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# Exergy Performance of Vortex Tube by Varying Geometrical Parameters

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***Abstract*— A simple hollow piece of metal called Ranque Hilsch vortex tube is a solution of wide variety of industrial applications like heating and cooling turning drilling welding etc. It is eco-friendly, low cost, light in weight and effective device in which a compressed air supplied from source at high pressure can separated into two streams hot and cold air at both outlets. Air is introduced via tangential nozzle a strong vortex flow will be created which will be split into two air streams. The main factors that affecting the performance of vortex tubes are inlet pressure, L/D ratio, cold mass fraction etc.**

**The main objective of this paper is to investigate the energy separation, flow variation in radial direction and the maximum efficiency of the vortex tube by exergy analysis to investigate the energy separation and flow phenomena within a vortex tube. Air is considered as working fluid or refrigerant .In this work for L/D ratio 32.5 is selected. Vortex tube of various geometrical parameters (no of nozzles 1,2,3,4, valve angle $30^0$,$45^0$,$60^0$,$90^0$. With varying cold mass fraction from 0.1 to 0.9 is selected. These parameters are used in an exergy analysis. Maximum Exergy efficiency is obtained at $60^0$ valve angle and at nozzle 4 which is 0.4022.**

***Index Terms*—Ranque-Hilsch, Vortex Tube, Cold mass fraction, Exergy analysis.**

## I. Introduction

The vortex tube (also called the Ranque – Hilsch vortex tube) is a ecofriendly 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 vortex tube was first discovered by Ranque [1, 2], a metallurgist and physicist who was granted a French patent for the device in 1932, and a United States patent in 1934. Since the vortex tube was thermodynamically highly unproductive, it was abandoned for several years. Interest in the device was revived by Hilsch [2], a German engineer, who reported an account of his own comprehensive experimental and theoretical studies aimed at improving the efficiency of the vortex tube. Since from the inventions no exact theory till today has arisen to explain the phenomenon satisfactorily.

There is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers Therefore; it was decided to carryout experimental investigations for understanding the heat transfer.

Characteristics in a vortex tube.

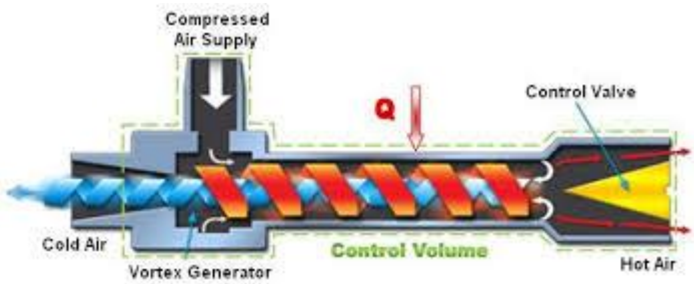


Fig. 1: Structure of vortex tube with flow pattern within the tube

The vortex tube was first discovered in 1930 by Georges Ranque. He was a French physics student. He was experimenting with a vortex pump he had developed at that time he noticed warm air exhausting from one end and cold air from other end. Ranque soon forgot his pump. He started a small firm to utilize the commercial potential of this device that produce hot and cold air streams both with no any moving parts. However, it soon failed and the vortex tube slipped into obscurity until 1945 when Rudolf Hilsch, a German physicist, published a widely read scientific paper on the device.

## II. Literature Survey

Researchers carried several experimentation to understand the flow behavior of vortex tube under different geometrical conditions.

Mete Avcı* [3] An experimental study is carried out to find out effects of nozzle aspect ratio and nozzle number on performance of vortex tube. Under different inlet pressures single nozzle set with AR 0.25, 0.44 and 0.69 and nozzles 2,3 were tested. Working media used is dry air. The Experimental results reveal that increase in nozzle aspect ratio leads to larger mixing zone, which decreases temperature difference between cold end and hot end. Single nozzle vortex tube gives better performance than 2 and 3 nozzles.

