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Effect of Changes in Different Necessities on the Performance of Vortex Tubes

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Abstract: *Refrigerating systems has emerged as an important necessity of human life in present century. Today, these systems are used in many applications. Present research work is devoted to the investigations for of an important category of refrigerant systems, vortex tubes. In the research work, combinations of six gases and two materials are made for analyzing pressure differences and thermal gradients for a vortex tube. The flowing gases were Argon, CO_2, Nitrogen, Oxygen, Helium, and air and the materials were copper and brass. As a result, combination of Helium and Brass emerged out as the best combination for the application.*
Keywords: *Vortex tube, working fluid, refrigeration.*

I. Introduction

Vortex tube is one of the non-conventional type refrigerating systems for the production of refrigeration. It is a simple device, which splits the pressurized gas stream into two low pressure streams (cold and hot streams). Vortex tube are known by different names, like Ranque vortex tube (on the name of inventor), and Hilsch vortex tube or Ranque-Hilsch, who enhanced the performance of these tubes after Ranque. Vortex tube is composed of nozzles' inlet (1), a chamber for creating vortex (vortex chamber) (2), cold end orifice (3), hot tube (4), hot control valve containing hot plug (5), exit for removal of hot air (6), as shown in Figure 1.1.

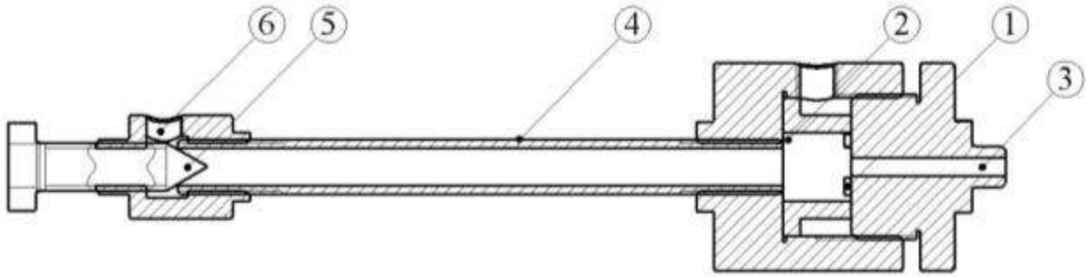


Figure 1.1: A vortex tube (El-Soghiar *et al.,* 2014)

The nozzles may be of any type depending upon the specifications of tubes, like converging or diverging or converging-diverging type as per the design. Here the objective of nozzle is to offer higher velocity, greater mass flow and minimum inlet losses. Chamber contains nozzle and facilities the entry of high velocity air-stream into hot side, from tangential direction. In most of the cases, the chambers are not of circular form, and are gradually converted into spiral form. Hot side is cylindrical in cross section and is of different lengths as per the requirement of design. Valve provides the obstacle to the flow of air via hot side and it also controls the quantity of hot air through vortex tube. Diaphragm represents a cylindrical piece having a small hole at the center. Air stream traveling through the core of the hot side gets emitted with the help of a diaphragm hole. Cold side is a cylindrical portion from which cold air passes. In present research work, performance evaluation of different gases and materials for vortex tube application is targeted by comparing pressure differences, and thermal gradients generated by them. The flowing gases are argon, CO_2, nitrogen, oxygen, helium, and air and the materials are copper and brass. For this purpose, approach of modeling and simulation of the system is carried out in ANSYS simulation software. The theoretical model used for this purpose if k-ε model.

Following are the objectives of the proposed research:
a) Modeling of a vortex tube;
b) Simulation of vortex tube for different materials and gases, and
c) Identification of different thermal propeties for tubes for different gases and different materials.

II. Literature Review

Table 2.1 shows the research outcomes and opinions of different researchers in the field of vortex tubes.

Table 2.1: Research Contributions of Different Researchers

S. No	Researcher(s)	Contribution
	Cao *et al*. (2017)	The spatial relationship between the energy dissipation slabs and also the vortex tubes is investigated supported the direct numerical simulation (DNS) of the channel flow. The spatial distance between these two structures is found to be slightly larger than the vortex radius. Comparison of the core areas of the vortex tubes and therefore the dissipation slabs offers a mean quantitative relation of 0.16 for the mean moving strength which of 2.89 for the mean dissipation rate. These results verify that within the channel flow the slabs of intense dissipation and therefore the vortex tubes don't coincide in space. Rather they appear in pairs offset with a mean separation of approximately 10 degree.
1.	Rafiee & Sadeghiazad (2017)	During this analysis the results of a replacement nozzle position (parallel injector), throttle orifice diameter (6.5–9.5mm) and length of parallel main tube (180–220mm) on the quality of the separation method wit in the Ranque–Hilsch and also the parallel air separator (PVT) are analyzed. The results show that the parallel vortex tube with optimized length, injection angle and orifice diameter provides 66.08% (14.83K) and 58.61% (13.88K) higher thermal separation performance as compared to the initial parallel vortex tube.
2.	Attalla *et al.* (2017)	The experimental results of the research work discovered that the utmost cold temperature distinction occurred at the inlet gas pressure of 6 bars and cold mass fraction of 0.4 for both VTS and VTP systems. The conducted results incontestable that the values of COP_{ref} for VTS system were over the values of VTP system. However, the VTP yielded higher values of COPHP over the span of investigation. The VTS system improved the COP_{ref} by twenty two.5% and 31.5% compared with the VTP and therefore the single vortex tube system (VTO), respectively. For t e case of VTP system, the COPHP is increased by 18.2% and 27.3% than VTS and VTO, respectively.
3.	Kolmes *et al.* (2017)	According to the researchers, we describe a quantitative model for heat separation in a fluid owing to motion along a pressure gradient. The physical model concerned has relevancy to one clarification for the temperature separation during a vortex tube. This impact features a point of saturation in which the fluid's temperature and pressure are connected at its boundaries by an adiabatic law. Vortex tube models typically assume that this saturation is achieved in physical devices. We conclude that this can be seemingly to be a secure assumption abundant of the time, but we describe circumstances during which saturation may not be achieved. We tend to propose a check of our model of temperature separation.
4.	Zhang *et al.* (2016)	To reveal the energy transferring mechanism in the vortex tube, which is a remarkable development in the area of heat and mass transfer, numerical simulation and analysis of the dynamic fluid flow were employed. In contrast to the previous static study, the main target of this paper is the dynamic process, or the oscillation, of the secondary circulation layer. based on the fluid flow results derived from the unsteady three-D computation, the existence of the forced or rankine vortex was confirmed, which conjointly verified the certainty of reverse flow in the cold end of the vortex tube. Then, the oscillation of the boundary layer of the central recirculation zone was emphasized and the periodical vibratory of the fluid flow within the secondary circulation zone, varying of its boundary, and therefore the typical frequencies of points on a cross section were provided. supported these results, a unique energy transferring mechanism in the vortex tube was planned, underneath the condition that stable oscillation of the boundary layer is the dominant mechanism for the heat and mass transfer process.
5.	Karthik (2015)	The vortex tube is cold equipment that produces each cold as well as hot air at both opposite ends. The vortex tube's construction is such it is made of a hollow tube of either metallic or fibre elements having a nozzle for letting in of compressed gas and a diaphragm or a orifice for dominant the flow rate of air. once compressed air passes through a nozzle into the diaphragm of the vortex tube, the air forms a spiral formed vortex, that causes the heating of air, and once this air returns back, it cools down quickly, producing a cooling impact. The most study in the Vortex tube is that the study of the temperature distribution of the rotating air. This impact was initially discovered by Ranque and later by Hilsch and thus this impact is termed Ranque- Hilsch impact.
6.	Agrawal *et al*. (2014)	An experimental investigation is administrated on Ranque–Hilsch vortex tube (RHVT). Influential parameters such as L/D ratio, cold mass fraction, inlet pressure etc. are investigated. Further, three completely different working media (air, nitrogen and carbon dioxide) are also tested. An in-house facility is developed to check the vortex tubes. A value of cold mass fraction is ascertained at which vortex tube performs optimally at the given pressure and L/D ratio. It is found that vortex tube performs higher with carbon dioxide as operating fluid.

