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FABRICATION AND ANALYSIS OF VORTEX TUBE REFRIGERATION SYSTEM

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ABSTRACT

In this paper, we 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. The general motivation of this thesis is to clarify the numerous assumptions and taking optimal data from various research papers in order to analyze the temperature difference obtained. 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.

The temperature drops of the cold air obtained and compare at a similar scale of separating conditions. The experimental results showed that the vortex tube with tangential inlet nozzles and cold tube diameter 12.7 mm yielded the highest temperature reduction which was found to be 6⁰C.

I. INTRODUCTION

The Ranque-Hilsch vortex tube is a mechanical device operating as a refrigerating machine without any moving parts, by separating a compressed gas stream into a low total temperature region and a high one. Such a separation of the flow into regions of low and high total temperature is referred to as the temperature (or energy) separation effect. 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. It has no moving parts.

Fig.1 Vortex Tube

II. TYPES OF VORTEX TUBES

Generally, the vortex tube can be classified into two types. One is the counterflow type (often referred to as the standard type) and the other is the parallel or uni-flow type.

Counter Flow Vortex Tube

The counterflow vortex tube consists of an entrance block of nozzle connections with a cold orifice, a vortex tube (or hot tube) and a cone-shaped valve. A source of compressed gas (e.g. air) at high pressure enters the vortex tube tangentially through one or more inlet nozzles at a high velocity. The expanding air inside the tube then creates a rapidly spinning vortex. The air flows through the tube rather than pass through the cold orifice located next to the nozzles because the orifice is of a much smaller diameter than the tube. Therefore, the cone valve is applied at the hot tube end in order to control the outlet hot air flow or to let the cold air pass through the cold orifice as needed. The length of the tube is typically between 30 and 50 tube diameters, and no optimum value has been determined between these limits. As the air expands down the tube, the pressure drops sharply to a value slightly above the atmospheric pressure, and the air velocity can approach the speedof sound. Centrifugal action will keep this constrained vortex close to the inside surface of the tube.

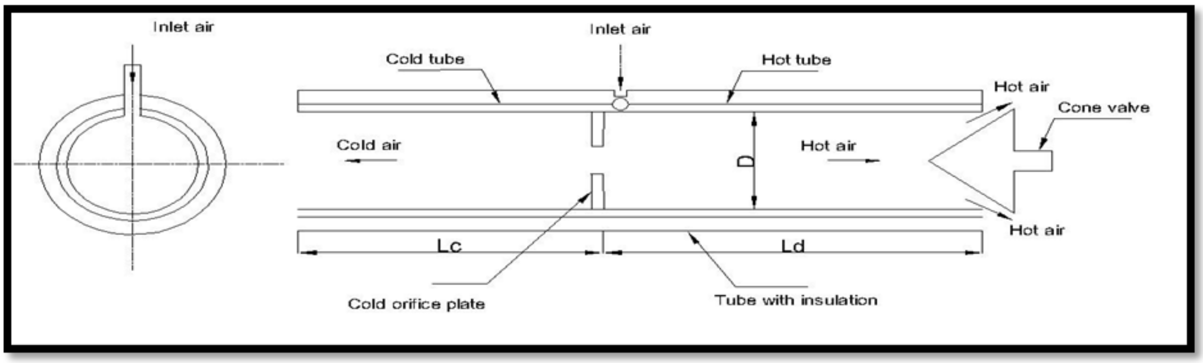


Fig 2. Schematic Sketch Of Counter-Flow Vortex Tube.

Uniflow Vortex Tube

The uniflow vortex tube comprises of an entrance block of inlet nozzles, a vortex tube and a cone-shaped valve with a central orifice. Unlike the more popular counterflow version, the cold air exit is located concentrically with the annular exit for the hot air. The operation of the uni-flow vortex tube is similar to the operation of the counter-flow one. Nowadays the property of vortex tube has a great variety of application in many industries. It has been widely used in the cooling industrial fields especially grilling, turning and welding on account of the various advantages of vortex tube such as cooling without moving part, non-electricity consuming, tiny, lightweight and inexpensive working chemical substance inside the vortex tube, uncomplicated cooling point, cleanliness, convenience and non-CFC's free from pollution.

