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A Review on Vortex Tube Performance Based on Various Geometric Parameters

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Abstract: This paper explains about the vortex tube performance based on various geometric parameters such as pressure, nature of gas, L/D ratio and cold mass fractions. The cold end temperature drop was taken as the experimental result. Inlet pressure varied with an increment of 1 bar from 3 to 5 bars along with thatthe cold mass fraction also varied from 20% to 90%. Maximum cold mass fraction was obtained at 60%. Maximum cold mass fraction was obtained at L/D ratio at 17.5 and at pressure 4 bar. While experimenting the various components like air, carbon-di-oxide and nitrogen gases, the maximumcold mass fraction has been obtained for Co_2 gas at L/D ratio at 17.5.Maximum temperature gradient occurred at 700 KPa inlet pressure in case of air, nitrogen, oxygen and argon etc. Maximum temperature difference was obtained for argonat 52.1^o C. Temperature gradient decreases with increase in nozzle number. Maximum temperature difference was obtained at nozzle number equals to 2. Finally it has been found that the performance of vortex tube varies due to the level of temperature at different parameters.

Introduction:

Refrigeration is a process of removing or adding of heat from a space i.e. maintaining low temperature or higher temperature compared to surroundings. Vortex tube refrigeration is one of the types of refrigeration system which is mainly used for spot cooling purposes.Vortex tube is a thermal device, which generates two streams at different temperature from a single injection. When the compressed gas is passed into the vortex tube tangentially, the compressed gas is then divided into two parts and exhausted as in a way that, temperatures are lower and higher than the inlet gas. In this way, cold and hot streams are generated by only the vortex tube without any additional components and no moving components are used. Based on the flow, vortex tube is classified into parallel flow vortex tube and counter flow vortex tube. In vortex tube, many parameters can be varied such as length of the tube, orifice diameter, inlet pressure etc.

Many research had been carried out to find the reason of separation of air streams happening inside the tube. Mischer and Bespalov explained that the ‘entropy generation leads to energy separation’, still the theory is unacceptable. Kassener and knoernschild in their work proposed that‘separation of air streams is caused by pressure difference in the vortex tube’. They also have undergone the work that converts initially free vortex into forced vortex. Changes in the components of vortex tube has been practiced and the results has also been analysed with the Ranque-Hilsch tube. A diffuser was placed in between the vortex tube outlet andthe cone valve, result obtained was that the refrigeration effectis increased and the cold air temperature TC reduced tremendously. The cylindrical tube geometry when converted to conical tube, the hot air temperature TH, and cold air temperature TC were quite high compared to conical tube. The results obtained were impressive by changing the aspect ratio (L/D), number of nozzles.

Vortex tube has many pros. It is a simple instrument, it doesn’t possess the properties like, moving parts, electricity or chemicals. The tube has its own qualities like its very compact , less weight, less cost, maintenance is low, sudden cold air, and also its durable because of the materials used (example: stainless steel, Aluminium), neat work media. Vortex tube has following applications it is used in spaced suits, for spot cooling in welding, in CCTV camera. In future because of its advantages vortex tube can be the best replacement over conventional refrigeration system.

Literature Review:

The Effects of the geometric parameters on vortextube performance have been investigated by many researches, using both experimental and numerical methods. The result has been obtained that, when different geometrical parameters were selected for testing a vortex tube,the temperature generated in cold and hot streams can be varied.Geometric parameters which can be varied are as length and diameter of the tube, shape and size of the inlet nozzle, cold and hot exits, and structures of the tube.

Tube Length

The effects of the tube length tube diameter and ratio of the tube length over tube.Diameter is summarized and it has been reported that the length of the tube should be longer than a critical length to achieve significant temperature separation within the vortex tube. The separating vorticities betweenmulti-circulation region and the cold core becomes weaker when the vortex tube is shorter than the critical valueand from the multi-circulation regionthe cold flow will subsequently mix with the hot flow. Hence, the temperature separation in very short vortex tube will not be significant.It is noted that the length of the tube denotes the separation of cold region and hot region. Thus it alwaysthe quality of separating temperature.The vortex tube'scritical length is different for different tube diameters.

