SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360 /doi:10.14445/23488360/IJME-V5I11P101

Volume 5 Issue 11, 1-6, November 2018

Design and Performance Evaluation of a Vortex Tube form by Copper Material

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Abstract

Refrigeration assumes a noteworthy part in preparatory nations, essentially for safeguarding nourishment, prescription, and for aerating and cooling. Ordinary refrigeration frameworks are utilizing Freon as a refrigerant, which makes the ozone layer depletion. A broad study is happening to interchange the concept of cooling frameworks. The vortex tube is not familiar with cooling equipment but which have no moving parts. It will supply cool air and hot air in spring and winter season, without any effect as in the pieces of equipment which releases Freon into nature. At the point at which the elevated weighted air inventively infuse inside the chamber, a brawny airstream will divide into a pair of streams. The present work predominantly centers around Design and creating the vortex container of Copper material. After manufacturing, the Vortex tube's execution is assessed for various measurements of opening and channel weights. Cooling impact and Heating impact are chosen and COP as execution measures. The present investigation aims to determine the suitable orifice diameter for getting the Cooling effect and Heating effect. To find out the suitable inlet pressure for obtaining the Cooling effect and Heating effect. To validate the best material for the chosen performance measures of COP.

Keywords – *Vortex Flow, Orifice, Tangential Nozzle, Vortex chamber formatting*

I. INTRODUCTION

The vortex tube was made-up by a French physicist named Georges J. Ranque in 1931 while considering forms in a tidy detached tornado. It was very disagreeable amid its origination on account of its evident wastefulness. For various years, the copyright and thought were left, anticipating 1947 when a German designer Rudolf Hilsch tweaked the tube's arrangement. From that point forward, numerous analysts have endeavored to discover approaches to advance its productivity. Until today, there is no single hypothesis that clarifies the spiral temperature division. The partition of gas blends, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air with the vortex tube(VT) was accounted for in 1967 by Linderstrom-Lang and in 1977 by J. Marshall. In 1979 steam was utilized as a working medium by Takahama. In 1979, two-stage propane was utilized as the working medium by Collins. In 1988 Balmer connected fluid water as the working medium. It was discovered that when the channel Pressure is high, for example, 20-50 bar, the vitality division impact still exists. So it demonstrates that the vitality partition process exists in incompressible (fluids) vortex stream also. In 2004, flammable gas as working medium and with the VT gaseous petrol was melted by Nikolay Poshernev.

The whole year 1928:

Inside the year1928, a French physicist called George Ranque ran a vortex-type pump and unintentionally imagined an alternate kind of vortex the tube with the vortex. While investigating his innovation, he saw a guaranteed item wherein he endeavored to showcase as a vortex tube. Sadly, people, those days didn't have any utilization for such an effective and practical gadget.

In 1945:

After seventeen years, in 1945, that creation left hibernation when another physicist, known as Rudolph Hilsch, composes articles in the diary, "Wirbelrohr," concerning the gadget. He was cited saying the usefulness with the container of vortex being a mechanical gadget. Over the long haul, a few applications and utilizations have been found by the monetary area is generally helpful.

Subscripts	Nomenclature
m_c	Mass Flow Rate At Cold Tube
m_h	Mass Flow Rate At Hot Tube
Tc	Cold Air Temperature
T_h	Hot Air Temperature
Ti	Inlet Temperature
Pa Pi	Atmospheric Pressure

	Inlet Pressure Of Air
	Cold Drop Temperature
	Hot Drop Temperature
Δ Tc	Relative Temperature Drop
ΔT_h	Temperature Drop At The Two
Δ Trel	Ends
ΔT	Atmosphere
A	Cold Air
c	Hot Air
h	Inlet Air
i	Isentropic
is	Cold Air Passing Orifice
d	Diameter (M)
D	Vortex Tube Diameter (M)
M	Mass Flow Rate (Kg/S)
P	Pressure (Pa)
Greek symbols	
η_{ab}	Adiabatic Efficiency
μc	Cold Mass Fraction
(β)	Cold Orifice Diameter
η	Efficiency (%)
COP	Coefficient Of Performance
Cp	Specific Heat Of Air At Constant Pressure

The gas is compressed to high pressures in the compressor, and the pressurized gas is injected tangentially into a swirl chamber and accelerated to a high rate of rotation. Due to the tapering nozzle at the end of the tube, only the compressed gas's external shell is authorized to run away at that end. The gas residue is forced to return in an inner vortex of reduced diameter within the outer vortex.

