Review of Performance Parameters in Selecting Various Applications of Vortex Tube as a Cooling Device

Kishorkumar L Makwana
Department of Mechanical Engineering
Government Polytechnic Porbandar, Gujarat, India

Abstract— Its long journey from primitive stage, vortex tube has attracted many researchers and industrial people for its distinguished features as spot and simultaneous cooling and heating device. The attractive features of vortex tube like Simple and compact design, easy to install and handle ,robust, maintenance free operation, instant cooling and heating, environmental friendly, low initial and running cost of this spot cooling device motivated to find its performance parameters in selecting Vortex Tube for various applications. It is suggested that modern simulation tools like CFD and precise measurement technology during actual experimentation may become counterpart and complementary to each other to reach to an ultimate conclusion.

Key words: Ranque- Hilsch Vortex Tube, Vortex Generator, Spot Cooling and Heating, CFD Simulation, COP

I. INTRODUCTION

“Friendly Little Demon” was predicted much earlier by J.C.Maxwell the great 19th century physicist. He postulated that since the heat involves the movement of molecules, we might someday be able to get hot and cold air from the same device, who would sort out and separate the hot and cold molecules of air.

The accidental invention on doing experiment on Vortex type pump by French Metallurgist and Physicist Georges J Ranque in 1928 formed formal base for Vortex tube.[1].There are many theories on the vortex tube also known as Ranque vortex tube, The Hilsch tube or Maxwell’s demon tube and also most common as The Ranque-Hilsch vortex Tube RHVT. The paper presented in 1933 at scientific society of France by French Physicist Georges J Ranque and improved upon by German Physicist Rudolf Hilsch in a notable paper published in 1947. Hilsch has published sufficient data at higher pressures and With the proper conditions cold gas escapes through the cold tube (temperatures as low as —48°C have been reported [2].

A. The Basics of Vortex Tube:

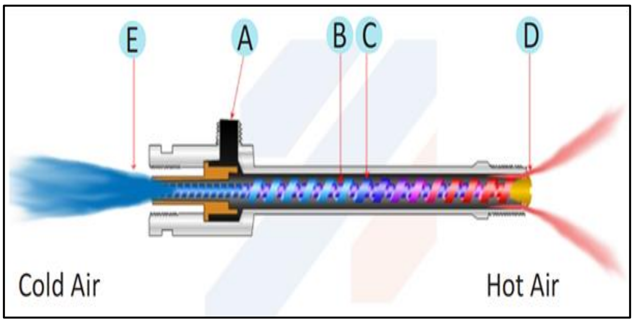

Fig. 1: Working of Vortex Tube [NEXFLOW]

Compressed air enters at point (A) Fig.1.inside the tube the compressed air is made to spin using a “generator”. It travels in one direction along the small (hot end) tube and then back inside itself in the reverse direction creating one stream of air (B) and the second stream of air (C) in the opposite direction. The outside stream of air gets hot and exhausts at point(D).The center column of air gets cold and exists at point (E).Temperature and capacities can vary by adjusting the hot end plug at (D) and by using different “generators”. Opening the adjusting valve at hot end, the cold end air flow decreases and the temperature drops, vice versa closing the valve at hot end the cold end air flow increases and the temperature rises. Vortex tube comprises of different parts with no mechanical movement and relative to each other are presented in detail view in Fig.2 are Body, Hot and Cold air Exhaust valves, Vortex generator with sleeve and O ring and compressed air supply end.

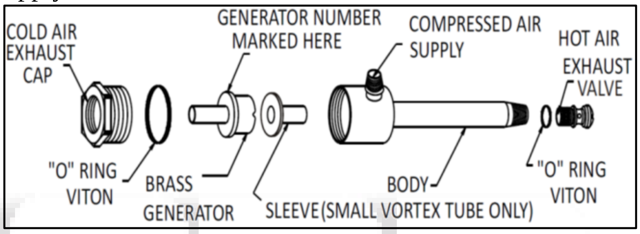

Fig. 2: Parts detail of Vortex Tube [NEXFLOW]

Fig.1 and Fig.2 [NEXFLOW: http://www.nexflowair.com /pdf/product_pdf/vortex_tubes.pdf]

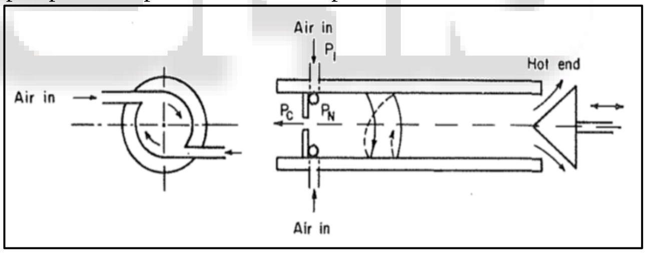

Fig. 3: Schematics of The Ranque-Hilsch vortex Tube. Y.soni et al.[3]

Through the years there have been many attempts, both the theoretical and experimental empirical, to determine the mechanism behind operation.

