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PERFORMANCE OF 2-STAGE PVC HOT CASCADE TYPE RANQUE-HILSCH VORTEX TUBE

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ABSTRACT

Vortex tube is a non-conventional cooling device, having no moving parts which will produce cold air and hot air from the source of compressed air without affecting the environment. When a high pressure air is tangentially injected into vortex chamber a strong vortex flow will be created which will be split into two air streams. It can be used for any type of spot cooling or heating application. In this paper, three Ranque-Hilsch vortex tubes were used, which have 25 mm inside diameter and length/diameter ratio was 12. Their performances were examined as one of the classical Ranque-Hilsch vortex tube and other was hot cascade type Ranque-Hilsch vortex tube. Performance analysis was according to temperature difference between the hot outlet and the inlet (ΔT_{hot}.), temperature difference between the inlet and the cold outlet (ΔT_{cold}.) and Coefficient of Performance (COP). The ΔT_{hot} values of hot cascade type Ranque-Hilsch vortex tubes were greater than the ΔT_{hot} values of classical Ranque-Hilsch vortex tube and ΔT_{cold} values of hot cascade type Ranque-Hilsch vortex tubes were greater than the ΔT_{cold} values of classical Ranque-Hilsch vortex tube, which were determined experimentally. It was found that hot cascade type vortex tube Ranque-Hilsch COP is better than the classical Ranque-Hilsch vortex tube COP.

INTRODUCTION

The vortex tube, also known as Ranque vortex tube, Hilsch vortex tube, and Ranque-Hilsch vortex tube, is a device that enables the separation of hot and cold pressurized gas that flows tangentially into the vortex chamber through inlet nozzles. A Ranque-Hilsch vortex tube contains one or more inlet nozzles, a vortex chamber, a cold-end orifice, a hot-end control valve, and a tube. In a vortex tube, high-pressure gas stream enters tangentially, and by lowering the pressure, it splits into a hot and cold temperature streams. Cold gas stream leaves the tube through a center orifice near the entrance nozzle, while hot gas stream flows toward the control valve and leaves the tube there (Kirmaci et al., 2010).The RHVT can be classified into two types: (1) the counter-flow RHVT and (2) the uni-flow RHVT, as shown in Fig. 1a and b, respectively. In general, the counter-flow RHVT is recommended over the uni-flow RHVT for its efficient energy separation. The RHVT is widely applied for both cooling and heating purposes. The major application is for cooling purpose, e.g. cooling of electric device, cooling of food, cooling of firemen’s suit, cooling of machinery during operation. In spite of its small capacity, the RHVT is very useful for certain applications because it is simple, compact, light, quiet in operation, and require no refrigerant (Eiamsa-ard et al., 2010).Until now, more than 100 investigations in the RHVT for both experimental and numerical works have been published. Some are briefly mentioned below. Secchiaroli et al. (2009) carried out a study on numerical simulation of turbulent flow in a Ranque-Hilsch vortex tube. They noted that a CFD analysis focused on velocity and temperature fields scaling with vortex tube dimensions could improve the potential of experimental verification of the internal flow field numerical prevision. Dincer et al. (2010) investigated experimental investigation and exergy analysis of the performance of a counter-flow Ranque-Hilsch vortex tube with regard to nozzle cross-section areas. Dincer et al. (2008a) conducted a study modeling of the effects of length to diameter ratio and nozzle number on the performance of counter-flow Ranque-Hilsch vortex tubes using artificial neural networks. Markal et al. (2010) investigated an experimental study on the effect of the valve angle of counter-flow Ranque-Hilsch vortex tubes on thermal energy separation. They noted that the effect of the valve angle on the performance changes according to the value of L/D and it has a weak influence on the system performance. Eiamsa-ard et al. (2010) carried out experimental investigation on energy separation in a counter-flow Ranque-Hilsch vortex tube: Effect of cooling a hot tube. They found that the temperature reduction of the cold tube and thus cooling efficiency in the RHVT with cooling of a hot tube is found to be higher than those of the RHVT without the cooling, under the similar operating conditions. Over the range investigated, the mean cold air temperature reduction and cooling efficiency of the RHVT with the cooling of a hot tube are, respectively, 5.5-8.8% and 4.7-9% higher than those of the RHVT without the cooling. There is lots of study in the literature about RHVT as the experimental, analytical and theoretical. Some of them are Eiamsa-ard and Promvonge (2007), Frohlingsdorf and Unger