II. IMPORTANT DEFINITIONS

In the present work, the definitions used in vortex tube work are very clearly given below.

A.COP

The coefficient of performance is defined as the ratio of cooling rate to the work input for cooling. Principle of an adiabatic expansion of ideal gas is employed, then the equation becomes

C.O.P = QC/W

$$C.O.P = 1.\ \frac{\text{Cooling effe}}{\text{Work inpu}}$$

$C.O.P = \eta_{ab}.\ \eta_{ac}.\ [(Pa/Pi)\ (\gamma-1)/\gamma]$

Where ηab, ηc, Pi, Pa and γ are the Adiabatic Efficiency, Compressor Efficiency, Inlet Pressure, and Atmospheric Pressure

B. ADIABATIC EFFICIENCY

To compute the vortex tube's cooling competence, the rule of an adiabatic expansion of ideal gas is applied. As the air flows into the vortex tube, the expansion in the isentropic process occurs. This can be written as follows:

$$\eta_{ab} = \frac{\text{actual cooling gained in vortex tube}}{\text{Cooling possible with adiabatic expansic}}$$

and

$\eta_{ab} = [\Delta T_h / (\Delta T_h + \Delta Tc)]\ *\ (\Delta Tc/\Delta T'c)$

Where η_{ab} = adiabatic efficiency, ΔT_h = hot air tube temperature raise of, ΔT_c = cold air tube temperature drop, and ΔT_c'= Static temperature drop due to expansion.

C. ICY ORIFICE DIAMETER (B):

Cold orifice diameter fraction (β) =

$$1.\ \frac{\text{cold orifice diamet}}{\text{vortex tube diame}} = d/D$$

2.4. COLD AIR TEMPERATURE DROP (ΔTC):

Cold air hotness lump or temperature decline is defined as the variation in temperature amid entry air temperature and cold air temperature:

$\Delta Tc = Ti - Tc$

In equation (4), Ti = Entering air temperature and Tc = cold air temperature

D. MASS FRACTION OF COLD AIR (M_C):

The cold air mass fraction is the generally main constraint denoting the vortex tube concert and the temperature to the vortex tube's energy separation. The cold air mass portion is clear as the relation of cool air mass current rate to inlet air mass flow rate. The cold air mass portion can be regulated by the tapered valve positioned at the hot tube end. This can be expressed as follows:

$\mu_c = m_c/m_i$ and

$\mu_c = \Delta T_h / (\Delta T_h + \Delta Tc)$

2.6. HOT AIR TEMPERATURE DROP (ΔTH):

Hot air temperature drop or temperature raise is defined as the difference in temperature between Hot air temperature and entry air temperature:

$\Delta T_h = T_h - T_i$.

In which Ti is the entry air temperature, and T_h is the hot air temperature.

2.7. RELATIVE TEMPERATURE DROP (ΔTREL):

The relative temperature drop is defined as the temperature drop of a cold air tube to a static temperature drop due to expansion.

$$\Delta T_{rel} = \Delta T_c / \Delta T_c'$$

III. REVIEW OF THE VORTEX TUBE

Whirl streams inside the vortex include broad mindfulness bigger than the history decades due to their utilization in mechanical applications. Vortex (or hoisted twirl) can likewise create a frosty heat stream inside the vortex tube. In mechanical accommodation for cooling and warming strategies of vortex tube, these are easy compact and light and quieted (inactivity) gadgets [6– 7]. A few analysts put a considerable measure of endeavors to clarify the wonders happening amid the vitality detachment inside the vortex tube. Research learns about these wonders were framed essentially into two gatherings. The first played out the trial work (geometrical and thermo-physical parameters) and after that, through the estimation of their outcomes, endeavored to clarify the marvels. The second played out the investigations in subjective, expository, and numerical courses to examine the systems introduced in the vortex tube.

