

A Critical Review of Vortex Tube Refrigeration System

Dr. K. Ashok Reddy

Professor

Department of Mechanical Engineering,

MLR Institute of Technology, Dundegal, Hyderabad-43, India

E-mail: kannaashok2016@gmail.com

Abstract

In a vortex tube, the incoming air was separated into two streams. One stream rejects energy, and hence becomes colder than the incoming air while the other receives the rejected energy and thus, its temperature is elevated. This can be done by either a counter flow (or) a unit flow arrangement. Many authors have presented technical papers using different methods to solve this problem in the vortex tube refrigeration industry. In this paper, we have presented a comprehensive review of different papers by erudite authors on the subject.

Keywords: Vortex tube, Refrigeration and Cooling etc.

INTRODUCTION

M. Selek, S. Tasdemir, K. Dincer, S. Baskaya [1] presented in their technical paper the cooling performance of the Ranque-Hilsch Vortex tube (RHVT), which was experimentally investigated by infrared thermograph method. For this purpose, experiments were conducted on the cutting tool nose point of the lathe at different diameters, cutting speeds and cutting depths for cases in which cooling was not performed and RHTV cooling was performed. The sample material was gray

cast iron in the form of round bars with 15 mm and 20 mm diameter respectively and a constant length of 100 mm. The inserts were manufactured by Sandvik Inc., with the ISO designation of TNMG 160404 MF (Triangular insert). The inserts were rigidly mounted on three different right hand style tool holders designated by ISO as MTJNR-L2020 K16T. In all instances, the side rake angle and back rake angle are 0° and fixed. The performance of RHVT was determined by using the temperatures obtained from thermal images (TIs). TIs

were taken from the FLIR E45 infrared camera at 30 frames per second. When all the experimental results were evaluated together, the maximum performance of RHVT was found to be, for a diameter of sample $\frac{1}{4}$ 15 mm, cutting depth $\frac{1}{4}$ 3 mm and cutting speed $\frac{1}{4}$ 800 rpm.

M. M. Rashidi, O. Anwar Be'g and A. Habibzadeh[2] presented in their technical paper, the application of a combined first and second law approach to study an ejector expansion Joule–Thomson cryogenic refrigeration cycle. The effects of the evaporator temperature, ejector pressure ratio and compressor function on the coefficient of performance (COP), exergy destruction and the exergetic efficiency have been investigated. The present study has been conducted for the evaporator and compressor temperature in the range of 75–135 and 270–330 K, respectively. The ejector pressure ratio was varied from 1.5 to 5.5. Simulation results show that COP and exergy efficiency increase with increasing evaporator temperature and ejector pressure ratio. In addition, it was found that the increase in the compressor temperature leads to the reduction in the first and second law efficiencies.

Nurhasanah Ismaila, Wirachman Wisnoeb, Muhammad Fairuz Remelic [3] presented in their technical paper experimental investigation of the orifice diameter, swirl generator and conical valve shape influence the cooling performance of Ranque-Hilsch vortex tube. From the experiment, its shows that conical valve shape has smallest effect on cooling performance (0.124) of the Ranque-Hilsch vortex tube. It also revealed that swirl generator gave the greatest (0.336) effects to the cooling performance of Ranque-Hilsch vortex tube and have the highest range of difference cooling performance (0.027 to 0.229) compared to conical valve shape (0.073 to 0.087) and orifice diameter (0.009 to 0.012).

Masoud Bovand, Mohammad Sadegh Valipour, Kevser Dincer, Smith Eiamsa-ard [4] attempted, in their technical paper, to evaluate the effect of certain geometrical parameters on cooling performance of Ranque Hilsch vortex tube (RHVT). A number of intakes in nozzle “n”, cold orifice diameter “dc” and inlet pressure “Pi” were selected as influencing parameters at different levels in $\frac{1}{4}$ 1, 2, 3; dc $\frac{1}{4}$ 7, 9, 11 mm and Pi $\frac{1}{4}$ 2, 2.5, 3 bar. The experiments are conducted based on three factors, two levels and central composite face centered design

