International Engineering Research Journal

Exergy analysis of multi-nozzle vortex tube by varying valve angle and cold mass fraction andusing air as working fluid.

Mr. A.S.Deshmukh†, Prof. Kiran D. Devade‡

†PG student, Heat & Power Engineering, ICEM, Pune, Pune University, India
‡Professorl, ICEM, Pune, Pune University, India

Abstract

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 multi nozzle vortex tube with various geometrical parameters (no of nozzles 1,2,3,4 ,valve angle 30^0,45^0,60^0,90^0) and operating parameters(pressure 2 to10 bar). With varying cold mass fraction from 0 to 1..These parameters are used in an exergy analysis.

Keywords:*Ranque-Hilsch vortex tube (RHVT), Exergy analysis, etc.*

1. Introduction

Vortex tube is a cooling eco-friendly device. Vortex tube converts a compressed tangential air flow into hot and cold air streams here we use air as a refrigerant. Vortex tube is a circular tube with two ends hot end and cold end with no of small nozzles and a throttle valve or a diffuser. It is very simple device with no moving parts so that it is maintenance free and eco-efficient. It has hot end far away from nozzle and cold end near the entry of nozzle. The compressed air separated into two layers .a gas layer near the axis is cold air stream and the layer inside the tube /periphery is hot air stream. This separation of temperature of layers leads the study of energy transformation inside the tube. So that the no of researchers working on the vortex tube to optimize the efficiency and enrgy separation but no one can explain the exact idea about this phenomenon of hot and cold temperature separation.

2. Literature Review

Nilotpala Bej, et al.[1] Ranque –Hilsch vortex tube is simple piece of equipment used for generating hot end and cold end outlet streams through compressed gas stream without use of any external source of energy. This paper reveals on hot cascade type vortex tube where the hot gas emerging out of one vortex tube is supplied to another tube to increase higher heating effect. A numerical simulation is carried out by using kω turbulence model by varying different cold mass fractions on second stage RHVT. Thus results obtained werecompared with experimental results which justified successful use of turbulence model for cascade type vortex tube.

Meisam Sadi , et al. [2] In order to increase the performance of Ranque Hilsch vortex tube a new design was invented which is called as Annular Vortex tube (AVT), it is experimentally tested and compared with RHVT, the hot stream after passing through hot conical valve passed towards outer wall of hot tube in AVT increased the heat loss from outer walls of hot tube. Results were shown as higher thermal separation performance was observed on AVT as compared to RHVT. AVT has 24 % cooling efficiency then RHVT for optimal cold mass fraction values. Also conical valve angle has no effect on thermal performance of AVT.It was also seen that by using three vortex generators for different nozzle areas, coefficient of performance is same in heating while vortex generator with higher nozzle gives better cooling efficiency than others.

N. Agrawal, et al. [3] An experimental investigation is carried out on Ranque – Hilsch vortex tube (RHVT) by varying parameters such as L/D ratio, cold mass fraction, inlet pressure etc. working fluid used were (air, nitrogen, carbon dioxide) were tested. A value of cold mass fraction is observed at which vortex tube performs optimally at given parameters such as l/D ratio, inlet pressures. It was seen that better results were observed with carbon dioxide as fluid.

Yunpeng Xue, et al. [4] To explain the working principle of vortex tube both experimental and numerical investigations has been carried out for temperature separation. It explains experimental study of flow properties in vortex tube focusing on energy transfer and thermal separation inside tube. The energy distribution inside tube indicates that kinetic energy transformation is responsible for temperature separation. The results obtained shows direct relationship between formation of hot and cold air streams along the tube.

Mete Avcı* [5] 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. [6] 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 and efficiency is increased by 4.3 % and 9.6 % respectively.

Mohammad O. Hamdan, et al. [7] 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.

S.N. Ram, et al. [8]Optimization of Ranque –Hilsch vortex tube is carried out by conducting computational fluid dynamics (CFD) and experimental studies. Different types of nozzle profiles and number of nozzles are evaluated by CFD analysis. The flow patterns, axial velocity and radial velocity components have been evaluated. by changing the L/D ratios and cold end diameter (dc) through CFD analysis and compared with Experimental results.

Abdol Reza BRAMO, et al. [9] This paper presents the attempt of Computational fluid dynamics CFD to investigate 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, 30.7 with six nozzles were investigated. It was seen that at L/D ratio 9.3 best performance was obtained. Also results discussed that closer distance to hot end produces larger magnitude of temperature difference.

R.S.Maurya, et al. [10] vortex tube is used in several applications due to its features like simple design, maintenance free service. It has simple design based on empirical relations. Complete flow and energy separation features are difficult to observe due complexity associated with flow investigation of vortex tube. The parameters used for experimentation are supply inlet pressure from 2 to 6 bars, the orifice diameters from 5 to 10 mm, L/D ratio from 4 to 20. The above parameters are used to completely explain mechanism of flow and energy separation.

