

Performance of Vortex Tube with Modified Nozzle with Internal Taper

P. Obulesu¹, K.L.Srinivasulu², Saik Md Younus³, P.Harish Kumar⁴

^{1,2,3,4} Assistant Professors in Department of Mechanical engineering, Santhiram Engineering College, Nandyal, A.P, INDIA.

Abstract: Vortex tube is a simple non-conventional cooling device having no moving parts, which is compact and simple to produce both cold and hot air from the source of compressed air without effecting the environment. When high pressure air is tangentially injected, a strong vortex flow will be created which will split into two air streams: hot escapes through outer periphery at one end, cold escapes through core at the other end. The main factor that affects the performance of vortex tubes is nozzle and orifice. In this work the performance of vortex tube is investigated with different diameters of orifice and a modified nozzle: providing with different levels of internal taper towards the hot end at various pressure and mass flow. The modified nozzle provided with taper boost up the desired flow pattern, makes the air to travel towards hot end without disturbing the next coming air at the inlet. The experimental investigations were carried out based upon maximum temperature drop. It is observed that effect of nozzle design is more important than orifice in getting higher temperature drops. The experimental results indicated that these modifications could remarkably improve the performance of vortex tube. In this work the best combination of modified nozzle and orifice with suitable conditions is suggested for better performance of vortex tube.

Key words: Nozzle taper, vortex flow, orifice, temperature drop.

I. INTRODUCTION

Vortex tube is a simple device which will separate the high energy molecules from low energy molecules. When high pressure air is injected through tangential nozzle a strong vortex flow will be created which will be spiral down through the tube and blocked by a conical valve. The air at high temperature near boundary of tube will escape through periphery. Whereas the air at lower temperature at the centre is reversed by conical valve and pass through the orifice which is placed near the nozzle.

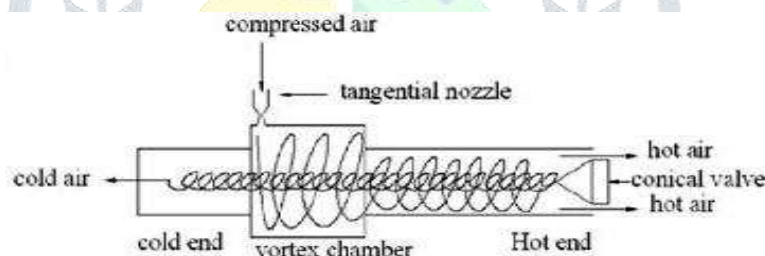


Fig 1: Flow pattern in Vortex Tube

The vortex tube was invented quite by accident 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 the other. Ranque soon forgot about his pump and started a small firm to exploit the commercial potential for this strange device that produced hot and cold air with no moving parts. However, it soon failed and the vortex tube slipped into obscurity until 1945 when Rudolph Hirsch [2], a German physicist, published a widely read scientific paper on the device. Ahlborn et al. [3] studied the temperature separation in a low pressure vortex tube and they state that separation is due to the secondary circulation. Behera et al., [4] carried out simulation of vortex tube using CFD. Aljuwayhelet al. studied the mechanism of flow and energy separation inside the vortex tube using renormalization group (RNG) k-ε and standard-ε models. They used a two-dimensional axisymmetric model along with the effects of the rotational velocity and reported that RNG k-ε model predicts better the function of the vortex tube [5]. Eiamsa-ard et al. experimentally studied the effect of the nozzle numbers on the performance of a vortex tube [6]. Pinar et al. (7) investigated the effects of inlet pressure, nozzle number and fluid type factors on the tube vortex performance by means of Taguchi method. Promvong and Eiamsaard. (8) Reported the effects of the number of inlet tangential nozzles, the cold orifice diameter and the tube insulations on the temperature reduction and isentropic efficiency of the vortex tube. Skye et al. (2006) [9] obtained the inlet and outlet temperatures in experimental and numerical form and compared them with each other. He used a standard

two dimensional turbulence $k-\epsilon$ model for simulating. [10-12] studied numerically the effect of length to diameter ratio (L/D) and stagnation point occurrence importance in flow patterns.

