experimental Setup

The vortex tube experimental setup consists of a two stage reciprocating air compressor and a receiver as a source of compressed air, control valve, a counter-flow vortex tube and measuring instruments as shown in fig.2.

Compressed air from the receiver of compressor is supplied through a hand operated control valve to control 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 help of a calibrated pressure gauge indicator. The temperature of the hot air and temperature of the cold air coming out of the vortex tube is measured with the RTD located immediately on the downstream of the cone shaped valve, and downstream of the cold orifice located next to the inlet respectively. The temperature of the air is also 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 orifice flow meters. The pressure difference across the orifice is measured by a U-tube manometer connected to the pressure tapping at distance D (tube diameter) on the upstream side and D/2 on the downstream side of the orifice. The ratio called a cold mass fraction is changed by regulating the cone-shaped valve opening. [7]

Fig. 2: Actual vortex tube experimental setup.

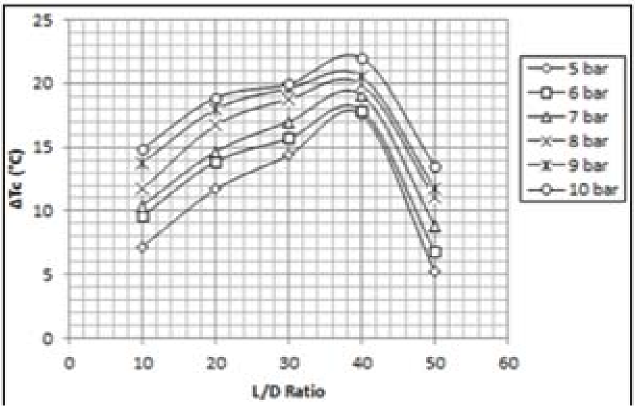

Fig. 3: The effect of L/D ratio on ΔTc.

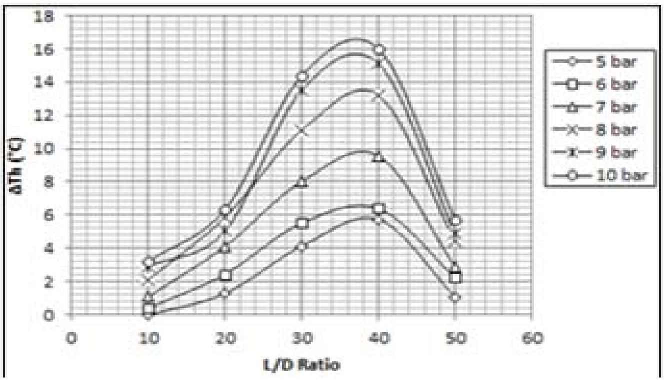

Fig. 4: The effect of L/D ratio on ΔTc.

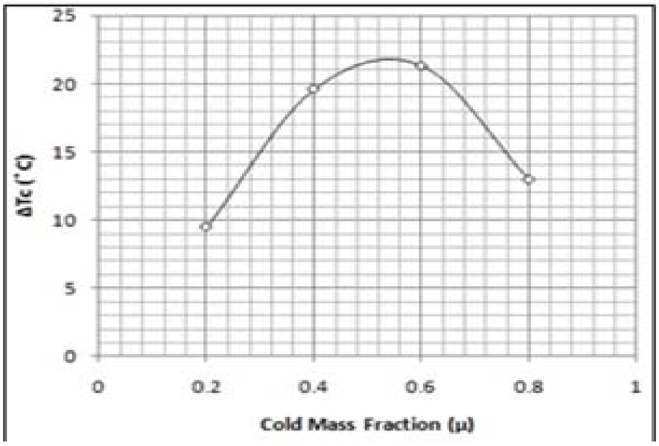

Fig. 5: The effect of cold mass fraction on ΔTc.

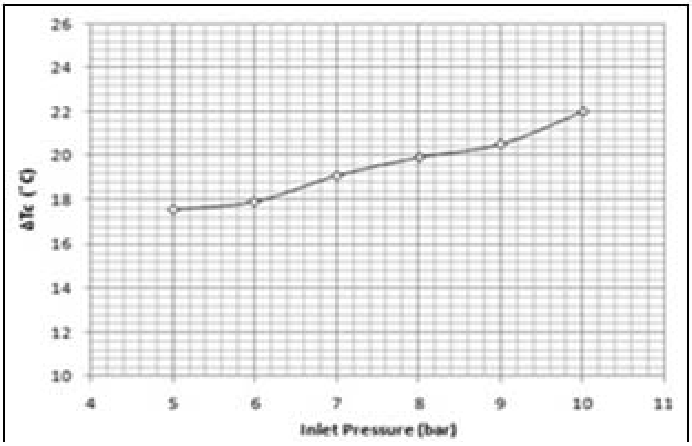

Fig. 6: The effect of L/D ratio on Temperature difference ΔTc

5. Results and Discussion

5.1 The effect of L/D ratio on Temperature difference

Fig.3 shows the effect of L/D ratio at various inlet pressure (Pi) on cold end temperature difference (ΔTc). It can be observed that ΔTc increases with increase in L/D ratio upto 40 and then decreases. The L/D ratio of 40 creates highest cold air temperature drop of 22° C at 10 bar and lowest ΔTc at 5 bar for 50 L/D ratio.

Hot end temperature difference (ΔTh) Vs L/D ratio at different pressure can be seen in Fig.4.The maximum ΔTh is obtained at 10 bar and for L/D ratio of 40 is 16.5° C. ΔTh is minimum for 10 L/D ratio at 5 bar.

5.2 The effect of Cold mass fraction on Temperature difference

Fig.5 shows the effect of cold mass fraction (μ) on cold end temperature difference (ΔTc) for L/D ratio of 40. The cold flow mass ratio (cold mass fraction) is the most important parameter used for indicating the vortex tube performance of RHVT. 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. From Fig.5 It can be observed that as cold mass fraction increases from 0.2-0.6, ΔTc also increases and then decreases. The ΔTc is maximum for range of 0.4-0.6 cold mass fraction.

5.3 The effect of inlet pressure on Cold temperature difference

Fig.6 shows the plot of inlet air pressure (Pi) on Cold end temperature difference (ΔTc) for L/D ratio of 40. It can be seen that ΔTc increases with increase in inlet pressure (Pi).The maximum ΔTc of 22° C is obtained at 10 bar inlet pressure and minimum ΔTc is obtained at 5 bar.

6. Conclusion

The following conclusions have been made from this experimentation**:**

1. The maximum temperature difference of 22° C is obtained on cold side while 16.5° C is obtained on hot side of Vortex tube.
2. The temperature drop increases with increase in inlet pressure.
3. The optimum value of L/D ratio is in range of 30-40 as in this range ΔTc and ΔTh is maximum.
4. The highest temperature drop is found between 0.4-0.6 cold air mass fraction.
5. At 10 bar Inlet pressure, 40 L/D ratio and 0.6 Cold mass fraction give the best result.

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