IV. LITERATURE REVIEW OF VORTEX TUBE

The Ranque [1, 2] is a metallurgist and physicist, and he got a French patent for the gadget in 1932, the underlying response has logical, and building groups for his creation were mistrust and lack of care. The vortex tube was thermodynamically deserted for a while. See in the contraption was renewed by Hilsch [3], a German designer, who detailed his very own record thorough trial and hypothetical investigations to enhance the vortex tube effectiveness. His studies effectively analyzed the impact of vortex tube with bay weight, and geometrical dimensions will exhibit a conceivable clarity on the process of vitality partition. A test contemplate was made by Scheper [4], who estimated the speed, weight, and aggregate and static temperature slopes in a Ranque– Hilsch vortex tube, utilizing tests and perception strategies. He inferred that the pivotal and spiral speed segments were considerably littler than the unrelated speed. His estimations demonstrated that the static temperature diminished in a radially outward way. This outcome was in opposition to most different perceptions that were made later. Martynovskii and Alekseev [5], (S.A.Mule) and yogeshbhosale et al. [6] obtained the impact of different parameters, for example, spout locale, cool hole district, hot end spot and chilly end part and L/D proportion of the tube estimation the long way to the tube breadth on the execution of vortex tube can be explored. Dr.Ing.Ramzi Raphael IbraheemBarwari et al. [7] recommended that by fluctuating the cone valve width (dc= 14, 12, 10, 8, and 6mm) on vortex tube utilizing two spouts with steady spout breadth (dn = 6.5 mm) and shifting the weight of the delta air (Piabs) and additionally chilly air mass ratio(Y) inside the reaches (Piabs = 2-6 bar) and (Y =0 – 1) consecutively. The analyses demonstrated an ideal outline of uni-stream vortex tube that gave high vitality division at cone valve distance across (dc= 12mm) for four vortex-tube measurements (D=30, 20, 15mm and decrease). M. Kshirsagar et al. [8] proposed in his experimentation of this paper is to comprehend the impact of different parameters like gulf weight of air, several spouts, frosty hole measurement, and hot end valve approach on the introduction of the vortex tube. Additionally by the writing audit unmistakably there is no hypothesis so immaculate, which gives the sensitive portrayal of the vortex tube understanding. Because of this clarification recipient play out the arrangement of directing tests to perceive the impact of different parameters specified above on the vortex tube's execution. the tube, which has 4 spouts. K. Kiran Kumar Rao et al. [9] recommended that in light of various materials of hot tubes like Mild steel, Aluminium and Copper utilized as a part of creation that the most extreme hot air temperature and least sum frosty air temperature began. The creation and trial examination was completed in light of by utilizing same L/D proportion 22/8 with the adiabatic procedure of hot tube; spout 8 mm distance across and opening 6 mm measurement utilized. Hemant V. Darokar et al. [10] proposed geometry for the cool end side, which has joined helical spouts in the 8mm to 3mm, disparity edge 60 hot tubes with 225mm term and measurement 12.5mm. Cool finishes are thought up with 7 mm opening measurement and 6 no. of spouts. The impact of bay weight (2 to 5bar in advance of 1 bar, cone-shaped valves in figure 8. (30°, 45°, 60°, 90°) on the routine of` vortex tube is broke down. The most extreme COP and isentropic effectiveness observed to be 0.376 and 23% for 45° funnel shaped valve at 5 bar weight were Toward the finish of concentrate. Aydın and Baki [11] examined tentatively the tube's geometry was streamlined to abuse the temperature difference among the cool and delta temperatures by moving the different size of the tube, for example, the term of the vortex tube-like width of the bay spout and edge of the control valve. Additionally, the impacts on distinctive temperatures inside the tube were likewise contemplated of different channel weight and diverse working gases (O_2 and N_2). Gao et al. [12] utilized an uncommon pitot tube and thermocouple strategies to gauge the weight, speed, and temperature dissemination inside the vortex tube. The pitot tube has just a measurement of 1mm with one opening (0.1mm breadth). In their work, the impact of various bay conditions was contemplated. They found that adjusting the passage can be upgraded, expanded the auxiliary course gas stream, and enhanced the framework's execution. [13] Revealed the impacts of (1) the quantity of bay distracting spouts, (2) the cool hole measurement, and (3) tube protections on the decrement of temperature and isentropic effectiveness of the tube. Promvonge and Eiamsa-ard [14] tentatively concentrated the vitality and temperature divisions in the vortex tube with a small entrance. Their investigation comes about the utilization of small access may expand the intense air temperature drop and recuperate the vortex tube's ability by examining with those of unique unrelated bay spouts. Singh et al. [15] the impact of different parameters is detailed. For example, chilly mass portion, spout, cool opening breadth, hot end territory of the tube, and L/D proportion on the vortex tube execution. They made a trial that the result of spout configuration was new imperative in getting higher temperature partitions than the chilly hole configuration and found that the tube's length had no result on the show of the vortex tube in the assortment 45– 55 L/D. [17] researched tidy partition attributes of a counter stream vortex tube with lime powders whose mean molecule sizes are 5mm and 14.6 mm. They suggested a vortex tube can be connected as a successful pre-skimmer to separate particles from industrial waste gases. Hartnett and Eckert [18, 19] demonstrated a straightforward model in light of a turbulent turning stream with strong body pivot gives a temperature contrast between the tube dividers and the hub, which is to some degree higher yet at the same time near their exploratory esteems. They likewise expressed that the stationary temperature slant expanded radially towards the dividers. The utilization of a scientific model to reproduce the warm detachment in a Ranque– Hilsch vortex tube was encountered by Eiamsa-ard and Promvonge [20, 21]. The work had been completed keeping in mind the end goal to comprehend the physical practices of stream, weight, and temperature in a vortex tube. A stunning limited volume approach with standard k– e demonstrate and an ASM with (Upwind, Hybrid, SOU, and QUICK plans) was utilized to do every one of the calculations. The calculations demonstrated that outcomes anticipated by both turbulence models, by and large, are in great concurrence with estimations; however, the ASM performs better understanding between the numerical outcomes and test information. The scientific calculations with sensible spring terms of the vitality condition undeveloped. [22] Demonstrated the diffusive exchange of mean dynamic impacted the most extreme temperature detachment happening close to the channel area. A long way from the inlet, expansion impacts and the pressure age with its angle transport was also critical in the downstream district. The majority of the writing calculations utilize the basic or first-arrange turbulence models that are viewed as unacceptable for mind-boggling, compressible vortex-tube streams.Behera et al. [23] researched the impact of the distinctive kinds of spout profiles and several spouts on temperature division in counter-stream vortex tube utilizing the code arrangement of Star-CD with 'Renormalization Group' (RNG) rendition of the k– e demonstrates.

