Experimental Study of the Effect of Wall Friction on Cooling Performance of RHVT

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ABSTRACT: *This paper presents the experimental results of the investigation performed on Ranque Hilsch Vortex Tube (RHVT) refrigerator with different control valve location on hot tube outlet side and the effect of wall friction on the inner wall of hot tube. Compressed air at a pressure of 40 psi, 50 psi, 60 psi, 75 psi and 85 psi was introduced at the inlet. At a particular inlet pressure, cooling effect was measured with and without wall friction with respect to valve positions at the hot tube outlet. The result indicates that with wall friction the energy separation is less effective as compared to without wall friction but in both the cases at a particular valve position, maximum energy separation is achieved. The results also indicate a decrease in cold side temperature with an increase in inlet air pressure for a particular valve position for both the cases.*

Keywords - *Vortex tube, compressed air, wall friction, energy separation.*

I. INTRODUCTION

The vortex tube is a simple yet intriguing mechanical device without any moving parts which when injected tangentially with pressurized gas causes it to separate into two low pressure streams at different temperatures – one colder than the inlet flow and the other hotter. Such a separation of the flow into two different temperature flows is termed as the temperature or energy separation effect. Tangential injection of gas through one or more inlet nozzles causes the gas to swirl at a high velocity.

The gas (usually air) swirls at a high velocity in the hot tube and moves towards the hot end. The presence of conical control valve at the hot end develops a back pressure and causes some of the air to turn back and flow through the orifice exhausting through the cold end as can be seen in Figure 1.

There may be many industrial applications of RHVT due to its compact design such as cooling of electrical parts, cutting tools, thermally stressed parts of machines, cooling suits/jackets etc. Due to no moving parts in the assembly, it is less prone to breakage or wear and hence less maintenance is required. But there is a requirement of a compressed gas source which limits its wide usage.

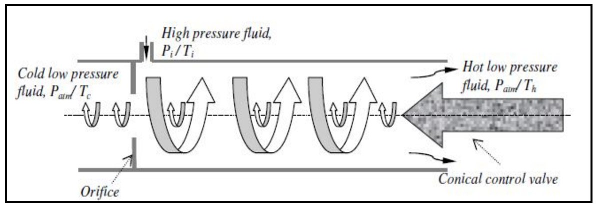

Fig. 1 Schematic diagram of Counter flow vortex tube

The vortex tube was first invented accidently in 1928. George Ranque [1] a French Physics student, was experimenting with a vortex type pump he had developed when he noticed warm air exhausting from one end, and cold air from other. Ranque soon forgot about his pump and started a small firm to exploit the commercial potential for this strength device. The design of vortex tube was improved by Hilsch [2].

Linderstrom-Lang [3] studied the gas separation occurring in the vortex tube. He concluded that the separation effect as a function of hot mass flow fraction varies with constructional parameters. Among these the ratio of the diameters of the two orifices through which the gas escapes from the tube, is dominant.

Dincer et al [4] determined experimentally the effects of position, diameter (5, 6, 7, 8 mm) and angle (30°–180°) of the movable plug, located at the hot outlet side in a Ranque–Hilsch Vortex Tube (RHVT), for best performance.

Nimbalkar et al [5] presented the results of a series of experiments focusing on various geometries of the “cold end side” for different inlet pressures and cold fractions.

Rahim et al [6] investigated numerically the effects of the number of nozzles on the flow and cooling performance of a counter-flow vortex tube. They observed that as the number of nozzles is increased, power of cooling increases significantly while cold outlet temperature decreases moderately.

Markal et al [7] experimentally studied the effects of conical valve angle on thermal energy separation in a counter-flow vortex tube. A new geometry was designed for the cold end side, which was named ‘helical swirl flow generator’.

Valipour et al [8] carried out a series of experiments to investigate the influence of uniform curvature of hot tube on the performance of the vortex tube. Results show that the curvature in the main tube had varied effects on the performance of the vortex tube depending on inlet pressure and cold mass ratio.

Xue [9] in his experimental study found that the flow in the tube consists of a forced vortex formed near the inlet gradually transforming to a free vortex at the hot end.

Agrawal [10] experimentally investigated the influential parameters such as L/D ratio, cold mass fraction, inlet pressure etc. on Ranque-Hilsch vortex tube, using air, nitrogen and carbon dioxide as a working gas. It was found that vortex tube performs better with carbon dioxide as working fluid.

In the present study, the effect of hot tube wall friction is investigated and it was found that wall friction decreases cooling performance.

II. EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows the line diagram of a Counter flow Ranque-Hilsch Vortex Tube and figure 2 shows the experimental setup. The vortex tube was made using PVC pipe having inner diameter of hot and cold tube of 25.4 mm. The length of hot tube was taken as 270 mm whereas length of cold tube was kept small at 75mm. A conical valve of mild steel having 25.4 mm diameter and conical angle 11.25^o was used to control the cold mass flow fraction. A two stage compressor Model 125L, Range 100 to 213 psi, Zen Air Tech Pvt. Ltd was used to supply pressurized air.

Fig. 2 The experimental setup

For providing wall friction on the inner surface of hot tube a cylindrical wire mesh was inserted as shown in figure 3.

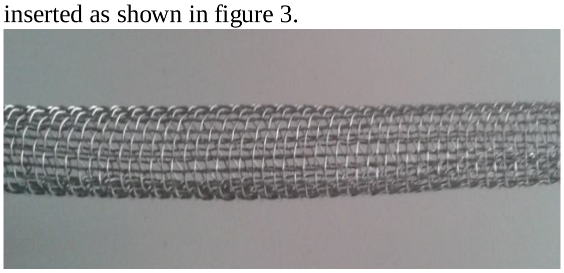

Fig. 3 The cylindrical wire mesh

Temperature was measured with CNX t3000 wireless K-Type temperature module with uncertainty of 0.1 ^oC. In the experiment, different inlet pressure sets were used in the test ranging from 40 psi to 85 psi at room inlet temperature.

All experiment runs were conducted in similar manner following a specific procedure, where compressor runs for one hour to allow reaching steady state temperature of inlet compressed air.

III. ERROR IN MEASUREMENTS

The errors associated with temperature and pressure measurements are examined in this section. The maximum possible errors in various measured parameters, namely temperature and pressure were estimated by Moffat [11]. Errors were estimated from the minimum values of output and the accuracy of the instrument. This method is based on careful specification of the uncertainties in the various experimental measurements. If an estimated quantity, Y depends on independent variables like x_i then the error in the value of "Y" is given by

$$\frac{\partial Y}{Y} = \sqrt{\sum_i^n \left(\frac{\partial x_i}{x_i}\right)^2}$$

Where

∂x_i = Accuracy of the measuring instrument

x_i = Minimum Value of the output measured

Error in temperature measurement:

A k-type digital temperature indicator thermocouple was used to measure the hot and cold end air flow temperatures. Temperatures were logged in file with accuracy of 0.1 ^oC. The maximum possible error in the case of temperature measurement was calculated from the minimum values of the temperature measured and accuracy of the instrument. The error in the temperature measurement is:

$$\frac{\partial T}{T} = \sqrt{\left(\frac{\partial T}{T_{\min}}\right)^2 + \left(\frac{\partial T_{\log}}{T_{\min}}\right)^2}$$

$$= \sqrt{\left(\frac{0.1}{4.3}\right)^2 + \left(\frac{0.1}{4.3}\right)^2} \approx 0.03 = 3\ \%$$

Error in pressure measurement

Pressure gauge was used to measure the gas pressure. Pressures directly were logged in pressure gauge with an accuracy of 1 psi. The error in the pressure measurement is:

$$\frac{\partial P}{P} = \sqrt{\left(\frac{\partial P}{P_{min}}\right)^2 + \left(\frac{\partial P_{log}}{P_{min}}\right)^2}$$
$$= \sqrt{\left(\frac{1}{40}\right)^2 + \left(\frac{1}{40}\right)^2} \approx 0.03 = 3\ \%$$

IV. RESULTS

In the present experimental study, performance of counter flow Ranque-Hilsch vortex tube with and without wall friction on its inner surface was investigated experimentally using different inlet pressures. Air coming from compressor was introduced to the vortex tube via the nozzle. Flow was controlled by a conical control valve on the hot outlet side, where the valve was changed from a fully closed position to its nearly open position.

The cooling performance is defined as

$$\Delta T_c = T_i - T_c$$

Where

T_c is the temperature of the cold stream.

T_i is the temperature of the inlet system.

The graph between ΔTc and valve position at different inlet pressure is shown in Figures 4 – 8.

Valve position 0 mm means the hot tube outlet is fully closed and all the air passed through the cold outlet whereas valve position 10 mm means hot tube outlet is nearly open and maximum air passed through the hot outlet.