Tube diameter

The performance of a vortex tube depends on the function of the tube diameter when it isoptimized. A perfect separation of the cold and hot regions provided by the diameter of vortex tube, which dictates the performance for the temperature separation. The temperature drop is reduced because of the diameter of the vortex tube is too small or too large. At the hot end, peak multi-circulation will be found in a vortex tube with large diameter, due to its small centrifugal force. Therefore, for a vortex tube with fixed length, there is a critical value of the tube diameter for the generation of maximum, temperature separation.

Ratio of tube length over diameter

In order to have significant temperature separation in vortex tube, the ratio of the tube length over diameter needs to begreater than 20. Once the ratio is greater than 45, it was reported that there is no further effect on the performance of the vortex tube.This is likely due to the fact that the cold core region and the multi-circulation region have been fully separated when the ratio of the length over diameter is 45. Therefore, it does not apparent that further lengthening of the vortex tube has any influence on the vortex tube performance.The increase and decrease in the tube length and tangential velocity respectively results to a slight change in the temperature drop of the stream by weakening the multi-circulation region has been observed .

Tube shape

It has been reported that a conical vortex tube can generate two streams whichexhibit significant temperature differences. Optimum conical angle has been proposed by several researchers. However, there has not been an explanation for the apparent successful application of the conical tube in shortening the length of the vortex tube. According to the abovementioned explanation, the separation of the cold core region and the multi-circulation region, in short conical vortex tube, still can be successfully achieved. Due to the conical angle of the tube, the formed, multi-circulation region in the rear part portion of the tube, which makes the radial dimension at the end of the multi-circulation 9away from the hot end), increase. Hence, the mixture of an enlarged multi-circulation and the cold region can be neglected. Thus, a short conical vortex tube still perform well with regard to the extent of the temperatureseparation.

Vortex angle

A new geometrical parameter, termed the vortex angle, has been investigated. It has been reported that the introduced vortex angle had effects on the magnitude of the temperature differential achieved. Based on the proposed explanation, the introduced vortex angle leads to a decrease of the tangential velocity and an increase in the axial velocity. Since both the temperature drop and temperature rise are produced by the strong swirling flow, the decrease of the tangential velocity is the reason for the reducing the temperature parting in a vortex tube with a vortex angle generator installed.

Inlet nozzle

The strong swirling flow, which is the reason for the temperature parting in thevortex tube, is generated by the injected maximum speed fluid through the inlet nozzle.Therefore, the inlet nozzle, which shows good characteristics in creating the swirling flow, is the primary instrument in creating the two streams which result in large temperature difference within the vortex tube. The dimension of inlet nozzle doesn`t exceed a critical value, in order to generate the strong swirling flow. Generally, an increase in the inlet nozzle number leads to greater injected flow and same flow in the tube, both of which lead to impressed temperature separation. Furthermore, too many inlet nozzles will cause a high back pressure inside the tube and lead to a decrease of the swirl velocity results in a reduction of the temperature separation. These is discussionsregarding the inlet nozzle with the results presented.

Effect of conical valve angles on cold temperature

The effect of conical valve angles and orifice diameter on cold end temperature. For5,6 and 7mm orifice diameters and valves 30^0,45^0,60^0,90^0 angles. The results depicted in state that the performance of 45o conical valves angles is best for highest supply pressure of 5bars and with orifice diameter as 7mmm; the temperature observed is 5^0C on cold end side. Performance of 90^0 valves is also comparable to that of 45^0 conical valves it also comparable to that of 45 conical valves is also produces the low temperature on cold end. The 30 and 60 degrees conical valve performance is not much expected. With change in valve angles the flow is guided and when valve angle is45 degree the reversal of flow is smooth and as the orifice diameter increases chances of secondary circulation are minimized hence there is no mixing of the hot stream and cold stream. The velocity along the axis increases because of convergent section and provides potential for the heat transfer among the hot stream and cold stream. The results also shows that the mass of air releasing out from the hot end is minimum. If the pressure is held constant, changes in valve angles shows change in temperature in the descending sequence of 60,30,90,45 degrees. Thus valve angle has effect on the energy separation. Almost 15 to 25% changes are observed with increasing valve angle from 30 to 45 degrees. The COP of vortex tube is usually very low but with converging type of vortex tube the efficiency is seen to be increased. The COP of the vortex tube primary depends on the cold mass of air and the cold end temperature produced. In case of converging type of tube low both mass flow rate of the cold air and the temperature drop are significant hence for majority of the cases as pressure increases the COP of the tube increase and for the orifice diameter of 7mm highest COP is observed for 45 degree valve.