II. CONSTRUCTION DETAILS

The vortex tube consists of the following components: The design details of Vortex tube: diameter $D=10\text{mm}$; Vortex tube length $L=1702\text{mm}$; $L/D=17$; Diameter of cold orifice $D_c=3, 4, 5\text{ mm}$; Nozzle taper= $0.16, 0.24, 0.3$; Material= MS steel;



Fig 2: Parts of Vortex tube used for experimentation

III. RESULTS AND DISCUSSION

The performance of vortex tube was marked by cooling effect (ΔT_c) and heating effect (ΔT_h), which were Defined as follows $\Delta T_c = T_i - T_c$, $\Delta T_h = T_h - T_i$, Where, T_i is the inlet temperature, T_c is the outlet temperature of cold end, T_h is the outlet temperature of hot end. Fig 3 shows the variation of temperature drop with inlet pressure for considered combinations of nozzle and diaphragm at 25% opening of the valve towards hot end. The graph shows that the temperature drop increases with increase in inlet pressure. The maximum temperature drop of 280 c is obtained for the combination of nozzle3- diaphragm1 at 25% opening towards hot end for 12bar pressure. It is observed that the temperature drop increases with increase in nozzle taper for small diameter diaphragm at all 25% opening towards hot end. Whereas, as using higher diaphragm the temperature drop decreases with increase of nozzle taper for 25% opening towards hot end. This is because at low diaphragm diameter, With increase of nozzle taper the air at the nozzle exit tends to move towards hot end which improves the desired flow pattern and there by the temperature drop increases. The lowest temperature obtained is nearly 40 c for a diaphragm having 3mm diameter and it is around 50 c and 100 c for 4mm and 5mm diaphragms respectively.

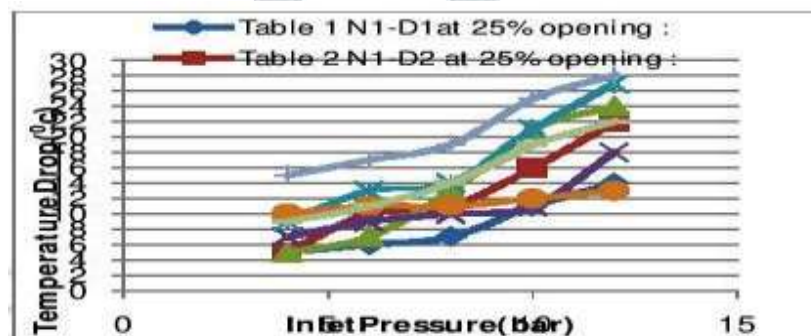


Fig 3: Pressure v/s temperature drop at 25% opening towards hot end

Fig 4 shows the variation of temperature drop with inlet pressure for considered combinations of nozzle and diaphragm at 50% opening of the valve towards hot end. The graph shows that the temperature drop increases with increase in inlet pressure. The maximum temperature drop of 260 c is obtained for the combination of nozzle2- diaphragm2 at 50% opening towards hot end at 12bar pressure. The graph indicates that the effect of diaphragm area is more predominant in getting higher temperature drops. The lowest temperature obtained is nearly 70 c for diaphragm

having 3mm diameter and it is around 60 c and 120 c for 4mm and 5mm diameter diaphragms respectively. This is because as the supply air pressure is increased it might help to speed up the flow and increase the mass flow rate which leads to strong swirl flow into the vortex tube. This gives rise to high friction dissipation between the boundaries of the flow and a higher momentum transfer from the core region to the wall region. Due to which we get maximum temperature separation at higher pressure.