Waraporn Rattanongphis et al. [4] Preliminary tests carried out suggests that cooling capacity increases as temperature at hot tube section of vortex tube is reduced. This paper suggests that by using thermoelectric module heat can be extracted from hot tube hot tube surface and release to the environment. Test rig is designed and constructed for experiment by varying parameters such as cold mass fraction from 0 to 1 for inlet pressure of 1.5 bar. It is observed that cooling capacity increases as thermoelectric module is placed to extract heat from hot tube surface of vortex tube. Rate of cooling capacity

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and efficiency is increased by 4.3 % and 9.6 % respectively.
K Dincer et. al. [5] carried out an experimental investigation an exergy analysis of the performance of a counter flow Ranque Hilsch vortex tube with regard to nozzle cross sectional areas. Experiment was performed under the inlet pressure of 260 Kpa and 300 Kpa. The total inlet exergy, total outlet exergy, total lost exergy and exergy efficiency have been reported. It was found that the exergy efficiency of various nozzle cross section areas for particular vortex tube design ranges from 1% to 39%.
Mohammad O. Hamdan, et al. [6] This paper reveals the effect of nozzle parameters on performance of vortex tube. the results indicate that maximum energy separation is obtained by tangential nozzle orientation while regularity of nozzles has minimum effect on performance of vortex tube. For given conditions and parameters it is seen that 4 nozzles gives maximum energy separation.
Mete Avcı* [7] An experimental study is carried out to find out effects of nozzle aspect ratio and nozzle number on performance of vortex tube. Under different inlet pressures single nozzle set with AR 0.25,0.44 and 0.69 and nozzles 2,3 were tested. Working media used is dry air. The Experimental results reveal that increase in nozzle aspect ratio leads to larger mixing zone, which decreases temperature difference between cold end and hot end. Single nozzle vortex tube gives better performance than 2 and 3 nozzles.
Kiran D.Devade and A.T.Pise [8] performed experimental investigation on short divergent vortex tube for producing refrigerant effect. Experimentation had been performed with varying their parameters of vortex tube to enhance the refrigeration effect. The vortex tube of short length having L/d = 6 and 2 nozzles of equal diameters 2.5 mm diametrically opposite having divergent hot end was developed. Vortex tube was tested with conical valve 300, 450, 600, 900 at pressures ranging from 2 to 6 bars. Short length vortex tube was found reasonable temperature drop as compared to other ie. upto 110C for a 450 valve at 6 bar pressure i.e, total drop of 36 percentage in temperature and the rise of 12 % is observed. The cold mass fraction was held constant at 0.8. The cooling effect was observed 53.24 J and COP was 0.05656.
Yunpeng Xue et al. [9] proposed an explanation for the temperature separation in vortex tube based on experimental study focusing on the flow structure and energy ( exergy analysis) of vortex tube. The design parameters: length 1260 mm, diameter 60 mm, nozzle cross section 1x 14 mm cold end diameter 6 mm was used for an experiment. Flow properties inside the vortex tube and exergy density distribution along the vortex tube were calculated. Exergy density in the peripheral region decreases from cold end to the hot end. The exergy density in a central region decreased from hot end to cold end. This trend of variation shows good agreement with experimental work and shows a validity of hypothesis.
Abdol Reza BRAMO, et al. [10] This paper gives the clear idea of CFD to explore the effects of L/D ratio on fluid flow characteristics and energy separation inside vortex tube. The L/D ratios of 8, 9.3, 10.5, 20.2, and 30.7 with six nozzles were investigated. It was seen that at L/D ratio 9.3 best performances was obtained. Also results discussed that closer distance to hot end produces larger magnitude of temperature difference.
Mohammed Baghdad et.al [11] carried out numerical investigation of energy separation in a vortex tube with different RANS models. The numerical investigation was aim to give a energy separation mechanism and the flow phenomenon within a vortex tube. Air was selected as a working fluid. 3D computational domain had been generated for the quarter of geometry, periodicity assume in azimuthally direction. The flow predictions reported were based on 4 turbulent models mainly K-r , K-w, and SST K-w two equation model and second movement closer model. The comparative study shows advanced RSM model gave more correctly cold and hot end temperature to experimental data. All other model predicted the mean temperature difference by values twice the measure data.
Kiran D. Devade and A.T. Pise [12] The effect of cold end orifice diameter, L/D ratio, an exit valve angle on heating and cooling performance of counter flow Ranque hilsch vortex tube. Air was used as working fluid, for experiment brass tube of cold end orifice 5, 6 and 7 mm diameter, 5 different L/D ratios (15 plain tube, 15-18 with 40 divergent angle) and exit valve angle (300-900) have been manufactured. Inlet pressure was adjusted from 200 to 600 Kpa with 100 Kpa increments. The exergy loss, exergy efficiency was determined. From experimental studies it was shown that exergy loss between hot and cold fluid was decreased with increase in cold end orifice diameter. Exergy efficiency decreases with increase in L/D ratio. It is also concluded that diverging vortex tube produces lower exergy loss as compared to plain tube and valve angle have a significant effect on hot end exergy loss of vortex tube.
Kiran D.Devade and A.T. Pise [13]: Performed experimental investigation on effect of cold orifice diameter and geometry of hot end valve on performance of converging type Ranque Hilsch vortex tube. They have raveled two different approaches one for attaining high cold mass fraction and other for attaining cold end temperature. The geometry was different for both. The result show that increase in cold mass fraction and cold end temperature. The overall change in cold end temperature drop was 63 %. The COP of converging tube increased 102 % than straight diverging tube for conical valve 400, supply pressure 5 bars and cold orifice diameter 7 mm lowest temperature observed i.e, 50C at CMF 0.9.

