PERFORMANCE IMPROVEMENT OF VORTEX TUBE WITH HOLLOW CONICAL VALVE

Shadab Shaikh Bismillah[1], Prof. K. M. Mahajan[2], Prof. V. H. Patil[3]
[1](*PG Scholar, Dept. of Mechanical Engineering, GF's Godavari COE, Jalgaon, Maharashtra, India*
Email: shadabsk54@gmail.com)
[2] (*Professor, Dept. of Mechanical Engineering, GF's Godavari COE, Jalgaon, Maharashtra, India*
Email: mahajankishor87@gmail.com)
[3] (*Professor, Dept. of Mechanical Engineering, GF's Godavari COE, Jalgaon, Maharashtra, India*

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.

In the present study the conical valve at the hot end in existing model is replaced with a hollow conical valve gives a provision for flow through the inner core. A conical valve is introduced at the orifice, directs the forced vortex yet again to hit back develops one more forced vortex flow, which escapes through the central core of the hollow conical valve. Thus the revised vortex tube with three outlets: one hot outlet and two cold outlets, is named as dual forced flow vortex tube (DFFVT). Tests were made to evaluate the suitable material for cylindrical tube on the performance of the modified vortex tube. Results reveal that UPVC material is the optimum for effective temperature separation. The temperature drop through both the ends I & II increases with increase of pressure.

Keywords *- Safety, Vortex tube, Compressed air, Stream, Orifice.*

1. Introduction

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. [1]

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. [2]

2. Experimental Plan

Vortex tube is a simple device that splits compressed air into hot and cold streams. The vortex tube was invented in1933 by French physicist George J. Ranque and later improved by Hilsch in 1947. The construction details of a vortex tube are shown in fig 3.1. 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.

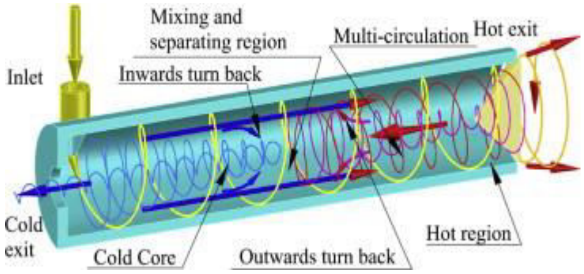


Fig. 2.1 Schematic diagram of flow pattern in vortex tube

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.

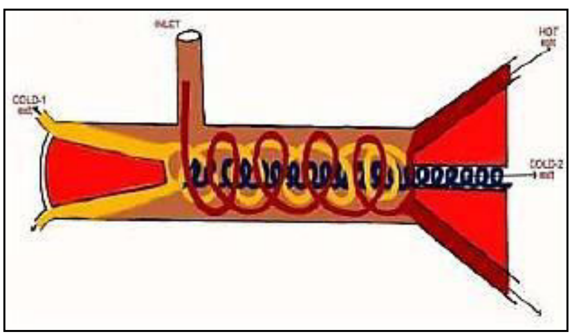


Fig. 2.2 Flow pattern of the modified vortex tube

The objective of the present work is to introduce and study the effect of end plugs on the performance of a modified vortex tube with dual forced vortex flow. [2]

3. Design Of Experimental Setup

From the early research work and literature survey it is clear that, the vortex tube characteristics are strongly dependent on the design, which has to be chosen properly to get the right flow field. There are a number of parameters that can be varied in designing a tube. The main ones are the length, diameter, nozzle area, cold end area and hot end area. These parameters, together with the cold and hot air ratio and the entrance conditions, will mostly determine the exhaust parameters of the tube, which are the cold end and hot end temperature, pressure and flow rate, and the flow velocity field. Most of the models that describe vortex tube performance require knowledge of the exhaust characteristics of the tube. There is not yet a model that predicts the performance of a tube based only on the input conditions and the geometry of the tube. Therefore, most of the guiding criteria in designing a vortex tube come from empirical relations and experiments. They are presented below;

