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Experimental Study of Performance of a Counter Flow Ranque-Hilsch Vortex Tube with Inner Threaded Body

Gürol Önal and Kevser Dincer

***Abstract*—**In this experimental study, performance of a counter flow Ranque-Hilsch vortex tube (RHVT) with threads cut on its inner surface was investigated experimentally (pitch is 1 and 2 mm). The inner diameter of the vortex tube used was D=9 mm and the ratio of the tube's length to diameter was L/D=12. The experimental system was a thermodynamic open system. Flow was controlled by a valve on the hot outlet side, where the valve was changed from a nearly closed position to its nearly open position. Fraction of cold flow (ξ) = 0.1-0.9, was determined under 300 and 350 kPa pressurized air. All experimental data were compared with each other, the maximum heating performance of the RHVT system was found to be 38.2 ^oC and the maximum cooling performance of the RHVT in this study was found to be -30.9 ^oC at pitch 1 mm.

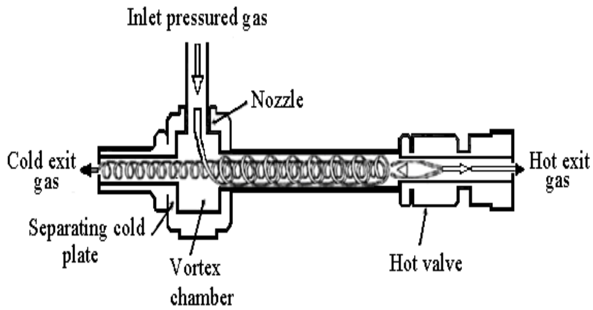
***Keywords*—**Ranque-Hilsch vortex tube, heating, cooling, temperature separation.

I. Introduction

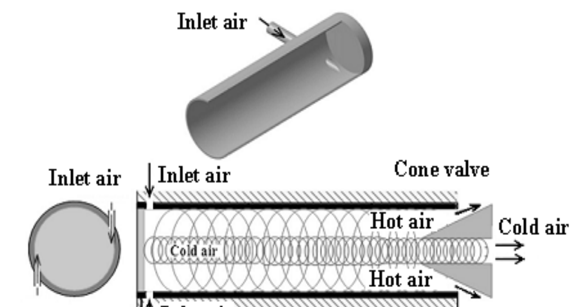
THE vortex tube, also known as Ranque Vortex Tube, Hilsch Vortex Tube, and Ranque-Hilsch vortex tube, is a device which enables the separation of hot and cold air as pressurized air flows tangentially into the vortex chamber through inlet nozzles. The vortex tube was first discovered in 1933 by metallurgist and physicist Ranque, and the German physicist Rudolf Hilsch improved the design. A Ranque-Hilsch vortex tube consists of one or more inlet nozzles, a vortex chamber, a cold-end orifice, a hot-end control valve and tube. Special internal configurations of the designed vortex chamber combined effects of pressure and accelerated air to a high rate of rotation (over million rpm) [1].

The vortex tube can be classified into two types. Both hot and cold flows in parallel flow RHVTs leave the vortex tube in the same direction (Fig. 1 (a)). It is not possible for cold flow to turn back after a stagnation point. In order to separate the flow in the center of the tube from the flow at the wall, an apparatus which has a hole in the center is used. The temperature of hot and cold flows can be changed by back and forth movement of this apparatus. In parallel flow RHVTs, hot and cold flows mix with each other. Working principle of the counter-flow RHVT can be defined as follows (Fig. 1 (b)). Compressible fluid, which is tangentially introduced into the vortex tube from nozzles, starts to make a circular movement inside the vortex tube at high speeds,

Because of the cylindrical structure of the tube, depending on its inlet pressure and speed. As a result of this, pressure difference occurs between the tube wall and tube center because of the friction of the fluid circling at high speeds. Speed of the fluid near the tube wall is lower than the speed at the tube center, because of the effects of wall friction. As a result, fluid in the center region transfers energy to the fluid at the tube wall, depending on the geometric structure of the vortex tube. The cooled fluid leaves the vortex tube from the cold output side, by moving towards an opposite direction, compared to the main flow direction, after a stagnation point. Whereas, the heated fluid leaves the tube in the main flow direction from the other end of the tube [2].