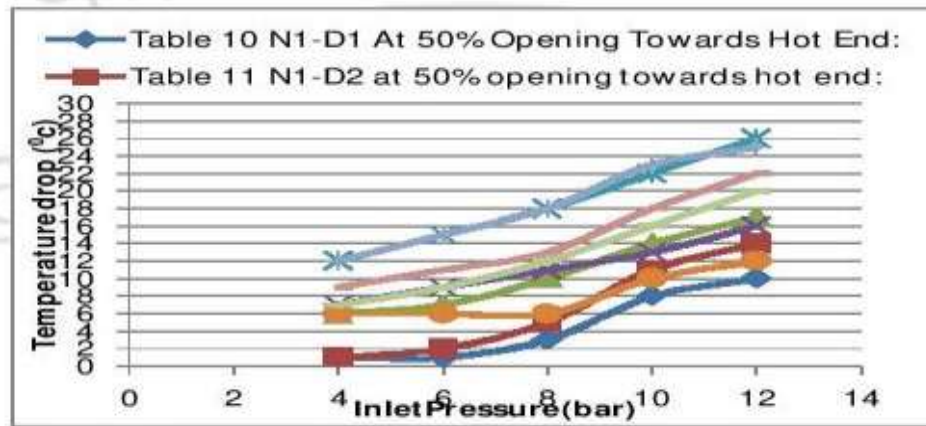


Fig 4: Pressure v/s temperature drop at 50% opening towards hot end

Fig 5 shows the variation of temperature drop with inlet pressure for considered combinations of nozzle and diaphragm at 50% opening of the valve towards hot end. The graph shows that the temperature drop increases with increase in inlet pressure. The maximum temperature drop of 230 c is obtained for the combination of nozzle3-diaphragm1 at 75% opening towards hot end at 12bar pressure. This is because as the opening of the valve increases more air escapes from the pipe easily through cold end which in turn decreases maximum temperature drop. The lowest temperature obtained is nearly 90 c for diaphragm having 3mm diameter and it is around 100 c and 150 c for 4mm and 5mm diameter diaphragms respectively.

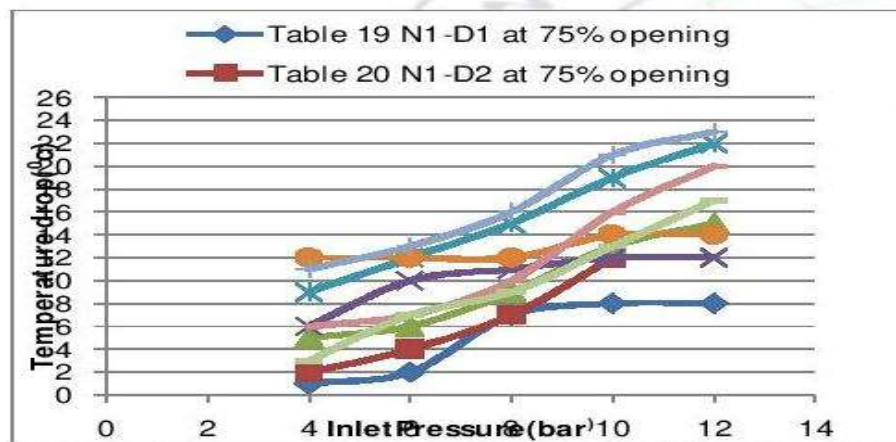


Fig 5: Pressure v/s temperature drop at 75% opening towards hot end

Fig 6 to 8 shows the effect of pressure on temperature rise for considered combination of nozzles and diaphragm with different opening percentage towards hot end. The trend of temperature rise is similar to that of temperature drop that increases with increase of pressure. The temperature rise is higher at smaller opening towards the hot end. The maximum temperature rise obtained is decreasing with increase of diaphragm diameter whereas; it is effective at moderate nozzle taper. This is because at higher diaphragm diameter the air from the inlet escapes through diaphragm without moving towards the hot end. Either low taper or higher taper of nozzle does not gives effective rise in temperature because at lower taper the air after tangential entry takes the swirl flow and hits the inlet air which disturbs the flow pattern and at higher taper the air particles can't be closely packed and the advantage of sliding friction between adjacent layers loses. Using nozzle-3 with diaphragm 1 at 25% opening towards hot end gives a maximum temperature rise of 200C.

