Experimental Investigation of Vortex Tube Refrigeration

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Abstract: *in the refrigeration field, this most notably crucial good quality connected with almost any analysis or even improvement is their green mother nature, by the virtue of which the idea fulfils your simple requirements without the injury to the environment. Currently, surroundings safety is now an essential aspect of this sectors and people in common. This specific cardstock is aimed at boost within effectiveness of merely one this kind of green technique named vortex tube used for commercial location cooling down along with process cooling down requirements, for instance Place cooling down, Weld cooling down, Cheap slitting, Extrusion cooling down, Food cooling down etc. This commonly used cooling down methods operate the fuel along with fluids that either deplete this ozone layer or even contribute inside the global increased temperatures within the same as $CO2$ does. Attempts are already created to consist of numerous features to get the optimum productivity along with information about this vortex tube. In this behalf of review, my aim is to construct a vortex tube with maximum efficiency at minimum cost ,for that I had optimized the vortex tube and done experimental investigation on the vortex tube by changing different variable such as nozzle numbers, vortex tube material, different cone angles , different mass fraction.*

Keywords: *Vortex tube, Refrigeration, Energy separation, Economic refrigeration, vorticity.*

1. INTRODUCTION

The actual vortex tube is a gadget which often divides a superior strain circulation stepping into tangentially straight into a couple lower strain moves, generally there by means of producing a heat transform. The actual vortex tubing doesn't have a transferring elements and also normally consists of a sale paper tubing using nozzles and a throttle control device. Underhand fuel makes its way into the actual vortex tubing tangentially over the nozzles which often boosts the angular pace and so yields the swirl influence. You'll find a couple generating a profit from the vortex tubing. The actual scorching quit is found in the actual external radius close to the much finish on the nozzle and the cool quit is usually in the center on the tubing close to the nozzle. The actual fuel divides straight into a couple tiers. The actual fuel closer to the actual axis has a lower heat and also is developed over the cool quit and the fuel close to the periphery on the tubing has a hot temperature which often is developed over the scorching quit. The actual distinction from the heat generated due to the swirl circulation was witnessed by means of Ranque over the examine regarding particles divorce cyclone and also he / she alluded this seeing that "temperature separation".

Vortex tubing is amongst the non-conventional sort refrigerating programs for that manufacturing regarding refrigeration. The actual schematic diagram regarding vortex tubing is usually found from the Fig. 1. It contains nozzle, diaphragm, control device, hot-air aspect, cold-air aspect. The actual nozzles are generally regarding converging as well as diverging as well as converging-diverging sort much like the planning. A powerful nozzle was created to get higher pace, greater large circulation and also minimal inlet deficits. Slot provided is a portion of nozzle and also services the actual tangential access regarding substantial pace air-stream straight into scorching aspect. Usually the chambers aren't regarding sale paper variety, but they are generally steadily became spin out of control variety. Warm aspect is usually cylindrical in combination segment which is regarding distinct program plans much like style. Device obstructs the actual circulation regarding air flow by way of scorching aspect and it also handles the amount of heat by way of vortex tubing. Diaphragm is a

cylindrical bit of little depth and also developing a little opening regarding specific diameter in the hub. Air flow mode travelling over the center on the scorching aspect is usually imparted over the diaphragm opening. Frosty aspect is a cylindrical percentage through which cool air flow is usually handed down.

Fig1. *Vortex Chamber*

1.1. Working of Vortex Tube

Pressurized air flow is usually transferred with the nozzle since revealed throughout Fig 1. The following, air flow increases and receives excessive velocity as a result of particular shape of the nozzle. A new vortex stream is made inside chamber and air flow vacations throughout spin out of control including motion on the periphery in the hot area. This stream is fixed with the valve. When the force in the air flow around valve is made over exterior through partially closing the valve, a reversed axial stream with the core in the hot area begins from high-pressure place in order to low-pressure place. On this practice, temperature move develops involving reversed mode and ahead mode. Consequently, air flow mode with the core will get refrigerated underneath the inlet temperature in the air flow inside vortex pipe, while air flow mode throughout ahead way will get warmed way up. Your cool mode is usually steered clear of with the diaphragm ditch in the cool area, while hot mode is usually transferred with the cracking open in the valve. By simply controlling the cracking open in the valve, the quantity of the cool air flow and temperature can be diverse..