V. DESIGN OF VORTEX TUBE

The setup is outlined and displayed utilizing the CAD &CATIA V5 R21 demonstrating bundle – Then CATIA demonstrating is changed over to STEP record (stp) design handling by the solver bundle.

Different strides in displaying to be completed in CATIA are talked about underneath.

Select the new part from CATIA V5 R21

Select the RIGHT-HAND SKETCH, give circle width and length

Select the work seat.

Draw the helix bend with the work seat

Select the point in the corner

Take cut towards the flute length

Select the opening apparatus, take after the profile of the helix

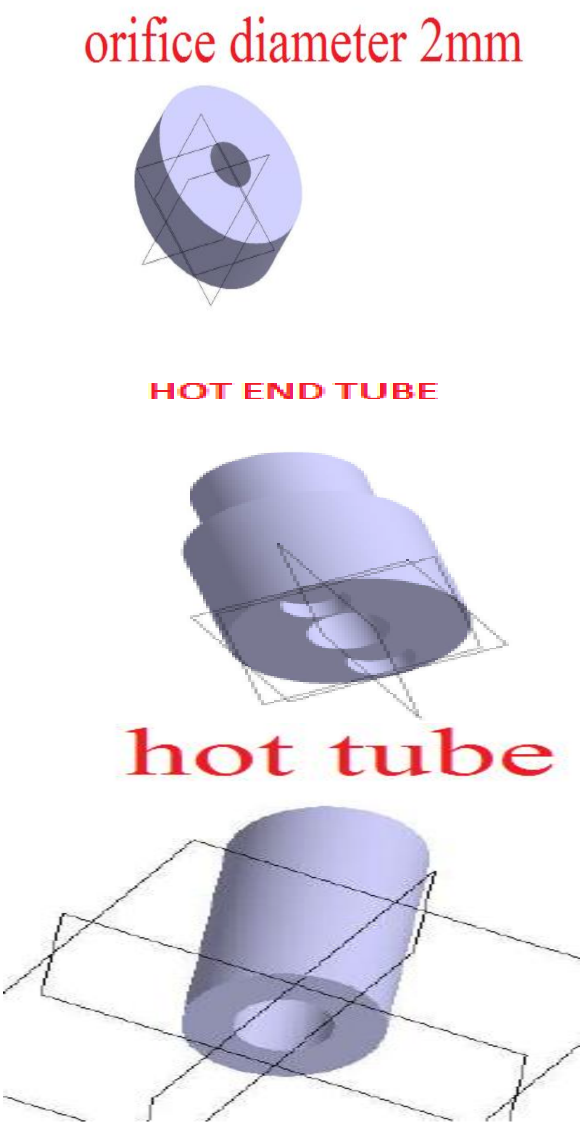

Figure 1.Basic Design and modeling of vortex tube parameters:(a)diameter orifice and (b) the hot end tube(c) the hot tube.

Figure2.Fabrication of copper vortex tube parameters:(a)diameter orifices and (b) the hot end tube (c) the hot tube.

