The effect of vortex generator materials and L/D ratios on performance of stainless vortex tube

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Abstract. The effect of vortex generator materials and the length to diameter ratios (L/D) on the performance of a vortex tube was investigated experimentally. The vortex tube was constructed from stainless material while the vortex generator materials are stainless and brass. The ratio of length to diameter of the vortex tube is 17.5 and 20. The test was carried out at an inlet air pressure of 1.5 bar and the cold mass fraction vary from 0.4 to 1. The results showed that the cold air temperature difference, hot air temperature difference and isentropic efficiency of the stainless vortex tube with stainless vortex generator were higher than the stainless vortex tube with brass vortex generator at 22%, 5% and 13.5% respectively. In term of L/D ratio, the result shows that the cold air temperature difference of the vortex tube with the ratio of 17.5 was 4% higher than the vortex tube with the ratio of 20. It is also found that the stainless vortex generator and the L/D ratio of 17.5 achieve the highest performance.

1. Introduction

The vortex tube is a device that can separate a single compressed air stream into cold and hot streams at the same time. The vortex tube is compact and made of a strong and durable material. There is no moving part when it operates; therefore, the device requires less maintenance and could have a long lifetime. Natural refrigerants such as air, nitrogen and carbon dioxide can be used. The vortex tube is employed in an industrial as the spot cooling device while others use to reduce the temperature of electronic components during operation. According to those advantages, the vortex tube has been attracted by many researchers. Several studies were done to improve its performance. Eiamsa-ard and Promvonge [1] reported an increase of the vortex tube performance depended on two important parameters that are physical parameters such as inlet pressure, working fluid, and cold mass fraction, and geometrical parameters such as tube length, tube diameter, hot valve shape, and number of inlet nozzle. Others were design for the optimum geometrical parameters. Darokar *et al*. [2] investigated the performance of the brass vortex tube by experimental testing. A vortex generator with 6 inlet nozzles and the conical valve angle of 60° were constructed. The result shows the highest cold air temperature difference roughly 12°C and the hot air temperature difference of about 9°C for an inlet air pressure of 2 bar. Im and Yu [3] studied the vortex tube made of steel that also has 6 inlet nozzles and conical valve angle 60° that experiment with the inlet air pressure of 1.57 bar. The result shows greater both cold and hot different temperature than previous research [2]. Darokar *et al.* [2] and Im and Yu [3] reported that material of the vortex tube has affected on vortex tube performance. Kargaran and Farzaneh-Gord [4] presented the effect of the length of vortex tube on the separated temperature at inlet pressure of 4.2 bar. It was found that the maximum cold air temperature difference was 5.8°C, 6.5°C, and 7°C for the L/D of 10, 20, and 30 respectively. It indicated that L/D in the range from 10 to

20 has higher temperature difference than L/D range from 20 to 30. Dincer *et al.* [5] studied the performance of heating and cooling of vortex tube at the length to diameter ratio (L/D) between 15 and 18 at inlet pressure of 4.5 bar. It was found the highest cold different temperature at the L/D of 18 and the maximum hot air temperature difference at the L/D of 17. The results from Kargaran and Farzaneh-Gord [4] and Dincer *et al*. [5] showed that the range of L/D ratio from 17 to 20 is good for the cooling and heating performance of the vortex tube.
The current research aims to study the performance of vortex tube regarding the vortex generator materials and the L/D ratio. The two vortex generators made of stainless and brass while the vortex tube made of stainless were investigated. Moreover, the length to diameter ratios (L/D) of 17.5 and 20 was selected for good performance.

2. Experimental study

In the present study, a vortex tube is constructed and test. The vortex tube material is stainless for all parts and an extra vortex generator made of brass. Two geometrical parameters included 6 nozzle intakes vortex generator materials, stainless and brass, and the length to diameter ratios, 17.5 and 20 were tested. The dimension of the cold orifice diameter is 5.3 mm. The inner tube diameter of the vortex tube is 10 mm. In the testing, the inlet air pressure was injected into the vortex tube at 1.5 bar. The cold mass fraction was adjusted at the control valve of the hot tube from 0.4 to 1. The set-up schematic diagram of the test is shown in figure 1.

