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A Review on Performance Improvement of Vortex Tube

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ABSTRACT— Now-a-days, the first and foremost important quality of any research or development is its eco-friendly nature. As we know environment safety has become an important aspect of the industries and people in common. Vortex tube is also known as non-conventional cooling device that will produce cold air and hot air when we passed compressed air from compressor without causing any harm to the nature. In vortex tube, when a compressed air from compressor is tangentially passed into vortex chamber vortex tube splits the compressed air into two parts: a free vortex as the peripheral warm stream at the conical valve end and a forced vortex as the inner cold stream through the orifice. It can be used for any type of spot cooling application. [1]

KEYWORDS- Safety, Vortex tube, Compressed air, Stream, Orifice.

I. INTRODUCTION

1. Why vortex tube

Refrigeration plays an important role in developing countries, primarily for the preservation of food, medicine and for air conditioning. Conventional refrigeration systems are using Freon as a refrigerant. As they are the main cause for depleting ozone layer, extensive research work is going on alternate refrigeration systems. Vortex tube is a non-conventional cooling device, having no moving parts which will produce cold air and hot air from the compressed air without affecting the environment. When a high pressure is tangentially injected into vortex chamber a strong vortex flow will be created which will be split into two air streams. It can be used for any type of spot cooling or heating application.

2. Vortex Tube

The vortex tube, also known as the Ranque-Hilsch vortex tube, is a mechanical device that separates a compressed gas into hot and cold streams. The air emerging from the "hot" end can reach temperatures of 200 °C, and the air emerging from the "cold end" can reach -50 °C. The vortex tube was invented in 1933 by French physicist George J. Ranque and later improved by Hilsch in 1947. The construction details of a vortex tube are shown in fig 1. When high pressure enters through tangential nozzle, a strong vortex flow created that splits into two streams: A warm stream escapes through the conical valve at the periphery and a cold stream at inner core escapes through the central orifice.

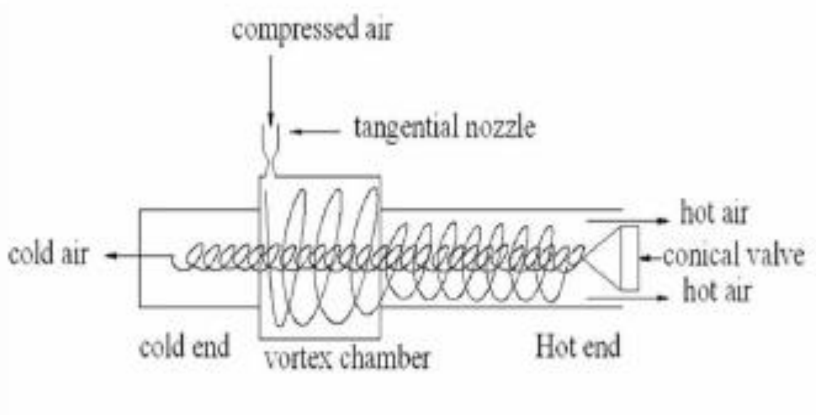


Fig.1: Vortex Tube

There are different explanations for the effect and there is debate on which explanation is best or correct. What is usually agreed upon is that the air in the tube experiences mostly "solid body rotation", which means the rotation rate (angular velocity) of the inner gas is the same as that of the outer gas. This is different from what most consider standard vortex behaviour where inner fluid spins at a higher rate than outer fluid. The (mostly) solid body rotation is probably due to the long length of time during which each parcel of air remains in the vortex allowing friction between the inner parcels and outer parcels to have a notable effect. It is also usually agreed upon that there is a slight effect of hot air tending to "rise" toward the centre, but this effect is negligible especially if turbulence is kept to a minimum. One simple explanation is that the outer air is under higher pressure than the inner air (because of centrifugal force). Therefore the temperature of the outer air is higher than that of the inner air. Another explanation is that as both vortices rotate at the same angular velocity and direction, the inner vortex has lost angular momentum. The decrease of angular momentum is transferred as kinetic energy to the outer vortex, resulting in separated flows of hot and cold gas. This is somewhat analogous to a Peltier effect device, which uses electrical pressure (voltage) to move heat to one side of a dissimilar metal junction, causing the other side to grow cold. When used to refrigerate, heat-sinking the whole vortex tube is helpful. [2]