3. **Experimental Setup**

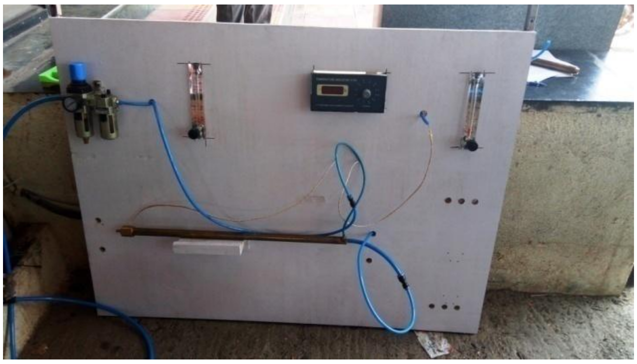


Fig.1 Experimental Setup

The experimental set up for investigation of vortex tube is shown in Fig. 1. It consists of air compressor of 7.5 kw, A single FRL unit , two rotameters, Two point temperature gauge, and two PT100 thermocouples. In the present study compressed air will be induced 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.

4.Observation table

Table 1Variation of Efficiency with exergy calcualtions by varying geometrical parameters

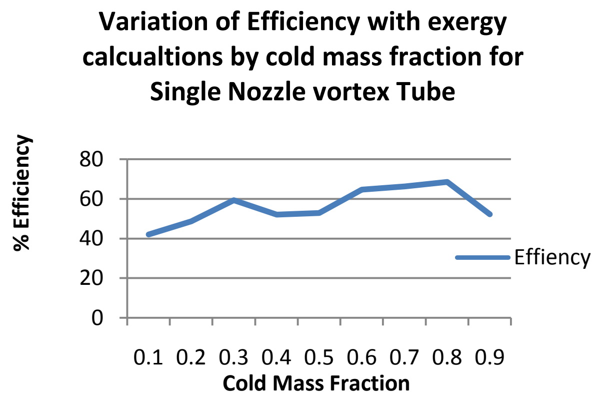
Nozzle	Cold Mass Fraction	Diffuser Angle	Effiency
1	0.1	60	42.00509
	0.2	60	48.67513
	0.3	60	59.28199
	0.4	60	51.99131
	0.5	60	52.74147
	0.6	60	64.53883
	0.7	60	66.2387
	0.8	60	68.47851
	0.9	45	52.20858
2	0.1	90	46.15998
	0.2	60	69.35978
	0.3	60	65.62763
	0.4	45	64.90733
	0.5	45	67.97184
	0.6	60	52.14472
	0.7	60	67.9592
	0.8	90	75.5667
	0.9	60	62.50392

3	0.1	30	40.9216
	0.2	45	42.77192
	0.3	45	57.91211
	0.4	45	53.8001
	0.5	45	52.22607
	0.6	60	61.06048
	0.7	45	65.80896
	0.8	45	68.24871
	0.9	60	59.3526
4	0.1	60	42.1219
	0.2	45	45.80936
	0.3	60	63.01902
	0.4	60	56.17414
	0.5	60	61.57955
	0.6	60	59.57366
	0.7	45	79.06016
	0.8	45	69.70048
	0.9	30	57.01821

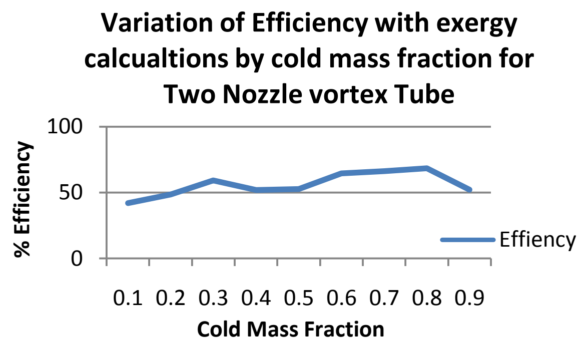
Above table shows the readings for vortex tube of 22.5 L/D ratio, varying cold mass fraction, varying number of nozzles and diffuser angle for maximum exergy efficiency.

5. Result and Discussion

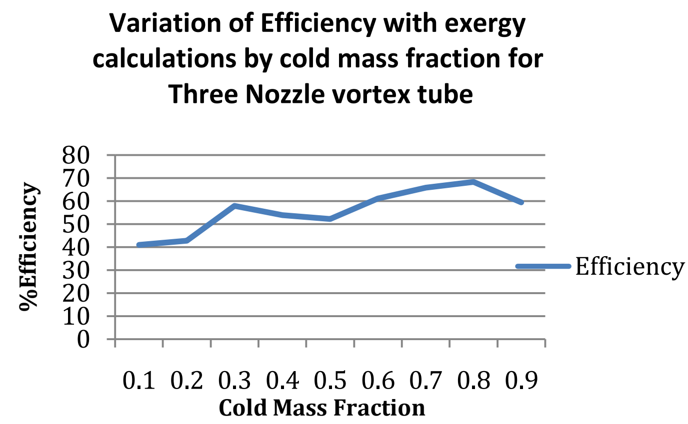
The Values of maximumexergy efficiency are calculated for constant L/Dratio 22.5, varying cold mass fraction (0 to 0.9) number of nozzles(1 to 4), diffuser angle(30^0,45^0,60^0.90^0).