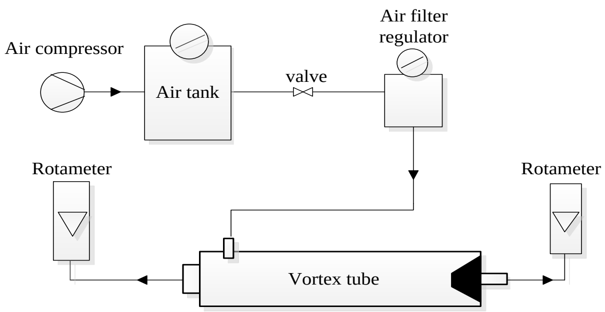

Figure 1. Schematic diagram of the experimental setup of vortex tube.

The air is compressed by an air compressor then is stored in the air tank. The compressed air is delivered to the air filter with pressure regulator as to filter the dust and humidity and to control the air pressure at constant inlet pressure for the vortex tube testing. The compressed air is injected into the vortex tube then separated into two air streams that are cold and hot air streams. The vortex tube has two outlets for cold and hot outlets. Both cold and hot outlet are connected with rotameter for measuring the air flow rate. The temperatures of the inlet tube and two outlet tubes were measured by thermocouple type K and recorded by a data logger.

3. Data reduction

Cold mass fraction is the ratio of cold air mass flow rate (m_{cold}) to inlet air mass flow rate (m_{in}) as can be written as

$$CF = m_{cold} / m_{in} \tag{1}$$

The cold air temperature difference (ΔT_c) and the hot air temperature difference (ΔT_h) expressed in equation (2) and (3) respectively. These two imply the performance of vortex tube, i.e.

$$\Delta T_c = T_{in} - T_{cold} , \tag{2}$$

$$\Delta T_h = T_{hot} - T_{in} , \tag{3}$$

where T_{in} is inlet temperature, T_{cold} is cold outlet temperature, and T_{hot} is hot outlet temperature.

The isentropic efficiency (η_{is}) of the vortex tube used the law of adiabatic expansion for an ideal gas is expressed as

$$\eta_{is} = \frac{T_{in} - T_{cold}}{T_{in}\left[1 - \left(P_{atm}/P_{in}\right)^{(k-1)/k}\right]} \quad (4),$$

where P_{atm}, P_{in}, and k are the atmospheric pressure, inlet air pressure and the specific heat ratio respectively.

4. Results and discussions

4.1. The effect of the vortex generator materials

Figure 2 shows the effect of the vortex generator materials on the temperature difference in the left of y-axis against variation of the cold mass fractions. It shows that the increasing hot air temperature difference (ΔT_h) varies directly to the cold mass fraction range from 0.4 to 0.8, but then dropped quickly for the cold mass fraction over 0.85. The maximum hot air temperature difference shows its highest value at the cold mass fraction of 0.8. The vortex tube with stainless vortex generator provide higher ΔT_h than the brass vortex generator with the ΔT_h of 23°C against 21.9°C. Moreover, at the cold mass fraction range from 0.4 to 0.49, the cold air temperature difference (ΔT_c) increased and then it decreased to the cold mass fraction of 0.49 due to the effect of opening control valve at hot outlet that has influenced to cold mass fraction. The vortex tube with both vortex generator offer maximum ΔT_c at the cold mass fraction of 0.49. The stainless vortex generator provides higher ΔT_c than the brass vortex generator. Im and Yu [3] found the vortex tube with 6 nozzle intakes operate at the inlet air pressure of 1.57 bar and cold mass fraction of 0.5 reached the maximum cold air temperature difference of 19°C which is similar to the current research results.

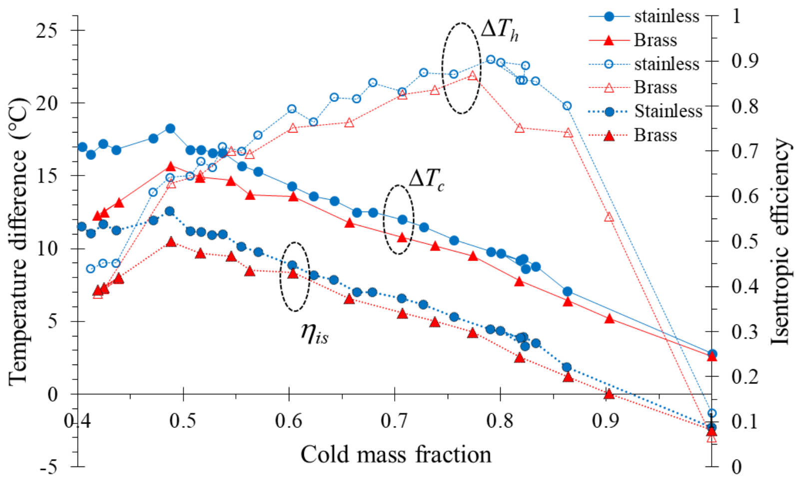

Figure 2. The effect of vortex generator materials on the temperature difference (ΔT_c, ΔT_h) and the isentropic efficiency (η_{is})

Figure 2 shows the isentropic efficiency (η_{is}) of vortex tube on the right y- axis that the vortex tube with stainless and brass vortex generator has the highest isentropic efficiency of 0.57 and 0.50 respectively at the cold mass fraction of 0.49. Figure 2 indicates the performance of vortex tube with stainless vortex generator is greater than the vortex tube with brass vortex generator according to the experimental results.