2.2 Types of Vortex tubes

There are two classifications of the vortex tube. Both of these are currently in use in the industry. The more Popular is the counter-flow vortex tube (Figure a). The hot air that exits from the far side of the tube is controlled by the cone valve. The cold air exits through an orifice next to the inlet. On the other hand, the uni-flow vortex tube does not have its cold air orifice next to the inlet (Figure b). Instead, the cold air comes out through a concentrically located annular exit in the cold valve. This type of vortex tube is used in applications where space and equipment cost are of high importance. The mechanism for the uni-flow tube is similar to the counter-flow tube. A radial temperature separation is still induced inside, but the efficiency of the uni-flow tube is generally less than that of the counter-flow tube. [10]

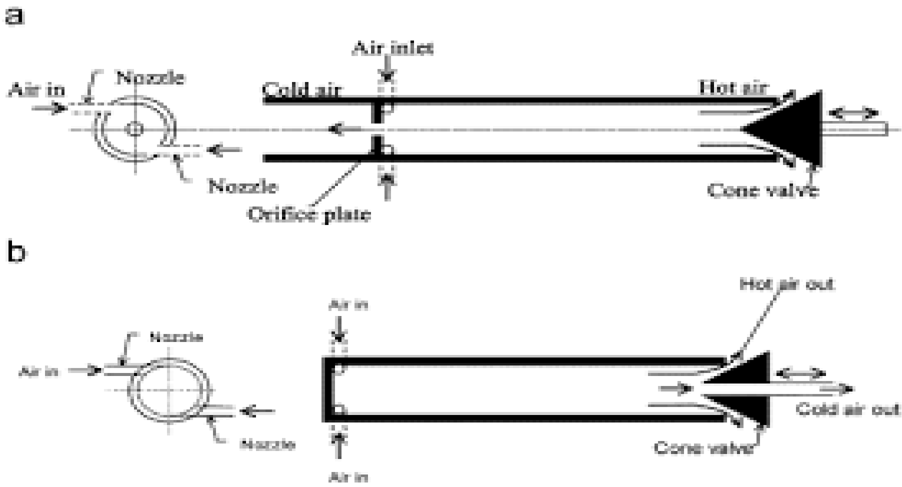


Fig.2 Vortex tubes

II. CONSTRUCTION & WORKING OF VORTEX TUBE

A. Construction:

The vortex tube consists of following parts;

1. Nozzle: A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe.

2. Diaphragm: A diaphragm is a sheet of a semi-flexible material anchored at its periphery and most often round in shape. It serves either as a barrier between two chambers, moving slightly up into one chamber or down into the other depending on differences in pressure, or as a device that vibrates when certain frequencies are applied to it.

3. Valve: A device for controlling the flow of fluids (liquids, gases) in a pipe or other enclosure. Control is by means of a movable element that opens, shuts, or partially obstructs an opening in a passageway. Valves are of seven main types: globe, gate, needle, plug (cock), butterfly, poppet, and spool.

4. Hot air side: Hot side is cylindrical in cross section and is of different lengths as per design.

5. Cold air side: Cold side is a cylindrical portion through which cold air is passed.

6. Chamber: Chamber is a portion of nozzle and facilities the tangential entry of high velocity air-stream into hot side. Generally the chambers are not of circular form, but they are gradually converted into spiral form.