1.2. Objective of Present Thesis

Some primary objectives of the present study are:

1. To optimize the vortex tube for maximum temperature difference from previous investigations.

2. To experimentally investigate the performance of this new optimized vortex tube.

3. To find out the maximum temperature difference of vortex tube.

4. To compare the performance of copper vortex tube and pvc vortex tube.

5. Analyze the experimental data of copper vortex tube and pvc vortex tube

2. LITERATURE REVIEW

L. H.. saidi et al[1] in 2003 performed trial and error exploration has become executed to achieve complete behaviour of your vortex tubing system. Inside their function focus has become centered on this class in the parameters which affects vortex tubing procedure. Your effective parameters tend to be split in 2 various sorts, that is geometrical as well as thermo physical versions. An honest test out rig has become intended as well as produced to look into the effect associated with geometrical parameters i. elizabeth. length as well as length of main tubing, length associated with store hole, shape of front door nozzle. Thermo-physical parameters which have been designated as well as learnt tend to be inlet petrol strain, kind of petrol, cool petrol mass proportion as well as dampness associated with inlet petrol. Giorgio De Observara et al[2] 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 hvac processes. Irrespective of it is simple geometry, this system of which produces this temperature separating into the tubing is fairly complicated. Quite a few observations as well as theories are discovered by means of unique researchers regarding that happening. Nited kingdom. Dincer et al[3]l in 2008 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 plug, based with the warm store part in the Ranque–Hilsch Vortex Tv (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 30or 58. Kun Chang et al [4] in 2009 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 centered on this divergence perspective associated with warm tubing, length of divergent warm tubing as well as variety of nozzle intakes. Nader Pourmahmoud et ing [5] in 2011 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.

Philippe Bournot et al[6] in 2011, as outlined by their, document offers any three-dimensional statistical style of Ranque-Hilsch vortex tubing while using industrial CFD code (Fluent) to study the effect in the ''cold stop diameter'' in the strength separating system into the vortex tubing; this constant point out presumption as well as practical factors reveal that the disturbance design should be used for you to stand for it is influence. The project documented in this article signifies that CFD examination will be able to predicting any temperature separating influence that is certainly according to this vortex tube's behaviour, also to consider his or her cold weather proficiency. It had been also observed that there is an perfect length associated with cold-end hole for accomplishing optimum strength separating. L Yilmaz et ing [7] in 2009 learnt yesteryear research in the pattern criteria associated with vortex tubes ended up overviewed plus the precise info has been shown on the pattern of these. Vortex tubes ended up categorized as well as the them has been explained. Almost all criteria on the pattern associated with vortex tubes were given in detail using trial and error as well as theoretical results on the previous so far Last but not least, this criteria on the pattern of these tend to be summarized. Rahim Shamsoddini et al[8] in 2009 analyzed numerically how the consequences in the nozzles amount on the move as well as strength associated with cooling of your vortex tubing tend to be learnt, using a three-dimensional statistical water powerful design. Vortex tubing provides interesting characteristics and several industrial purposes, as well as, being a freezer, it is applied being a area cooling gadget in sector. High-pressure compressible water enters this vortex tubing as well as actually leaves it is cool as well as warm sites from reduced as well as better temperature ranges than of which in the inlet move, respectively. Mohammad Sadegh Valipour et ing [9] in 2011 done a series of findings has become completed to look into this affect associated with consistent curvature associated with main tubing on the overall performance in the vortex tubing. Your curvature