a) Parallel flow RHVT



b) Counter-flow Ranque-Hilsch

Fig. 1 The schematic representation of Ranque-Hilsch vortex tube principle

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In this experimental study, performance of a counter flow Ranque-Hilsch Vortex tube with threads cut on its inner surface was investigated experimentally. When all the experimental results were evaluated together, $\Delta T_{h,max}$ and $\Delta T_{c,max}$ values obtained were as follows:

- $\Delta T_{h,max}$ =38.2 ^oC at ξ=0.9, pitch 1 mm and 350 kPa.
- $\Delta T_{c,max}$ = -30.9 ^oC at ξ= 0.3 pitch 1 mm and 350 kPa.

where $\Delta T_{h,max}$ is the maximum heating performance of the RHVT and $\Delta T_{c,max}$ is the maximum cooling performance of the RHVT.

II. Experimental Study

In this experimental study, performance of a counter flow Ranque-Hilsch vortex tube with threads cut on its inner surface was investigated experimentally (pitch is 1 and 2 mm). The inner diameter of the Vortex tube used was D=9 mm and the ratio of the tube's length to diameter was L/D=12. The experimental system was a thermodynamic open system. Number of nozzle is 5. The conical edges of the plugs have a slope of 30º. Conical tip plugs were mounted right over the hot fluid exit of the vortex tube and have diameters of 5 mm. Compressed air was supplied by a rotary screw compressor. Air coming from the compressor was introduced to the vortex tube via the nozzles. Flow was controlled by a valve on the hot outlet side, where the valve was changed from a nearly closed position to its nearly open position. Fraction of cold flow (ξ)=0.1-0.9, was determined under 300 and 350 kPa pressurized air. The conical edges of the plugs were set at a slope of 30º angle.

The temperatures of cold outlet flow, hot outlet flow and the inlet flow were measured with 24-gauge copper-constantan thermocouples. Throughout the tests, the valve on the cold stream exit side was set at full throttle whereas that on the hot exit was set to a near closed position gradually from full throttle, in this way, the system pressure, temperature and volumetric flow rates were measured and used for calculations. In this study, heating and cooling performance of RHVT, which has been made of brass (it contains 33 percent zinc) was investigated experimentally. The heating performance (ΔT_h) of RHVT is defined in (1) and its cooling performance (ΔT_c) is defined in (2).

$$\Delta T_h = T_h - T_i \tag{1}$$

$$\Delta T_c = T_c - T_i \tag{2}$$

where T_h is the temperature of hot stream and T_c is the temperature of cold stream. Here T_i is the temperature of inlet stream. In this study, the heating and cooling performance of RHVTs was determined by taking cold stream fraction into consideration. The cold flow fraction (ξ) is defined as the ratio of the mass flow rate of the cold stream ($\dot{m}_c$) to the mass flow rate of the inlet stream ($\dot{m}_i$). ξ is given as follows [3], [4].

$$\xi = \frac{\dot{m}_c}{\dot{m}_i}$$

In this study, flow was controlled by a valve on the hot outlet side, whereby this valve was changed from a nearly closed position from its nearly open position. In this case, ξ=0.1-0.9 was determined.