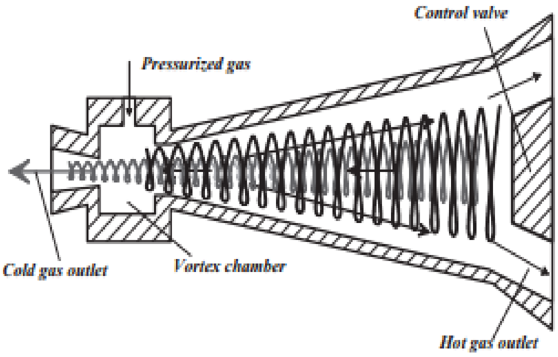
B. Working:

When compressed air is passed from compressor through the nozzle we have made holes at an angle (tangentially) and then it passes through that hole with high velocity and hence, air moves towards the control valve through the hot side pipe. Then 2 types of vortex flow is created in this chamber i.e., free and forced one and air travels in circular like motion along the circumference of hot side. As the air travels in the hot side pipe towards the control valve by using the opening of this valve the flow can be restricted. When the pressure inside the hot side tube near to the valve is greater than outside atmospheric pressure by using the valve, then reversed flow starts through the central portion of hot side pipe from high pressure region to low pressure region. In this process, energy interaction takes place between these 2 streams (i.e., reversed and forward) and therefore air stream through the central portion has lower temperature than the inlet whereas the air stream in forward direction has higher temperature than inlet temperature. Then, the air stream which gets back towards the diaphragm and when it passes through the hole present in this diaphragm hole the air gets cooled and comes out from the cold side pipe, while another air stream is passed through the opening of the valve. With the change in control valve openings, we can get various values of temperature difference at cold end and hot end [3, 4].

III. LITERATURE SURVEY

1. Sarath Sasi, Sreejith M (2014), construct a vortex tube with maximum efficiency at minimum cost, for that they 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. 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. [5]

2. Vortex tube with cylindrical and conical hot tubes performance is compared. It was found that the vortex tube with a conical angle of about 2.5° surpassed the cylinder tube by 25%~30% in COP. The conical vortex tube reaches the same or more performance than the normal tube but with a smaller length. From the results obtained, it was found that the performance of the vortex tube is better for conical hot tube. The optimum end gate value opening gives the best performance. The effect of nozzle design is more important than the cold orifice design in getting higher temperature drops. The surface finish of the nozzle and the hot tube plays a great role in the performance of the vortex tube, good surface finish leads to the better performance. So, care to be taken while fabrication of the parts to obtain to get good surface finish. From the above results, it is suggested to have the conical angle of 2° to 3°. [6]



3. Pramod Bajarang Vhankade (2015) Experimenting with changing vortex generator and vortex casing design, are few major newly changes. These alterations affect the outlet exit temperature at hot end and cold end.

Results and Discussions:

i. The effect of change in inlet pressure on ΔTc: It was observed that the temperature difference increased with the increase in the inlet pressure. For an inlet pressure of 10 bar, the cold end temperature

(Tc) was obtained as -18.4°C and the cold side temperature difference (ΔTc) was 57.2°C. For an inlet pressure of 4 bar, the cold end temperature obtained was 9.1°C and the cold side temperature difference was 29.7°C.

ii. The effect of change in inlet pressure on ΔTh: It was observed that the temperature difference increased with the slight difference with the increase in inlet pressure. For an inlet pressure of 10 bar, the hot end temperature (Th) was obtained as 53°C and the hot side temperature difference (ΔTh) was 14.2°C. For an inlet pressure of 4 bar the hot end temperature was obtained as 43.1°C and the hot side temperature difference was 4.3°C. The lowest temperature using 30D hot side length. Using 0.4D (5mm) diameter diaphragm we get lower temperature at cold end, whereas using 0.5D (6.25mm) we get higher temperatures at hot end. Due to the present running research it will certainly take good market & the wide field of applications in near future. [7]

4. Mahesh Kumar Dhangar, Manujendra Sharma, Mangu Singh Chouhan, (2015)**,** check the performance of counter flow vortex tube by changing the various geometrical parameters such as length and diameter of hot end pipe and cold end pipe and also changing the nozzle number of the orifice so that we increase the COP of the vortex tube. They had also predicted some of the experimental data that are available and observed the performance variation by changing working parameters at inlet such as temperature and pressure. [8]