## III. PROBLEM STATEMENT

In the present work it is decided to experimentally verify the performance of vortex tube in the atmospheric conditions for good range of various working and geometrical parameters. The exergy efficiency is obtained by the experiment. For this experiment a vortex tube of L/D ratio 22.5, cold orifice diameter 5mm is used. Different parameters are experimentally tested for 1, 2, 3 and 4 nozzles with different valve angles ($30^0$, $45^0$, $60^0$, and $90^0$) at different cold mass fraction 0.1 to 0.9.

## IV. Governing Equations

In order to evaluate the exergy efficiency of vortex tube some operational parameters should be calculated as

$$CMF = \frac{m_c}{m_i} \quad (1)$$

Vortex tube is assumed adiabatic, steady flow with zero interactions of heat and work with surrounding. According to conservation of mass principle,

$$\dot{m}_i = \dot{m}_c + \dot{m}_h \quad (2)$$

According to first law of thermodynamics, and assume potential energy and kinetic energy are negligible,

$$\dot{m}_i h_i = \dot{m}_c h_c + \dot{m}_h h_h \quad (3)$$

$$h_i = CMF h_c + (1 - CMF)\, h_h \quad (4)$$

By using adjusted parameters like Number of nozzles, cold mass fraction, valve angle the exergy analysis was performed according to second law of thermodynamics.

$$ei = (hi - ha) - ta(si - sa) \quad (5)$$

$$ec = (hc - ha) - ta(sc - sa) \quad (6)$$

$$eh = (hh - ha) - ta(sh - sa) \quad (7)$$

$$eout = (CMFec) + (1 - CMF)eh \quad (8)$$

Exergy efficiency as per second law analysis is given by

$$\beta = \frac{e_{out}}{e_{in}}$$

## V. Design Specifications

Vortex tube is manufactured in material brass because brass has good thermal conductivity. The constructional details are as given in Table 1

Table 1. Design details of vortex tube

| Sr. No. | Design Parameters | Dimensions and numbers |
|---|---|---|
| 1 | Diameter of vortex tube, D | 13 mm |
| 2 | Length of vortex tube, L | 292.5 mm |
| 3 | L/D ratio | 22.5 |
| 4 | Diameter of nozzle inlet | 3 mm |
| 5 | Number of inlet nozzle | 1,2,3,4 |
| 6 | Conical valve angle | $30^0$, $45^0$, $60^0$, $90^0$ |
| 7 | Cold mass fraction | 0.1to 0.9 |
| 8 | Cold end orifice diameter | 5 mm |