2.1Gaps in the Research

On the basis of analysis of theoretical considerations, and research contributions made by different researchers, following gaps in the research are being identified.

a) There is almost nil research available which compares the performance of vortex tubes with different gases and materials used in the vortex tubes; and
b) There is almost nil research available which suggests the ranking of gases and materials for vortex tubes.

III. Solution Methodology

Present section tells about the details of software used in the research work. In the present research work ANSYS R 15.0 simulation software, the details of which are presented as follows.

3.1 ANSYS

ANSYS is considered as one of the renounced tools in the field of simulation, developed by ANSYS Inc., USA. It can be used successfully for the purpose of simulating problems of thermal analysis, structural analysis, computational fluid dynamics, harmonic analysis, modal analysis, transient dynamics, buckling, and other categories. In addition to this, software also offers the facility to develop simple models. With the help of inbuilt library, one can find out the properties of materials, and even add the desired properties or new materials with the known values of properties. ANSYS also include a set of models to solve complex problems of engineering, architecture, physical sciences, mathematical models and other applications.

IV. Case Study

Present section is devoted to the details of solution methodology adapted to for solving the research problem, and explains in details about problem formulation, development of vortex tube model, and different properties used for simulation of model with the applications of constrains.

4.1 Model Formulation

First step in the research work was the formulation of model of vortex tube. For this purpose dimensions of a standard vortex tube are used. The adopted vortex tube is called *Ranque-Hilsch* vortex tube, the details of which are presented in Figure 4.1.

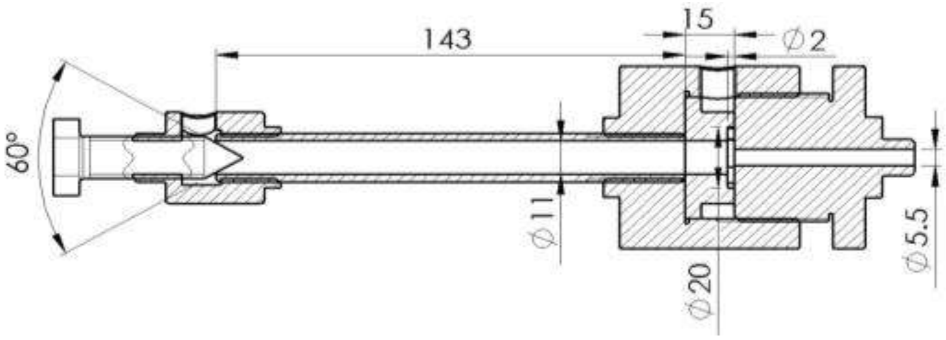


Figure 4.1: Dimensions of Conventional Vortex Tube (El-Soghiar *et al., 2014*)

Figure 4.2 shows the details of arrangements of nozzles of above mentioned vortex tube.

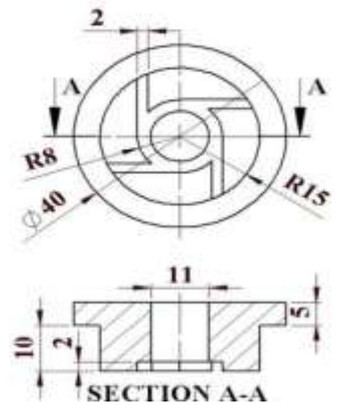


Figure 4.2: Nozzle arrangements for Conventional Vortex Tube (El-Soghiar *et al.*, 2014)

Following are the details of specifications of above mentioned vortex tube.

Table 4.1: Specifications of Vortex Tube (El-Soghiar *et al.*, 2014)

S. No	Dimension	Value	Material
1.	Inlet nozzle	Brass, Copper	(No. off 4), 2 x 2 mms
2.	Hot tube	Brass, Copper	diameter = 11 mm and length = 143 mm
3.	Cold orifice	Brass, Copper	5.5 mm
4.	Hot plug	Brass, Copper	60^0

5.	Modified vortex chamber	Brass, Copper	D = 12, 16, 20 mms, and L = 10, 15, 20 mm

In present research work, effect of nozzle openings on the performance of conventional vortex tube is investigated. For this purpose, first of all a model of vortex tube was developed in modeling software using above mentioned details, and then imported in a well known simulation software ANSYS 15.0 Following are the details of model.

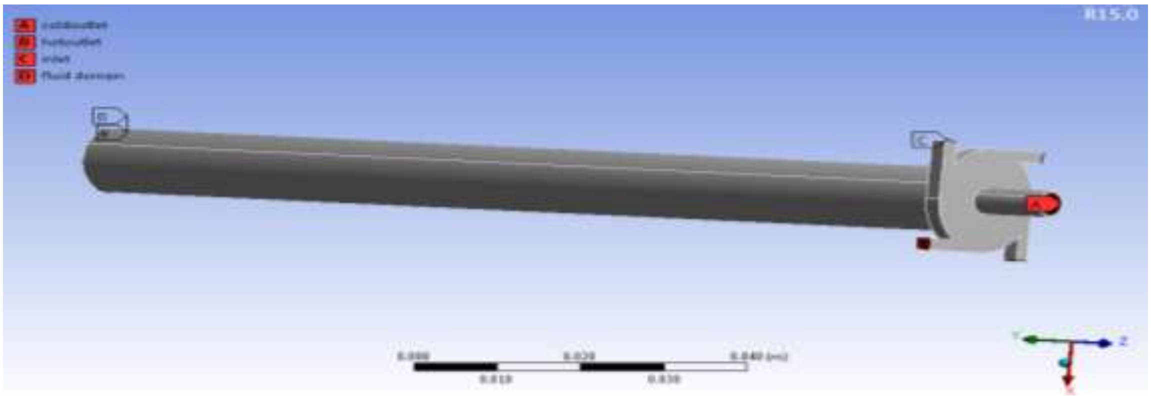


Figure 4.3: Model of Vortex Tube

4.2 Solution of the Model

After formulation of model, its solution was derived. For this purpose, first of all meshing of the model was carried out. With the help of meshing, a body can be made deformable due to which, it can show changes in its properties, dimensions, stress levels, etc. The chosen elements for meshing were tetrahedron elements. Selection of mesh size was software based. Figure 4.4 shows the mesh diagram for the vortex tube.

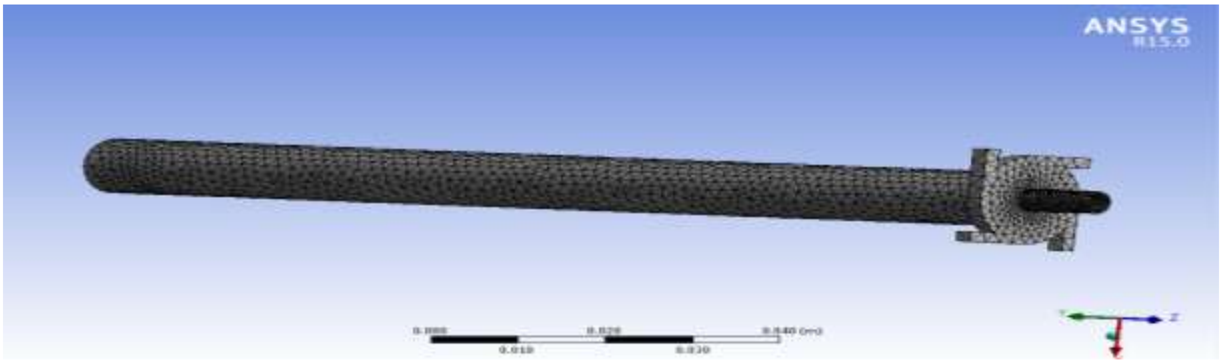


Figure 4.4: Mesh structure of Vortex Tube

In next step inlet and outlet domains were decided as mentioned in Figure 4.5, given below.