(CCF) with full factorial. The results are analyzed according to the principle of Response Surface Methodology (RSM). The equation to the response surface was developed using the design of experiments features in the commercial software package MINITAB-16. The goodness of fit of the regression model is examined using the Analysis of Variance (ANOVA) and the F-ratio test. The values of R^2 and R^2 (adj.) are close to 100%, which shows a very high correlation between the observed and predicted values. Results show sensitivity value of $DT_{c, \max}$ respect to $v_{Re}/v_A < 0$). It means that with an increase in n , decreasing in $DT_{c, \max}$ results. In case of a low orifice diameter, this has a significant effect. The cold orifice diameter has more effect on $DT_{c, \max}$. Its sensitivity value was 65.8% and 51.1% more than n and P_i , respectively. It was shown that for $d^*c < 0.5$, ($d^*c = \frac{1}{4} d_c/D$), increasing d^*c causes the cold air temperature difference to increase and for $d^*c > 0.5$, increasing d^*c tends the cold air temperature difference to decrease. The results show that the optimum value of d^*c for the maximum cold air temperature difference and efficiency was $d^*c = \frac{1}{4} 0.5$. The RHVT was optimized using RSM based on CCD. The optimum values of n , d_c , and P_i were 2, 9.48 mm, and 3.2 bar respectively, where

46.44 °C ($DT_{c, \max}$) could; be obtained from the proposed model.

Mohammad Mahmudur Rahman et al [5] presented in their technical paper attempt has been made to construct a vortex tube with locally available materials. Effects of the number of inlet tangential nozzles, the tube diameter, and the diameter of the inlet nozzle on the temperature reduction in the tube were experimentally investigated. Throughout the project several number of vortex tubes were constructed by locally available materials like PVC pipe for performance test. The temperature drops of the cold air obtained from these experiments were not in good agreement with available data for comparison at a similar scale of separating conditions.

The experimental results showed that the vortex tube with two inlet nozzles and cold tube diameter 12.7 mm yielded the highest temperature reduction which was found 4. Wirachman Wisnoe et al [6] presented in their technical paper temperature at cold outlet, cold mass fraction and isentropic efficiency in the Ranque-Hilsch Vortex Tube (RHVT) are experimentally measured and derived. For the experiment, different pressures (absolute) (between 290 to 800 kPa) were applied as source, 3 types of swirl generator and 3 shapes of

conical valve were used. The lowest temperature obtained during the experiment was -11.6 for a cold mass fraction which gave the highest was entropic efficiency (0.336) at source pressure of 790.2 kPa. However, the highest cold mass fraction was given by source pressure of 790.2 kPa with isentropic efficiency of 0.042 and the cold temperature was 20. K. Kiran Kumar Rao et al [7] presented in their technical paper the fabrication and experimental investigation was carried out based on different materials of Hot tubes like Mild steel, Aluminium and Copper used in fabrication by that the maximum hot air temperature and minimum cold air temperature were found. The fabrication and experimental investigation was carried out based on nozzle 8 mm diameter and orifice 6 mm diameter used in fabrication by that the maximum hot air temperature and minimum cold air temperature were found and by using same L/D ratio 22 with adiabatic process of Hot tube.

Suraj S Raut et al [8] presented in their technical paper experimental investigation has been performed to realize thorough behavior of a vortex tube refrigeration system. The counter flow vortex tube has been designed, manufactured and tested. The vortex tube is a non-conventional

cooling device, which operates as a refrigerating unit without affecting environment. It has capability to separate hot and cold air stream from a high pressure inlet air; such phenomenon is called as temperature or energy separation process. The vortex tube performance depends on two types of parameters, firstly air or working parameters such as inlet pressure of compressed air, cold mass fraction and secondly tube or geometric parameters such as length of hot side tube, cold orifice diameter, number of nozzles, diameter of nozzle, cone valve angle and also material of vortex tube affects Coefficient of Performance (COP). This paper discusses the experimental investigation of effect of above working parameters on the performance of Ranque-Hilsch vortex tube. The Chlorinated Poly Vinyl Chloride (CPVC) material has been used for manufacturing of the vortex tube as it has lower thermal conductivity than metals and less fluid friction losses. In this experimental study the performance of vortex tube has been tested with compressed air at various pressures from 5-10 bar, which supplied through two tangential inlet nozzles. The L/D ratio of hot side tube varied from 10-50 and cold mass fraction varied from 0.20 – 0.80.

