ISSN 2348 – 7968

Performance Improvement of Ranque-Hilsch Vortex Tube by Varying inside Surface Roughness of Hot Tube

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Abstract

Refrigeration plays an important role in developing countries, primarily for the preservation of food, medicine, and for air conditioning. Conventional refrigeration systems are using Freon as refrigerant. As they are the main cause for depleting ozone layer, extensive research work is going on alternate refrigeration systems. 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, counter flow vortex tube with different surface roughness hot tubes performance is compared. It was found that the vortex tube with a surface roughness of R_a=6.264 µm surpassed the hot tubes with a surface roughness of R_a=4.510 µm & R_a=3.133 µm by 6% to 26% and 16% to 52% in COP respectively. The COP of the vortex tube increases with the increase of inside surface roughness of hot tube.

Keywords: *Ranque-Hilsch vortex tube, Temperature separation, surface roughness.*

1. Introduction

Vortex tube (VT) is a device that generates cold and hot air stream from the source of compressed air. It contains the parts inlet nozzle, vortex chamber, cold-end orifice, hot-end control valve and tube. Fig.1 shows the construction of vortex tube. When high pressure gas is tangentially injected into the vortex chamber through the inlet nozzles, a swirling flow is created inside the vortex chamber. In the vortex chamber, part of the gas swirls to the hot end and another part exist through the cold end directly, part of the gas in the vortex tube reverses for axial component of the velocity and move from the hot end to the cold end. At the hot end, the air escapes with higher temperature, while at the cold end, the air has lower temperature compared to that of the inlet temperature pass through the orifice. This was discovered by Ranque (1933) and later developed by Hilsch (1947). In memory of their contribution the Vortex tube is also known as Ranque-Hilsch vortex tube (RHVT). Analytical study on vortex tube was discussed by Lay (1959). Soni and Thomson (1975) gave the expressions for designing vortex tube. Hartnet and Eckert (1957) investigated with large size vortex tube. Gao (2005) investigated that the entry to the hot end is important for the energy separation. Behera et al., (2005) carried out simulation of vortex tube using CFD. Arjomandi and Yenpeng (2007) used new hot end plug which improved the performance of vortex tube. kirmaci (2009) used statistical method to optimize the vortex tube. RHVT has the following advantages compared to the normal commercial refrigeration device. Simple in constructions, no moving parts, no chemicals, light weight, low cost, maintenance free, instant cold air, durable for its application. Therefore, if compactness, reliability and lower equipment cost are the main factors, then the vortex tube is recommended for spot cooling. Now lot of research works is going on the vortex tube to improve its performance.

2. Working Principle

Compressed air at high pressure enters the vortex tube through tangential nozzle where the flow gets accelerated. Due to tangential entry, the air has high velocity and rotates at very high speed. Thus the air has whirling or vortex motion in vortex chamber, which subsequently spiral down the tube to right side (depends on the direction of spiral). The central core of the air is reversed by means of a conical valve, which control the pressure in the system. The end of the cold pipe, which built up with the vortex chamber, is fitted with a washer that has the half the diameter of the pipe. Washers with different diameter are also used to adjust the system. The reversed air at low temperature moving through the washer to the cold section. Thus cold air is produced at the left side of vortex chamber. Hot air is produced at the right side through the conical valve.

3. Design and Construction Details

The design details of vortex tube: Diameter of vortex tube D = 20 mm; Length of vortex tube L = 135 mm. Diameter of orifice Do = 6 mm, Diameter of nozzle D_N = 5 mm, No of nozzle= 1,

ISSN 2348 – 7968

Material= Mild steel, Inlet pressure= 4 - 8 bar, Surface roughness values of hot tube 3.133, 4.510 and 6.264 µm.

4. Experimental Part

The experimental setup consists of compressor, vortex tube and temperature indicator. A stop valve at the compressor reservoir exit controls the inlet air to the vortex chamber. The inlet pressure is measured using pressure gauge. The temperatures of the air at inlet, at cold end, at hot end and ambient air are measured using thermocouple (copper constantan). Fig. 2 shows the overall view of the experimental setup. The compressor was initially run for about 20 min. to get a stable compressor air tank pressure of 4 bar (g). Temperatures at all location are tabulated. Then the same sets of readings are taken at a pressure of 4, 5, 6, 7 and 8 bars. The temperatures of the air at cold and hot end are the vital parameters that determine the COP of the vortex tube. The experiment is conducted with different surface roughness hot tubes.