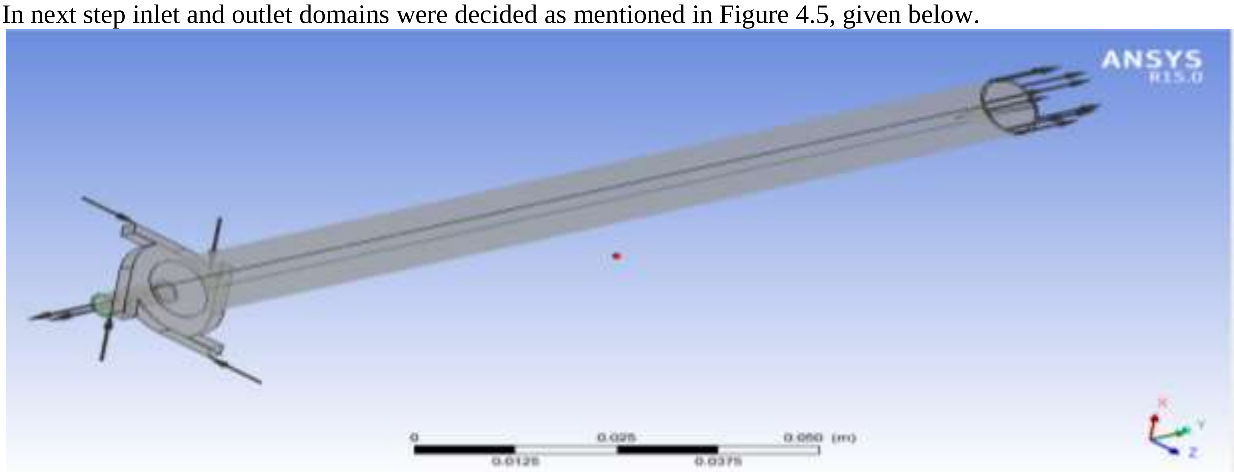


Figure 4.5: Inlet and Outlet Domain Finalization for the Vortex Tube

Following are the details of parameters used for investigations, chosen with the help of expert opinion.

Table 4.2: Parameters used in finding different thermal properties from Vortex Tube

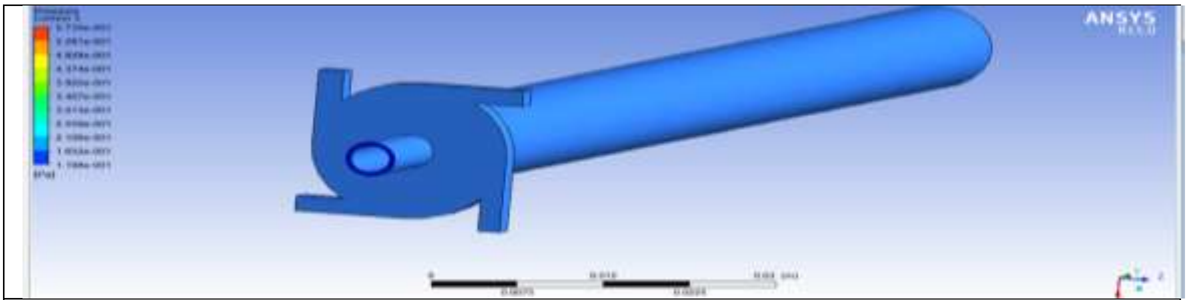
S. No	Parameter	Value
1.	Inlet pressure	5 bar
2.	Inlet temperature	303 K
3.	Outlet Pressure (hot end)	1 bar
4.	Outlet Pressure (cold end)	0.5 bar

V. Results and Discussion

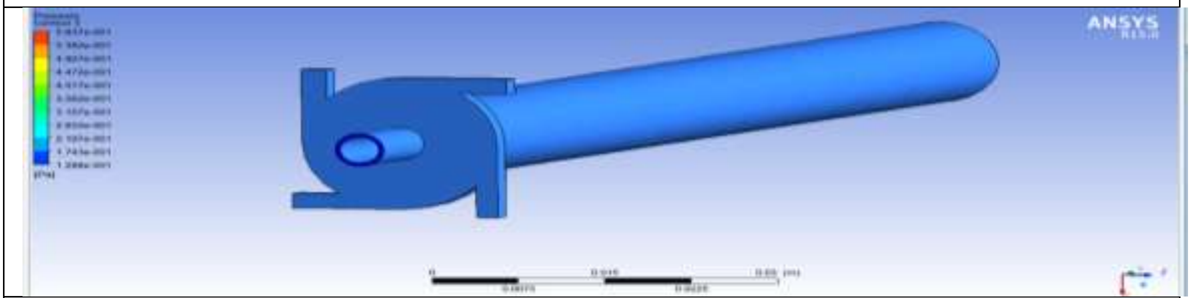
Present chapter is devoted to results and discussions about the research work. In present research work, on applying different gases and materials, values of pressures and temperature gradients are investigated. The details of the results obtained, and discussion made on the basis of yielded results are presented in succeeding chapters.

5.2 Results

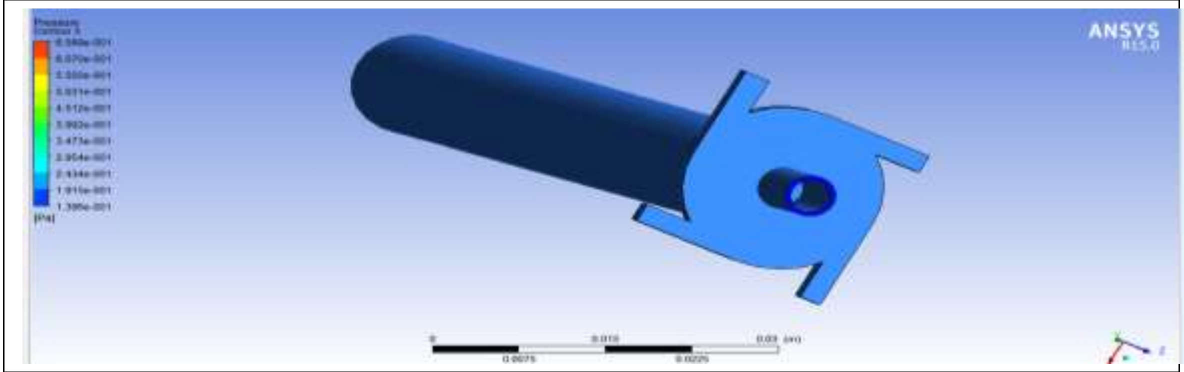
Following are the results obtained from calculations for pressures of different materials and gases used in vortex tubes with different materials.