5. Krishna Kumar Karothiya, Siddharth Chauhan, (2016) have constructed a vortex tube refrigeration system. Effects of inlet tangential nozzles, the tube diameter, and the diameter of the inlet nozzle on the temperature reduction in the tube were experimentally investigated. Compared to previous studies, standard measurements and the fabrication techniques are improved to achieve accurate results. New measurements are obtained with the help of two novel techniques:

i) Nozzle is fitted to let the compressed air flow tangentially.

ii) Insulation is provided to remove the chances of heat loss.

Results and Discussion:

The inlet pressure is varied to visualize the variations of temperature drop with pressure drop and a constant mass fraction of approximately maintained by a cone shape. The material for the tube was chosen as PVC which is locally very much available in the market and also cheaper than any other such material.

Because of better installation of nozzle to provide tangential flow of the compressed air inside the tube so that better vortex can be formed and by providing insulation of foam to protect heat losses.

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Conclusion:

Maximum temperature difference achieved is 6^0C at 5 bar pressure. [9]

6. In this work the vortex tube made of UPVC material to study the effect of length and diameter on the performance of the refrigeration system, how different parameters are change with the inlet pressure and at different openings of control valve is also investigated. The results are drawn for the vortex tube with better performance.

A. Geometrical Parameters

Sr. No.	Design Parameters	Dimensions mm
1.	Tube inner	20.32
2.	Cold plate orifice diameter	8.1
3.	Inlet nozzles diameter	3
4.	No. of inlet nozzles	5
5.	Hot end length	920
6.	Cold end length	50
7.	Pressure range	0-8 bar

Inlet pressure in bar	inlet air temp °C	Cold side temp °C	Hot side temp °C	Refrigerating effect Watts	C.O.P
8	29	22	42	100.56	0.1436
7	29	20	40	145.47	0.1325
6	29	14	43	277.05	0.9815
5	29	13	37	273.68	0.0412
4	29	15	46	129.75	0.0531
3	29	16	41	104.03	0.0486
2	29	19	39	51.31	0.0435

B. Observations: Results for ½ valve opening :

C. Results and Discussions

- In this variable investigation shows that five nozzles with UPVC as vortex tube material have the best cooling effect.
- The maximum temperature difference of 17°C is obtained on cold side while 16° C is obtained on hot side of Vortex tube.
- The temperature drop increases with increase in inlet pressure up to 6bar.The optimum value of L/D ratio is in range of 45 as in this range ΔTc and ΔTh is maximum.
- The highest temperature drop is found between 0.45 -0.6 cold air mass fractions.At 6 bar Inlet pressure, 45 L/D ratio, ½ throttle valve opening and 0.6 Cold mass fractions give the best performance on vortex tube.
- The maximum COP (Coefficient of Performance) for the model 1 obtained at 6bar inlet pressure is 0.10745 Even through the COP of the system is very low it is always acceptable to use the waste energy to generate useful form of energy.

D. Conclusion

Using UPVC vortex tube material, the maximum temperature difference is obtained at inlet pressure of 6bar. [11]

7. Chaitanya M. Joshi, Shivraj K. Jadhav, Pravin D. Patil and Himani B. Kadam, A vortex tube is designed and fabricated and several parameters (like length of pipe, orifice diameter, length of nozzle, selection of material for pipe and nozzle i.e. plastic pipe and brass for nozzle, acrylic for orifice and again plastic for reducers and collar.) are studied for the performance of the vortex tube.

The material used for pipe, socket, and reducer is U-PVC. For nozzle brass and for orifice acrylic is used. The orifice diameters are chosen with constant increments and it is ensured that the ratio of orifice diameter to tube diameter should be within 0.20 to 0.55. Certain modifications have been made in the design. The spiral chamber is modified due to fabrication constraint. The modified spiral chamber consists of a ring. A tangential hole of required diameter drilled through it. The hole is made tangential to the inner circle of the ring.

