Design and Performance Evaluation of a Vortex Tube Form by Aluminum Material

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Abstract. Vortex tube is a non–conventional cooling device, having stationary 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 the vortex chamber, a strong vortex flow will be created which will be split into two air streams. The present work mainly focuses on design and fabricating the vortex tube with aluminium material. After fabricating, the performance of the Vortex tube is evaluated for different diameters of orifice and inlet pressures. Cooling effect and Heating effect are selected and COP as performance measures.

Key words: Vortex Flow, Orifice, Tangential Nozzle, Vortex chamber

1. Introduction
The vortex tube, otherwise called the Ranque-Hilsch vortex tube (RHVT) is a device which produces isolated streams of cold and hot gases from a single compressed gas source. The vortex tube was imagined very coincidentally in 1931 by George Ranque[1,2], a French material science under study, while trying different things with a vortex-type pump that he had created, and afterward he saw warm air debilitating from one end, and icy air from the other. Ranque soon observed that his pump and began a little firm to abuse the business potential for this weird device that created hot and chilly air with no moving parts. Often this vortex tube slipped into indefinite quality until 1945 when Rudolph Hilsch, a German physicist, distributed a broadly read logical paper on the device. Significantly prior, the colossal nineteenth century physicist, James Clerk Maxwell[4], found that warm includes the development of atoms, sometimes or other we have the capacity to get hot and cold air from a similar device with the assistance of a "friendly little demon" who deal and isolate the hot and chilly particles of air.

Table 1: Nomenclature used in the paper.

| Subscripts | Description                |
|------------|----------------------------|
| mₐ         | mass flow rate at cold tube|
| mₜ         | mass flow rate at hot tube |
| Tₐ         | cold air temperature       |
Subsequently, the vortex tube has been differently known as the "Ranque Vortex Tube", the "Hilsch Tube", the "Ranque-Hilsch Tube", and "Maxwell's Demon". By any name, it has as of late picked up acknowledgment as a basic, dependable and minimal effort reply to a wide assortment of modern spot cooling issues. At the point when high-weight gas is digressively infused into the vortex chamber through the gulf spout, a whirling stream is made inside the vortex chamber. In the vortex chamber, some portion of the gas exists by means of the cool fumes specifically, and another part called as free vortex twirls to the hot end, where it inverts by the control valve making a constrained vortex moving from the hot end to the chilly end. Warmth exchange happens between the free end and the constrained vortices there by creating two streams, one hot stream and the other is cold stream at its closures.

2. Objectives
To determine the suitable orifice diameter for getting Cooling effect and Heating effect.
To find out the suitable inlet pressure for obtaining Cooling effect and Heating effect.
To validate the best chosen performance measures of COP.

Specifications Of The Air Compressor Used:
Compressor H.P = 7.5
No of cylinders = 3
Diameter of two L.P cylinders = 2 x 0.0936 m
H.P cylinders = 0.07 m
Stroke length = 0.076 m
Number of stages = 2
3. Calculations:

Specimen Calculations For The Inlet Pressure Of Air, Pi = 7 Bar

Observations:

- Atmospheric pressure Pa = 1.013 bar
- Inlet pressure of air Pi = 7 bar
- Inlet temperature of air Ti = 270°C
- Cold air exit temperature Tc = 90°C
- Hot air exit temperature Th = 510°C

Calculations:

- Cold drop temperature ∆Tc = Ti - Tc
  - ∆Tc = 180°C
- Hot raise temperature ∆Th = Th - Ti
  - ∆Th = 240°C
- Temperature Drop at the two ends ∆T = Th - Tc
  - ∆T = 420°C
- Cold mass fraction μ = \(\frac{\Delta T_h}{\Delta T_h + \Delta T_c}\)
  - μ = 0.571

Static Temperature Drop Due To Expansion

\[\Delta T'c = Ti - T'c = Ti[1 - (Pa/Pi)(\gamma - 1)/\gamma]\]

Relative Temperature Drop (ΔTrel) = \(\Delta Tc / (\Delta T'c)\) = 1.5720°C

Adiabatic Efficiency (\(\eta_{ad}\)) = \(\frac{\text{actual cooling gained in vortex tube}}{\text{Cooling possible with adiabatic expansion}}\)

\[\eta_{ad} = \mu \times \Delta Trel = 0.8976\]

Coefficient of Performance (\(\text{C.O.P}\)) of Vortex Tube

\[\text{C.O.P} = \eta_{ad} \times \eta_{ac} \times ([P_a/P_b](\gamma - 1)/\gamma)]\]