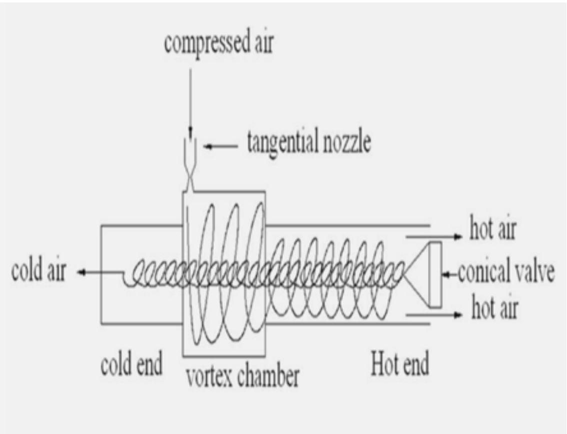

Fig.1. Construction of vortex tube

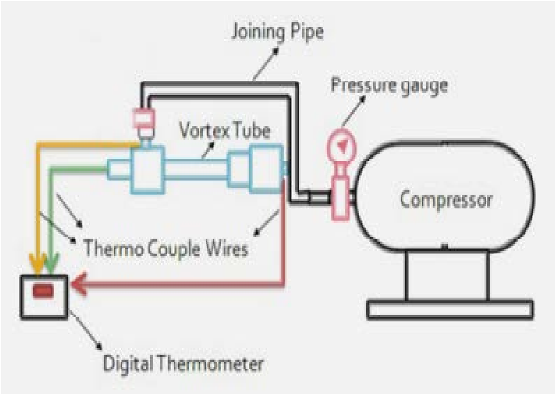

Fig. 2.Experimental setup

Fig.3. Vortex tube assembly

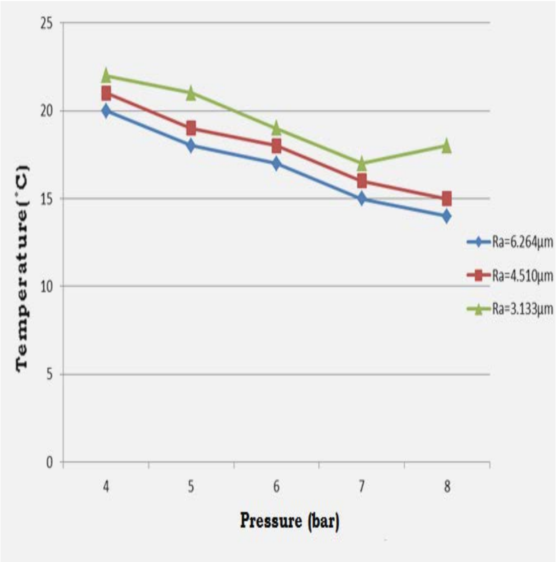

Fig.4. Inlet pressure Vs
Cold End Temperature

ISSN 2348 – 7968

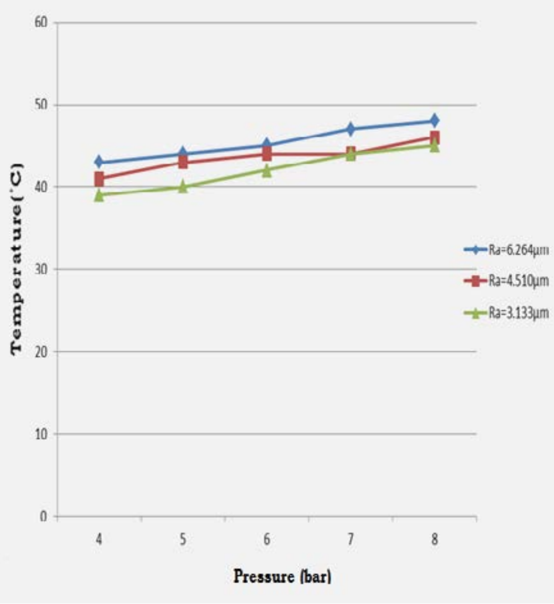

Fig.5. Inlet pressure Vs
Hot End Temperature

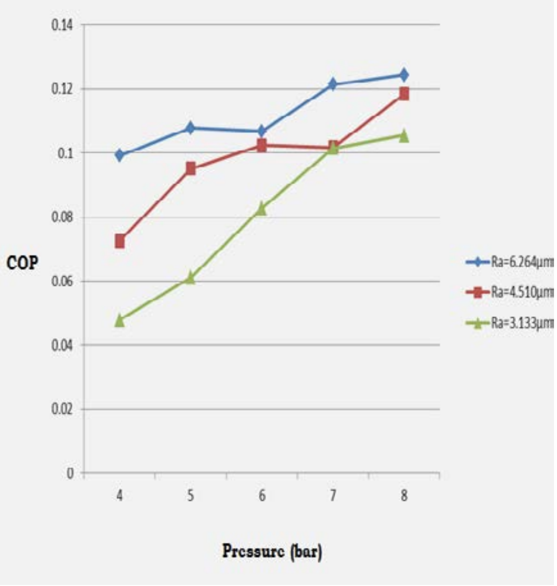

Fig.6. Inlet pressure Vs COP

5. Results and Discussion

From the Fig. 4 it is clear that at any given pressure the Cold End Temperature of the 6.264 µm surface roughness hot tube is better when compared to 3.133 µm and 4.510 µm surface roughness hot tubes and the temperature difference between them is inversely proportional to pressure i.e., the temperature difference is increasing progressively with pressure. From the Fig. 5 the Hot End Temperature of the 6.264 µm surface roughness hot tube is more compared to 3.133 µm and 4.510 µm surface roughnesses hot tubes. From this we can say that temperature difference between them is proportional to pressure i.e., the temperature difference is increasing progressively with pressure. Fig. 6 is plotted for pressure V/s COP. From the graph it is noted that the COP of the vortex tube with 6.264 µm surface roughness hot tube is higher than the 3.133 µm and 4.510 µm surface roughness hot tubes. From the Fig. 4, Fig. 5, Fig. 6 it is noted that the performance of the vortex tube with 6.264 µm surface roughness hot tube is better than the vortex tube with 3.133 µm and 4.510 µm surface roughness hot tubes . After evaluating the performance of vortex tube with cylindrical hot tubes of different surface roughness it was found