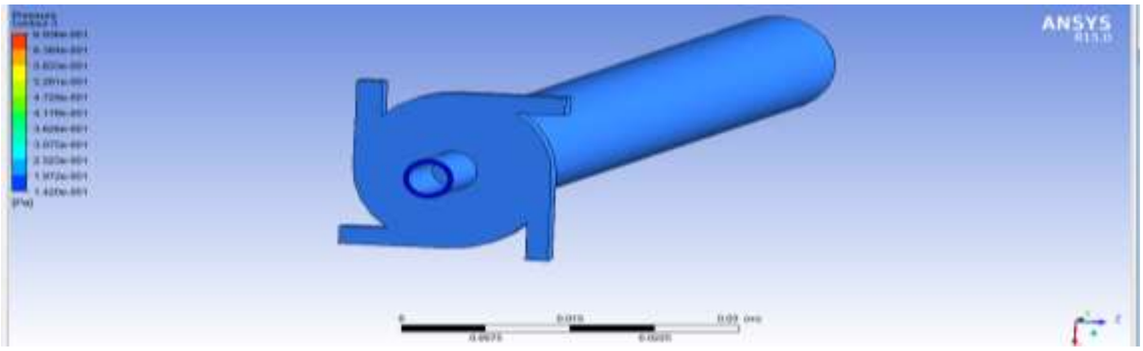
(a) Argon



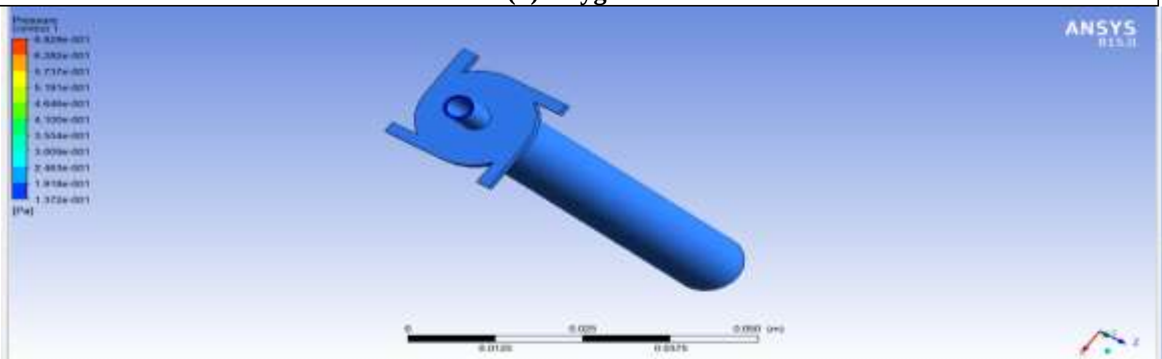
(b) Carbon dioxide



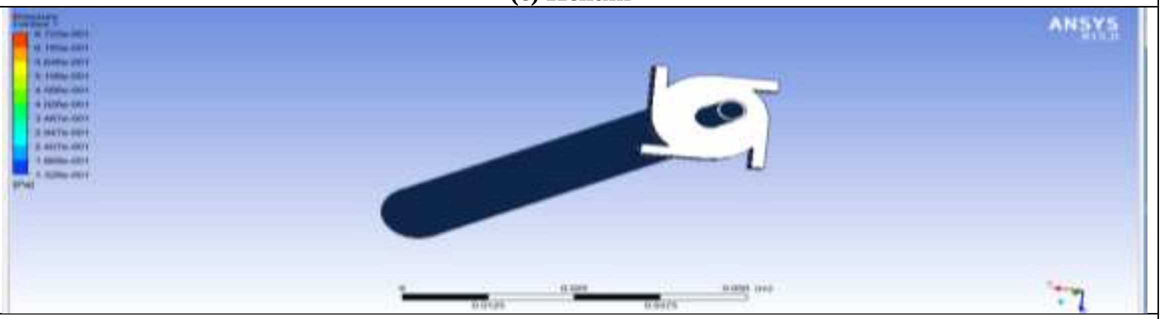
(c) Nitrogen



(d) Oxygen

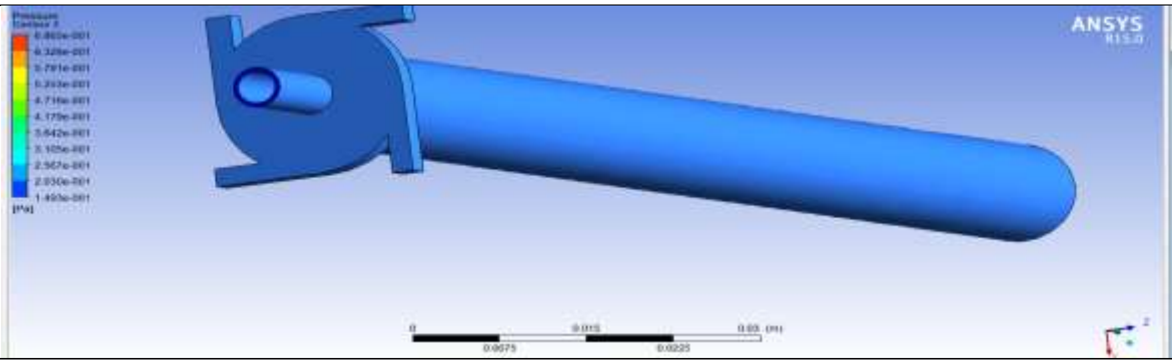


(e) Helium

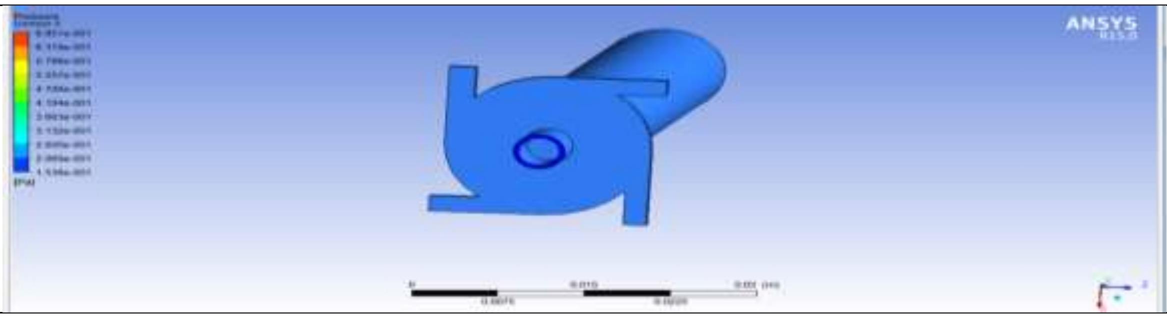


(f) Air

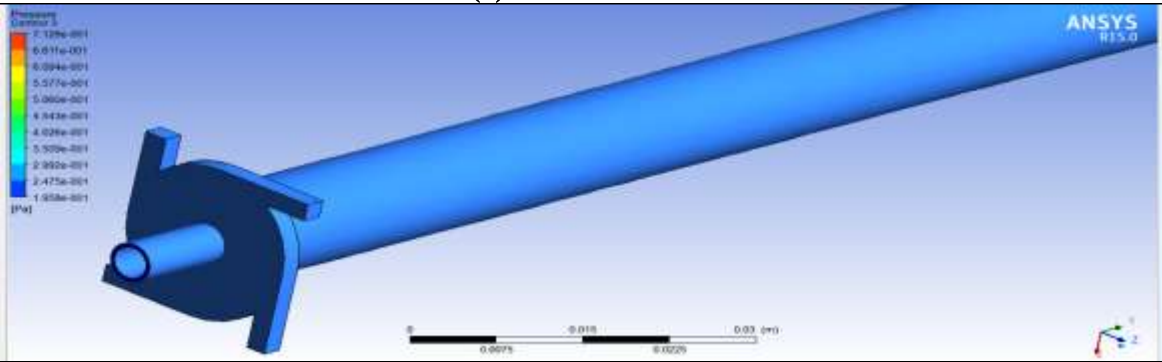
Figure 5.1:Values of pressures for different gases with Cu tube