in main tubing provides unique effect on this overall performance associated with vortex tubing determined by inlet strain as well as cool mass proportion. Your overall performance associated with tendency vortex tubing will be counted on the price associated with rotating perspective as well as dimensionless parameter. The ideal temperature change belonged for you to right vortex tubing, type A new nevertheless the optimum refrigeration ability belonged for you to tendency vortex tubeY. T. Wu et ing [10] in 2007 this individual perused inVortex tubing (VTtube) as well as figured vortex is really a simple strength separating gadget which can be sleek and stylish as well as all to easy to produce also to operate. Even though demanding research has become completed in several international locations over the years, this proficiency is reduced. So as to enhance the strength distinct proficiency associated with vortex tubes, three revolutionary systems ended up placed on vortex tubes. A new nozzle using the same gradient associated with Mach amount and also a fresh ingestion move penetration associated with nozzles using the same move acceleration ended up intended as well as developed to relieve this move reduction. A new type of diffuser developed by means of us all has been put in for lowering friction decrease in air-flow strength by the end in the warm stop tubing associated with vortex tubing, that may significantly enhance the overall performance associated with vortex tubing. Your experiment results suggested why these modifications may astonishingly enhance the overall performance associated with vortex tubing. Your developed vortex tubing wasn't merely finer quality than the typical vortex tubing but additionally finer quality than of which made by 2 businesses in earth under massive cool petrol mass move proportion. Throughout found, this above all critical quality associated with any kind of research or progress will be it is friendly to the environment mother nature, with the virtue of which that fulfils our essential requires without the difficulties for the type. Nowadays, environment basic safety is now a vital element of this industrial sectors and the wonderful in keeping. This particular document is aimed at enhance in proficiency of a single this kind of friendly to the environment system branded vortex tubing employed for industrial area cooling as well as course of action cooling requires, for instance Area cooling, Weld cooling, Cheap slitting, Extrusion cooling, Food cooling and so on. Your common cooling techniques operate the petrol as well as drinks which either diminish this ozone layer or play a role in the world-wide heating in exactly like CARBON does. Efforts are meant to contain various features to get the optimum output regarding H. I. P. (COEFICIENT ASSOCIATED WITH PERFORMANCE) as well as know-how about this vortex tubing. Within this benefit associated with examine, our purpose is to develop any vortex tubing using optimum proficiency from bare minimum price, seeing that how many nozzle will be improving proficiency also improving. In papers i have read the nozzle number is used up to three, so my objective turned to construct a vortex tube with four nozzles. Also the material used in vortex tube also changes the cooling capacity here i am selecting pvc tube. Because in all experiments i have read vortex tube is made up of conductor only. Also i am planning this experiment to compare with a copper tube of same specifications of the pvc vortex tube. The past investigations are studied and the result obtained from their investigations is given below, also we considered the availability of the items and related specifications. Vortex tube length=110cm,Vortex tube diameter=3.6cm,Diameter of nozzles=1cm,Cold orifice diameter=1.8cm,Hot flow control valve=50 degree, Vortex tube geometry=Straight cylinder, Air is selected as working fluid, Copper tube and pvc tube is selected as vortex tube material.

3. EXPERIMENTAL INVESTIGATIONS

Figure 2 shows the layout of my fabricated experimental setup. Compressed air for the vortex tube is generated using air compressor. Air cooled and oil splashing reciprocating compressor is used for my experiment study.

3.1. Experimental Set Up

The layout of the experiment setup is given below,
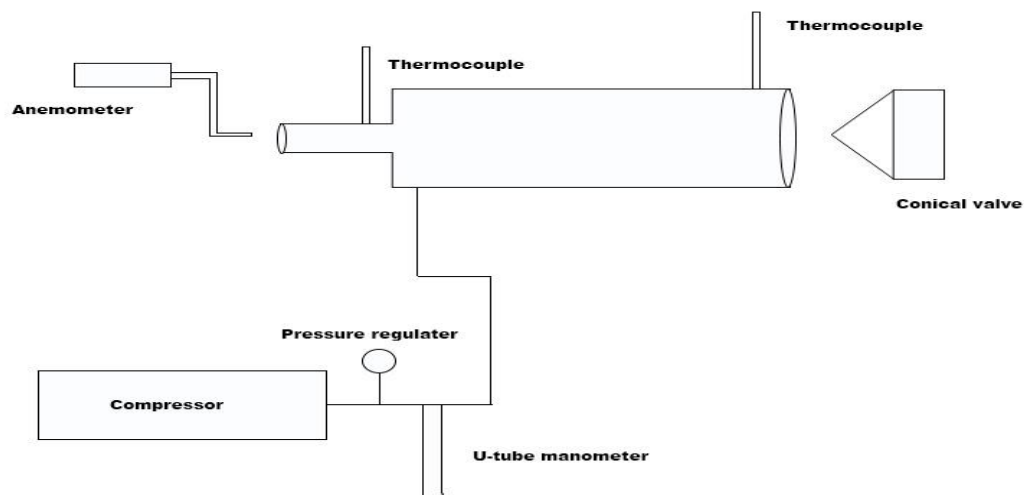