We are using the CAD&CATIA V5 R21 and designing and modeling vortex tube parameters or parts like main body, hot tube, cold tube, inlet nozzle, control valve, hot end tube, and orifice diameter s 4,5,6,7,8 mm, respectively.

A diaphragm is the most important part to be manufactured in the vortex tube. The diameter orifice (Figure. 1a,2a) is manufacturing, modeling, and designed using copper material. The thickness is 9mm, and the outer diameter is 25mm, and a hole of 8mm is made at the center.

Hot end tube (Figure. 1b,2b) copper material of size 60mm diameter meters and 70mm length is used. First, the material is turned to a diameter meter of 44mm and faced to a length of 53mm. The external threading of 14 TPI of the division that is removable to the main body is executed to the duration of 18 mm, a hole with 37mm diameter to a depth of 33mm is drilled with internal threading of 14 TPI to a length of 18mm at the control end side. Three small holes, one at the center and two on each side of the center hole with 9mm diameter, are drilled to facilitate the control valve and exit to hot air.

A hot tube is the main part to be fabricated in the vortex tube. The hot tube (Figure. 1c, 2c) is fabricated, modeling, and Designed using copper material. The hot tube's length is 135mm, and the through-hole 12.5 diameters are made external threads of 1.5mm pitch are made on either side to the length of 20mm.

VI. OBSERVATIONS AND CALCULATIONS

The experimental investigation was conducted to find the effect of different orifice diameters and inlet pressures on the vortex tube's performance. After experimenting, the observations are noted as given below: For different Orifice diameter (d) at different input pressure by using copper material

Table 1. Summary of experimental studies on vortex tubes (Copper Orifice diameter: 8mm)

s.no	Pi, bar	(Tc) ^{0}C	(T_h) ^{0}C	μ	$\eta_{Adiabatic}$	COP
1	7	12	50	0.60	0.7921	0.2053
2	6	13	48	0.6	0.7807	0.2113
3	5	15	44	0.61	0.7436	0.2120
4	4	18	44	0.65	0.6674	0.2028

VII. RESULTS AND DISCUSSION

A. Inlet pressure vs. ΔTh (From Copper material)

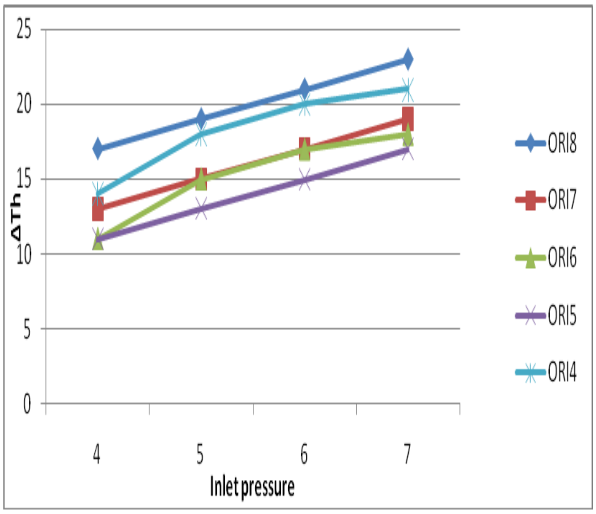

Figure 3.Inlet pressure vs. COP (From Aluminium material)

At 7 bar pressure, the orifice with 8mm diameter performs well, and the maximum hot temperature drop is obtained as 23^{o}c, and the maximum temperature difference is obtained as 38^{o}c.

At 4 bar pressure, the orifice with 4mm diameter the performance is very poor and hot temperature drop is obtained as 14^{o}c, and the temperature difference is obtained as 31^{o}c.

Copper material: After evaluating the vortex tube's performance by varying the orifice diameters and inlet pressures, it was found that the vortex tube with an 8mm diameter orifice and at a pressure of 7bar gives the best performance. As shown [Table1].

8. CONCLUSION

The well-suited diameter orifice(8mm) at pressure 7 bar for getting superlative cooling effect(120C) from copper material.

The felicitous orifice diameter (8mm) at pressure 7 bar for getting utmost heating effect (500C) from copper material.

The adaptable orifice diameter (4mm) at pressure 7bar gives poor co-efficient of performance (0.1663) from copper material.

The convenient orifice diameter (8mm) at pressure 4 bar for getting supreme co-efficient of performance (0.2028) from copper material.

While optimizing orifice diameter, inlet pressure for Aluminum and Copper, Aluminum gives better performance.

The heating effect was the cooling effect and better COP at 8mm orifice diameter and 7 bar inlet pressure.

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