T sankar Ram and K Anish raj [9] presented in their technical paper the phenomenon of temperature distribution in confined steady rotating gas flows is called Ranque-Hilsch effect. The simple counter-flow vortex tube consists of a long hollow cylinder with tangential nozzle at one end for injecting compressed air. The flow inside the vortex tube can be described as rotating air, which moves in a spring-shaped vortex track. The peripheral flow moves toward the hot end where a hot end plug is placed and the axial flow, which is forced back by the plug, moves in the opposite direction towards the cold end. R.Madhu Kumar et al [10] 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 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 source of compressed air without affecting the environment. When a high pressure air 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. In this paper, vortex tube with cylindrical and conical hot tubes performance is compared. It was found that the vortex tube with a conical angle of about 2.5° surpassed the cylinder tube by 25%~30% in COP. The conical vortex tube reaches the same or more performance than the normal tube but with a smaller length.

S Nagane et al [11] presented in their technical paper that a cooling purpose was very important for both man and machine. In general, vapour compression refrigeration system and vapour absorption refrigeration system are used for refrigeration purpose. Non-conventional type of cooling system means Vortex tube cooling system which is not used widely for cooling purpose. Vortex tube has many advantages over the conventional cooling system. Separating cold and hot streams by using vortex tube can be used in industrial application such as cooling equipment's and refrigerants. Important parameters in vortex tube are cross section area of cold and hot end, nozzle area of inlet compressed air, cold orifice area, and hot end area of the tube. J. Velmurugan et al [12] presented in their technical paper refrigeration and air conditioning has become essential field of research these days due to its vast applications. Thus

developing non conventional methods of refrigeration is needed. Our project “Fabrication of experimental setup of vortex tube” can be seen as an optional method for many cooling purpose. In this project we have made an experimental model of vortex tube which divides inlet stream of compressed air into two streams a cold at one side and hot on other, thus providing cooling and heating effect at same time. Aim of our project is to make efficient vortex tube using dual inlet. We have selected proper design of the same by researching on various studies on the same topic and through this research we have selected optimum design and fabricated the same. Details of vortex flow and working principle of the tube is provided. The project has various applications for spot cooling in machining process, for reheating and cooling purposes in process industries where hot compressed gases are exhausted. The data obtained is stored in cloud.

Gupta U. S. et al [13] presented an experimental study in their technical paper that was conducted to for thermodynamic analysis of the vortex tube. During the study the cold mass fraction was varied from 0.2-0.8 for a fix inlet pressure of 4 bar and the inlet pressure was varied between 2 -7 bar for a fix opening of the

cone valve. The maximum temperature drop was observed for cold mass fraction of 0.4 and the effective refrigerating effect was observed between the 0.35-0.65 of the cold mass fraction, as the refrigerating effect is a function of mass of the cold air and the temperature drop. Kalal M. Matas R and Linhart J. [14] presented in their technical paper experimental study of the vortex tube performance has been carried out to investigate the parameters affecting vortex tube operation. Four cases have been studied, in which the influences of the tube length L, the number of entrance nozzles Nz, cold air orifice diameters d_c and inlet pressure under various condition. The effects of these parameters on the hot and cold outlet temperature as function of cold air mass ratio ($\frac{m_c}{m_h}$) are discussed and presented. And also the coefficient of performance (COP) of the vortex tube as a refrigerator and as a heat pump has been calculated. Three Dimension numerical modelling of vortex tube has been evolved through CFD analysis by using the k- ϵ turbulence model. Axial, radial and tangential components of the velocity together with the temperature and pressure fields within the vortex tube are simulated. Predictions from the present CFD simulations were compared with data obtained from our experiments under the

same geometrical and operating conditions.

Yunpeng Xue et al [15] presented in their technical paper the mechanism of the temperature separation in a Ranque–Hilsch vortex tube has been investigated. In spite of being investigated by many researchers, no consensus has yet been reached regarding the mechanism's hypothesis. This paper reports on a study in progress exploring the temperature separation in a counter-flow vortex tube. The effects of the geometrical parameters, including inlet nozzles, cold exit, hot exit and length of the tube, were investigated, which indicated the settings for the best performance of the vortex tube. Flow properties in the vortex tube were measured and used to understand the flow structure inside the tube. Accurate measurements of the three-dimensional velocity distribution in the tube were conducted. The results provided enough evidence that the flow in the tube consists of a forced vortex formed near the inlet gradually transforming to a free vortex at the hot end. Experimental results found in this research show the vortex transformation along the tube and support the hypothesis proposed in previous study.