A. Observations

Sr. No.	Orifice diameter (mm)	Press. (bar)	$T=T_h-T_c$ (°C)	RE (KJ/Kg)	COP
1.	2	5	16.6	15.47	0.021
2.	3	2	4.7	4.32	0.012
3.	4	2	4.4	3.81	0.013

B. Results and Discussions

i. Flow analysis

From the flow analysis the temperature difference & COP are maximum at the pressure of 5 bar.

ii. Fluent analysis

For orifice of 2mm diameter temperature change ranges between hot and cold side is found out to be 307K to 290K. For orifice of 4mm diameter temperature change ranges between hot and cold side is found out to be 3
04K to 285K.

C. Conclusion

The conclusion found out from the analysis is that sudden expansion near the cold end is consider as the main reason for the temperature drop, since there is no energy transferred outwards from the central region. Kinetic energy is transferred outwards from the rotational vortex in the central region and contributes to the temperature rise in the periphery near the hot end. [12]

8. A.M. Dalavi, Mahesh Jadhav, Yasin Shaikh, Avinash Patil, reveals investigations to understand the heat transfer characteristics in a vortex tube with respect to various parameters like cross section area of cold and hot end, nozzle area of inlet compressed air, cold orifice area, hot end area of the tube, and L/D ratio. As such there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. The maximum temperature difference of 27°C is obtained in cold end side while 18°C is obtained in hot end side. With increase in inlet pressure, COP, cooling effect and isentropic efficiency of the vortex tube increases. [13]

IV. PROPOSED WORK

The vortex tube was invented in 1933 by French physicist George J. Ranque and later improved by Hilsch in 1947. The construction details of a vortex tube are shown in fig 1. When high pressure enters through tangential nozzle, a strong vortex flow created that splits into two streams: A warm stream escapes through the conical valve at the periphery and a cold stream at inner core escapes through the central orifice. Pongjet and smith investigated the vortex thermal separation in a vortex tube refrigerator, using two different tubes, insulated and non-insulated. The average temperature difference between the insulated and Non-insulated tubes were in a range of 2 to 3^0C for cold tube. Eiamsa-ard and promvonge conducted a numerical investigation to understand the flow behavior and the energy separation mechanism in vortex tube. Arjomandi and Yenpeng used new hot end plug and focused on effect of size of hot nozzle, which improved the performance of the vortex tube and obtained a maximum cooling efficiency of 16%. Bdolreza Bramo and Pourmahmoud carried an investigation to study the effect of length to diameter on the performance of the vortex tube and found that the best performance was obtained when the ratio of vortex's length to the diameter was 9.3. Sachin. U et al examined the role of the cold orifice to determine the conditions for maximum temperature and energy flux separation over a range of parameters. Y.T.Wu had made an experimental study on the performance of vortex tube with innovative modifications of new intake nozzle and hot end pipe diffuser. Through the modification to the design of nozzle, temperature drop is 5° C higher compared to Archimedes model and 2.2°C higher than normal rectangular cross section was achieved. Upendra Behera investigated the flow behavior and energy separation in vortex tube and found that increasing L/D ratio improves the energy transfer performance by 25%. Promvonge and Eiamsa-ard experimentally studied the energy and temperature separations in the vortex tube with a snail entrance. In their experimental results, the use of snail entrance could help to increase the cold air temperature drop and improve the vortex tube efficiency in comparison with those of original tangential inlet nozzles. B. Ahlborn carried CFD studies to verify the existence of secondary circulation flow in vortex tube and its influence on temperature separation for different dc/D values. .The highest value of temperature reduction was found to be 17.4°C at cold fraction around 0.31. Eiamsa-ard carried experimental investigation on the performance of vortex tube using multiple snail entries. Also found that 0.5 is the optimum ratio of cold orifice diameter to tube diameter. [15, 16]

V. VORTEX TUBE WITH HOLLOW CONICAL VALVE

Vortex tube is a simple device that splits compressed air into hot and cold streams. The vortex tube was invented in 1933 by French physicist George J. Ranque and later improved by Hilsch in 1947. When high pressure enters through tangential nozzle, a strong vortex flow created that splits into two streams: A warm stream escapes through the conical valve at the periphery and a cold stream at inner core escapes through the central orifice.