Giorgio De Observara et al, this year perused upon Ranque-Hilsch vortex tubing as well as made their view level in vortex tubing has become employed for several years in numerous architectural purposes. Due to its sleek and stylish pattern as well as small maintenance needs, it is quite popular in processes. Regardless of it is simple geometry, this system of which produces this temperature separating into the tubing is fairly difficult. Quite a few observed results as well as theories are discovered by means of unique researchers regarding that happening. United kingdom.

Dincer et al, in this article these people learnt, consequences associated with placement, length (5, 6, 7, 8 mm) as well as perspective (30–180) of your cellular pluge, based with the warm store part in the Ranque–Hilsch Vortex Tube (RHVT), ended up established experimentally for ideal overall performance. Besides plug parameters, consequences associated with offer strain (200–420 kPa) also learnt. it might be viewed how the most efficient (maximum DT) combination of parameters will be purchased for just a plug length associated with 5 mm, word of advice perspective associated with 30 or 58.

Kun Chang et al, learnt strength separating overall performance associated with vortex tubing could be increased by using a divergent warm tubing. Trials tend to be completed to look into this affect in the geometrical parameters upon vortex tubing refrigeration ability by utilizing nitrogen for the reason that working water. Within this function, this parameters tend to be centred on this divergence perspective associated with warm tubing, length of divergent warm tubing as well as variety of nozzle intakes.

Nader Pourmahmoud et al, content computational water dynamics examination of your 3-D steady-state compressible as well as thrashing move has become completed by having a vortex tubing. Your statistical types operate the k-ε disturbance design for you to replicate an axisymmetric computational area in conjunction with routine boundary conditions. The present research provides centered on the force separating as well as move discipline behaviour of your vortex tubing with the use of equally right as well as helical nozzles. About three types of nozzles established contain associated with 3 as well as 6 right as well as 3 helical nozzles are perused as well as his or her primary consequences seeing that cold weather change has been compared.

As Saidi and Valipour, in their experimental work examined the working media as a parameter. They used three working mediums as air, oxygen, helium and they observed that helium produces higher cold temperature difference than oxygen and air.

Stephan et al, also used these three working medium and investigated that helium produces more energy separation than air and oxygen, they believed that this is due to molecular weight of helium is much smaller than oxygen and air. They also found that there is no difference in distributions of the cold gas temperature difference between air and oxygen.

S.Rejin, H.Thilakan, done an experimental analysis on different conical valve angles in vortex tube refrigerator, in this the vortex tube refrigerator with different conical valve angle at the hot side and the effect of cold orifice diameter at cold side. In this experiment only air is used, no other gases are uses as the inlet for vortex tube.At pressure of 5bar, the maximum temperature reduction obtained is 7°C for an operating condition of 10° conical valve angle and cold orifice diameter of 6mm.

