Performance Analysis of Nylon Made Vortex Tube

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ABSTRACT
A Vortex tube is a cooling machine which separates the flow of air or gas into two components: hot and cold streams. In spite of its limited use, it has several advantages over the conventional cooling system. In this study, an experimental investigation is carried out to find the performance of Nylon made vortex tube. Effects of varying cold mass fraction on the thermodynamic features of the tube were examined. A thermodynamic analysis is also performed to determine the key aspects of the tube.

Keywords: Ranquee Hilsch vortex tube (RHVT); Nylon; Refrigeration.

1. Introduction

Refrigeration is one of the research areas that are deeply associated with human lives. Refrigeration system provides cooling effect which is necessary to store food and for human comforts. Refrigeration system uses many refrigerants. The use of refrigerants can lead to the problems like ozone depletion and global warming. So it is necessary to look for a system that is eco-friendly. A vortex tube is a nonconventional eco-friendly device which was initially invented by the French physicist Georges J. Ranque in 1933. It was then developed by the German engineer Rudolf Hilsch in 1947 [1]. That is why it is called Ranquee Hilsch vortex tube (RHVT). In this device fluid like oxygen, air is used as the working medium for refrigeration process. The construction of the tube is simple as all the parts are stationary. It contains following components [2-3].

- Vortex Chamber
- Inlet nozzles
- Working tube
- Control valve (in hot end)
- Orifice (in cold end)

One of the main advantages of vortex tube is that it has no rotating part .It is circular in shape. A high - pressure gas is made to pass to the vortex tube through the tangential nozzles. As a result, velocity is increased which produces an effect called the swirl effect. Hot and cold end make up the two exits of the vortex tube. The hot exit is located in the outer radius near the far end of the nozzle and the cold exit is in the center of the tube near the nozzle. Being lower in temperature closer to the axis, the gas comes out through the cold exit. The gas coming out through the hot exit has a high temperature near the periphery of the tube. Figure1 shows flow structure in a vortex tube [4].

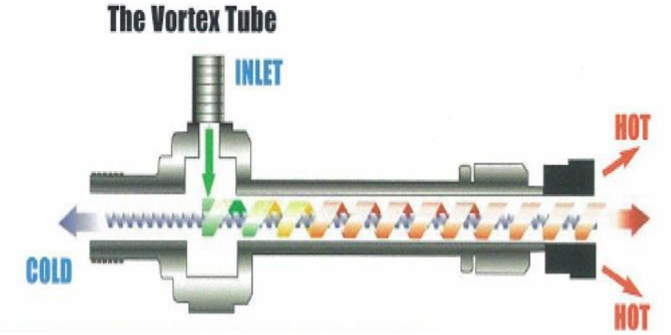

Figure 1: Flow structure in a vortex tube

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- Mass flow rate is constant

2. Literature Review

A great number of studies have been conducted to analyze the performance of the vortex tube. The effect of various parameters such as pressure gradient, viscosity, flow structure and acoustic structure on energy separation in vortex tube was reported by Xue and Arjomandi (2010)[5]. Rafiee et al. (2017) conducted numerical and experimental study about heat transfer and energy separation in a counter - flow vortex tube by using different shapes of hot outlet control valves [6]. An experimental analysis conducted by Kırmacı (2009) shows the refrigeration performance of a vortex tube which uses air and oxygen as working fluids [7]. Thakare et al. (2017) showed that the insulated condition of vortex tube gives better performance than non-insulated condition [8]. Effect of different nozzle materials on the thermal performance of the vortex tube was shown by Kırmacı et al (2017) [9]. Saidi and Yazdi (1999) carried out an exergy analysis of vortex tube to optimize vortex-tube energy separation [10]. Dinçer et al. (2010) investigated the performance of the vortex tube with a range of inlet pressure 200 kPa to 380 kPa [11]. Performance of PVC as vortex tube material was shown in [12]. In this study, an attempt is made to find out the performance of a counter-flow nylon made vortex tube. Here Oxygen gas is used as the working fluid due to its availability. No other study to authors knowledge has been conducted before to use nylon as vortex tube material. This study attempts to find out the feasibility of nylon as vortex tube construction material.

3. Assumptions

The followings assumptions are made for analysis

- No heat transfer towards and from the surrounding. The process is adiabatic.
- Flow is assumed to be turbulent.
- The outlet and atmospheric pressure are equal.
- No friction and losses take place.