Fig2. *Experimental layout of vortex tube*

The experiment set up consists of compressor, pressure regulator, U tube manometer, nozzles, vortex tube, thermometer, conical valve, anemometer. the experiment is designed so as to do the experiment in vortex tube.The materials used for the construction of this new type of vortex tube is inexpensive and easily obtainable in the market.My experiment is set up with reciprocating compressor which can deliver a pressure upto 10 bar and vortex tube of 36 mm diameter and length 110cm and pressure regulator which regulates the flow in the range of 10 to 12 bar pressure, an orifice meter is for measuring flow and two thermometers one in cold end and one in hot end and by using anemometer we measure outlet velocity and thereby calculating mass fraction. Also hot flow control valve for regulating the mass fraction and the vortex tube that build by mine is with pvc and copper.this is selected because that one is conductor and another one is insulator, that is because to compare the cooling effect. By using this material we can give a correct idea where the cooling effect stronger. And the my experiment set up photo of copper vortex tube and pvc vortex tube is given below.

Figure.3.Vortex tube experiment set up

The experiment set up is done copper tube as tube material and pvc as tube material, by considering these two material we can compare the cooling effect of a conductor and insulator. Copper is good conductor while pvc is a insulator. The pressure regulator can regulate the flow from 2 bar to 12 bar.

3.2. Experimental Procedure

In this experiment compressed air from the compressor is given to the vortex tube through the pressure regulator ,pressure regulator regulates the flow that is we can select the required amount of pressure by pressure regulator, here in this experiment set up we considered 2 bar to 8 bar pressures. Then in this experiment setup we measured the total mass flow rate using orifice meter, Orifice of diameter 10mm, by measuring the reading of two limbs of manometer thereby we calculated the total mass flow rate. Then this compressed air was given to the vortex tube through the nozzles. Here the experiment is conducted first in one nozzle and taken all the readings, then in two nozzles and then in four nozzles. In the hot end side conical valve was adjusted to keep the mass fraction constant at every inlet pressures. And also various mass fraction was considered. Two thermometers are set, one at hot end and other at cold end for measuring the temperature. Also anemometer is used at cold end inorder to measure the velocity and there by calculating the cold mass flow rate and cold fraction. This whole experiment is done in copper vortex tube initially then with pvc the experiment procedure is repeated.

Some important definitions of vortex tube are given below

3.3. Mathematical Relations

Cold mass fraction-The cold flow mass ratio (cold mass fraction) is the more important parameter that the vortex tube performance and temperature separation inside the RHVT. The performance of the vortex tubes is evaluated based on cold fraction. The cold mass fraction is percentage input compressed air that released through the cold end of the tube. It is defined mathematically as the mass flow rate of cold gas divided by the mass flow rate of the inlet gas:

$$\varepsilon = \dot{m}_c / \dot{m}_{in}$$

(1)

Cold and hot temperature difference-Cold temperature difference is defined as the difference in temperature between inlet flow temperature and the cold flow temperature.

$$\Delta T_c = T_{in} - T_c$$

(2)

where T_{in} is the inlet flow temperature and T_c is the cold flow temperature. Similarly hot air temperature difference is defined as

$$\Delta T_h = T_h - T_{in}$$

(3)