(1999), Gao et al. (2005), Lewins and Bejan (1999), Saidi and Valipour (2003), Wu et al. (2007), Dincer et al. (2008b), Kirmaci (2009), Pinar et al. (2009). The others are Ahlborn and Gordon (2000), Saidi and Allaf Yazdi (1999), Aljuwayhel et al. (2005), Dincer et al. (2008c, d), and Behera et al. (2005). The exergy of an energy form or a substance is a measure of its usefulness or quality or potential change. Exergy is defined as the maximum work, which can be produced by a system or a flow of matter or energy and it comes to equilibrium with a specified reference environment (dead state). Unlike energy, exergy is conserved only during ideal processes and destroyed due to irreversibilities in real processes (Prommas et al., 2010). Exergy analysis is a thermodynamic method of using the conservation of mass and energy principles together with the second law of thermodynamics for the design and analysis of thermal systems. The purpose of an exergy analysis is generally to identify the location, the source and magnitude of true thermodynamic inefficiencies in a given process (Casasa et al., 2010). Sarhaddi et al. (2010) carried out exergetic performance assessment of a solar photovoltaic thermal (PV/T) air collector. They noted that that the thermal efficiency, electrical efficiency, overall energy efficiency and exergy efficiency of PV/T air collector is about 17.18%, 10.01%, 45% and 10.75%, respectively, for a sample climatic, operating and design parameters. Krasae-in et al. (2010) investigated exergy analysis on the simulation of a small-scale hydrogen liquefaction test rig with a multi-component refrigerant refrigeration system. They found that major losses resulted from the compressors, heat exchangers and expansion valves. To highlight the importance of exergy, the exergy efficiency indicated the proximity to the ideal minimum, whereas energy efficiency did not. Wang et al. (2010) investigated exergy performance and thermodynamic properties of the ideal liquid desiccant dehumidification system.

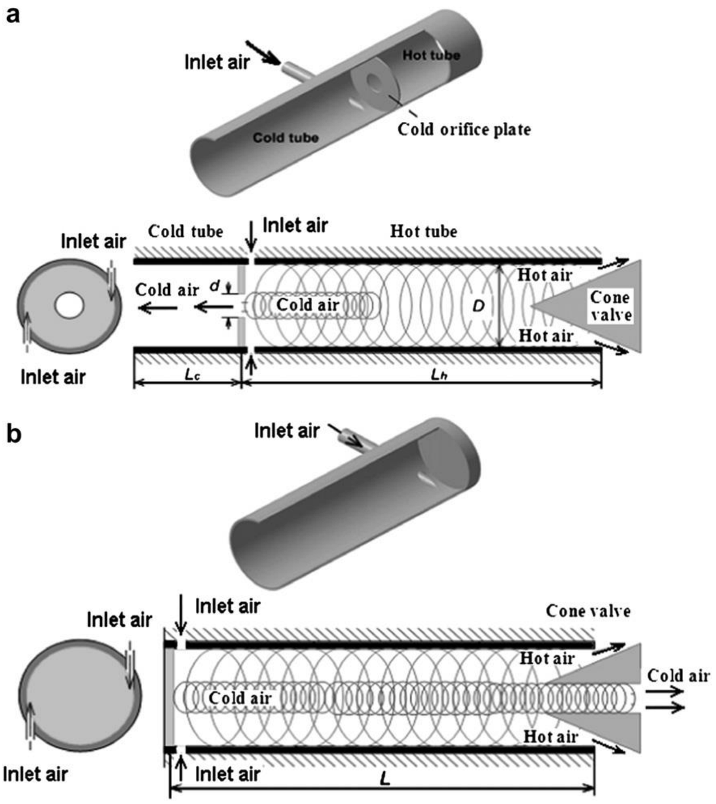

Fig. 1 Ranque-Hilsch vortex tube (RHVT) for (a) counter-flow type, and (b) uni-flow type

EXPERIMENTAL STUDY

In this study, three RHVTs have been examined as experimentally. One of them is a classic RHVT (Fig. 2). The other two are hot cascade type RHVT. In the hot cascade type RHVT, hot output of first RHVT was connected to input of second RHVT (Fig. 3). Three Ranque-Hilsch vortex tubes, with an internal diameter of 25mm and a length to diameter ratio of 12 were produced and tested with air. Compressed air has been provided from reciprocating air compressor. Air coming from the compressor was introduced to the vortex tube via the nozzle. The temperatures of the inlet flow, cold outlet flow and hot outlet flow were measured with thermocouples.

Flow was controlled by a valve on the hot outlet side, and the valve at the hot outlet side was changed from a nearly closed position from its nearly open position. In experiments, pressure and temperatures were measured. These measurements can be made by utilizing calculations, its effect on performance of temperature of hot stream were examined for classical RHVT and hot cascade type RHVT. Performance of the system varies with changing the temperatures between the hot output stream and the inlet stream ($\Delta T_{hot} = T_{hot} - T_i$) and temperatures between the cold output stream and the inlet stream ($\Delta T_{cold} = Ti - T_{cold}$).