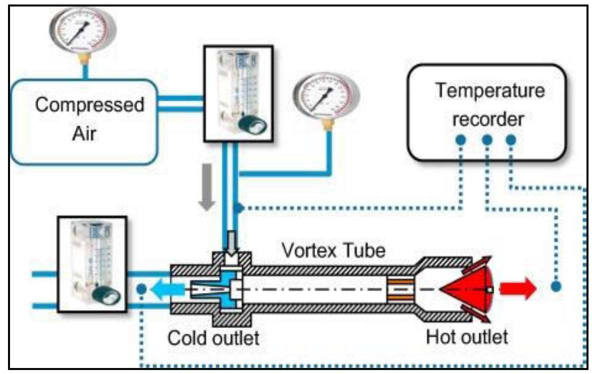


Fig. 3.1 Flow pattern of the vortex tube

4. Experimentation

The investigational unit consists of subsequent components: (a)vortex chamber with inlet nozzle, (b)a tube, (c)hollow cone shaped valve for a way out at hot flow and cold flow-II (hot end and cold end-II), and (d) 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 2.1 and 2.2 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. [2]

4.1 Procedure of Experimentation

The following procedure is adopted for the experimentation:

Initially compressor is operated for a certain time to attain steady state and then pressurized air at room temperature is made to enter the vortex tube tangentially passing through a pressure gauge to measure inlet pressure. Steady state means that the pressure inside the compressor should not change even unit is running constantly. When the compressor motor first turns on, it has to pump a lot of air in to the compressor tank; eventually the tank reaches a state where pressurized air in = pressurized air out (air that enters vortex tube). That is the "steady state" (which, theoretically, in reality of course pressure will oscillate a bit).This is needed for the system to warm up and tank temperature to stabilize. The compressor maximum rated pressure is 14 bars, even though all runs where for inlet pressures of 2bar to 8bar. Three J-type thermocouples are arranged to measure the inlet, hot side, and cold ends I & II temperatures.

Due to tangential entry, the air attains swirling motion and travels towards partially opened hollow conical valve, where part of the air escapes through it as hot air and the remaining air converges and forced back in the opposite direction where a conical valve is arranged. Again, a part of air escapes through the opening of the cone valve as cold air and the still remaining air is converging to the core, travels back, and escapes through the inner core of hollow conical valve as still colder air. Thus, the tube posses' three exits say; hot exit, cold exit-I and cold exit-II. At the hot exit and cold exit-I, Opening of hollow cone valve results in higher flow rate through hot exit and vice versa. Similarly opening of solid cone valve gives higher flow rate through cold end-I and vice versa.

Fig 4.1.1 Instruments of experimentation

In the present work, DFFVT with a tube length to diameter (L/D = 16) are tested. One UPVC pipe and one MS pipe with length 240mm are used. Throughout the study, the 15mm diameter pipes with 2mm nozzle diameter is used. A provision is prepared at the other end to measure the hot gas temperature. The cold end-I outlet at the nozzle end have provided with a cylindrical piece to measure the temperature. Cold end-II orifice has threaded to the other end where the cold gas temperature is measured. The test is repeated with different pressures.

4.2 Experimental Assumptions

The experimental analysis is based on following assumptions

1. The mass flow rate of air is; m= 1kg/s.

2. The materials are with constant thermal conductivity.

3. The specific heat at constant pressure; C_p= 1.005j/kg-K.

4. The temperature of the surrounding air is uniform.

5. The average temperatures of thermocouples after achieving steady state are used for calculating experimental results.

6. There are no heat sources within the VT itself.

7. Neglecting friction between the internal surface of the vortex tube and outer vortex of air.

8. Neglecting friction in the supply pipe of vortex tube.

4.3. Material Selection

The material used for the study throughout (nozzle, vortex chamber, cold and hot sides, solid conical valve etc.) is Mild Steel (M.S), except UPVC for one pipe and Teflon for Hollow conical valve.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 or UPVC.In previous study 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.[4]

4.4 Geometrical Parameters

Table 4.4 Geometrical Parameters

Sr. No.	Design Parameters	Dimensions mm
1.	Tube inner diameter, D	15
2.	Cold plate orifice diameter	4
3.	Inlet nozzles diameter	2
4.	No. of inlet nozzles	6
5.	Hot end length	240
6.	Cold end length	60
7.	Hole Diameter of Hollow conical valve	2
8.	Pitch for solid & hollow conical valve	1.25
9.	Pressure range	2-8 bar

4.5 Experimental Observations

Ti = Inlet Temperature
Pi = Inlet Pressure
Th = Temperature at hot side
Tc1 = Temperature at cold end-I
Tc_2 = Temperature at cold end-II
Ti-Tc_1 = Temperature difference between hot side and cold side-I
Ti- Tc_2= Temperature difference between hot side and cold side-II