Normalised temperature drop/rise-Normalized cold temperature drop is defined as the ratio of cold temperature difference to inlet temperature:

$$\frac{\Delta T_c}{T_{in}} = \frac{(T_c - T_{in})}{T_{in}}$$

(4)

Similarly normalised hot temperature rise is defined as

$$\frac{\Delta T_h}{T_{in}} = \frac{(T_h - T_{in})}{T_{in}}$$

(5)

Cold orifice diameter-Cold orifice diameter ratio (β) is defined as the ratio of cold orifice diameter (d_c) to vortex tube diameter (D):

$$\beta = \frac{d_c}{D}$$

(6)

Coefficient of performance-The coefficient of performance (COP) as a refrigerator is defined as the ratio of the cooling power gained by the system to the work power.

$$COP = \frac{\dot{Q}_c}{W}$$

(7)

Here the cooling power can be calculated according to the cooling capacity of the cold exhaust gas (e.g. the heat necessary to heat up the cold exhaust gas from the cold exhaust temperature to the applied temperature)

$$\dot{Q}_c = \dot{m}_c C_p (T_{in} - T_c)$$

(8)

In the orifice meter we measure the difference in manometer reading, and calculate the discharge, from discharge we calculated the total mass flow rate, the governing equations of the orifice meter is given below

$$Q = \frac{C_d A_1 A_2 \sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}}$$

(9)

Where A_1 is the area of pipe and

A_2 is the area of the orifice,

g is acceleration due to gravity,

C_d is the coeffient of discharge of orifice meter,

Also $\quad A_1 = \frac{\pi}{4} D^2$ (11)

$$A_2 = \frac{\pi}{4} d^2$$ (12)

Where d is the diameter of orifice and D is the diameter of pipe

The result obtained was analysed and compaired and graph is plotted .The graph plotted.

4. RESULTS AND DISCUSSION

The results obtained from the experimental investigation is drawn below, various graphs are drawn, first up all we had drawn the temperature at cold end versus cold mass fraction is drawn. Here we consider 8 bar pressure because the experiment shows by increasing pressure temperature difference also increasing so that we selected maximum pressure that a compressor can give, in our experiment set up we selected 8 bar for comparing the results
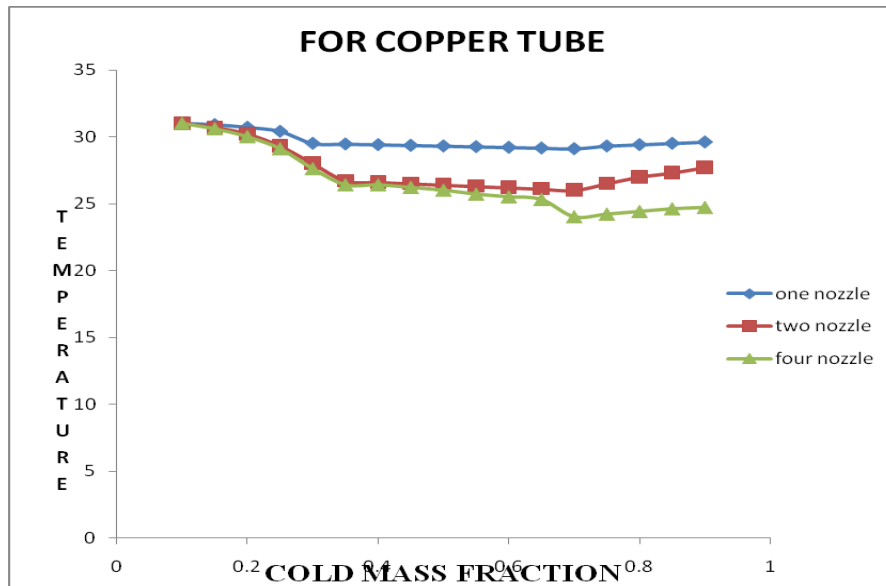
Fig4. *cold end temperature v/s cold mass fraction*