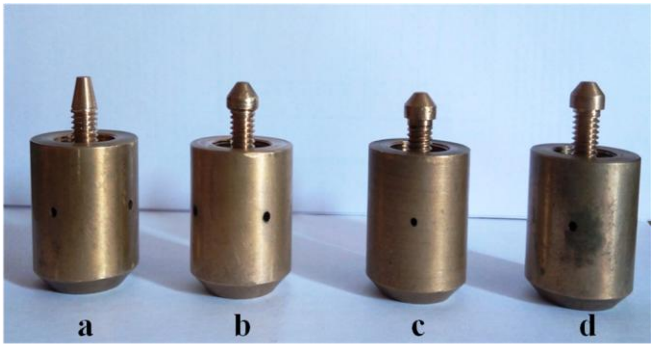


Fig. 2: Conical valve a) $30^0$ b) $45^0$ c) $60^0$ d) $90^0$

Fig. 3: Inlet nozzles used for experimentation

## VI. Experimental Setup

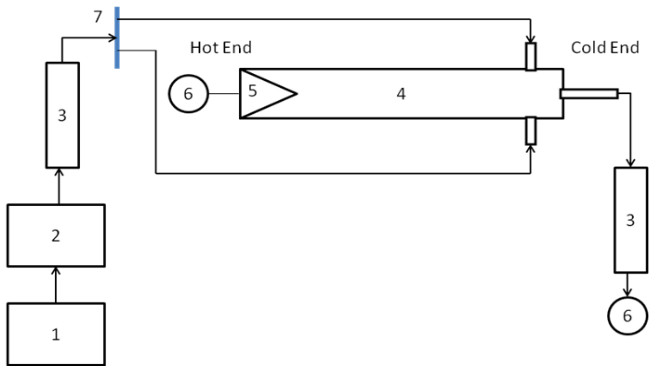


Fig. 4: Block diagram of Experimental Setup

The experimental set up for investigation of vortex tube is shown in Fig. 1. It consists of air compressor (1) of 7.5 kw, A single FRL unit (2) , two rotameters (3,4), vortex tube (5), and conical valve (6) with adjusting screw (7). In the present study compressed air will be inducted into the inlet of Nozzles and thus air enters tangentially into the vortex chamber through inlet nozzles. The air will swirl inside the vortex chamber and thus energy separation is created inside tube and stream of hot air and cold air is generated and thus the thermocouples are placed at hot end and cold end which will indicate temperatures of hot and cold end respectively. Thus by changing Nozzles and tubes data will be recorded simultaneously. The mass flow rate at inlet and outlet will be measured and recorded to calculate cold mass fraction.

## VII. Result and Discussion

a) The Effect of CMF on Exergy Efficiency for $\theta = 30^0$

Figure shows the relation between cold mass fraction and Exergy Efficiency. It can be seen that the maximum Exergy Efficiency get at nozzle 4, at cold mass fraction 0.9 and the minimum Exergy Efficiency found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 32.5and valve angle $30^0$ kept constant. It is observed that Exergy Efficiency increases with increase in nozzle number; the maximum Exergy Efficiency found is 0.6938.

The reason can be as cold mass fraction increases cold exergy increases as compared to hot exergy. Also as cold mass fraction goes on increasing total energy obtained is more and exergy losses goes on decreasing, hence the exergy efficiency increases.

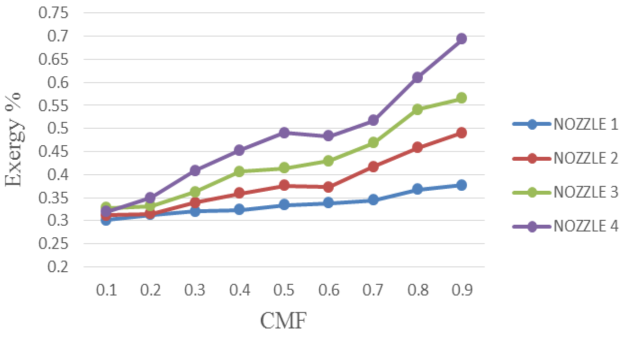


Fig.5: Variation of Exergy Efficiency vs. CMF at $\theta = 30^0$

b) The Effect of CMF on Exergy Efficiency for $\theta = 45^0$

Figure shows the relation between cold mass fraction and Exergy Efficiency. It can be seen that the maximum Exergy Efficiency get at nozzle 4, at cold mass fraction 0.9 and the minimum Exergy Efficiency found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 32.5and valve angle $45^0$ kept constant. It is observed that Exergy Efficiency increases with increase in nozzle number; the maximum Exergy Efficiency found is 0.4481. The reason can be as cold mass fraction increases cold exergy increases as compared to hot exergy. Also as cold mass fraction goes on increasing total energy obtained is more and exergy losses goes on decreasing, hence the exergy efficiency increases.