4. Design and Constructional Features

Some of the constructional features of vortex tube are shown below:

- Material : Nylon
- Cold tube length =215 mm
- Cold inner tube diameter=12 mm
- Cold outer tube diameter= 19mm
- Hot tube outer diameter=39mm
- Hot tube inner diameter=24 mm
- Hot tube length= 505 mm
- Nozzle = 2mm
- Number of nozzle used=6
- Nozzle material=Nylon
- Chamber outer diameter =93mm
- Chamber inner diameter=49mm

5. Thermodynamic analysis:

This section represents some of the basic thermodynamic concepts for analyzing the Vortex tube. Cold mass fraction is the most essential parameter while analyzing a vortex tube. It can be defined as the ratio of cold mass released to the total input mass.

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

Where, m_c = Cold mass released, m_i= mass input, T= Temperature, i , c, h represents inlet , cold and hot.

Hot air temperature difference is the between hot air temperature and inlet temperature while cold air temperature difference is the difference between the inlet temperature and the cold air temperature.

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

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

Considering the gas behave like an ideal gas and the expansion is isentropic, the isentropic efficiency can be written as , $\eta_{is} = \frac{T_c}{T_{is}}$ (4)

The exit temperature of gas for isentropic expansion can be written as:

$$T_{is} = T_i \frac{(P_e)^{\frac{\gamma-1}{\gamma}}}{(P_i)} \quad (5)$$

Where, P_e is outlet pressure equaling ambient pressure and P_i is inlet pressure.

Cooling effect produced by the cold air of vortex tube can be written as:

$$Q_c = m_c\, C_p\, (T_c - T_i) \quad (6)$$

Here, m_c is cold mass flow rate and C_p is constant pressure specific heat for gas.

The heating effect produced by the vortex tube is:

$$Q_h = m_h\, C_p\, (T_h - T_i) \quad (7)$$

Here, is m_h hot mass flow rate.

The Coefficient of performance (COP) of a refrigerator can be defined as the ratio of refrigerating effect produced by the RHVT and work done on the system. The COP of a RHVT can be expressed as,

$$COP = \frac{\gamma \in}{\gamma - 1} \times \frac{(T_i - T_c)}{T_i (\ln \frac{P_i}{P_e})} \quad (8)$$

6. Results and Discussion:

In this analysis, the aim is to determine the effect of the cold mass fraction on various properties of vortex tube such as isentropic efficiency, COP, cold air temperature drop and hot air temperature drop while keeping the mass flow rate constant to 1 kg/s. The various data and parameters used in this study are shown in Table 1and Table2.

Table1. Data of the vortex tube used in this study .

P (bar)	T_i(^{0}C)	T_h(^{0}C)	T_c (^{0}C)	ϵ
2	26.9	33.4	23.5	0.66
3	26	37.5	18.3	0.60
4	21.8	40.1	10.1	0.61
5	18.1	43	4.9	0.65

Table2: Calculated parameters of the vortex tube

ΔT_c °C	ΔT_h °C	T_{is} ^{0}C	η_{is}	COP	Q_c (watt)
3.4	65	32.72	0.72	0.04	3.12
7.7	11.5	35.48	0.52	0.05	7.06
11.7	18.3	29.74	0.34	0.06	10.74
13.2	24.9	28.54	0.18	0.062	12.11

Figure 2 shows the effect of the cold mass fraction on cold temperature difference and hot temperature difference. With the decreasing of the cold mass fraction, hot temperature difference at first increases for 0.65 but gradually it decreases for 0.61 and 0.60.When cold mass fraction decreases from 0.66 to 0.65, cold air temperature difference increases from 3.4 to 13.2 K. Further decreasing of the cold mass fraction results in decreasing cold air temperature difference.

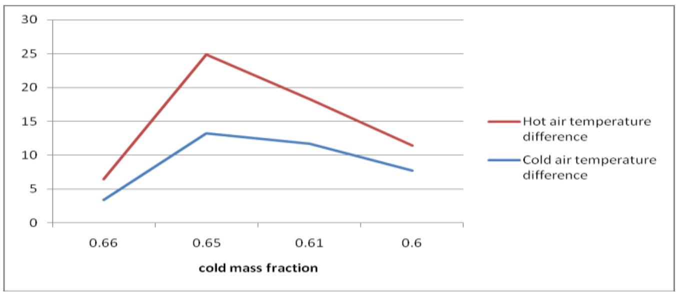

Figure 2. Effect of cold mass fraction on hot and cold air temperature difference .