Various Parameters Influencing Vortex Tube Performance:

N. Agrawal et al, in their experimental work examined three different single nozzle vortex tubes of the length 125 mm,175 mm and 225 mm also L/D ratio of 12.5, 17.5 and 22.5 with tube diameter as 10 mm and inlet nozzle diameter as 2 mm. Inlet pressure is also varied with increment of 1 bar from 3 to 5 bar. For the testing, cold mass fraction is varied with step size of 10% from10 to 90%. At 4 bar pressure, It can be seen that for each L/D ratio, initially cold end temperature drop increases to maximum at an optimum value of cold mass fraction of 60%.Maximumvalue of cold end temperature drop of 29 °C is obtained for L/D ratio 17.5 at 60% cold mass fraction while with L/D ratio of 12.5 and 22.5, maximum cold end temperature drop values are about 26 °C and 24 °C, respectively. This may due to incomplete separation of the cold air and hot air streams beyond a certain L/D ratio for a specific vortex tube, cold stream mixes with hot stream resulting drop in cold end temperature drop.

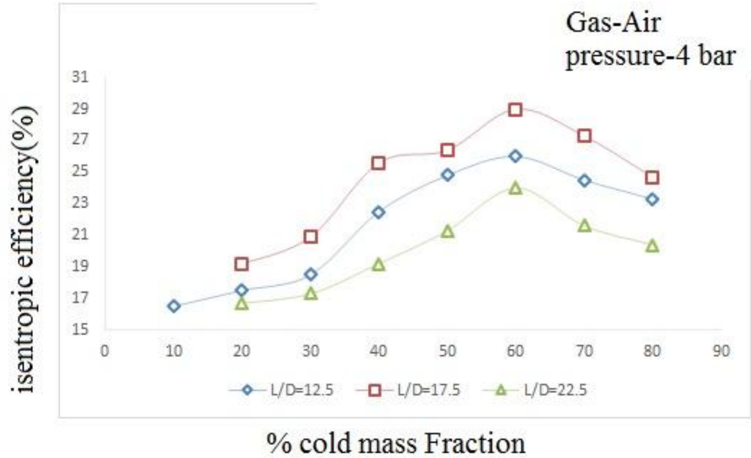


Figure-1variation of cold end temperature drop with cold mass fraction at various L/D ratios

Similarly, by varying the cold orifice diameter [D_C] as in diameter of 3mm, 4mm, 5mm vortex tubes, When experimenting pressure at 3 bar, highest temperature drop is obtained with cold orifice diameter of 4 mm and the maximum cold temperature drop obtained for cold orifice diameter 3 mm is 23 °C and 5 mm is 24 °C. The orifice diameter is too small, there is a significant pressure drop across the orifice leading to a higher back pressure in the vortex tube resulting in low energy separation.

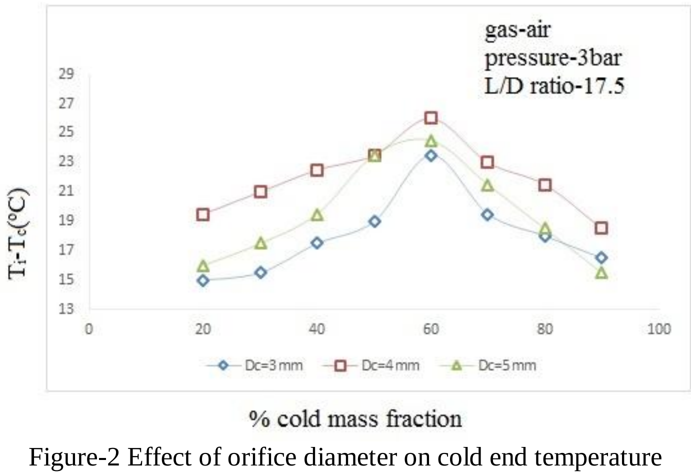


Figure-2 Effect of orifice diameter on cold end temperature

N. Agrawal et al, is also experimenting on varying the pressure ranging from 3 to 6 bar with increase of 1 bar. It is shown that increasing the inlet pressure increases the cold end temperature drop up to cold mass fraction of 60%.The highest temperature drop measured is 32 °C at the inlet pressure 5 bar while 29 °C and 26 °C temperature drop were obtained at 4 bar and 3 bar pressure supply, respectively. The highest cold end temperature drop at the respective operating pressures is seen at 60% cold mass fraction. This is because mixing of hot and cold mass of working fluid leads to net reductionin cold temperature drop. It is that the cold end temperaturedrop is at the maximum at 5 bar, it can be said that the chosen vortextube of L/D 17.5 is capable of causing full expansion of theworking mediumair at this pressure.