Ankita Adana and P.M. Khanwalkar [16] presented in their technical paper the technology was proliferating and making our environment unwell for existence, by emission of hazardous elements that causes depletion of ozone layer and affect the human comfort. The objective of the dissertation was to study the concept of vortex tube that can be used for refrigeration purpose and in future can be the best replacement over conventional refrigeration systems. This paper reviews the research to enhance the refrigeration effect by changing nozzle geometry, changing the geometry of the cylindrical tube in to conical tube at various cone angles, installing a diffuser between the vortex tube outlet and hot valve and the reason of energy separation within the vortex tube.

A. M. Dalavi et al [17] presented in their technical paper the vortex tube was a simple device, having no moving parts, which produces hot and cold air streams simultaneously at its two ends from a source of compressed air. Literature review reveals investigations to understand the heat transfer characteristics in a vortex tube with respect to various parameters like cross section area of cold and hot end, nozzle area of inlet compressed air, cold orifice area, hot end area of the tube, and

L/D ratio. As such there was no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. Therefore, it was thought to perform experimentation Mahmoud S. Ahmed et al [18] The present paper investigates an experimental work to study the performance of manufactured counter flow vortex tube incorporated with set of generator nozzles of $N = 2, 3, 6$ and aspect ratio, $AR = 1.4$. The effects of inlet air pressure, hot tubes length to diameter and number of nozzles on the splitting air temperature are studied. The study includes evaluation of the COP for the cooling and heating processes. It is found that an optimum value of $COP_{ref} = 0.24$ as well as for $COP_{HP} = 0.3$ are obtained. The findings encourage using the vortex tube in the applications of cooling and heating processes.

G. F. Nellis S. A. Klein [19] presented in their technical paper that the vortex tube was a structurally simple device with no moving parts that was capable of separating a high pressure flow into two lower pressure flows with different energies, usually manifested as a difference in temperatures. The vortex tube was relatively inefficient as a stand-alone cooling device but it may become an

important component of a refrigeration system when employed as an alternative to the conventional throttling valve. A cycle augmented with a vortex tube can offer several advantages including: efficient operation above the Joule-Thomson inversion curve, relative insensitivity to heat exchanger size, and the ability to operate with a lower pressure ratio. The extent to which these advantages are realized depends on the cycle configuration, the fluid properties, the operating conditions, and the behavior of the vortex tube. In this paper, a semi-empirical model of the vortex tube was presented using one hypothesis regarding its underlying physics. Predictions made using this model are found to compare favorably with the limited experimental data that are available. The vortex tube model is integrated into a model of a vapor compression refrigerator and a Joule-Thomson cryogenic refrigerator. The potential for increasing the performance of a refrigeration cycle using the vortex tube was found to be extremely limited for the vapor compression cycle. However, it was shown that the vortex tube may present a significant opportunity to improve the performance of refrigeration systems using the Joule-Thomson cycle and may allow efficient operation at lower pressure ratios, with smaller recuperative heat exchangers,

and with less expensive working fluids than are currently used. More complex cycles are discussed in which the vortex tube can be used to simultaneously perform phase and energy separation.

Upendra S. Gupta et al [20] presented in their technical paper that the vortex tube also known as Ranque tube, that is a reliable device with no moving parts, produces hot and cold gas streams simultaneously from the source of the compressed gas, an experiment has been conducted to evaluate the thermodynamic analysis of the vortex tube. During the study the cold mass fraction was varied from 0.2-0.8 for a fix inlet pressure of 4 bar and the inlet pressure was varied between 2 -7 bar for a fix opening of the cone valve. The maximum temperature drop was observed for cold mass fraction of 0.4 and the effective refrigerating effect was observed between the 0.35-0.65 of the cold mass fraction, as the refrigerating effect and heating effect was a function of mass of the cold air and the temperature drop. A thermodynamic model has been used to investigate vortex tube energy separation, the results indicated that as hot tube length or inlet pressure increases the temperature difference increases too, the second law analysis shows that the for air,

it was middle tube which generates lowest entropy.