Figure3 shows the effect of the cold mass fraction on cooling effect of the vortex tube. From Figure 4, it can be seen that when ∈ is decreased from 0.66 to 0.65 the cooling effect increases from 3.12 watt to 12.11 watt. With the further decrease of ∈ , cooling effect decreases resulting in 7.06 watt.

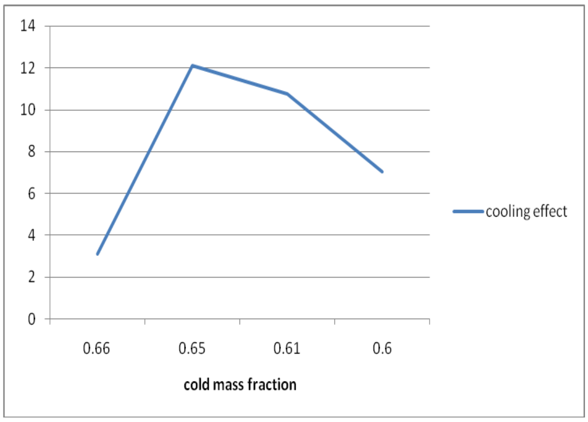

Figure3. Effect of cold mass fraction on cooling effect of vortex tube .

Figure 4 shows the effect of ∈ on COP. Maximum COP obtained is 0.06 and minimum COP obtained is 0.04. Here we assumed that the compression occurs in reversal isothermal process.

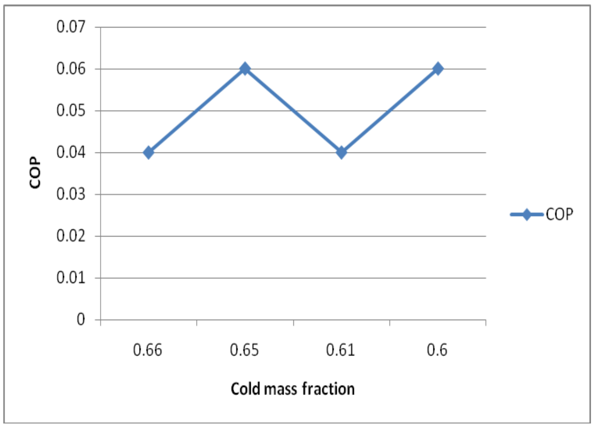

Figure 4. Effect of cold mass fraction on COP.

Figure 5 shows the effect of the cold mass fraction on the isentropic efficiency of the vortex tube. When cold mass fraction ∈ decreased from 0.66 to 0.65, then the isentropic efficiency decreases from 72 % to 18% . With the further decrease of ∈ to 0.60, isentropic efficiency increases to 52%.

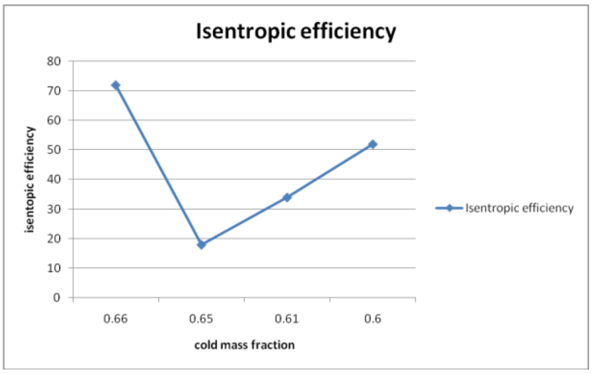

Figure 5: Effect of the cold mass fraction on the isentropic efficiency of the vortex tube.

8. Conclusion:

In this analysis, an experimental investigation has been carried out on the performance of nylon made vortex tube. Effect of the cold mass fraction on various properties of vortex tube has been presented while keeping the mass flow rate constant. Some of the major findings of the study can be summarized as below:

- Maximum COP is 0.06.
- Maximum isentropic efficiency is 72%.
- Maximum cooling effect is 12.11 watt.
- With the decreasing of the cold mass fraction, hot air temperature difference at first increases but gradually it decreases.

The study mainly focuses on finding the prospect of nylon in constructing the vortex tube and evaluating various thermodynamic prospects while keeping the mass flow rate of gas constant. The results can be varied by changing the mass flow rate and changing the assumptions as mentioned above.

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