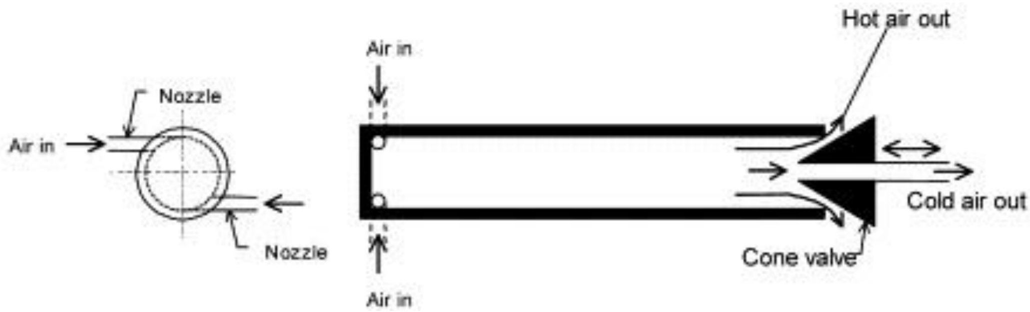


Fig 3. Schematic Sketch Of Uni-Flow Vortex Tube

III. 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.
- Are powered by filtered compressed air.

Benefits

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

IV. EXPERIMENT WORK AND METHODOLOGY

4.1 Theory

It is one of the non-conventional type refrigerating systems for the production of refrigeration. The schematic diagram of vortex tube is shown in the Fig.3.2. It consists of nozzle, diaphragm, valve, hot-air side, cold-air side. The nozzles are of converging or diverging or converging-diverging type as per the design. An efficient nozzle is designed to have higher velocity, greater mass flow and minimum inlet losses. 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. Hot side is cylindrical in cross section and is of different lengths as per design. Valve obstructs the flow of air through hot side and it also controls the quantity of hot air through vortex tube. Diaphragm is a cylindrical piece of small thickness and having a small hole of specific diameter at the center. Air stream traveling through the core of the hot side is emitted through the diaphragm hole. Cold side is a cylindrical portion through which cold air is passed.

4.2 Working

The layout of a vortex tube is given in fig. it consist of following parts. :