that the vortex tube with high surface roughness hot tube gives the better performance than the cylindrical hot tube with low surface roughness i.e. there is an increase in COP of about 7%-52%. The Cold temperature, hot temperature and COP values obtained for cylindrical hot tubes at various pressures are

Table.1. Vortex Tube with 6.264 µm surface roughness hot tube

S:NO	Pressure Pi(bar)	Cold temperature Tc (˚C)	Hot temperature Th (˚C)	COP
1	4	20	43	0.0992
2	5	18	44	0.1078
3	6	17	45	0.1067
4	7	15	47	0.1214
5	8	14	48	0.1266

Table.2. Vortex Tube with 4.510 µm surface roughness hot tube

S:NO	Pressure Pi(bar)	Cold temperature Tc(˚C)	Hot temperature Th(˚C)	COP
1	4	21	41	0.0721
2	5	19	43	0.0951
3	6	18	44	0.1024
4	7	16	44	0.1017
5	8	15	46	0.1189

ISSN 2348 – 7968

Table.3. Vortex Tube with 3.133 μm surface roughness hot tube

S:NO	Pressure Pi(bar)	Cold temperature Tc (˚C)	Hot temperature Th (˚C)	COP
1	4	22	39	0.0478
2	5	21	40	0.0611
3	6	19	42	0.0828
4	7	17	44	0.1015
5	8	18	45	0.1054

Table.4. Comparison of COP of cylindrical hot tubes with Ra=6.264 μm & Ra=4.510 μm

S.NO	Pressure in Bar	COP of cylindrical hot tube R_a=6.264μm	COP of cylindrical hot tube R_a=4.510μm	% increase in COP of R_a=6.264μm hot tube
1	4	0.0992	0.0726	26.81
2	5	0.1078	0.0951	11.78
3	6	0.1067	0.1024	04.03
4	7	0.1214	0.1017	16.23
5	8	0.1266	0.1184	06.48

Table.5. Comparison of COP of cylindrical hot tubes with Ra=6.264 μm & Ra=3.133 μm

S NO	Press ure in Bar	COP of cylindrical hot tube Ra=6.264μ	COP of cylindrical hot tube Ra=3.133μm	% increase in COP of Ra=6.264μm hot tube
1	4	0.0992	0.0478	51.81
2	5	0.1078	0.0611	43.32
3	6	0.1067	0.0828	22.39
4	7	0.1214	0.1015	16.39
5	8	0.1266	0.1054	16.75