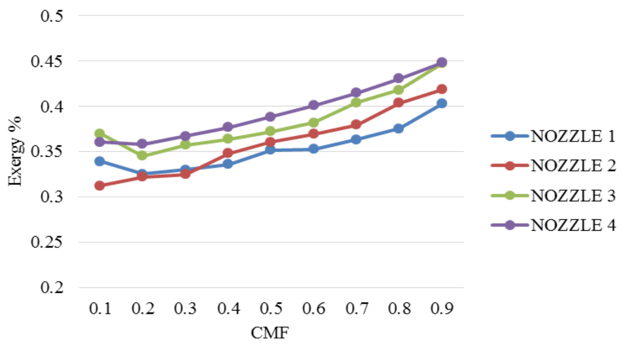


Fig.6: Variation of Exergy Efficiency vs. CMF at $\theta = 45^0$

c) The Effect of CMF on Exergy Efficiency for at $\theta = 60^0$

Figure shows the relation between cold mass fraction and Exergy Efficiency. It can be seen that the maximum Exergy Efficiency get at nozzle 4, at cold mass fraction 0.9 and the minimum Exergy Efficiency found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 32.5and valve angle $60^0$ kept constant. It is observed that Exergy Efficiency increases with increase in nozzle number; the maximum Exergy Efficiency found is 0.4922. The reason can be as cold mass fraction increases cold exergy increases as compared to hot exergy. Also as cold mass fraction goes on increasing total energy obtained is more and exergy losses goes on decreasing, hence the exergy efficiency increases.

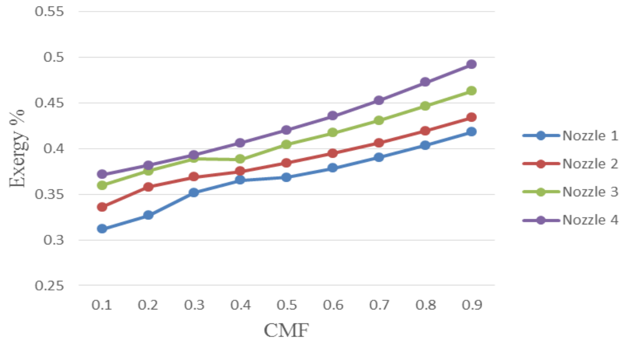


Fig.7: Variation of Exergy Efficiency vs. CMF at $\theta = 60^0$

d) The Effect of CMF on Exergy Efficiency for $\theta = 90^0$

Figure shows the relation between cold mass fraction and Exergy Efficiency. It can be seen that the maximum Exergy Efficiency get at nozzle 4, at cold mass fraction 0.9 and the minimum Exergy Efficiency found at nozzle 1 at cold mass fraction 0.1 for vortex tube of L/D ratio 32.5and valve angle $90^0$ kept constant. It is observed that Exergy Efficiency increases with increase in nozzle number; the maximum Exergy Efficiency found is 0.6538. The reason can be as cold mass fraction increases cold exergy increases as compared to hot exergy. Also as cold mass fraction goes on increasing total energy obtained is more and exergy losses goes on decreasing, hence the exergy efficiency increases.

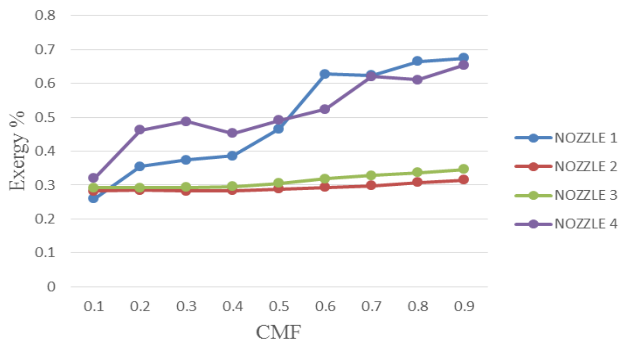


Fig.8: Variation of Exergy Efficiency vs. CMF at $\theta = 90^0$

e) The Effect of CMF on Exergy Efficiency for L/D ratio 32.5

Figure 9 indicates the effect of valve angle and cold mass fraction on Exergy Efficiency for vortex tube of L/D 32.5at constant pressure 2 bar. It can be seen from below graph that Exergy Efficiency is maximum at $30^0$ valve angle and it is minimum at $45^0$ valve angle. The maximum Exergy Efficiency is 0.6938 at $30^0$ valve angle and inlet nozzle number 4 with cold mass fraction 0.9.