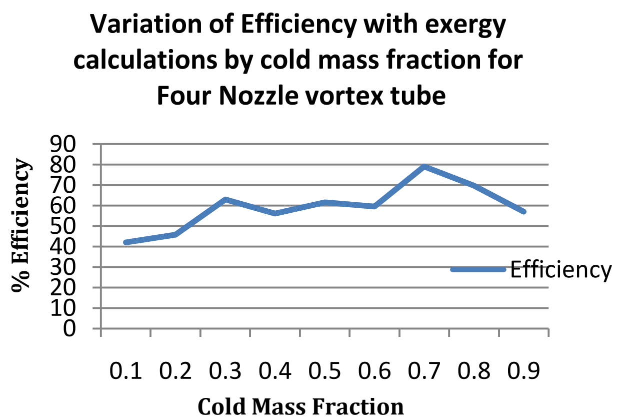
Graph 1:-The above graph shows variation of exergy efficiency of Two Nozzle Vortex Tube for different cold mass fraction with varying valve angles having L/D ratio 22.5.Maximum efficiency is found 68.47% at 0.8 CMF for 60^0 valve angle.



Graph 2:-The above graph shows variation of exergy efficiency of Two Nozzle Vortex Tube for different cold mass fraction with varying valve angles having L/D ratio 22.5. Maximum efficiency is found 75.56% at 0.8 CMF for 90^0 valve angle.



Graph 3:-The above graph shows variation of exergy efficiency of Three Nozzle Vortex Tube for different cold mass fraction with varying valve angles having L/D ratio 22.5.Maximum efficiency is found 68.80% at 0.8 CMF for 45^0 valve angle.



Graph 1:-The above graph shows variation of exergy efficiency of Two Nozzle Vortex Tube for different cold mass fraction with varying valve angles having L/D ratio 22.5.Maximum efficiency is found 79.07% at 0.7 cmf for 45^0 valve angle.

6.Conclusions

After investigating the present study and plotting the graphs we can conclude as follows:

1. For a single nozzle vortex tube of L/D ratio 22.5 as the cold mass fraction increases exergy efficiency also increasesit is maximum at cold mass fraction 0.8afterwards it decreases. Exergy efficiency is maximumat valve angle $60^0$for CMF 0 to 0.8. for CMF 0.9 maximum exergy efficiency is obtained at valve angle 45^0.
2. For two nozzle vortex tube of same L/D ratio maximum efficiency is found at cold mass fraction 0.3 is 80.62%.
3. For three nozzle vortex tube of same L/D ratio maximum efficiency is found at cold mass fraction 0.8 is 68.24 %. For valve angle 45^0 .
4. For four nozzle vortex tube of same L/D ratio maximum efficiency is found at cold mass fraction 0.7 is 68.24 %. For valve angle 45^0 .

From above we conclude that for two nozzle vortex tube exergy efficiency is found maximum.

7 References

[1] Nilotpala Bej*, K.P. Sinhamahapatra,(2014), Exergy analysis of a hot cascade type Ranque-Hilsch vortex tube using turbulence model IJR 45 13-24.

[2]Meisam Sadi, Mahmood Farzaneh-Gord,(2014) Introduction of Annular Vortex Tube and experimental comparison with Ranque-Hilsch Vortex Tube, JIJR 2827.

[3]N. Agrawal, S.S. Naik, Y.P. Gawale,(2014) Experimental investigation of vortex tube using natural substances,ICHMT52, 51-55.

[4] Yunpeng Xue, Maziar Arjomandi, el (2013) Experimental study of the thermal separation in a vortex tube,Experimental Thermal and Fluid Science 46 175–182

[5] Mete Avcı,(2013), The effects of nozzle aspect ratio and nozzle number on theperformance of the RanqueHilsch vortex tube,Applied Thermal Engineering 50 302-308.

[6]WarapornRattanongphisata, and Krairin Thungthong, (2014), Improvement vortex cooling capacity by reducing hot tubesurface temperature: Experiment, Energy Procedia 52, 1 – 9.

[7] Mohammad O. Hamdan Basel AlsayyedEmad Elnajjar (2012), Nozzle parameters affecting vortex tube energy separationperformance, Heat Mass Transfer012-1099-2.

[8] S.N. Ram , K. Dinesh , S. Jacob,(2012),CFD analysis and experimental investigations towardsoptimizing the parameters of Ranque–Hilsch vortex tube.

[9] Abdol RezaBramo And Nader Pourmahmoud, (2011),Computational Fluid Dynamics simulation of length to diameter ratio effects on the energy separation in a vortex tubeThermal Science, year 2011, vol. 15, no. 3, pp. 833-848

[10] R.S.Maurya & Kunal Y.Bhavsar.Energy and flow separation in vortex tube: A numerical investigation.,