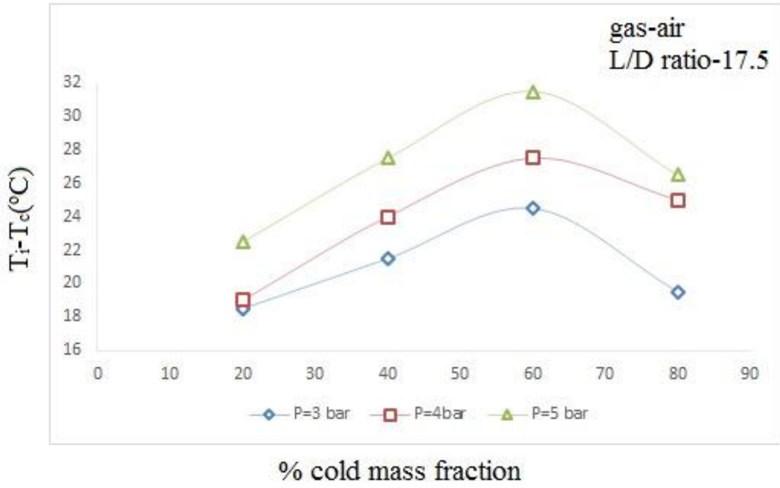


Figure-3 Effect of pressure on cold end temperature drop.

N. Agrawal et al, also done an experimental work on examining three different gases[carbon-di-oxide, nitrogen and air] in the vortex tube. The result obtained is CO2 produces higher cold end temperature drop than air and nitrogen. At pressure of 4 bar cold temperature drop for CO2, nitrogen and air are 23 °C, 18 °C and 20 °C, respectively. The highest temperature drop is obtained with CO2 due to the higher molecular weight and lower gas constant of CO2 in comparison to other gases. Thus, the cooling effect produced by the vortex tube depends on properties of the gas, molecular weight and specific heat ratio. The vortex tubes perform better with carbon dioxide compared to air and nitrogen owing to its high molecular weight and low specific heat ratio.

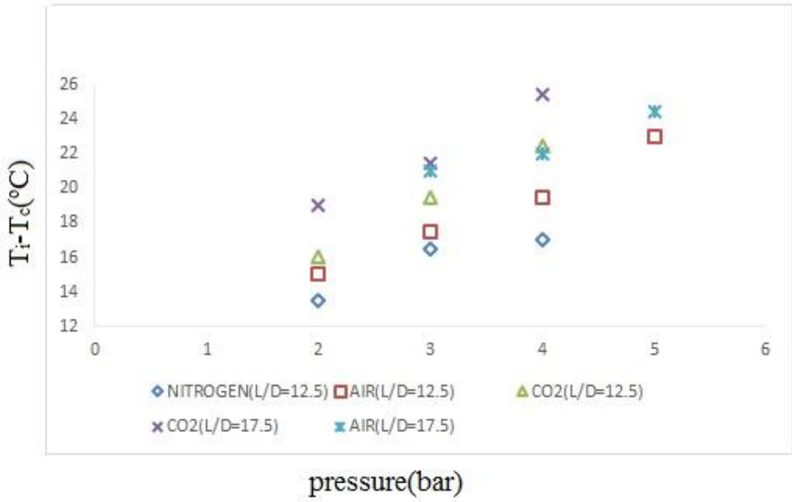


Fig-4 Comparison of cold end temperature drop of air, nitrogen and CO2.

Volkan Kirmaci et al.has done an experimental investigation of Performance analysis of a counter flow vortex tube having various Nozzle numbers at different inlet pressures of Air, Oxygen, Nitrogen, and Argon, at nozzle number 2 with different inlet pressure, for air as a working fluid, maximum temperature difference 40 K was occur at inlet pressure equal to 700 KPa. Same was observed for nitrogen as a working fluid where maximum temperature difference 40 K was occur at 700 KPa.When oxygen was used as a working fluid maximum temperature difference was 45 K at 700 KPa. Similarly for argon maximum temperature difference 52.1 K was occur at 700 KPa.