= 0.2322

Where \(\eta_{ac}\) is the adiabatic efficiency of the air compressor = 0.45

4. Literature review of Vortex Tube

The vortex tube was first found by Ranque [1,2], a metallurgist and physicist who was allowed a French patent for the device in 1932, and a United States patent in 1934. The wonderful response obtained for the logical and designing groups to his development. Since the vortex tube was thermodynamically very complicated, it was deserted for quite a long while.
K. Kiran kumar Rao et al [5] proposed some experimental results by the different investigators on the effect of various geometrical parameters, like nozzles, orifice, conical needle modifications, and different material like metallic and non metallic and experiment, to improve cop and cooling performance of vortex tube. It is clear to that the performance of vortex tube is directly proportional to inlet compressed air. Geometry for cold conical valves is improving at 45° valve and 90° a best result. The effect of the conical hot tube also influences on cop. Guillaume and Jolly [6] exhibited that two vortex tubes set in a charged arrangement or put in arrangement by associating the cold release of one phase into the delta of the accompanying stage. They found that the comparative $\Delta T$, a two-arrange vortex tube could be delivered a higher temperature lessening than one of the vortex tubes working automatically. Manohar and Chetan [7] utilized a vortex tube for isolating methane and nitrogen from a blend and found that there was incomplete gas division prompting a higher centralization of methane at one exit in contrast with the delta and a lower fixation at the other exit. Eiamsa-ard S and Promvonge P et al [8,9] presented a diagram of the marvels happening inside the vortex tube amid the temperature/vitality partition on both the counter stream and parallel stream writes. From the previous investigators and the figuring’s introduced in past examines the partition temperature of the vortex tube. The examination comprised of two critical parameters, the first is the geometrical variables of the vortex tube (for instance, the distance across and length of the hot and cool tubes, the width of the cold hole, state of the hot (dissimilar) tube, number of bay spouts, state of the channel spouts, and state of the cone valve. The second is cantered around the thermo-physical parameters, for example, gulf gas weight, cold mass division, dampness of bay gas, and sort of gas (air, oxygen, helium, and methane). For every parameter, the temperature partition instrument and the stream field inside the vortex tubes is investigated by estimating the weight, speed, and temperature fields. Tejshree Bornare et al [10] investigate the effect of geometrical parameters i.e. diameter and length of main tube, diameter of outlet orifice, shape of entrance nozzle. Thermo-physical parameters are inlet gas pressure, type of gas, cold gas mass ratio and moisture of inlet gas. Prabhakaran j et al [11,12] has directed the examination by supplanting the barrel shaped hot tube with a cone shaped hot tube at different bay weights. It was discovered that the vortex tube with tapered hot tube gives the preferable execution over barrel shaped hot tubes. There is an expansion in COP around 25%-30%. O. M. Kshirsagar et al [13] from his study we can understand the effect of various parameters like inlet pressure of air, number of nozzles, cold orifice diameter and hot end valve angle on the performance of vortex tube. From by the literature review it is clear that there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon. Due to this reason researcher conduct the series of experimentation to understand the effect of various parameters mentioned above on the performance of vortex tube, the effect of 2, 4, and 6 nozzles on the performance of the vortex tube, when the operating pressure is increased. An increase in pressure at the entrance of the vortex tube results in an increase in the performance of the vortex tube with 2, 4, 6 nozzles. The best performance is obtained with the vortex tube which has 4 nozzles.. K. Kiran Kumar Rao et al [14] studied the maximum hot air temperatures and minimum cold air temperatures of different materials like Mild steel, Aluminium and Copper by fabricating. The fabrication and experimental investigation was carried out based on L/D ratio 22 /8 with adiabatic process of Hot tube, nozzle 8 mm diameter and orifice 6 mm diameter. Aydin and B每隔 [15] examined the vitality division in a counter-stream vortex tube with different geometrical and thermo-physic parameters. The geometry of the tube was improved to augment the temperature distinction between the icy and bay temperatures by changing the different measurements of the tube. For example, the length of the vortex tube, the breadth of the bay spout, and the point of the control valve. Besides, the impacts of different bay weight and distinctive working gases (air, oxygen, and nitrogen) on temperature diverse in a tube were likewise contemplated. Gao et al. [16] utilized an extraordinary pitot tube and thermocouple strategies to gauge the weight, speed and temperature circulation inside the vortex tube which the pitot tube has just a measurement of 1mm with one opening (0.1 mm distance across). In their work, the impact of various bay conditions was considered. They found that the adjustment of the passage can be upgraded and expanded the auxiliary course gas stream, and enhanced the framework's execution. Promvonge and Eiamsa-ard [17] again revealed the impacts of the quantity of channel unrelated spouts, the cool hole measurement, and tube protections on the temperature decrease and isentropic effectiveness in the
vortex tube. Singh et al. [18] revealed the impact of different parameters, for example, icy mass division, spout, cold opening distance across, hot end region of the tube, and L/D proportion on the execution of the vortex tube. They watched that the impact of spout configuration was more essential than the cold hole configuration in getting higher temperature divisions and found that the length of the tube had no impact on the execution of the vortex tube in the range 45–55 L/D. Trofimov [19] confirmed that the elements of inner rakish force prompts this impact. The use of a numerical model for the reproduction of warm partition in a Ranque–Hilsch vortex tube was accounted for by Eiamsaard and Promvonge [20,21]. The work had been done with a specific goal to give a comprehension of the physical practices of the stream, weight, and temperature in a vortex tube. A stunned limited volume approach and an ASM with (Upwind, Hybrid, SOU, and QUICK plans), was utilized to complete all the calculations. The calculations demonstrated that results obtained from both turbulence models for the most part are in great concurrence with estimations yet the ASM provides better correlation between the numerical results and test information. At last, The numerical calculations with particular source terms of the vitality condition suppressed[22] examined the impact of the diverse sorts of spout profiles and number of spouts on temperature detachment in the counter-stream vortex tube utilizing the code arrangement of Star-CD with 'Renormalization Group' (RNG) variant of the k-ε display.