By analyzing the above graph by increasing the cold mass fraction at certain valve,the temperature is decreasing, after a certain value it is going on increasing, that is temperature decreases upto .7 mass fraction then temperature increases, also we noted that by increasing nozzle from one to four here the temperature decreases. Temperature is lesser than the vortex tube with four nozzle, then two nozzle, then one nozzle
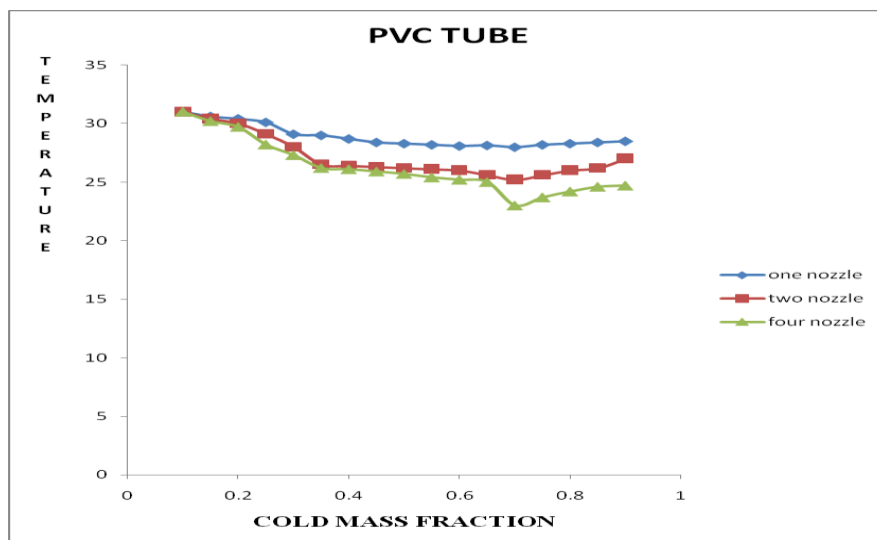

Fig5. *Cold end temperature v/s cold mass fraction*

Like wise the copper tube pvc shows same behavior, but gives lesser temperature than copper tube. By analyzing the above graph by increasing the cold mass fraction at certain valve,the temperature is decreasing, after a certain value it is going on increasing, that is temperature decreases upto .7 mass fraction then temperature increases, also we noted that by increasing nozzle from one to four here the temperature decreases.temperature is lesser than the vortex tube with four nozzle, then two nozzle, then one nozzle,Then we drawn graph analyzing the nozzle by compairing the vortex tube material. There also the graph shows that pvc can give better performance than copper tube
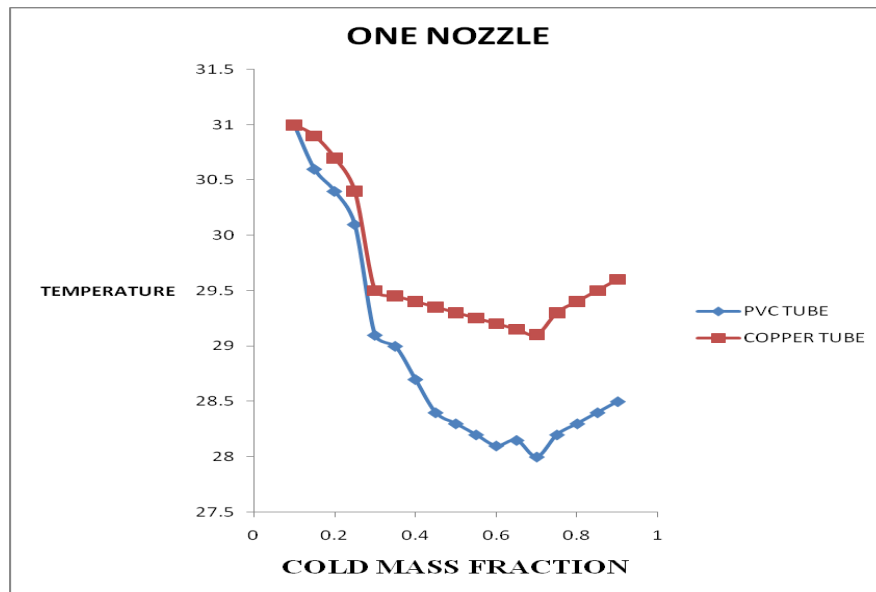