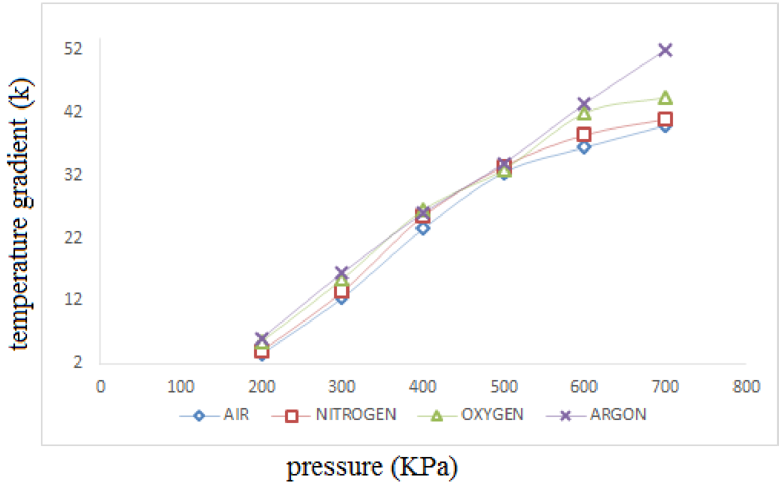


Figure -5 at Nozzle number-2 Working fluids Vs. Temperature gradient

Then at nozzle number 3 for different inlet pressure and working fluids. For air as a working fluid, maximum temperature difference 40 K was occur at inlet pressure equal to 700 KPa. Same was observed for nitrogen as a working fluid where maximum temperature difference 40 K was occur at 700 KPa. Oxygen and Argon resulted maximum temperature difference 45 K and 47 K respectively at 700 KPa.

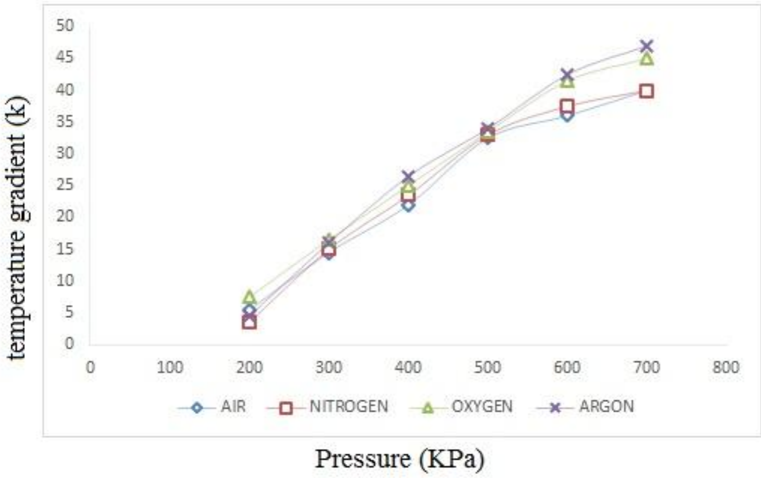


Figure-6 at Nozzle number-3 Working fluids Vs. Temperature gradient

Then, at nozzle number 4 for different inlet pressure ranging from 200 KPa to 700 KPa. For air and oxygen as a working fluid, maximum temperature difference 27 K and 35 K respectively was occur at inlet pressure equal to 700 KPa. Oxygen as a working fluid, the maximum temperature difference observed at 700 KPa about 36 K. Similarly for argon maximum temperature difference 42 K was occur at 700 KPa.