B. Working:

Basic thermodynamics involved for causing separation of two distinct temperature fluid streams while in expansion process. The two different streams of air at long and short end are hot and cold in temperature in a device called vortex tube which having no mechanical movement inside it. Compressed air is to be entered in vortex generator using single to multiple entries and two separate stream of hot and cold can available at its different ends.

C. Advantages of Vortex Tube over Its Counterpart:

1) Advantages:

Low cost, small easy to install, lightweight, reliable in various spot cooling applications, No moving parts, Driven by air not electricity, small and light weight-portable, low in cost compared to most others, maintenance free operation, superior in design and performance, adjustable temperature range, generators are interchangeable, made of durable stainless steel and metal parts, Quite operation, No chemical dependency, Instant cold Air,

2) Limitations:

Low COP i.e. less than 1, availability of Electricity to run compressors, managing two streams hot and cold without thermal mixing, Manufacturing accuracy to meet design parameters.

D. Various Applications:

Applications: Spot cooling and heating, solder cooling, cool electronic component, set hot melt adhesives, cool welding horns on ultrasonic, cool heat shrink tubing, cool plastic machine parts, cool molded plastics, Adjusting Thermostat. Cooling CCTV cameras, Cooling Machining Components, Cooling Gas Samples, Cooling environmental chambers, Process cooling,

Mini spot cooling applications like needle cooling on sewing machine, cooling small blades, grinding lenses and small parts, cooling small tools. .

II. Comparison of Influencing Parameters:

Refer Fig 3 in which Y. Soni et al. adopted pragmatic approach to find out optimum performance due to large variables are AN (nozzle area/tube area) = 0.11 ± 0.01 (0.084 ± 0.001),A* (orifice area/tube area) = 0.08 ± 0.01 (0.145 ± 0.035) L/D > 45 (>45); D = 26 mm (18 mm) that optimum performance was associated with a particular value of β(the ratio of the actual temperature drop between the inlet and the cold end to the isentropic temperature drop through the inlet nozzle) equal to 0.43.and considering orifice coefficient (0.61) [3]

Jeffery Lewins et al. suggested two optimization theory, at any given fraction of the cold stream for best refrigerative load is at half the maximum loading result in no lift. The second optimization shows that the optimum cut is an equal division of the vortex streams between balanced hot and cold streams.[4]

G. F. Nellis et al. noticed that increase in performance of different refrigeration cycles like vapor compression cycle, carbon dioxide refrigeration cycle, Joule-Thomson refrigeration cycle, multi-stage cryogenic refrigeration systems by the application of a vortex tube [5]

In their experimental and Computational fluid dynamics (CFD) study of 12 mm diameter vortex tube they evaluated different types of nozzle profiles and number of nozzles. It was shown that the cold end diameter of 7 mm is ideal for producing maximum hot gas temperature, while cold end diameter of 6 mm is optimum for reaching the minimum cold gas temperature. The investigations have shown that L/D ratio in the range of 25–35 by Upendra Behera et al.[6]

Pongjet Promvonge et al. investigated experimentally that for an insulated vortex tube with 4 inlet nozzles and cold orifice diameter of 0.5D yielded the highest temperature reduction (temperature separation) is about 30 ^{o}C and isentropic 33% [7].

N.F. Aljuwayhel explained the energy separation mechanism and flow phenomena within a counter-flow vortex tube using CFD analysis and found that the energy separation exhibited by the vortex tube can be primarily explained by a work transfer caused by a torque produced by viscous shear acting on a rotating control surface that separates the cold flow region and the hot flow region. This work transfer is from the cold region to the hot region. They also reported that the magnitude of the energy separation increases as the length of the vortex tube increases to a critical length. [8]

In their experimental study they use Three different working gases: air, oxygen and nitrogen to investigate different design parameters and found that Optimum values for the angle of the control valve, the length of the pipe, and the diameter of the inlet nozzle are obtained to occur approximately in the ranges θ=50, L/D=20 and d/D=1/3 respectively.[9]