The performance of the vortex tube was evaluated by conducting the experiment by replacing the cylindrical hot tubes with different surface roughness at various inlet pressures. The other parameters like orifice diameter, nozzle is kept unchanged. The highest COP is obtained at 8 bar for cylindrical hot tube of Ra=6.264 μm and the value is 0.1266. The lowest cold temperature for vortex tube with cylindrical hot tube of Ra=6.264 μm is 14˚C at 8 bar and with cylindrical hot tube of Ra=4.510 μm is 15˚C at 8 bar and with cylindrical hot tube of Ra=3.133 μm is 18˚C at 8 bar. The highest hot temperature for vortex tube with cylindrical hot tube of Ra=6.264 μm is 48˚C at 8 bar and with cylindrical hot tube of Ra=4.510 μm is 46˚C at 8 bar and with cylindrical hot tube of Ra=3.133 μm is 45˚C at 8 bar. Cold mass fraction obtained is better for the vortex tube with the cylindrical hot tube of Ra=6.264 μm than the cylindrical hot tubes of Ra=4.510 μm & Ra=3.133 μm as shown in tables above. The maximum of 34˚C difference between hot and cold ends temperature for vortex tube with the cylindrical hot tube of Ra=6.264 μm and maximum of 31˚C difference between hot and cold ends temperature for vortex tube with the cylindrical tube of Ra=4.510 μm is obtained and maximum of 27˚C difference between hot and cold ends temperature for vortex tube with the cylindrical tube of Ra=3.133 μm.

6. Conclusions

The effect of the cylindrical hot tubes on the cold temperature drop, hot temperature raise, and COP of the Vortex tube are analyzed and the results obtained. The Cold drop temperature ΔTc increases with increase in inlet air pressure. The Hot temperature raise ΔTh 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 vortex tube is better for high surface roughness hot 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. The surface finish of the nozzle and the hot tube plays a great role in the performance of the vortex tube , good surface finish leads to the better performance .so ,care to be taken while fabrication of the parts to obtain to get good surface finish. The graphs drawn are showing the effect of increasing the inlet pressure with the temperature drop shows an increase trend i.e. initially with increase in the inlet pressure the temperature drop.

7. References

[1]. R. Hilsch. The use of expansion of gases in a centrifugal field as cooling process. *The review of scientific instruments*, 18 (1947), 2, pp. 108–113

[2]. S. Martynovskii and V. P. Alekseev. Investigation of the vortex thermal separation effect for gases and vapors. *Soviet Physics*, 1 (1957), 10, pp. 2233–2243

[3]. H. Takahama. Studies on vortex tubes (1) experiments on efficiency of energy separation (2) on profiles of velocity and temperature. *Bulletin of JSME*, 8 (1965), 31, pp. 433–440

[4]. C. U. Linderstrom-lang. Gas separation in the Ranque-Hilsch vortex tube. *International Journal of Heat and Mass Transfer*, 7 (1964), pp. 1195–1206

[5]. M. H. Saidi and M. S. Valipour. Experimental modeling of vortex tube refrigerator. *Applied thermal engineering*, 23 (2003), pp. 1971–1980

[6]. N. F. Aljuwayhel, G. F. Nellis, and S. A. Klein. Parametric and internal study of the vortex tube using a CFD model. *International journal of refrigeration*, 28 (2005), 3, pp. 442–450

[7]. P. Promvonge and S. Eiamsa-ard. Investigation on the vortex thermal separation in a vortex tube refrigerator. *Science Asia*, 31 (2005), pp. 215–223

[8]. P. K. Singh, R. G. Tathgir, D. Gangacharyulu, and G. S. Grewal. An experimental performance evaluation of vortex tube. *IE Journal -MC*, 84 (2004), pp. 149–153

[9]. Behera et. al. Numerical investigation on flow behavior and energy separation in Ranque-Hilsch vortex tube. *International Journal of Heat and Mass Transfer*, 51 (2008), 25-26, pp. 6077–6089

[10]. Behera et. al... CFD analysis and experimental investigations towards optimizing the parameters of Ranque-Hilsch vortex tube. *International Journal of Heat and Mass Transfer*, 48 (2005), 10, pp. 1961–1973

[11]. O. Aydin and M. Baki. An experimental study on the design parameters of a counter-flow vortex tube. Energy, 31 (2006), 14, pp. 2427–2436

[12]. J. E. Lay. Experimental and Analytical Study of Viscous Compressible Flow in a Uniflow Vortex Tube. Ph.D thesis, University of Michigan, Ann Arbor, Michigan, United States, 1956.

[13]. U. Scheper. The vortex tube; internal flow data and a heat transfer theory. *Journal of ASRE, Refrigeration Engg.*, 59 (1951), pp.985–989

[14]. J. P. Hartnett and E. R. G. Eckert. Experimental study of the velocity and temperature distribution in a high velocity vortex-type flow. Trans Am. Soc. Mech Engrs. Series C, J. Heat Transfer, 79 (1976), pp. 751–758.

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