4.2. The effect of the ratios of length to diameter (L/D)

Figure 3 shows the effect of length to diameter ratios (L/D) on the temperature difference. It indicated that both of L/D ratios, 17.5 and 20, have nearly the same value of the cold air temperature difference **(**ΔT_c**)** and the hot air temperature difference **(**ΔT_h**)**. The highest of ΔT_c is 18.3°C and 17.6°C for L/D of

17.5 and 20 respectively at a cold mass fraction of 0.49, while the ΔT_h for both L/D ratios is the same of 23°C at the cold mass fraction range 0.73 to 0.82. This picture also shows the result of the isentropic efficiency on L/D ratios that has the same trend line of the cold air temperature difference. The result found that the maximum isentropic efficiency of the L/D ratios at 17.5 and 20 was the same for 0.55 at the cold mass fraction 0.49.

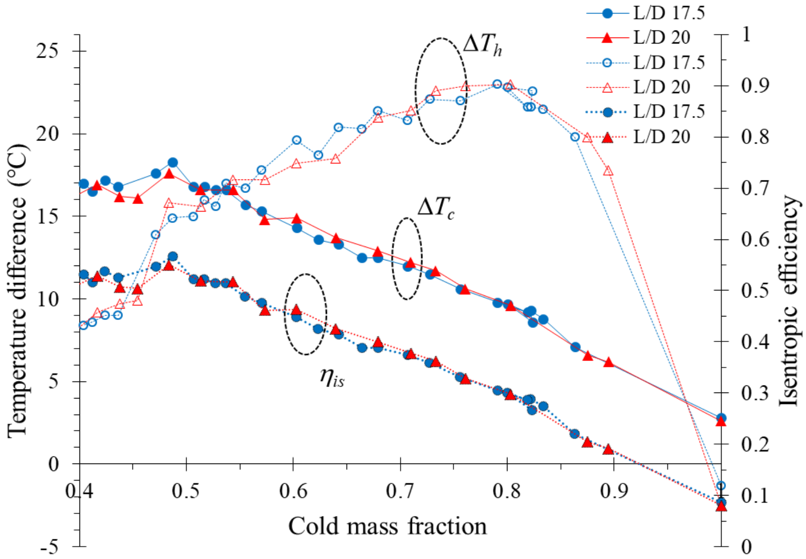

Figure 3. The effect of L/D ratios on the temperature difference (ΔT_c ,ΔT_h) and the isentropic efficiency (η_{is})

5. Conclusions

This experimental result shows that the performance of a vortex tube is affected by vortex generator materials and length to diameter ratios. The vortex tube with a stainless vortex generator offers the highest cold air temperature difference, hot air temperature difference, and isentropic efficiency of 23°C, 18.3°C, and 0.57 respectively. It is indicated that vortex tube with stainless vortex generator has higher performance than a brass vortex generator according to the research experimental results.

Acknowledgments

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References

[1] Eiamsa-ard S and Promvonge P 2008 Review of Ranque–Hilsch effects in vortex tubes *Renew. Sust. Energ. Rev.* **12** 1822

[2] Darokar H V, Borse S L and Devade K D Experimental Investigations on Divergent Vortex Tube with Convergent Entry Nozzles *Int. J. Eng. Res. Technol.* **1** 6

[3] Im S Y and Yu S S 2012 Effects of geometric parameters on the separated air flow temperature of a vortex tube for design optimization *Energy* **37** 154

[4] Kargaran M and Farzaneh-Gord M 2013 An experimental study of the effect of pressure inlet gas on a counter-flow vortex tube *Front. Heat Mass Trans.* **4** 6

[5] Dincer K, Berber A and Ozen D N 2013 Investigation of Performance of Heating and Cooling of Counter Flow Ranque-Hilsch Tubes with L/D=15, 16, 17, 18 for Brass *Appl. Mech. Mater.* **372** 350