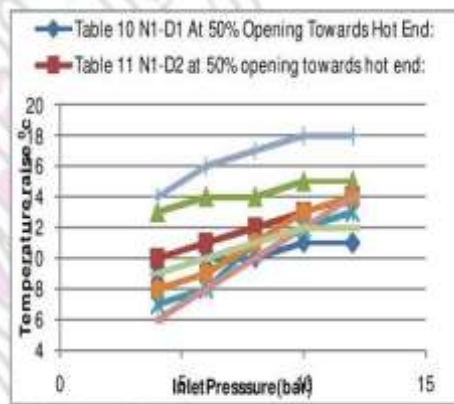


Fig 7: Pressure vs temperature rise at 50% opening towards hot end

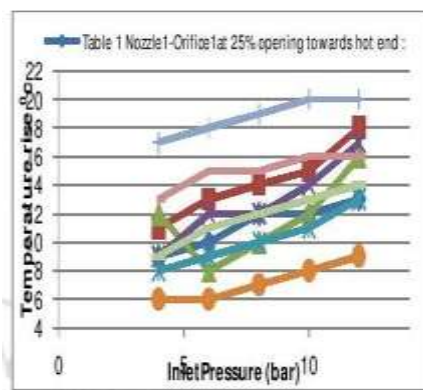


Fig 6: Pressure vs temperature rise at 25% opening towards hot end

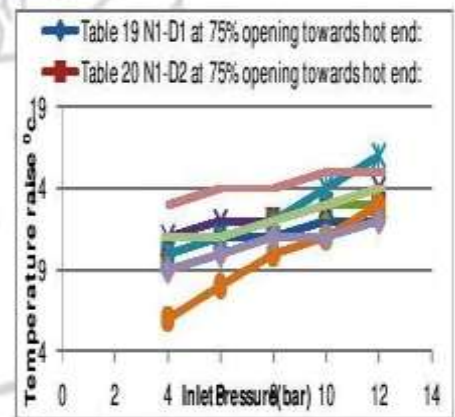


Fig 8: Pressure vs temperature rise at 75% opening towards hot end

The Effect of Pressure on Temperature Difference: The effect of inlet pressure on temperature drop and temperature rise is shown in above graphs. It can be observed that maximum temperature drop is obtained at 12bar for N3-D1 at 25% opening towards hot end. As the pressure increases the temperature drop also increases this is because as the inlet pressure increases the intensity of swirl increases and at high swirl intensities the heat exchange between two layers becomes predominant. That causes the central stream of air to get cooled giving of heat to the layer at the periphery. The rate of temperature drop increase is slow at low pressure and is high at high inlet pressure. The maximum temperature difference of 280• c is obtained towards cold end side while 200 c is obtained towards hot end side. With increase in inlet pressure cooling effect,• heating effect increases. Minimum cold end temperature of air obtained is 40 c while maximum hot end temperature of air obtained is 520 c. The maximum temperature drop of 280• c is obtained for nozzle3-diaphragm1 (3mm) at 25% opening towards hot end whereas the maximum temperature rise of 200 c is obtained for nozzle3-diaphragm1 (3mm) at 25% opening towards hot end. The diameter of the orifice influences the• expansion that takes place in the vortex chamber. When the diameter of the orifice is 3 mm, it produces best cooling effect. When the diameter of the orifice is 5 mm, it produces best heating effect, because both the hot air and cold air as flowing out were mixed together which further affected the cold air to have higher temperature. When the diaphragm diameter is 3mm and 4 mm, it has higher back pressure and makes the temperature reduction at the cold tube lower, it shows that the diameter of the diaphragm is an important factor for the energy separation. The optimum diaphragm diameter obtained in present study is 3mm.