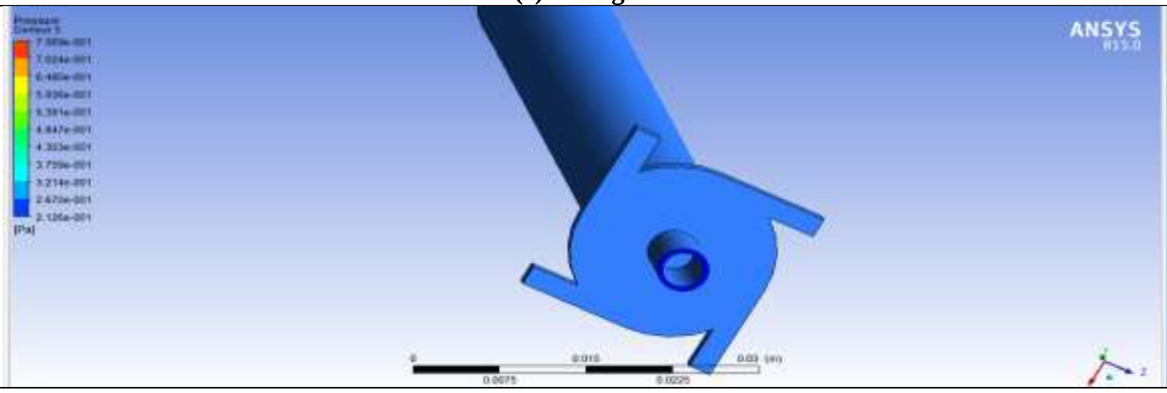
(a) Argon



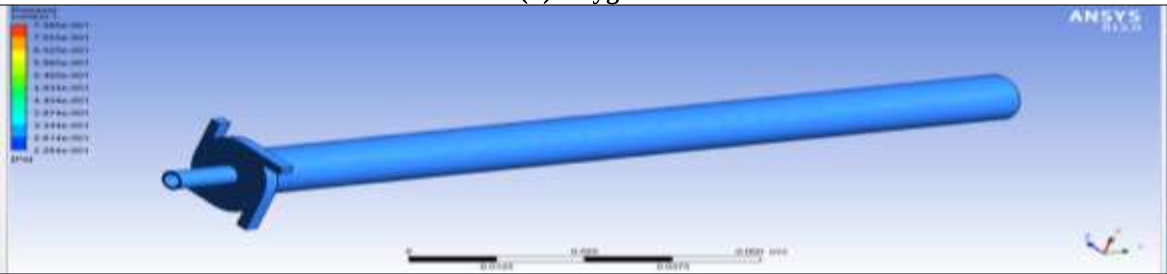
(b) Carbon dioxide



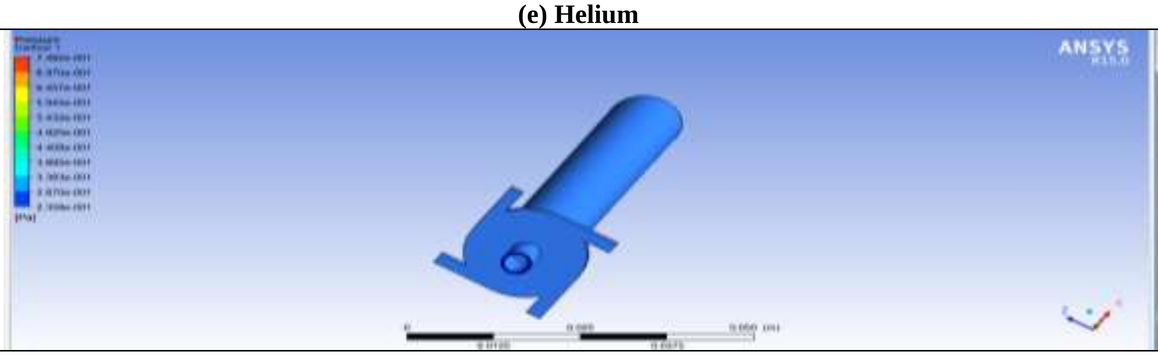
(c) Nitrogen



(d) Oxygen



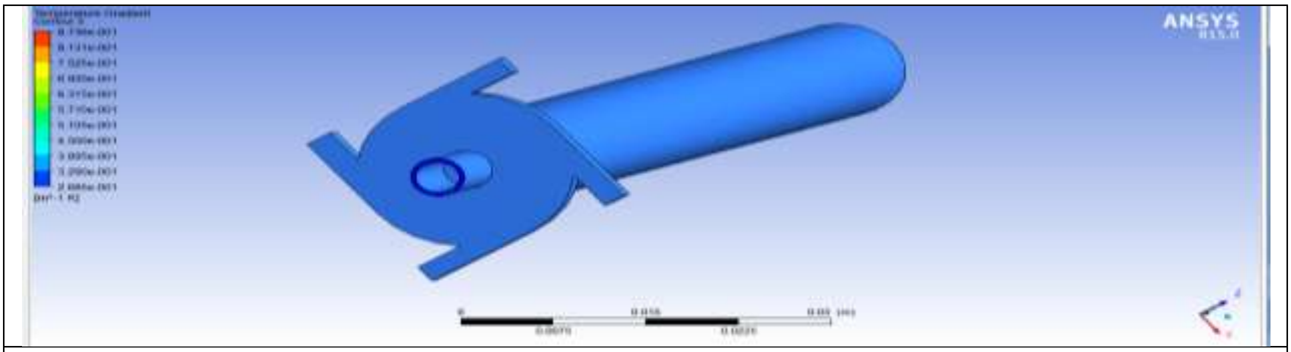
(e) Helium



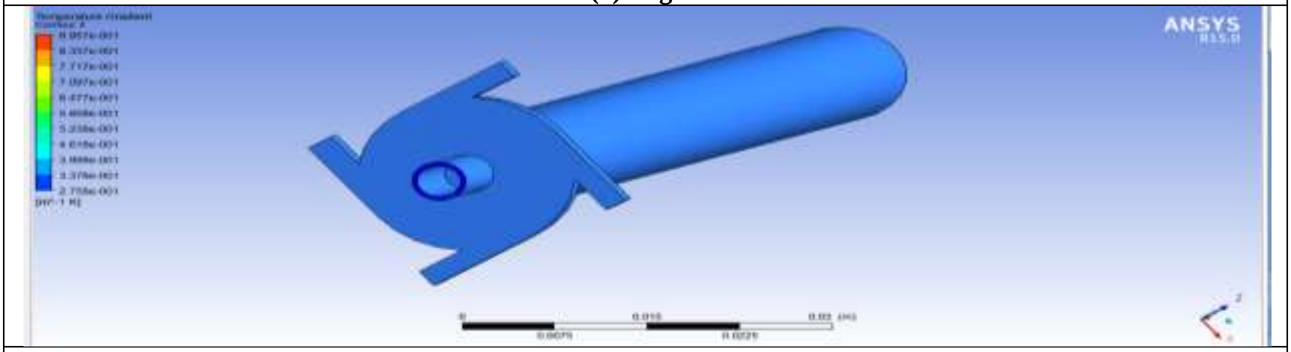
(f) Air

Figure 5.2:Values of pressures for different gases with Brass tube

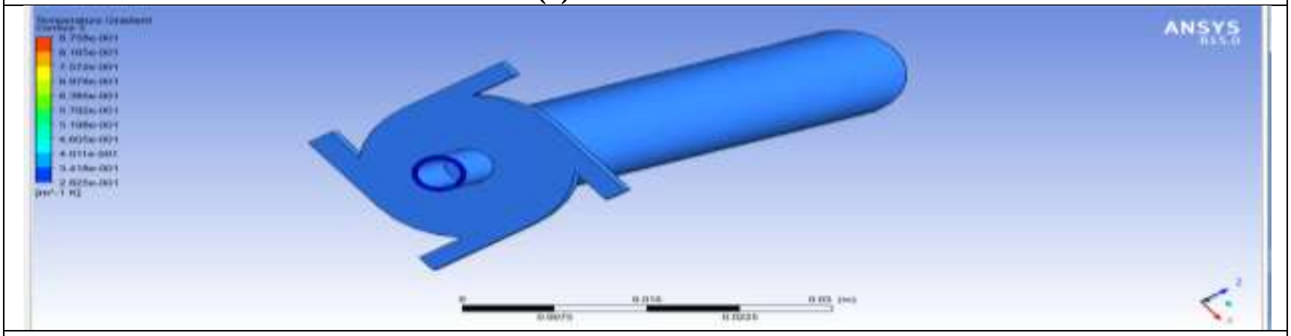
Following are the results obtained from calculations for thermal gradients of different gases used in vortex tubes with different materials.