5. Design of vortex tube
The setup is design and modelled using the CAD &CATIA V5 R21 – Then CATIA modelling is converted to STEP file (stp) format processing by the solver package. Various steps in modelling to be carried out in CATIA are discussed below.
Select the new part from CATIA V5 R21
Select the RIGHT HAND SKETCH, give circle diameter and length
Select the work bench.
Draw the helix curve with the work bench
Select the point in corner
Take cut towards the flute length
Select the slot tool, follow the profile of helix
Select the cut out of helix angle
Select the centre plane, for shank part
Draw sketch of shank in the plane
Select the revolve action with reference of centre axis
Select the sketch for slot

Figure 1. Basic design and modelling of vortex tube parameters: a) diameter orifice and (b) the hot end tube(c) the hot tube.
we are using the CAD & CATIA V5 R21 and to designed and modelling of 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, 3a) it is manufactured, modelled and designed by using aluminium and copper material. The thickness is 9mm and the outer diameter is 25mm and hole of 8mm is made at the centre.

Hot end tube (Figure. 1b, 2a, 3b) copper material of size 60mm diameter and 70mm length is used. First the material is turned to a diameter of 44mm and faced to a length of 53mm. The external threading of 14 TPI of the part is attachable to main body is executed to the length of 18 mm, A hole with 37mm diameter to a depth of 33mm is drilled with an internal threading of 14 TPI to a length of 18mm at the control end side and three small holes one at centre and two on each side of the centre 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, 3c) it is fabricated, modelled and designed by using aluminium material the length of hot tube is 135mm and the through hole 12.5mm diameter is made with external threads of 1.5mm pitch are made on either side to length of 20mm.

6. Observations and Calculations

The experimental investigation was conducted to find the effect of different orifice diameters and inlet pressures on the performance of vortex tube. After conducting the experiment the observations are noted and given below with different Orifice diameter and different input pressure by using aluminium material.
Table 2. Summary of experimental studies on vortex tubes (Aluminium Orifice diameter: 8mm)

| S.no | Pi, bar | (Tc)\(^\circ\text{C}\) | (Th)\(^\circ\text{C}\) | \(\mu\) | \(\eta_{\text{Adiabatic}}\) | COP |
|------|---------|----------------------|----------------------|--------|----------------|------|
| 1    | 7       | 8                    | 51                   | 0.571  | 0.897          | 0.2322 |
| 2    | 6       | 10                   | 50                   | 0.575  | 0.909          | 0.2458 |
| 3    | 5       | 12                   | 48                   | 0.583  | 0.884          | 0.2578 |
| 4    | 4       | 12                   | 47                   | 0.571  | 0.976          | 0.2964 |

7. Results and Discussion

7.1. Inlet pressure vs. \(\Delta T_h\) (From Aluminium material):

As per the figure 4 States the impact of opening measurement and weight on the \(\Delta T_h\). As the bay weight expands, the temperature contrast is expanded. At 7 bar weight the hole with 8mm distance across performs well and the most extreme hot temperature dropped as 24\(^\circ\text{C}\) and the greatest temperature contrast is acquired as 42\(^\circ\text{C}\). At 4 bar weight the hole with 4mm distance across the execution is extremely poor and hot temperature drop is acquired as 4\(^\circ\text{C}\) and the temperature distinction dropped as 15\(^\circ\text{C}\). Aluminum material: After assessing the execution of vortex tube by shifting the hole widths and delta weights it was discovered that the vortex tube with 8mm distance across opening and at a weight of 7 bar gives the best execution. As indicated [Table 1].

8. Conclusion

From the above study I found that for the design and fabrication of vortex tube made with Aluminium material by varying orifice diameters and inlet pressure of compressed air that the well suited diameter orifice (8mm) at pressure 7 bar for getting superlative cooling effect 80\(^\circ\text{C}\) from Aluminium material and The felicitous orifice diameter (8mm) at pressure 7 bar for getting utmost heating effect 51\(^\circ\text{C}\) from Aluminium material for The convenient diameter orifice(4mm)at pressure 7 bar for getting poor COP (0.09) from aluminum material but The adaptable diameter orifice(8mm) and at a pressure of 4 bar will gives supreme COP (0.2964) of a vortex tube fabricated with Aluminium material. In case of heating and cooling effect for obtaining better COP we can conclude the orifice diameter as 8mm and inlet pressure as 7 bar.
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