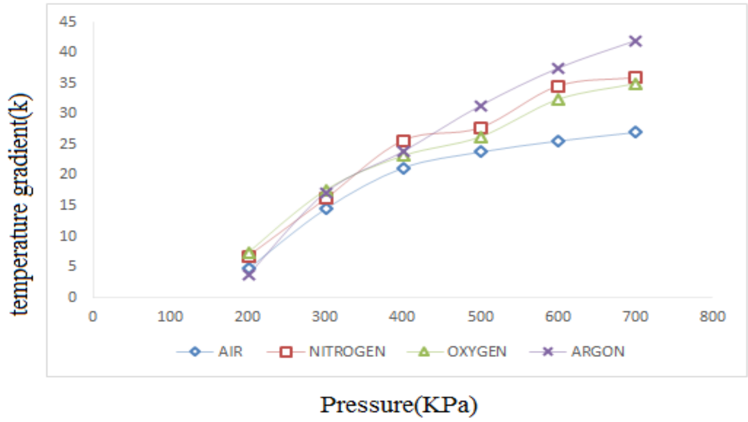


Figure-7 at Nozzle number-4 Working fluids Vs. Temperature gradient

At nozzle number 5 for different gasses at different inlet pressure. Air, nitrogen, oxygen and argon resulted same observation as seen in previous cases where maximum temperature gradient was achieved at 700 KPa about 24 K, 30 K, 35K and 39 K respectively

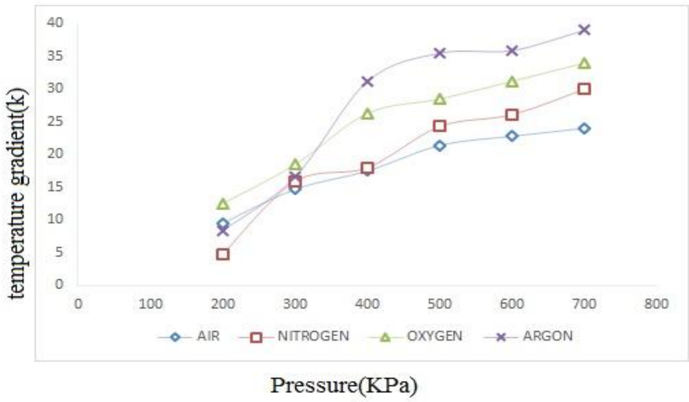
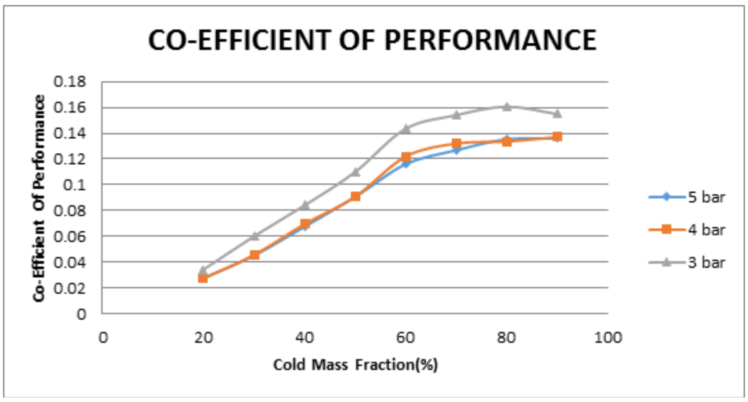


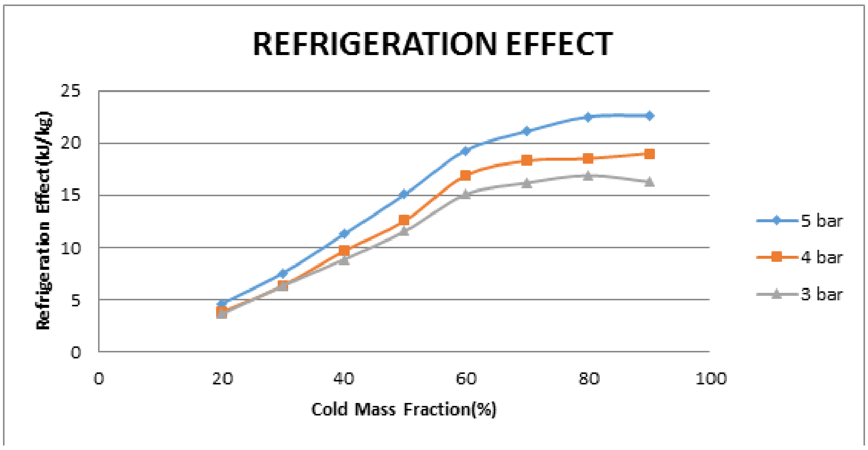
Figure-8 at Nozzle number-5 Working fluids Vs. Temperature gradient