Karthik S [21] presented in their technical paper that the vortex tube was a refrigerating equipment that produces both cold as well as hot air at both opposite ends. The vortex tube's construction was such that it was made up of a hollow tube of either metallic or fibre components having a nozzle for letting in of compressed air and a diaphragm or a orifice for controlling the flow rate of air. When compressed air passes through a nozzle into the diaphragm of the vortex tube, the air forms a spiral shaped vortex, that causes the heating up of air, and when this air returns back, it cools down rapidly, producing a cooling effect. The main study in the Vortex tube was the study of the temperature distribution of the rotating air. This effect was first discovered by Ranque and later by Hilsch and hence this effect is called Ranque-Hilsch effect.

Mohammad Sadegh Valipour, Nima Niazi [22] presented in their technical paper that vortex tube is a mechanical device that operates as a refrigerating machine. This device separates a compressed gas stream into hot and cold streams. In this paper a series of experiments has been carried out to investigate the influence of uniform

curvature of main tube on the performance of the vortex tube. Results show that the curvature in the main tube has different effects on the performance of the vortex tube depending on inlet pressure and cold mass ratio. It was found that the maximum temperature difference belonged to straight vortex tube, type A, however the maximum refrigeration capacity belonged to curved vortex tube, type C. Non-dimensional cold temperature difference and non-dimensional refrigeration capacity are found to be independent of the curvature of the vortex tube.

M.H. Saidi, M.S. Valipour [23] presented an experimental investigation in their technical paper that was conducted to realize the behavior of a vortex tube system thoroughly. In this work attention has been focused on the classification of the parameters affecting vortex tube operation. The effective parameters are divided into two different types, namely geometrical and thermo physical ones. A reliable test rig has been designed and constructed to investigate the effect of geometrical parameters i.e. diameter and length of main tube, diameter of outlet orifice, shape of entrance nozzle. Thermo-physical parameters which have been designated and studied are inlet gas pressure, type of gas, cold gas mass ratio

and moisture of inlet gas. Prabakaran J et al [24] presented in their technical paper Vortex tube was a device that produces cold and hot air simultaneously from the source of compressed air. In this work an attempt has been made to investigate the effect of three controllable input variables namely diameter of the orifices, diameter of the nozzles and inlet pressure over the temperature difference in the cold side as output using Response Surface Methodology (RSM). Experiments are conducted using central composite design with three factors at three levels. The influence of vital parameters and interaction among these are investigated using analysis of variance (ANOVA). The proposed mathematical model in this study has proven to fit and in line with experimental values with a 95% confidence interval. It is found that the inlet pressure and diameter of nozzle are significant factors that affect the performance of vortex tube.

Tejshree Bornare et al [25] presented in their technical paper that refrigeration plays an important role in developing countries, primarily for the preservation of food, medicine and air conditioning. Conventional refrigeration systems are using freon as refrigerant. As they are the main cause for depletion of ozone layer,

extensive research work was going on alternate refrigeration systems. Vortex tube was a non-conventional cooling device, having no moving parts which will produce cold air and hot air from the source of compressed air without affecting the environment. When a high pressure air was tangentially injected into vortex chamber a strong vortex flow will be created which will be split into two air streams, one hot stream and the other was cold stream at its ends. An experimental investigation was to be performed in order to realize the behavior of a vortex tube system. In this work attention has to be focused on the classification of the parameters affecting vortex tube operation. The effective parameters are divided into two different types, namely geometrical and thermo-physical ones. A reliable test rig was to be designed and constructed to investigate the effect of geometrical parameters i.e. diameter and length of main tube, diameter of outlet orifice, shape of entrance nozzle.

CONCLUSION:

1. The effect of the conical hot tube on the cold temperature drop, hot temperature raise, and COP of the Vortex tube are shown with increase in inlet air pressure.

2. From experimental investigation [6], the minimum temperature at cold outlet ($T_c = -11.6^\circ\text{C}$) was achieved when the source pressure was 452.33 kPa using swirl generator SG3 and conical valve CV2. The highest value of cold mass fraction ($\mu_c = 1.024$) was obtained when using CV3, SG1 at inlet pressure 417.9 kPa. The highest isentropic efficiency was obtained using CV2 with SG3 at the inlet pressure 452.3 kPa. This was because, when using CV2 with SG3, the temperature different was very high ($T = 34.8^\circ\text{C}$).

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