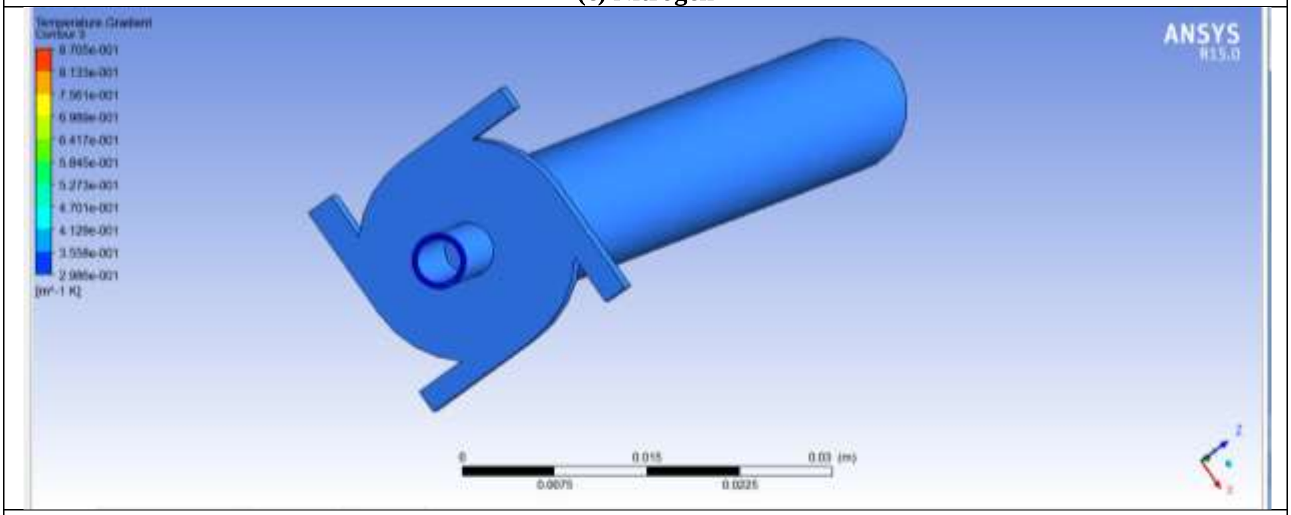
(a) Argon



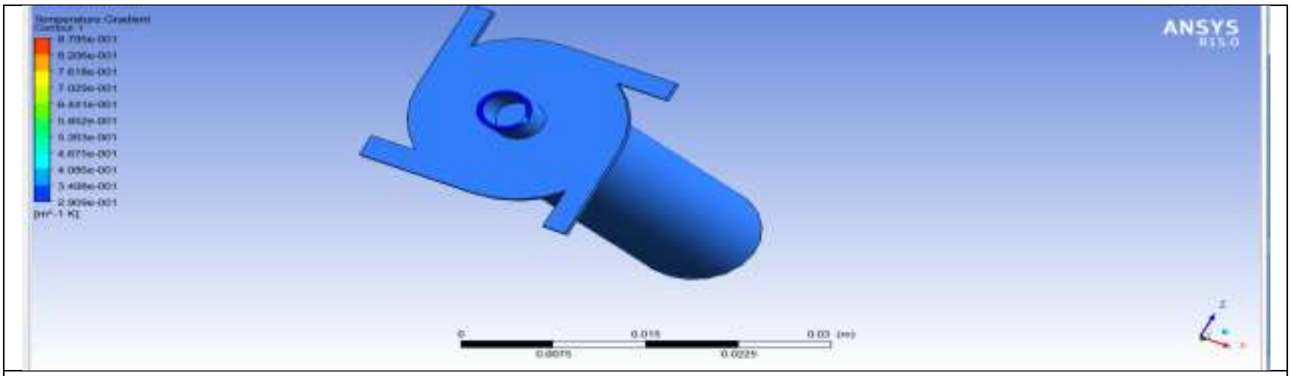
(b) Carbon dioxide



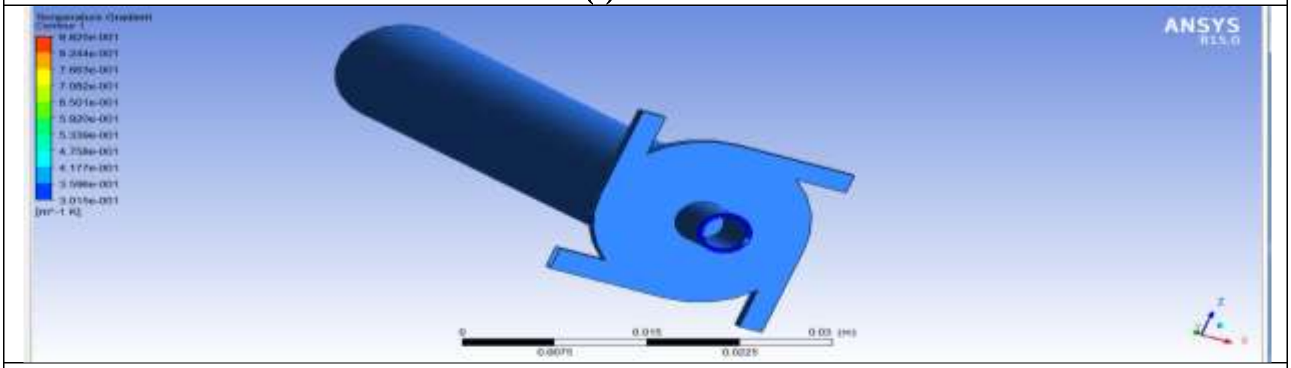
(c) Nitrogen



(d) Oxygen

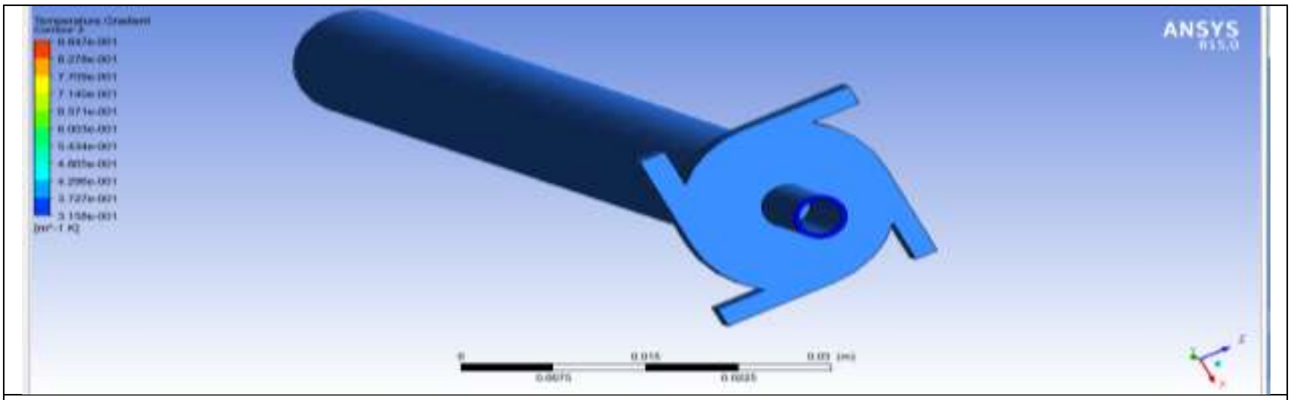


(e) Helium

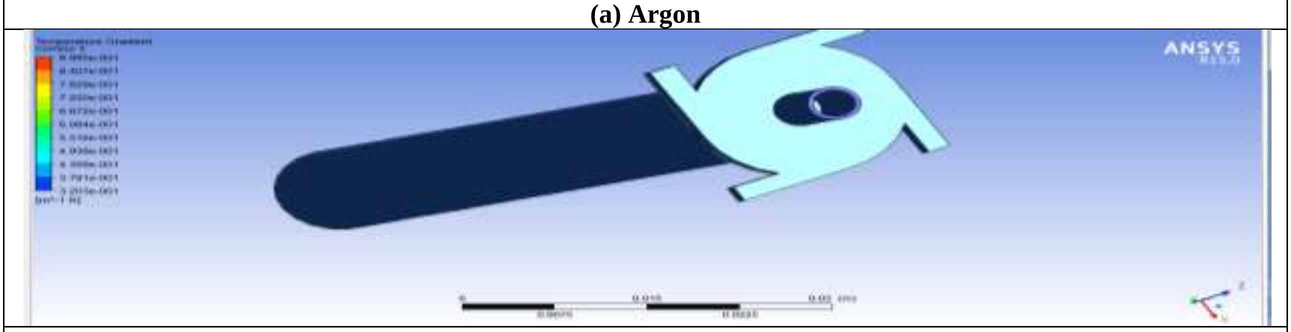


(f) Air

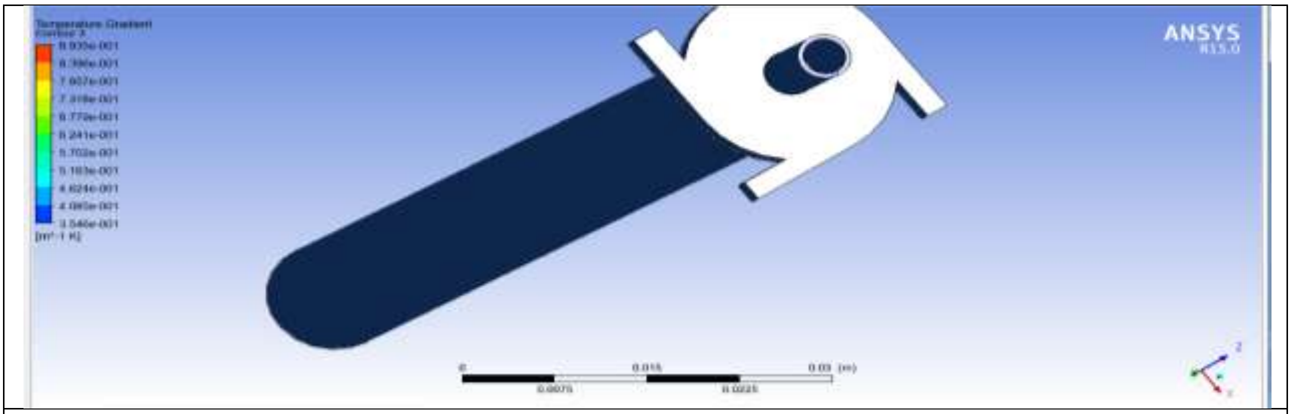
Figure 5.3:Values of thermal gradients for different gases with Cu tube



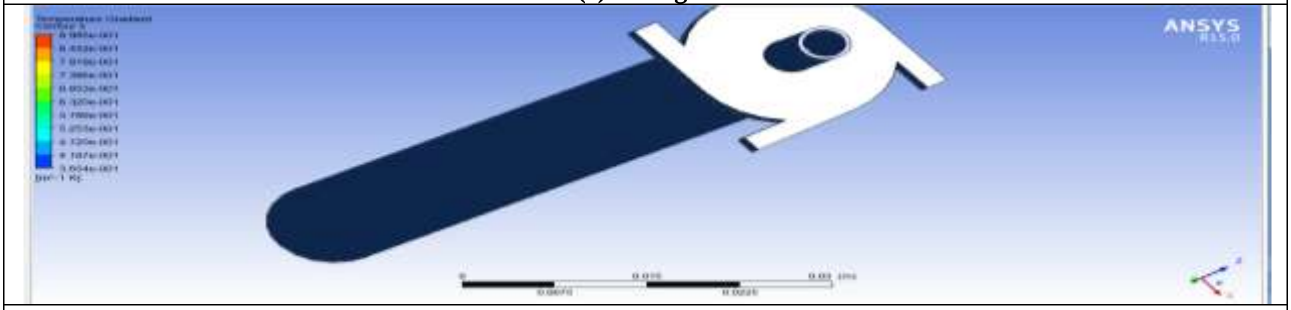
(a) Argon



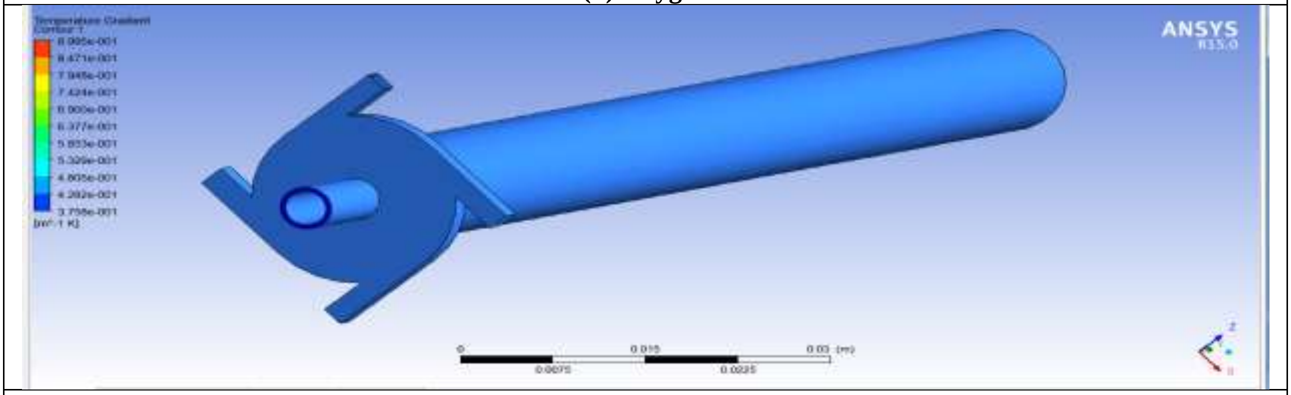
(b) Carbon dioxide



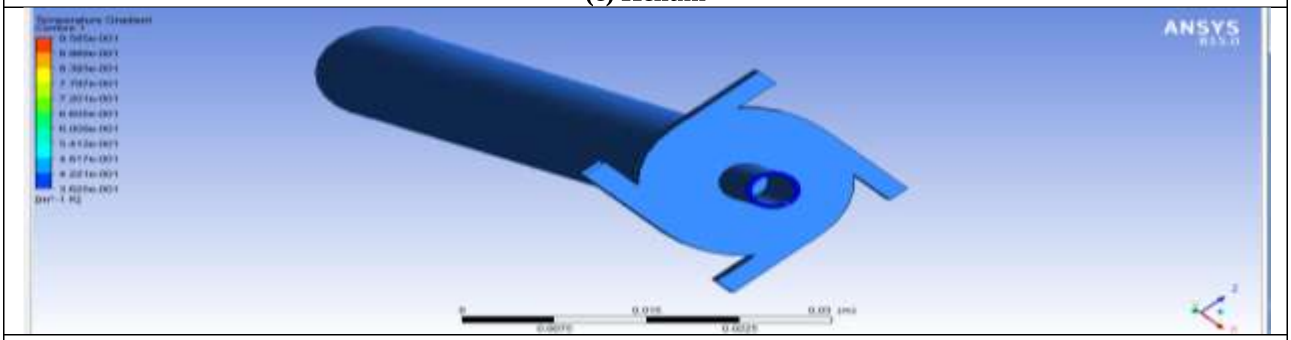
(c) Nitrogen



(d) Oxygen



(e) Helium



(f) Air

Figure 5.4:Values of thermal gradients for different gases with Brass tube

5.3 Discussion

From the results obtained, it can be found that there are two criteria on which rankings of the alternatives can be made; pressure difference, and temperature gradient. Reason behind choosing pressure difference as a criterion is that more is the pressure difference, more will be the temperature difference obtained.