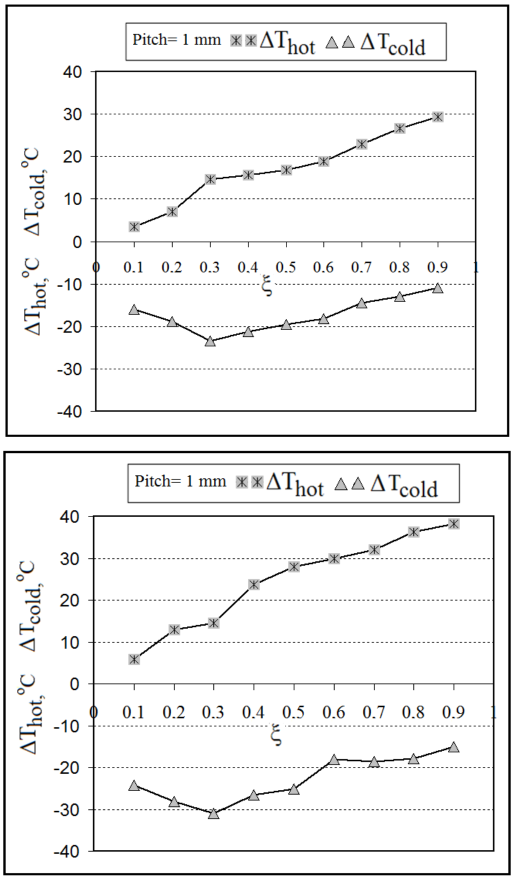
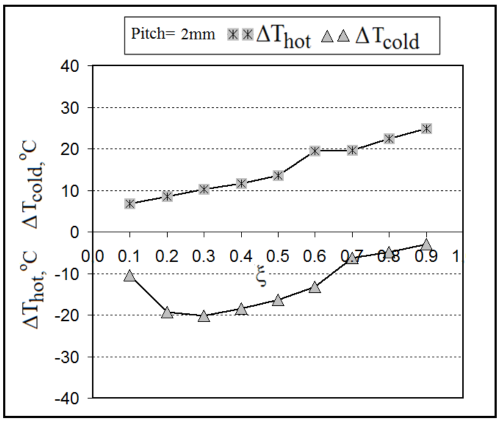


Fig. 2 Heating performance and the cooling performance of RHVT at 300 kPa

III. Result and Discussion

In this study, flow was controlled by a valve on the hot outlet side. Working fluid was compressed air provided by a rotary screw compressor. Compressed air reached the vortex tube via the nozzles Particularly, the system was initially brought to a thermal steady state, before the experiments were performed. The experimental system reached the steady state in about 10 min. The heating performance of RHVT was calculated using (1) while the cooling performance was calculated using (2). In this case, ξ=0.1-0.9 was determined. In

Figs. 2-3, the heating performance and the cooling performance of RHVT have been presented. Increase in ξ, was caused by the increase in mass flow rate of cold stream and by decrease in mass flow rate of hot stream. When all the experimental results were compared with each other, it was found that, the maximum heating performance of the RHVT was 38.2 ^{o}C (at pitch=1 mm, 350 kPa) and the maximum cooling performance was -30.9^{o}C (at pitch=1 mm, 350 kPa).



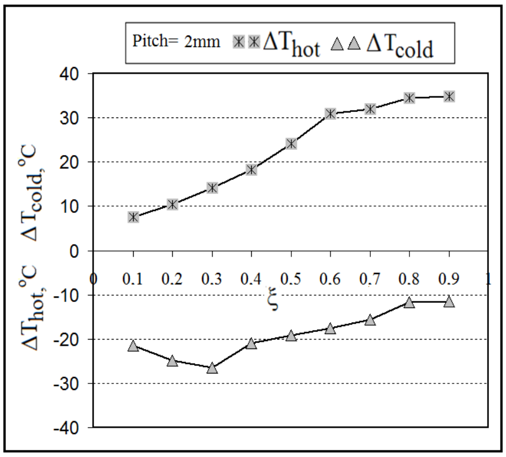


Fig. 3 Heating performance and the cooling performance of RHVT at 350 kPa

IV. Conclusions

In this experimental study, performance of a counter flow Ranque-Hilsch vortex tube with threads cut on its inner surface was investigated experimentally, and the conclusions drawn in this paper are summarized as follows:

- The ΔT_h has increased when the effects of increasing ξ were taken into account.
- At ξ=0.9, mass flow rate of the cold stream is maximum while hot stream mass flow rate is minimum.
- When the mass flow rate of the cold stream was maximum (at ξ=0.9), heating performances of RHVT were maximum and cooling performances of RHVT were minimum.
- All experimental data were compared with each other, the maximum heating performance of the RHVT system was found to be 38.2 ^{o}C (350 kPa) and the maximum cooling performance of the RHVT in this study was found to be -30.9 ^{o}C at pitch 1 mm (350 kPa).

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