1. Nozzle
2. Diaphragm
3. Hot Air Side
4. Valve
5. Orifice
6. Cold Air Side

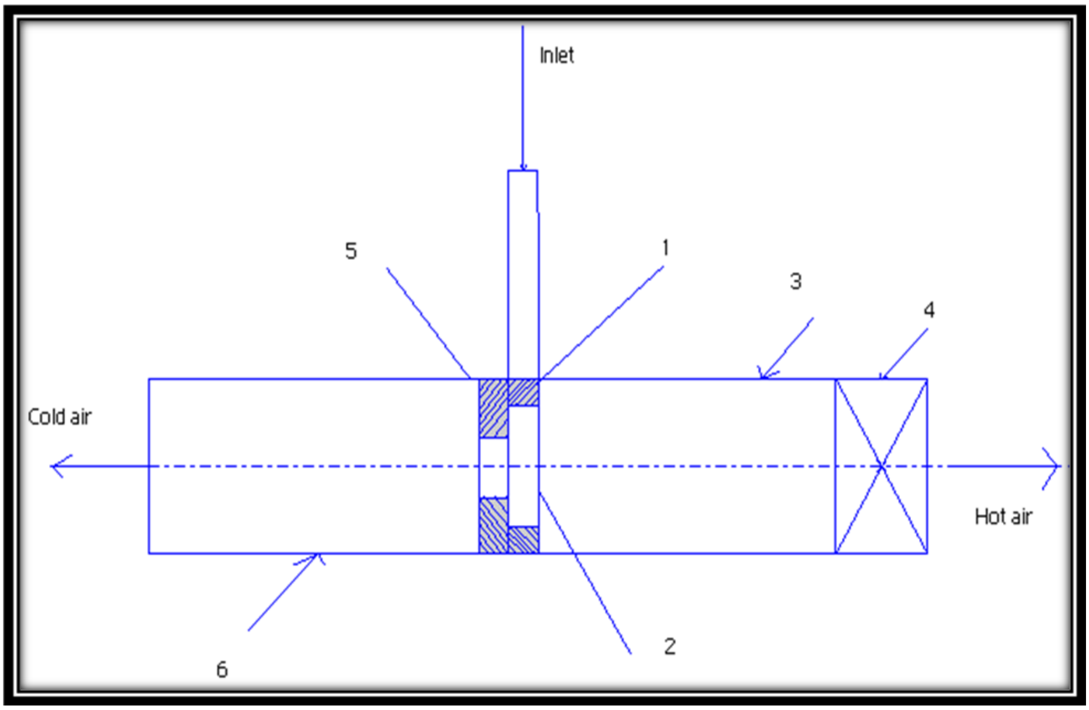


Fig 4. Schematic Diagram of Counter Flow Vortex Tube

Compressed air is passed through the nozzle as shown in Fig.3.2. Here, air expands and acquires high velocity due to particular shape of the nozzle. A vortex flow is created in the chamber and air travels in spiral like motion along the periphery of the hot side. This flow is restricted by the valve. When the pressure of the air near valve is made more than outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region to low-pressure region. During this process, heat transfer takes place between reversed stream and forward stream.

Therefore, air stream through the core gets cooled below the inlet temperature of the air in the vortex tube, while air stream in forward direction gets heated up. The cold stream is escaped through the diaphragm hole into the cold side, while hot stream is passed through the opening of the valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied

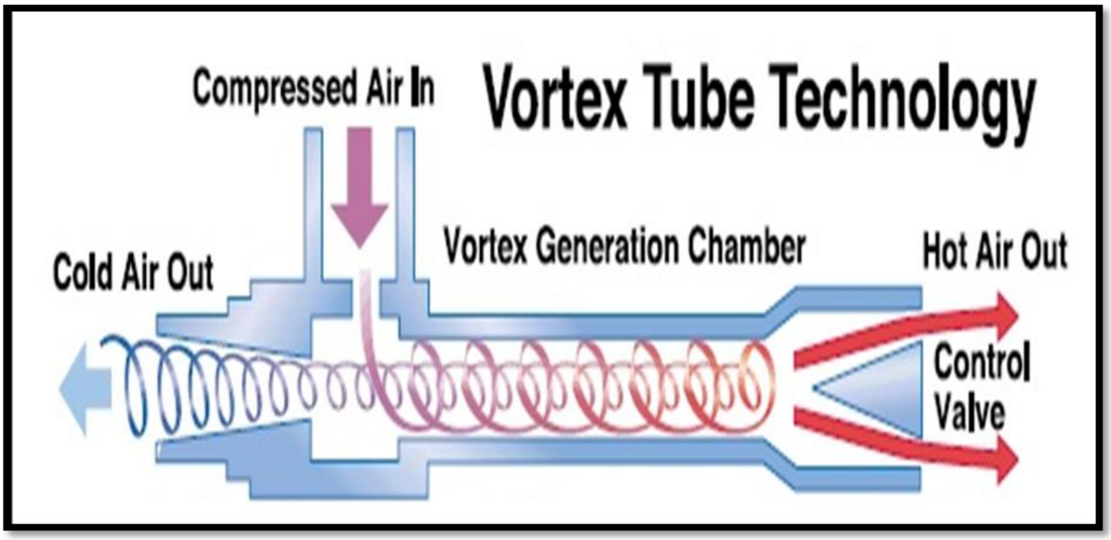


Fig 5. Air Flow Inside The Vortex Tube

V. EXPLANATION OF WORKING CYCLE.

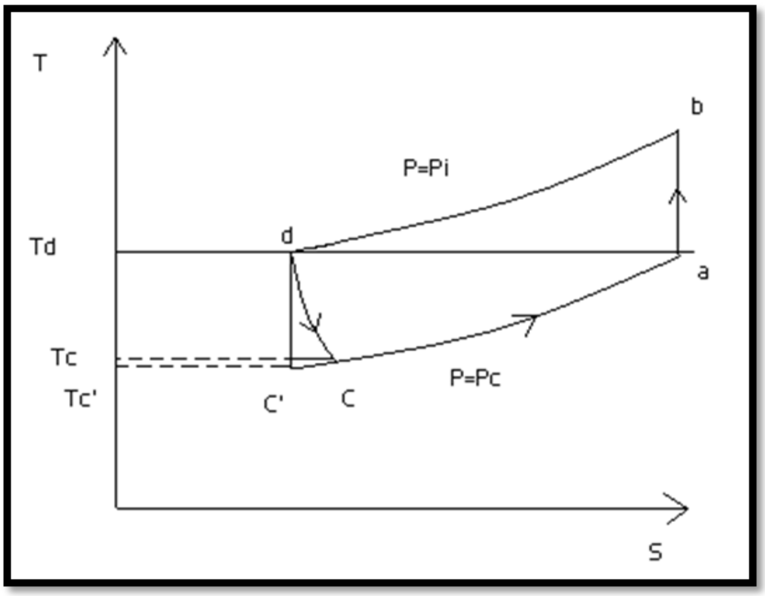


Fig 6. T-S Diagram of Vortex Tube Mechanism

Air is admitted to the compressor at atmospheric temperature Ta and pressure Pa (point a). This air is compressed adiabatically to pressure Pi. This air is then cooled at constant pressure Pi to the atmospheric temperature by water cooling. It then enters the vortex tube where it is separated in two streams (hot & cold streams).

VI. FABRICATION

The fabrication is based on some previous experimental results to get the best possible outputs with the proposed material. The design parameters are:

a. Cold tube length, diameter.

b. Hot tube length, diameter.

c. Vortex chamber specification.

All the data is taken from the paper published by **Mohammad Mahmudur Rahman** On "**Design, Construction And Performance Test Of A Vortex Tube Cooling System Constructed By Locally Availablematerials"** and the limitations under that paper were tried to be removed.

The diameter of the cold tube was taken as D = 12.70 mm (0.50 inch) according to Rudolf Hilsch. The length of the cold tube was taken as 10D, hot tube is 45D and the diameter of cold orifice or diaphragm hole is taken as 0.5D in accordance with Hilsch, Pongjet Promvonge and Smith Eiamsaard. The diameter of the nozzle is taken as D/3 according to Guillaume and Jully. 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.

After fabrication the setup was set on a wooden frame and prepared for experiment. An insulating chamber was made to measure the temperature of the cold air at the cold end of the tube.

Design Parameters Table

Sr. No	Design Parameters	In Inches	In MM
1	Tube Diameter	0.5	12.7
2	Cold Tube Length	5	127
3	Hot Tube Length	22.5	571
4	Orifice Diameter	0.25	6.4
5	Nozzle Diameter	0.1667	4.2

Table 1. Design Parameters

VI. MATERIAL SELECTION

Vortex tube cab be formed from either steel and pvc.In previous papers mostly pvc material due to its availability and economically aspects.Further working with pvc is easy and do not require heavy tools.

PVC

PVC (polyvinyl chloride) is a versatile thermoplastic material obtained from ethylene (petrochemistry 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

VII. METHADOLOGY

Firstly a solid model of vortex tube was prepared in Solid-Works software for further reference in the fabrication process. Model was made with referenced data and no tolerances was taken, so in the actual fabrication the required tolerances was taken to make fabrication process easy. Material required for the fabrication was purchased from the market and are listed below—

i. PVC Pipes
ii. Nozzle
iii. PVC pipe connector
iv. Orifice - Steel washer
v. Conical Valve - Wooden conical piece
vi. Wooden Block - For Support
vii. M-Seal - For fixation and leak proof