The reason for this can be as cold mass fraction increases the total exergy obtained is more and exergy losses goes on decreasing. Exergy at inlet is constant at all CMF but total exergy changes or increases, nut in case of valve angle it does not show any relation only it has great significant on exergy efficiency.

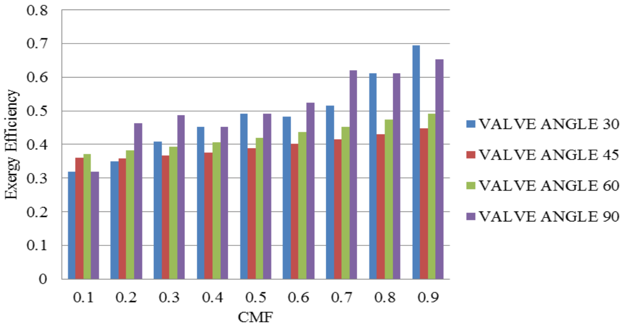


Fig.9: Variation of CMF vs. Exergy Efficiency for different valve angle at L/D ratio 32.5

## VIII. Conclusion

The following conclusion has been drawn from the experimentation:

1. Exergy Efficiency of vortex tube increases with increase in cold mass fraction. It is found maximum for CMF 0.9. It complies good with previous literature.
2. For L/D 32.5Exergy Efficiency increases with increase in inlet nozzle number. It is maximum at nozzle 4.
3. Conical valve angle contributes significant effect on Exergy Efficiency. For valve angle $30^0$ Exergy Efficiency is maximum.

More work is required on vortex tube for improving exergy efficiency with the use of different working fluids, L/D ratios, orifice diameter, nozzle cross section and valve angle geometry.

## References

[1] G. Ranque, “Method and Apparatus for Obtaining from a Fluid Under Pressure Two Outputs of Fluid at Different Temperatures,” no. US Patent 1:952,281, 1934..
[2] R. Hilsch, “The use of the expansion of gases in a centrifugal field as cooling process,” Rev. Sci. Instrum, no. Rev. Sci. Instrum, pp. 108-113, 1947.
[3] Mete AVCI*, “The effect of Nozzle aspect ratio and nozzle number on the performance of Ranque-Hilsch vortex tube”, International Journal of ATE,50, pp. 302-308, 2013..
[4] Waraporn Rattanongphisata, and Krairin Thungthong, Improvement vortex cooling capacity by reducing hot tube surface temperature: Experiment, Energy Procedia 52, 1 – 9. 2014
[5] K Dincer., Baskaya S., Uysal B.Z, “Experimental investigation of the effects of length to diameter ratio and nozzle number on the performance of counter flow Ranque– Hilsch vortex tubes.” Heat and Mass Transfer, Vol. 44, pp. 367–373, 2008..
[6] Mohammad O. Hamdan Basel Alsayyed Emad Elnajjar Nozzle parameters affecting vortex tube energy separation performance, Heat Mass Transfer 012-1099-2. 2012
[7] Mete AVCI*, “The effect of Nozzle aspect ratio and nozzle number on the performance of Ranque-Hilsch vortex tube”, International Journal of ATE,50, pp. 302-308, 2013..
[8] Kiran D. Devade, “Investigation of Refrigeration Effect using Short Divergent Vortex Tube”, International Journal of Earth Sciences and Engineering, vol. 5, pp. 378-384, 2012.
[9] Yunpeng Xue, “Energy analysis within a vortex tube” , Experimental Thermal an fluid Science , Vol. 52, pp. 139-145, 2014.
[10] Abdol Reza Bramo And Nader Pourmahmoud, (2011), Computational Fluid Dynamics simulation of length to diameter ratio effects on the energy separation in a vortex tube Thermal Science, year 2011, vol. 15, no. 3, pp. 833-848
[11] Baghdad M., Ouadha A., Imine O., Addad Y., “Numerical study of energy separation in a vortex tube with different RANS models.” International Journal of Thermal Sciences, Vol. 50, pp. 2377-2385, 2011
[12] Kiran D. Devade, “Exergy analysis of a counter flow Ranque-Hilsch vortex tube for different cold orifice diameters, L/D ratios and exit valve angles”, Vol. 016, pp. 1962-1967, 2016
[13] Kiran D. Devade, “Investigation of Refrigeration Effect using Short Divergent Vortex Tube”, International Journal of Earth Sciences and Engineering, vol. 5, pp. 378-384, 2012.