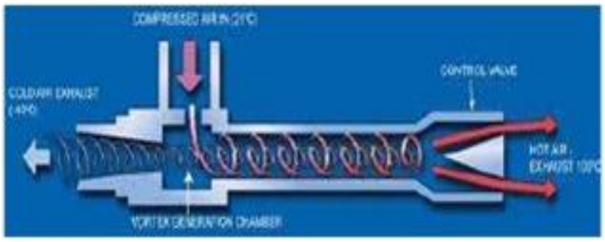

Fig. 3 Schematic diagram of flow pattern in vortex tube

After studying the previous literature ,the vortex tube performance depends on two types of parameters, firstly air or working parameters such as inlet pressure of compressed air, cold mass fraction and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, cone valve angle and also material of vortex tube affects Coefficient of Performance (COP).The experimental investigation of effect of working parameters on the performance of Ranque-Hilsch vortex tube. The Aluminium, Mild steel (M.S) and Brass has been used for manufacturing of the vortex tube. Vortex tube cab be formed from either steel and UPVC. In previous papers mostly UPVC material due to its availability and economically aspects. Further working with UPVC is easy and do not require heavy tools.

PVC: PVC (polyvinyl chloride) is a versatile thermoplastic material obtained from ethylene (petro-chemistry product) and salt by vinyl chloride polymerization.

Properties

- Weathering stability: PVC is resistant to aggressive environmental factors is therefore the material of choice for roofing.
- Versatility: PVC can be flexible or rigid.

- Fire protection: PVC is a material resistant to ignition due to its chlorine content.
- Longevity: PVC products can last up to 100 years and even more.
- Hygiene: PVC is the material of choice for medical applications, particularly blood and plasma storage containers.
- Energy recovery: PVC has high thermal power; when utilized in incinerators PVC provides power and heat for homes and industries, and all that without any environmental impact.
- Barrier properties: PVC can be made impervious to liquids, vapours and gases.
- Eco-efficiency: Only 43% of PVC's content comes from oil (57% comes from salt); it therefore contributes to the preservation of that highly valuable natural resource.
- Recyclability: PVC is very recyclable, more so than many other plastics.
- Public Safety: PVC has often fallen under unfounded attempts so that today it is one of the best explored materials in the world due to serious scientific researches carried in order to disprove accusations.
- Economical efficiency: PVC is the cheapest of large-tonnage polymers providing many products with the best quality-price ratio.

In the present study an innovative design modification is implemented by which the forced vortex flow at cold end is made to hit back again to form one more forced vortex flow. Thus, the modified vortex tube is named as dual forced flow vortex tube consists of three outlets: one hot outlet and two cold outlets (Cold end-I and Cold end-II). The schematic diagram of the modified vortex tube is shown in fig 2.