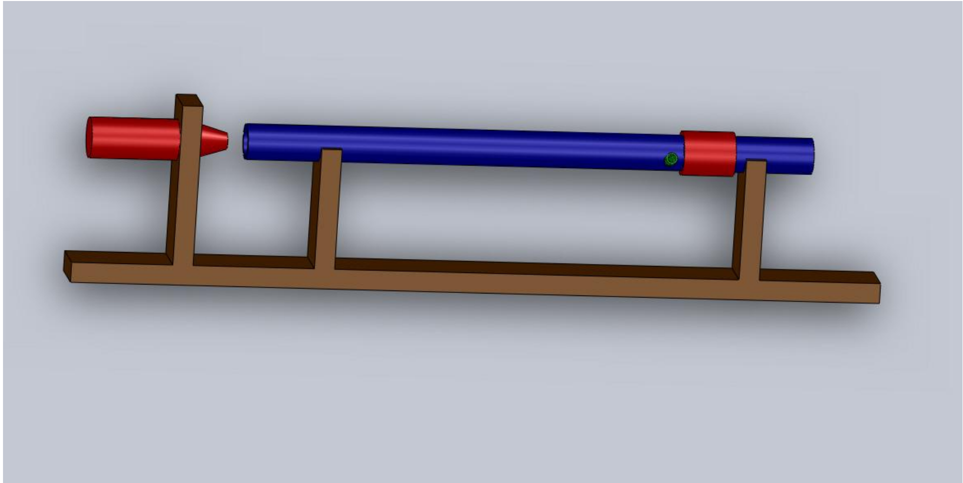


Fig 7. Assembly of Vortex Tube

Actual Fabricated Vortex Tube Refrigeration System

Fig 8. Fabricated Vortex Tube

VIII. RESULT AND CONCLUSION

Data taken at 2 bar pressure

Sr.No	Inlet Temperature (Ti)	Inlet Pressure (Pi)	Cold Temperature (Tc)	Hot Temperature (Th)	Temperature difference (Ti-Tc)
1	36	2	34.5	37	**1.5**
2	36	2	34	38	**2**
3	36.5	2	34	38.5	**2.5**
4	37	2	34.5	38	**2.5**
5	36	2	33.5	38.5	**2.5**

Table 2: Data at Pressure 2 bar

Data taken at 3 bar pressure

Sr.No	Inlet Temperature (Ti)	Inlet Pressure (Pi)	Cold Temperature (Tc)	Hot Temperature (Th)	Temperature difference (Ti-Tc)
1	37	3	34.5	39.5	**2.5**
2	38	3	35	40.5	**3**
3	38	3	35	40	**3**
4	37	3	33.5	40	**3.5**
5	37.5	3	34	40	**3.5**

Table 3: data at Pressure 3 bar

Data taken at 4 bar pressure

Sr.No	Inlet Temperature (Ti)	Inlet Pressure (Pi)	Cold Temperature (Tc)	Hot Temperature (Th)	Temperature difference (Ti-Tc)
1	37	4	32.5	40	**4.5**
2	36	4	32	40	**4**
3	36.5	4	32.5	41	**4**
4	37	4	32.5	41	**4.5**
5	37	4	32.5	41	**4.5**

Table 4: Data at Pressure 4 bar

Data taken at 5 bar pressure

Table 5: Data at Pressure 5 bar

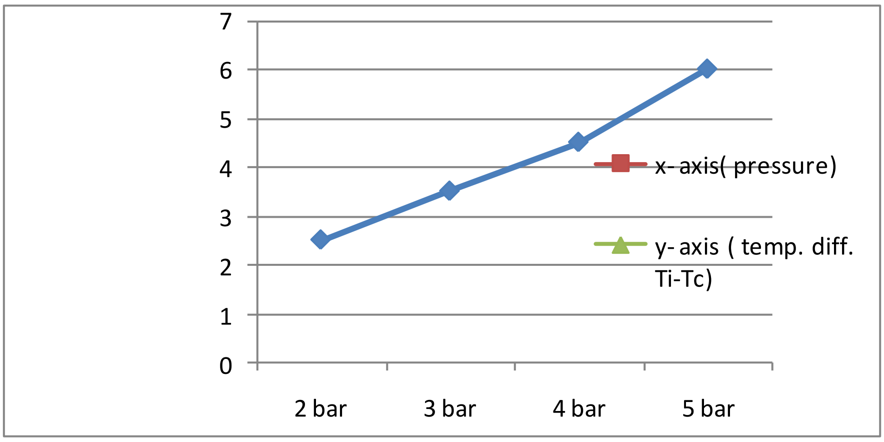
Sr.No	Inlet Temperature (Ti)	Inlet Pressure (Pi)	Cold Temperature (Tc)	Hot Temperature (Th)	Temperature difference (Ti-Tc)
1	36	5	30.5	42	**5.5**
2	36.5	5	32	43	**4.5**
3	36.5	5	30.5	42	**6**
4	37	5	31.5	43	**5.5**
5	36	5	30	43	**6**

DATA OPTIMIZATION

Data is optimized by taking last 2 consecutive values at respective pressures and graph is plotted to see the variation of temperature difference at corresponding inlet pressure.