The last criteria are temperature gradient which represents the change in temperature with respect to the change in length of the vortex tube. Table 5.1 shows the summarized results of the analysis.

Table 5.1: Summarized results of analysis

S.No	Material	Gas	Pressure Max	Pressure Min	Pressure Difference	Rank	Temperature Gradient	Rank
1.	Copper	Argon	5.735E-001	1.198E-001	4.54E-01	15	3.290E-001	12
2.		Carbon di Oxide	5.837E-001	1.288E-001	4.55E-01	14	3.378E-001	11
3.		Nitrogen	6.589E-001	1.396E-001	5.19E-01	8	3.418E-001	10
4.		Oxygen	6.936E-001	1.420E-001	5.52E-01	1	3.558E-001	8
5.		Helium	6.828E-001	1.372E-001	5.46E-01	2	3.498E-001	9
6.		Air	6.725E-001	1.328E-001	5.40E-01	4	3.596E-001	7
7.	Brass	Argon	6.805E-001	1.493E-001	5.31E-01	6	3.727E-001	6
8.		Carbon di Oxide	6.851E-001	1.538E-001	5.31E-01	5	3.781E-001	5
9.		Nitrogen	7.128E-001	1.958E-001	5.17E-01	9	4.085E-001	4
10.		Oxygen	7.569E-001	2.126E-001	5.44E-01	3	4.187E-001	3
11.		Helium	7.585E-001	2.284E-001	5.30E-01	7	4.282E-001	1
12.		Air	7.482E-001	2.358E-001	5.12E-01	10	4.221E-001	2

Figure 5.5 and Figure 5.6 show the graphical representation of above results.