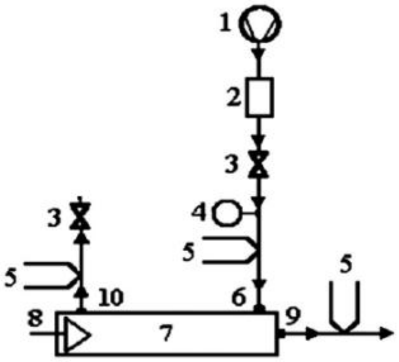

Fig. 2 Schematic diagram of the classical RHVT experimental setup. 1: Compressor; 2: pressure tank; 3: valve; 4: pressure gauge; 5: thermocouple; 6: nozzle; 7: Ranque-Hilsch vortex tube; 8: plug; 9: cold output; 10: hot output.

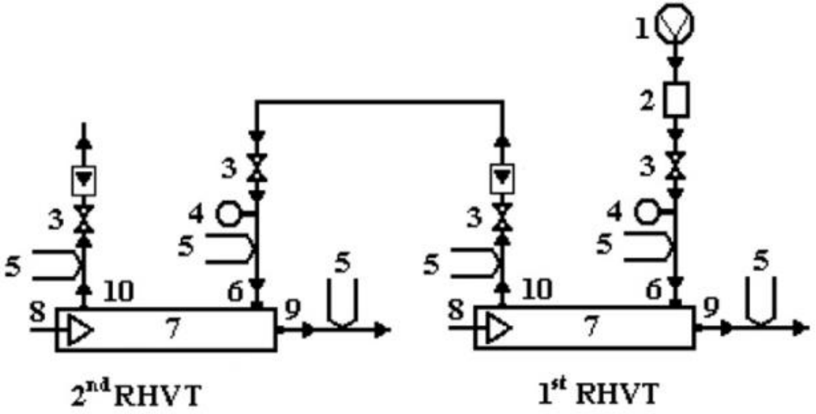

Fig. 3 Schematic diagram of the hot cascade type RHVT experimental setup. 1: Compressor; 2: pressure tank; 3: valve; 4: pressure gauge; 5: thermocouple; 6: nozzle; 7: RanqueeHilsch vortex tube; 8: plug; 9: cold output; 10: hot output.

RESULTS AND DISCUSSION

Vortex tubes are classified into two groups according to their flow characteristics: counter flow RHVT and parallel flow RHVT. The efficiency of parallel flow RHVT is low. For this reason, in this study the counter flow RHVT was used. In this study, Ranque-Hilsch vortex tube was investigated experimentally changing the inlet pressure of air. From the Fig. 4 it is clear that at any given pressure ΔT_{cold} values of hot cascade type Ranque-Hilsch vortex tubes were greater than the ΔT_{cold} values of classical Ranque-Hilsch vortex tube. From the Fig. 5 at any given pressure ΔT_{hot} values of hot cascade type Ranque-Hilsch vortex tubes were greater than the ΔT_{cold} values of classical Ranque-Hilsch vortex tube. From the Fig. 6 hot cascade type vortex tube Ranque-Hilsch COP is better than the classical Ranque-Hilsch vortex tube COP.