Similarly, experimenting for various nozzle numbers they observed that as nozzle number increases, the temperature difference between hot and cold air decreases, also temperature gradient (difference between hot and cold gas temperature) increases with increase in inlet pressure. Maximum temperature gradient occurred at 700 KPa inlet pressure in case of air, nitrogen, oxygen and argon etc. Maximum temperature difference was obtained for argon i.e. 52.1° C. Temperature gradient decreases with increase in nozzle number. Maximum temperature difference was obtained at nozzle number equal to 2.

At Pressures of 3 bar, 4 bar, 5 bar, the graph between COP and cold mass fraction, It is found that the COP of the Vortex Tube is maximum at a cold mass fraction of 90% for pressure of 5 bar, 4 bar and at a cold mass fraction of 80% for 3 bar.



At Pressures of 3 bar, 4 bar, 5 bar, the graph between Refrigeration effect and cold mass fraction**,** It is found that the Refrigeration Effect of the vortex tube is maximum at a cold mass fraction of 90% for pressure of 5 bar, 4 bar and at a cold mass fraction of 80% for 3 bar.



Conclusion

Performance evaluation of the Ranque–Hilsch vortex tube has been carried out theoretically. There is a value of cold mass fraction at which vortex tube has the highest temperature drop for all the given pressures at the L/D ratio of 17.5. The maximum cold end temperature drop is obtained at cold mass fraction of 60%. For the given L/D ratio, as the gas pressure increases, cold end temperature difference increases but the optimum value of cold mass fraction remains same. In the tested range, COP and Refrigeration effect increases as the cold mass fraction increases at the pressure of 4 bar and 5 bar. At a pressure of 3 bar the maximum COP and Refrigeration effect is attained at a cold mass fraction of 80%. It is also observed that the cooling effect produced by the vortex tube depends on properties of the gas, molecular weight and specific heat ratio. The vortex tube performs better with carbon dioxide compared to air and nitrogen owing to its high molecular weight and low specific heat ratio.

Reference

[1]. Kun Chang , Qing Li , Gang Zhou , Qiang Li -Experimental investigation of vortex tube refrigerator witha divergent hot tube.
[2]. N. Agrawal , S.S. Naik, Y.P. Gawale-Experimental investigation of vortex tube using natural substances.
[3]. Volkan Kırmacı Onuralp Uluer Kevser Dincer-An Experimental Investigation ofPerformance and Exergy Analysisof a Counterflow Vortex TubeHaving Various Nozzle Numbersat Different Inlet Pressures of Air,Oxygen, Nitrogen, and Argon.
[4]. S.Rejin, H.Thilakan-Experimental Analysis on Vortex Tube Refrigerator Using Different Conical Valve Angle.
[5]. Saidi MH, Valipour MS. Experimental modeling of vortex tube refrigerator. Appl Therm Eng 2003;23:1971–80.
[6]. Saeid Akhesmeh, Nader Pourmahmoud and Hasan Sedgi- Numerical Study of the Temperature Separation in the Ranque-Hilsch Vortex Tube.
[7]. K.Stephan †S.Lin‡M.Durst†F.Huang§D.Seher†-An investigation of energy separation in a vortex tube.
[8]. Smith Eiamsa-arda, Pongjet Promvongeb- Review of Ranque–Hilsch effects in vortex tubes.
[9]. Ranque GJ. Experiments on expansion in a vortex with simultaneous exhaust of hot air and cold air. J PhysRadium (Paris) 1933;4:112–4 S-115, June. Also translated as General Electric Co., Schenectady Works Library 1947; T.F. 3294.