Following reading are taken from experimentation

Table 4.5.1 Observation table for UPVC pipe of L= 240 mm

Sr. No.	Ti °C	Pi bar	T_h °C	Tc_1 °C	Tc_2 °C	Ti – Tc_1 °C	Ti – Tc_2 °C
1.	29	2	29.4	28.1	27	0.5	2
2.	29	4	29.9	27.7	26.8	1	2.2
3.	29	6	30	27.6	26.6	1	2.4
4.	29	8	30.3	27.3	26.3	1.5	2.7

Table 4.5.2 Observation table for M.S. pipe of L= 240 mm

Sr. No.	Ti °C	Pi bar	T_h °C	Tc_1 °C	Tc_2 °C	Ti – Tc_1 °C	Ti – Tc_2 °C
1.	29	2	29.5	28.5	27.7	0.5	1.3
2.	29	4	29.9	28	27.4	1	1.6
3.	29	6	30	28	27.3	1	1.7
4.	29	8	30	28	27	1	2

Table 4.5.2 Observation table for Maximum temperature difference

Sr. No.	Pi (bar)	UPVC pipe Th-Tc2 (°C)	MS pipe Th-Tc2 (°C)
1.	2	2.4	1.8
2.	4	3.1	2.5
3.	6	3.4	2.7
4.	8	4	3

4.6 Data Reduction

The key governing parameters of the function of dual forced flow vortex tube are expressed as follows:

4.6.1 Cold Fractions:
In this case we have two cold fractions (i) Cold fraction-I, μ_1(ii) Cold Fraction-II, μ_2
Cold Fraction-I is the ratio of air through cold end-I to the inlet air mass flow rates, where as Cold fraction-II is the ratio of air through the cold end-II to the inlet air mass flow rate

$$\mu_1 = (T_h - T_i)/(T_h - T_{c1})$$

$$\mu_2 = (T_h - T_i)/(T_h - T_{c2})$$

Hot gas fraction,

$$\mu_h = 1 - \mu_1 - \mu_2$$

The cold gas temperature drop of the tube is expressed as:

ΔTc1 – Temperature drop at exit-I

$$\Delta Tc1 = Ti - Tc1$$

ΔTc2 – Temperature drop at exit-II

$$\Delta Tc2 = Ti - Tc2$$

The temperature rise of the hot air tube is defined as:

$$\Delta Th = Th - Ti$$

4.6.2 Refrigerating effect: RE

The cooling effect produced by the cold air leaving the tube is known as exergy and it is defined as, Exergy is an energy available within the boundary limit and is given as,

$$RE = m\ Cp\ (Ti - Tc)$$

4.6.3 Coefficient Of Performance: (COP)

This can be obtained as,

$$COP = \frac{\mu\ T\ \eta ac}{\left[Ti\left\{\left(\frac{Pi}{Pa}\right)^{\frac{k-1}{k}}\right\}\right] - 1}$$

Where,

T - Temperature difference

η_{ac}– adiabatic efficiency of compressor [3]

Analyzing the vortex tube process as isentropic expansion,

Isentropic efficiency of cooling process at the end-I is expressed as follows;

$$\eta c1 = \frac{Ti - Tc1}{Ti(1 - (\frac{Pa}{Pi})\frac{k-1}{k}}$$

Isentropic efficiency of cooling process at the end-II is expressed as follows;

$$\eta c2 = \frac{Ti - Tc2}{Ti(1 - (\frac{Pa}{Pi})\frac{k-1}{k}}$$

5. Results and Discussion

Table 5.1: Result of UPVC pipe

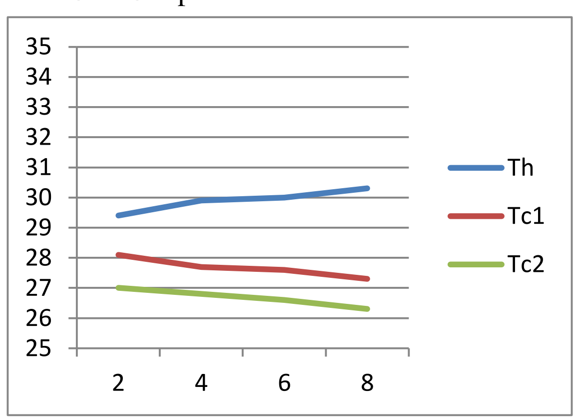
Sr. No.	Pi	μ_1	μ_2	RE_2	$\eta c1$	$\eta c2$	COP
1.	2	0.3076	0.1666	2.010	0.1727	0.3838	0.01047
2.	4	0.4090	0.2903	2.211	0.1370	0.2319	0.01924
3.	6	0.4166	0.2941	2.412	0.1204	0.2065	0.01899
4.	8	0.4333	0.325	2.7135	0.1077	0.2078	0.0227