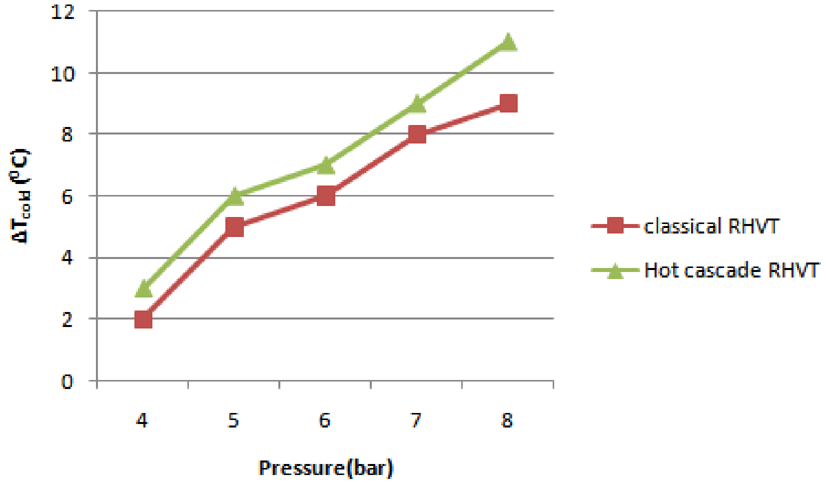

Fig. 4 ΔT_{cold} variation at different pressures

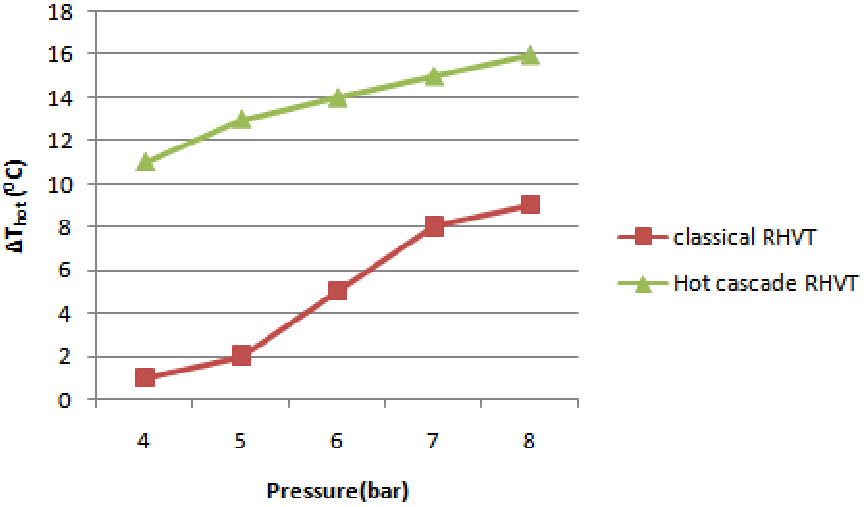

Fig. 5 ΔT_{hot} variation at different pressures

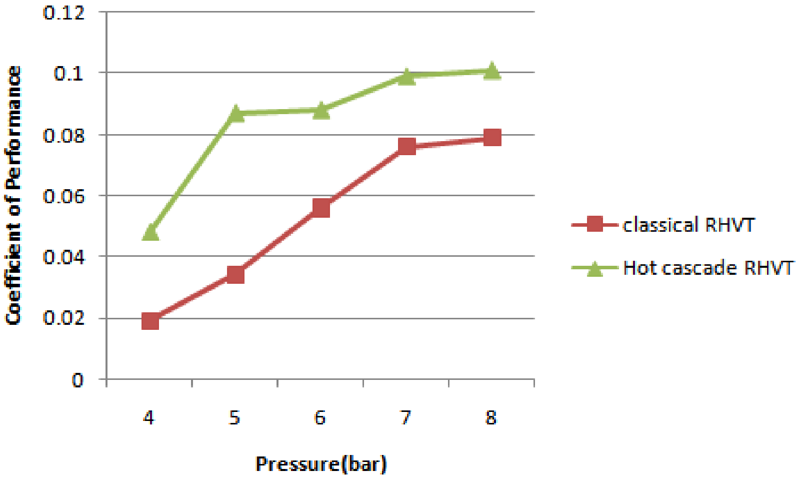

Fig. 6 Coefficient of performance (COP) variation at different pressures

The ΔT_{cold}, ΔT_{hot} and COP values obtained for classical Ranque-Hilsch vortex tube and hot cascade type vortex tube Ranque-Hilsch at various pressures are the performance of the Classical Ranque-Hilsch vortex tube and Hot Cascade type Ranque-Hilsch vortex tube were evaluated by conducting the experiment at various inlet pressures. The other parameters like orifice diameter, nozzle is kept unchanged. The highest COP is obtained at 8 bar for hot cascade type vortex tube and the value is 0.101.The lowest cold temperature for Classical Ranque-Hilsch vortex tube is 21˚C at 8 bar and hot cascade type vortex tube is 19˚C at 8 bar. The highest hot temperature for Classical Ranque-Hilsch vortex tube is 39˚C at 8 bar and hot cascade type vortex tube is 46˚C at 8 bar.

Table 1. ΔT_{cold}, ΔT_{hot} and COP values Classical Ranque-Hilsch vortex tube

Pressure(bar)	$\Delta T_{cold}(^0C)$	$\Delta T_{hot}(^0C)$	COP
4	2	1	0.019
5	5	2	0.034
6	6	5	0.056
7	8	8	0.076
8	9	9	0.079

Table 2. ΔT_{cold}, ΔT_{hot} and COP values Hot Cascade type Ranque-Hilsch vortex tube

Pressure(bar)	$\Delta T_{cold}(^0C)$	$\Delta T_{hot}(^0C)$	COP
4	3	11	0.048
5	6	13	0.088
6	7	14	0.09
7	9	15	0.099
8	11	16	0.101

CONCLUSION

The effect of the hot cascade type vortex tube on the cold temperature drop, hot temperature raise, and COP are analyzed and the results obtained. The Cold drop temperature ΔT_{cold} increases with increase in inlet air pressure. The Hot temperature raise ΔT_{hot} increases with increase in inlet air pressure. The COP of the vortex tube increases with increase in inlet pressure. From the results obtained, it was found that the performance of the hot cascade type vortex tube is better than classical vortex tube. The optimum end gate value opening gives the best performance. The effect of nozzle design is more important than the cold orifice design in getting higher temperature drops.

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