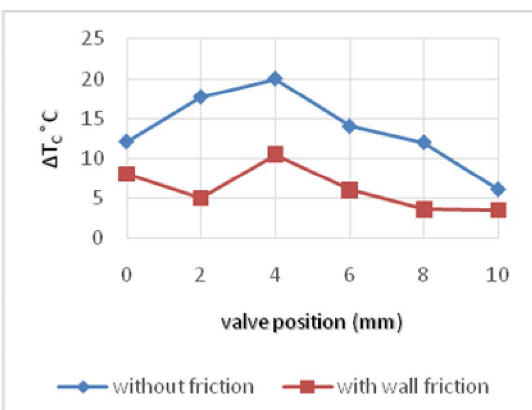

Fig. 4 Effect of wall friction on temperature separation at inlet pressure 40 psi

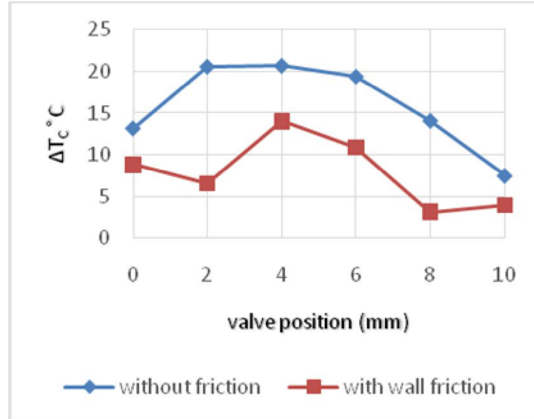

Fig. 5 Effect of wall friction on temperature separation at inlet pressure 50 psi

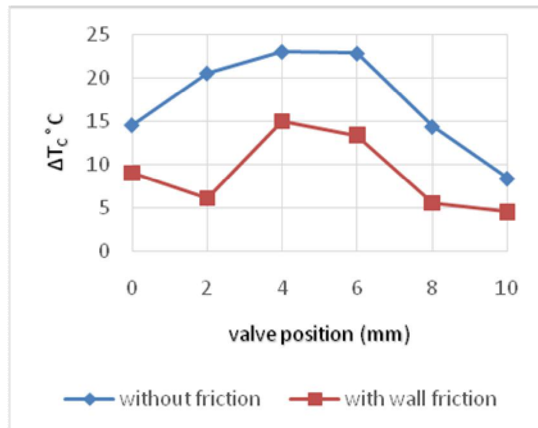

Fig. 6 Effect of wall friction on temperature separation at inlet pressure 60 psi

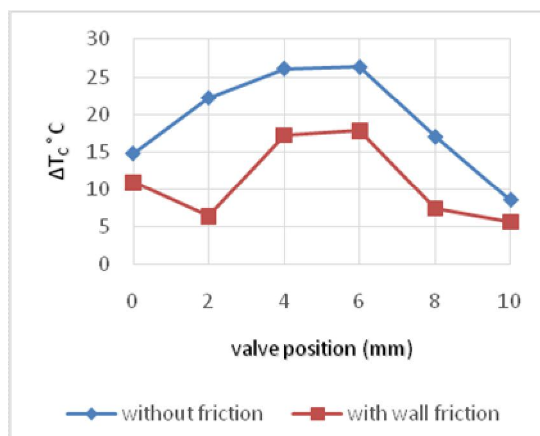

Fig. 7 Effect of wall friction on temperature separation at inlet pressure 75 psi

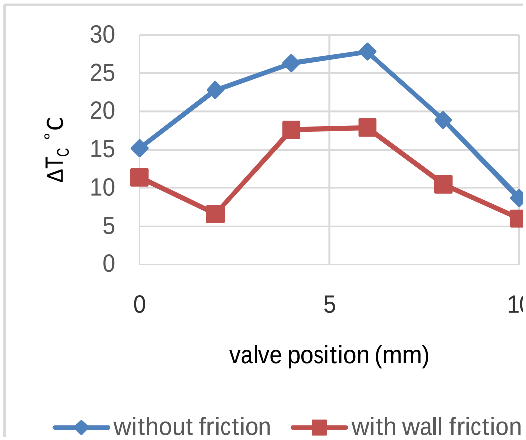

Fig. 8 Effect of wall friction on temperature separation at inlet pressure 85 psi

V. CONCLUSIONS

In this experimental study, performance of a counter flow Ranque-Hilsch vortex tube with and without wall friction on its inner surface was investigated. It was concluded that the energy separation is less effective with wall friction as compared to vortex tube without wall friction as can be observed in Figures 4- 8.

Also for a particular test run, it can be noted that cooling performance reaches a maxima at a particular valve position for both the cases of with and without friction. The effect of friction could be an increase of temperature near the periphery of hot tube which also affects the inner flow temperature thus reducing the cold end fluid temperature.

Thus it can be concluded that inner wall friction of the hot tube is an important parameter in temperature separation and efforts should be made to make the surface smooth so that high level of cooling can be achieved with vortex tube.

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