Table 5.2: Result of M.S pipe

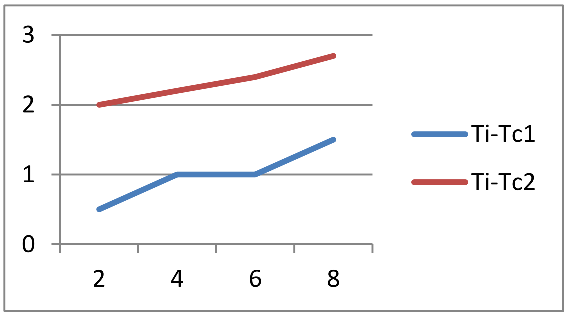
Sr. No.	Pi	μ_1	μ_2	RE_2	$\eta c1$	$\eta c2$	COP
1.	2	0.5	0.2777	1.3065	0.0959	0.0546	0.01309
2.	4	0.4736	0.36	1.6080	0.1054	0.0772	0.01924
3.	6	0.5	0.3703	1.7085	0.0860	0.1463	0.01898
4.	8	0.5	0.3333	2.01	0.0769	0.1539	0.01740

5.2 Effect of Inlet Pressure

5.2.1 For UPVC Pipe

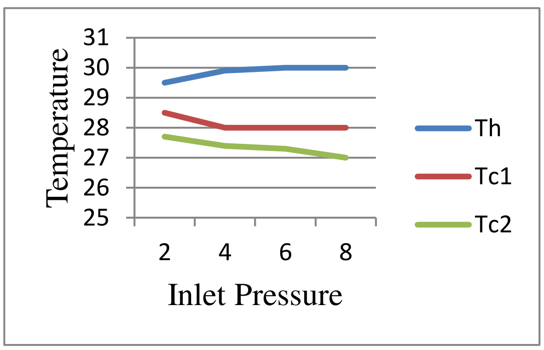


Graph 5.2.1: Variation in inlet pressure Vs. Temperatures

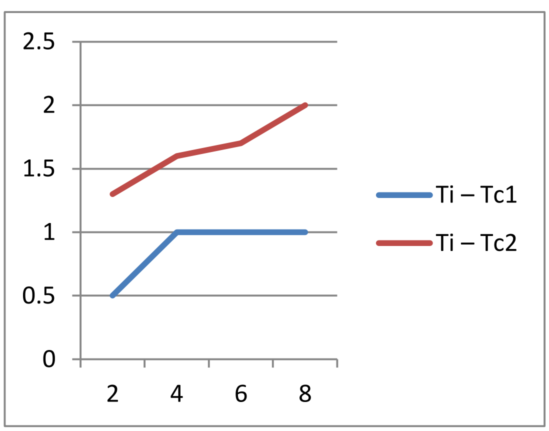


Graph 5.2.2: Variation in inlet pressure vs. Ti-Tc1or Ti-Tc2

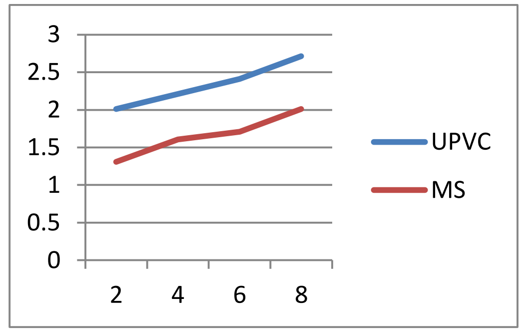
5.2.2 For M.S. Pipe



Graph 5.2.3: Variation in Variation in inlet pressure Vs. Temperatures



Graph 5.2.4: Variation in inlet pressure vs. Ti-Tc1/Ti-Tc2



Graph 5.2.5: Comparison of UPVC & MS pipes with Pi & RE

6. Conclusion

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.

Using modified vortex tube, also be known as Dual Forced Flow Vortex Tube (DFFVT) the maximum temperature difference can be obtained, the condition is that proper design and control of the hollow conical valve at hot end and solid conical valve at cold end. So higher refrigerating effect can obtained. Also UPVC material gives higher temperature drop as compare to the MS material

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