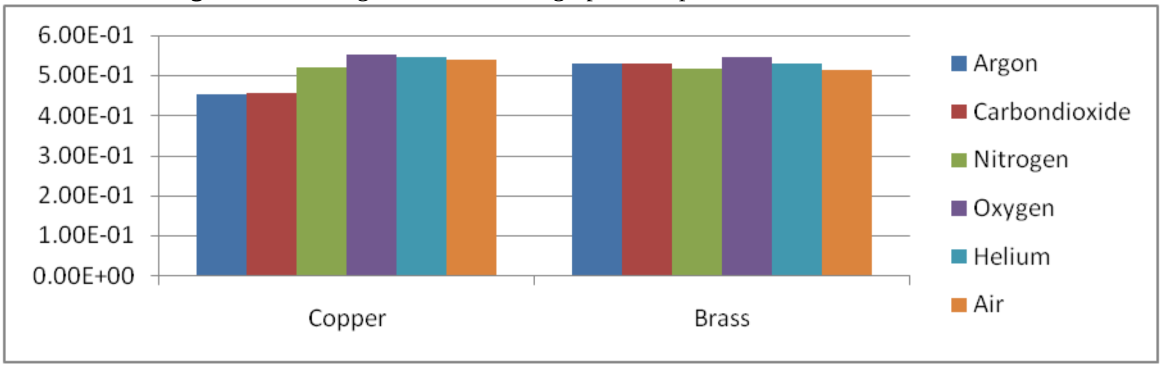


Figure 5.5: Graphical Representation for Results obtained for Pressure Difference

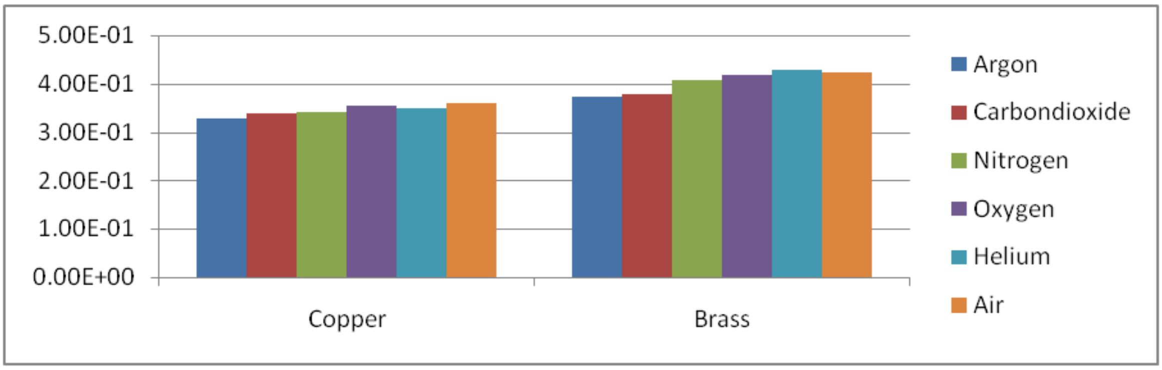


Figure 5.6: Graphical Representation for Results obtained for Temperature Gradient

From above mentioned results it can be analyzed that the brass can be treated as the best material out of available alternatives, as it shows the best performance on the criteria, pressure difference and thermal gradient.

From Figure 5.5, it can be found out that there is a considerable difference in the scores for pressure differences for different gases in materials. For Copper, Oxygen scores rank one while Argon scores rank six, but for Brass, Oxygen ranks one but air ranks six. Considering these results one can say that oxygen should be chosen on pressure difference criteria.

But due to explosive nature of the gas, it cannot be recommended, in spit, other option can be proposed. In the Figure 5.5, it can be found that Helium scores rank two for both Brass and Copper. Helium is the first noble gas in the periodic table. Considering the properties of the gas, it can be proposed as the best option for the operation in vortex tube. After Helium, air scores the ranking second for the materials Brass and Copper. After air Nitrogen can be considered as the third option for the materials.

From Figure5.6, it can be found that Helium for Brass and air for Copper scores rank one. For rank two, air for Brass, Oxygen for Copper, appear as suitable alternatives. For rank three, Oxygen appears as an option for all the materials. For rank four, Nitrogen appears as the suitable option. In all the cases Argon scores rank six.

Considering these diverged results, it can be found that unique ranking from both the criteria is not possible. Therefore, following pattern of rankings is proposed

Table 5.2: Overall rankings of Materials and Gases

S.No		Criteria		
	Rank	**Pressure Difference**	**Thermal Gradient**	**Remarks**
1.	I	Brass-Helium	Brass-Helium	Oxygen is not recommended for rank one
2.	II	Brass-Air	Brass-Air	
3.	III	Brass-Nitrogen	Brass-Nitrogen	Oxygen is not recommended for rank three

VI. Conclusion, Limitations and Future Scope of the Research

In this section, details of conclusion, limitations and future scope of the research are presented.

6.1 Conclusion

Present research work is focused on the thermal analysis of a vortex tube for performance enhancement. For this purpose a standard vortex tube was selected and thermal analysis on it was performed using *six* different gases, including the air. The gases selected for the purpose of analysis were argon, carbon dioxide, nitrogen, oxygen, helium and air. In the analysis, three materials, Copper and Brass were also used. Thermal analysis of was done on very popular analysis software ANSYS 15.0, under which maximum pressure, minimum pressure for the calculation of pressure difference and thermal gradient were investigated. Following points represent the conclusion of the research work.

1. **Conclusion for Materials:**

a) Brass shows the best performance out of all available options and ranks *one*; and
b) Copper scores rank *two.*

2. **Conclusion for Working Fluids:**

a) For both the criteria, helium ranks *one*;
b) For both the criteria, air scores rank *two*; and
c) For both the criteria, Nitrogen scores ranks *three*.

6.2 Limitations and Future Scope of the Research

Following are the limitations of research work.

- The research work is limited to investigations to vortex refrigeration system only;
- The research work is also limited to investigations about limited properties of the gases; and
- The research work is also limited to performance evaluation of a small set of properties.

Following points indicate the future scope of research work.

- On the criteria of pressure difference, Oxygen showed the best performance however it was recommended. A research considering Oxygen blended with some inert gases may be initiated;
- A research work considering a broader set of refrigeration systems may be initiated;
- A research work can also be initiated which shall consists of a broader set of thermal properties of gases; and
- A research work considering broader sets of properties can also be undertaken.

References

[1]. Agrawal, N., Naik, S. S., & Gawale, Y. P. (2014). Experimental investigation of vortex tube using natural substances. *International Communications in Heat and Mass Transfer*, *52*, 51-55.
[2]. Attalla, M., Ahmed, H., Ahmed, M. S., & El-Wafa, A. A. (2017). An experimental study of nozzle number on Ranque Hilsch counter-flow vortex tube. *Experimental Thermal and Fluid Science*, *82*, 381-389.
[3]. Cao, L. K., Li, D. X., Chen, H., & Liu, C. J. (2017). Spatial relationship between energy dissipation and vortex tubes in channel flow. *Journal of Hydrodynamics, Ser. B*, *29*(4), 575-585.
[4]. Karthik, S. (2015). An Experimental Setup of Vortex Tube Refrigeration System. *International Journal of Engineering Research & Technology (IJERT) ISSN*, 2278-0181.

[5]. Kolmes, E. J., Geyko, V. I., & Fisch, N. J. (2017). Heat pump model for Ranque–Hilsch vortex tubes. *International Journal of Heat and Mass Transfer*, *107*, 771-777.
[6]. Rafiee, S. E., & Sadeghiazad, M. M. (2017). Efficiency evaluation of vortex tube cyclone separator. *Applied Thermal Engineering*, *114*, 300-327.
[7]. Zhang, B., Guo, X., & Yang, Z. (2016). Analysis on the fluid flow in vortex tube with vortex periodical oscillation characteristics. *International Journal of Heat and Mass Transfer*, *103*, 1166-1175.