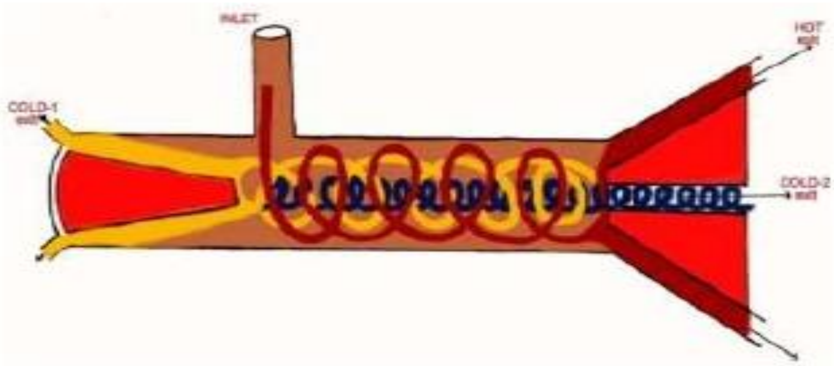

Fig.4 Flow pattern of the modified vortex tube

The investigational unit consists of subsequent components: (a) inlet nozzle, (b) vortex chamber, (c) a tube, (d) hollow cone shaped valve for a way out at hot flow and cold flow-II (hot end and cold end-II) and (e) tapered valve at the cold end-I. In the Vortex tube (DFFVT) the air enters tangentially through the nozzle attains spiral flow on the way to one end, choked-up where part of air escapes through opening called as hot exit and the remaining air is reversed by hollow conical valve, controls the pressure in the system. The reversed axial flow is forced to flow by forward vortex flow, moves towards the conical valve at the opposite end where part of air escapes through the opening of solid cone valve called as cold exit-I and the remaining air which is again converging to the central core and travels back as forced flow through the inner core of the hollow conical valve called as cold exit-II. Thus the modified vortex tube consists of dual forced vortex flow. Figures 1 and 2 shows a schematic plan of DFFVT and setup. The flow towards hot exit can be controlled by operating hollow conical valve, whereas the flow towards cold exit-I can be controlled by solid conical valve.

VI. FEATURES & BENEFITS

Features

- Cool without refrigerants (CFCs/HCFCs) or moving parts or reliable, trouble-free operation.
- Use no electricity-intrinsically safe, no RF interference.
- Include an integral muffler for quiet operation-within OSHA noise specifications.

Benefits

- Uses only compressed air –no electricity or refrigerants.
- Maintenance free –no moving parts. Exceptionally reliable.
- Compact and light weight. Cycle repeatability within ± 1°.
- Drops inlet temperature by up to 100°F.

VII. APPLICATIONS

The Vortex Tube may be used in a temperature control project & is very effective & economical where the compressed air is readily available. We can't take better advantage of this where the characteristics like weightlessness, cooler cum heater are desired & the compressed air which is the main cost is present with us.

- Vortex tubes are now commercially used for low-temperature applications, e.g. to cool parts of machines, to set solders, to cool electronic control cabinets, to chill environmental chambers, to cool food, to test temperature sensors, and they are also applied to dehumidify gas samples.
- Vortex tube is a simple device with no moving parts. Most of the applications reflect the benefits in terms of performance, energy, compactness or as an alternative to the conventional method. Vortex air coolers are preferred for different industrial applications.
- The personal air suit uses vortex tube to allow workers to work under adverse conditions for longer hours.
- Modern tool tips are already capable of maintaining their cutting edge at higher temperatures, but even with these improvements in tool materials, the cutting edge will eventually break down. Applying cold air to the tool interface of these modern tool tips will also extend their tool life reducing the cost of metal cutting.

VIII. CONCLUSION

Although several explanations for the temperature separation vortex tube have been proposed, due to the complexity of the internal flow, there has not been a well-accepted explanation and the physical process inside the vortex tube remains unclear. As such there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. Therefore, it was thought to perform experimentation.

In the existing vortex tube model, the occurrence of stagnation point and thereby the development of secondary flow should be towards the hot end to reduce the extent of mixing of cold air elements and hot air elements (multiple circulation near hot zone), which in turn declines the performance of the tube. Thus, it is possible to reduce the effect of the existence of secondary flow but cannot avoid completely. In the present modified vortex tube the existence of secondary flow is utilized for further higher level of temperature separation. Here for higher temperature drop the secondary flow should initiate towards the nozzle end and thereby can get enough time for energy transfer. However, again, it is observed that too close to the nozzle results in mixing of cold air through the end-I mix up with inlet air and disturb the flow. Therefore, moderate, hot fraction yields higher temperature drops.

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