IV. CONCLUSION

From the series of tests conducted on the performance of vortex tube with modified nozzle the following conclusions are drawn:

- The temperature drop at cold end and temperature rise at hot end increases with increase of inlet pressure. The temperature drop increases with increase in nozzle taper for small diameter diaphragm at all % opening towards hot end. Whereas, by using higher diaphragm the temperature drop decreases with increase of nozzle taper for all % opening towards hot end.
- The lowest temperature obtained is nearly 40 c for a diaphragm having 3mm diameter and it is around 50 c and 100 c for 4mm and 5mm diameter diaphragms respectively. The maximum temperature obtained is nearly 520 c for a diaphragm having 3mm diameter and it is around 500 c and 480 c for 4mm and 5mm diameter diaphragms respectively.
- The lowest temperature obtained is nearly 40 c for 25% opening towards hot end and it is around 60 c and 90 c for 50% and 75% opening towards hot end. The maximum temperature obtained is nearly 520 c for 25% opening towards hot end and it is around 500 c and 480 c for 50% and 75% opening towards hot end. The temperature rise at hot end decreases with increase of diaphragm diameter. The temperature rise is lower at either low or too higher nozzle taper. The temperature drop at cold end and temperature rise at hot end decreases with increase of percentage opening of control valve towards hot end.

- The diaphragm of 3mm diameter with nozzle-3 Taper at 25% opening through hot end is the optimum combination which gives a maximum temperature drop of 280C and maximum temperature rise of 20 0C. After comparing the performance parameters of vortex tube for different combinations of nozzle and diaphragm and for different throttle valve openings it is concluded that for nozzle3-diaphragm1 at 25% opening towards hot end provides maximum performance of vortex tube with modified nozzle.

REFERENCES

1. Ranque, “Experiments on expansion in vortex with simultaneous exhaust of hot air and cold air”. *Le journal de Physique ET le Radium (Paris)* pp 112-114(1965)
2. R. Hilsch, The use of the expansion of gases in a centrifugal field as cooling process, *Rev. Sci. Instrum.* 18 (2) (1947) 108–113.
3. Behera U and Paul PJ (2005) CFD analysis and experimental investigation towards the optimizing the parameter of Ranque-Hilsch vortex tube. *Int. J. Heat Mass Transfer.* 48, 1961-1973.
4. Aljuwayhel, N. F., Nellis, G. F., Parametric and Internal Study of the Vortex Tube Using CFD Model, *Inc. Refrigeration*, 28 (2005), 3, pp. 442-450.
5. Eiamsa-ard, S., Promvong, P., Investigation on the Vortex Thermal Separation in a Vortex Tube Refrigerator, *Science Asia*, 31 (2005), 3, pp. 215-223.
6. Pinar, A. M., Uluer, O., and Kirmaci, V., 2009, Optimization of Counter Flow Ranque-Hilsch Vortex Tube Performance Using Taguchi Method, *International Journal of Refrigeration*, Vol. 32 (6), pp. 1487-1494.
7. Promvong, P., and Eiamsa-ard, S., 2005, Investigation on the Vortex Thermal Separation in a Vortex Tube Refrigerator, *Science Asia*, Vol. 31 (3), pp. 215-223.
8. Skye, H.M., G.F. Nellis and S.A. Klein, “Comparison of CFD analysis to empirical data in a commercial vortex tube,” *Int. J. Refrigeration.*, 29 (2006) 71-80.
9. Bramo, A. R., Pourmahmoud, N., A Numerical Study on the Effect of Length to Diameter Ratio and Stagnation Point on the Performance of Counter Flow Vortex Tube, *Aust. J. Basic & Appl. Sci.*, 4 (2010), 10, pp. 4943-4957.