Fig6. *Cold end temperature v/s cold mass fraction*

Here the graph is drawn between cold end temperature versus two nozzle where pvc and copper tube is selected as vortex tube material, in the graph it is clear that the cold temperature is lesser in pvc as the tube materials by compairing with the copper tube.
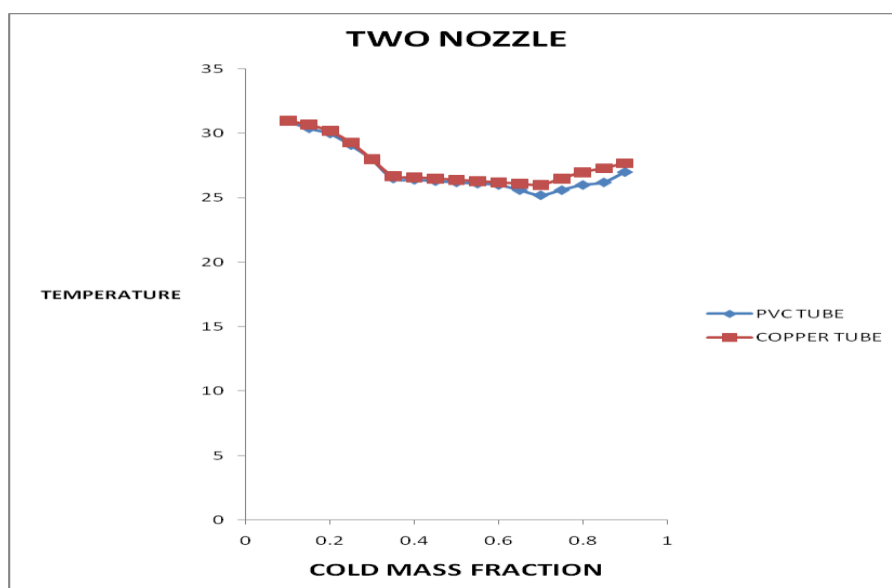

Fig7.*cold end temperature v/s cold mass fraction*

Here the graph is drawn between cold end temperature versus two nozzle where pvc and copper tube is selected as vortex tube material in the graph it is clear that the cold temperature is lesser in pvc as the tube materials by compairing with the copper tube
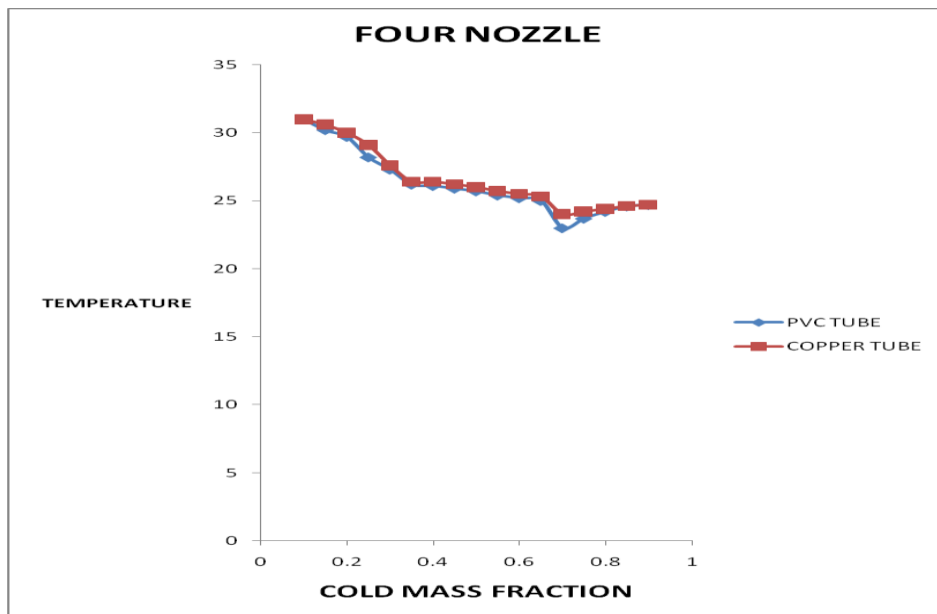
Fig8. *cold end temperature v/s cold mass fraction*