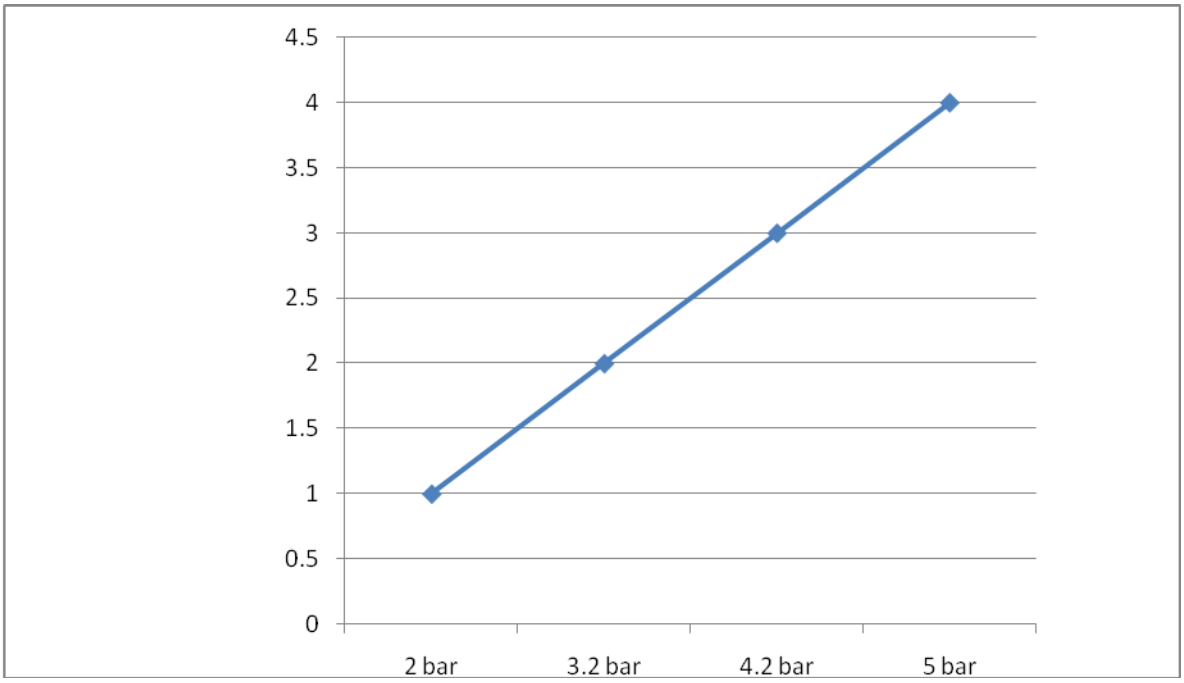
Sr.No	Inlet Presure in Bar	Temperature difference (Ti-Tc) ^{0}C
1	2	2.5
2	3	3.5
3	4	4.5
4	5	6

Table 6: Optimezed Data Corresponding To Inlet Pressure Corresponding To Inlet Pressure



Graph 1 Temperature Difference(Ti-Tc) V/S Inlet Pressure

REFERENCE GRAPH



Graph 2 Temperature Difference(Ti-Tc) V/S Inlet Pressure[]

IX. CONCLUSION

From the previous two graph its is resulted that the graph 1 shows a high temperature difference at the same inlet pressure in comparision to the reference graph 2 of the reference paper "Design, Construction And Performance Test Of A Vortex Tube Cooling System Constructed By Locally Available Materials" [4] .

Maximum temeperature difference achieved is 6^0C at 5 bar pressure 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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