Here the graph is drawn by hot end temperature and hot mass fraction and analysed below. Also by analyzing the nozzle number , in both cases that is in copper tube and pvc tube four nozzle gives the maximum temperature difference between cold end temperature and hot end temperature
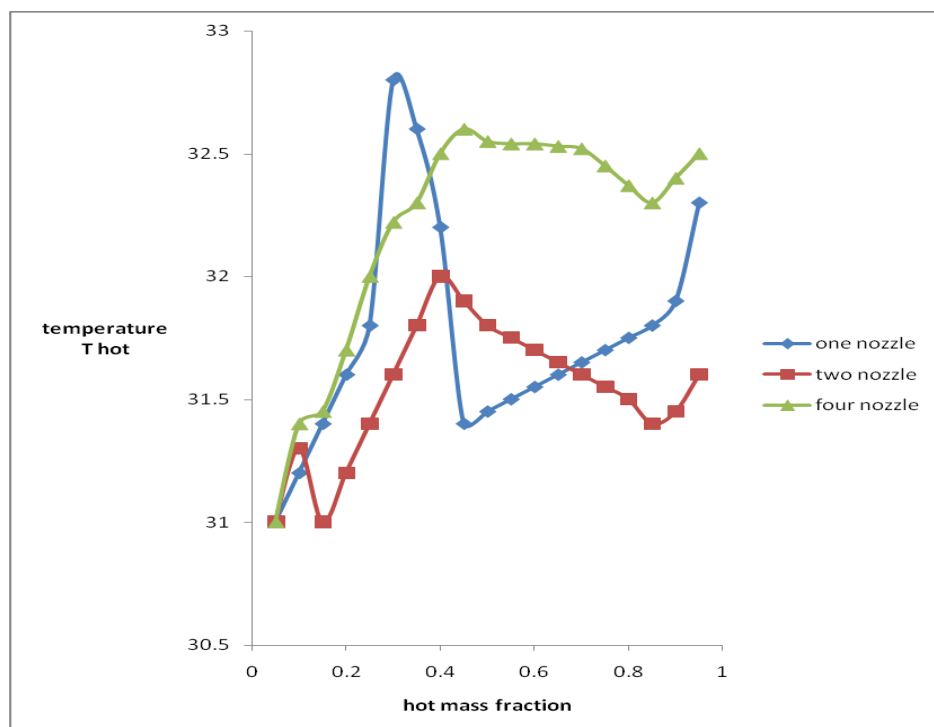

Fig9. *Hot end temperature v/s hot mass fraction*

By analyzing the experiment results, by compairing the results, pvc tube gives minimum temperature at the same mass fraction,also by the experimental analysis it is clear that vortex tube with pvc as material is better than copper tube. Also by analyzing the nozzle number , in both cases that is in copper tube and pvc tube four nozzle gives the maximum temperature difference between cold end temperature and hot end temperature**.**

5. CONCLUSION

Experimental investigation of optimized vortex tube is done and the performance of modified vortex tube is analysed. The results of the experiments show that the performance of pvc vortex has higher temperature difference than copper tube, that is hot temperature and cold temperature difference. Also the number of nozzle number is analysed here, the investigations showed that four nozzles gives maximum temperature difference. Experiment shows that by increasing the number of nozzles the temperature difference between hot end and cold end also increases. Also by increasing the inlet pressure the cold outlet temperature decreases simultaneously that is temperature difference increases. The cold mass fraction of about 0.7 gives minimum temperature in all conditions. In my variable investigation shows that four nozzles with pvc as vortex tube material have the best cooling effect. This type of vortex tube refrigeration can be attach in automobiles for cooling the cabin in future works

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