H.M. Skye et al. described that good comparison can be done between CFD and empirical data by demonstration of the successful use of CFD in this regard, thereby providing a powerful design tool to optimize vortex tube dimensions and assess its utility in the context of new applications.[10]

Y.T. Wu achieved improvement in cooling effects up to 5 degrees by new improved nozzle with Archimedes' spiral and new improved diffuser.[11]

In their review Smith Eiamsa-ard et al. presented comparative Summary of experimental studies between Ranque(1933) to Aljuwayhel et al.(2005) by geometrical characteristics and thermo-physical parameters. They found the inlet gas pressure should be 2 bar (for optimal efficiency) and optimum values for the cold orifice diameter (d/D), the angle of the control valve (f), the length of the vortex tube (L/D), and the diameter of the inlet nozzle (d/D) are found to be approximately d/DE0.5, fE501, L/DE20, and d/DE0.33, respectively, which are expected to be fruitful for vortex tube designers.[12]

The temperature separation was studied using standard CFD k-εturbulence model is employed to numerically study and found The maximum hot exit temperature separation for a cold mass fraction of 0.81[13]

The effect of vortex angle on the efficiency was investigated. The result shows A smaller vortex angle demonstrated a larger temperature difference and better performance at lower values of input pressure.[14]

For evaluating different design criteria, the past investigations of the vortex tubes were overviewed and the detailed information was presented and summarised to understand it more clearly.[15]

Burak Markal et al. in their experimental study investigate effects of the conical valve angle on thermal energy Separation using four different conical valves have been used with the angle of 30, 45, 60 and 75.Mainly the effect of the valve angle for a counter-flow vortex tube is studied for varying design and operating parameters. It is disclosed that this effect is generally negligible and small values of L/D, this effect becomes considerable.[16]

Nader Pourmahmoud et al. carried out numerical study using length to diameter ratios (L/D) of 8, 9.3, 10.5, 20.2, 30.7, and 35 with six straight nozzles and found that the L/D= 9.3 for best performance.[17]

H. Khazaei in their CFD numerical study used three turbulent models, namely, RSM, Standard k-epsilon and Spalart–Allmaras, have been used out of which the Standard k-epsilon model better predicts the results in most regions. The results have shown that the hot outlet size and its shape do not affect the energy distribution in the vortex tube, and a very small diameter will decrease the temperature separation and Helium was found to have the most cold temperature difference than other gases.[18]

An experimental study carried out and get optimum values d / D = 8 / 25 =0.32 and L/D= 769 / 25 = 30.76 to reach the maximum proficiency of a vortex tube.[19]

The results indicate that maximum energy separation is achieved with tangential nozzle orientation while the Symmetry/asymmetry of nozzles has a minimal effect on the performance and the use 4 optimum number of nozzles to get maximum energy separation [20]

R.S.Maurya et al carried out numerical investigation using 3D model Fluent 6.3 as solver with ICEM pre-processor of vortex tube with 6 nozzles and an adjustable cone valve and with supply air pressure from 2 to 6 bars, the orifice diameter from 5 to 10 mm, L/D ratio from 4 to 20.They concluded that Energy separation is most effective close to cold orifice where L/D ratio is less than 10 and Cold orifice to shell diameter ratio must be close to 0.583.[21]

B.Sreenivasa Kumar Reddy et al. experimentally observed that the compressed air used in Vortex Tube Refrigeration System is nontoxic, zero ozone depletion and global warming potential, inflammable and free of cost and also the operating and running cost per ton of refrigeration is less. Vortex Refrigeration System is 4 H.P. compared to conventional VCRS i.e.6 H.P. So Vortex Refrigeration System is economical.[22]

Experimental investigation was carried out design generator parameters (Cold orifice angle, Cold orifice diameter and Nozzle area) and to find its effect vortex tube performance. They determined that for cold orifice angle of 4.1degree, cold orifice ratio of 0.64 and nozzle area ratio of 0.14 are able to get highest efficiency.[23]

R.Madhu Kumar performed experiments to examine effect of Varying Surface Roughness of Hot Tube. They explained that the COP of the vortex tube increases with the increase of inside surface roughness of hot tube and the vortex tube with a surface roughness of RRaR=6.264 μm surpassed the hot tubes with a surface roughness of RRaR=4.510 μm & RRaR=3.133 μm by 6% to 26% and 16% to 52% in COP respectively.[24]

Sudhakar Subudhi et.al. Presented review of different experimental data available on Ranque–Hilsch vortex tube experiments using air as the working fluid.[25]

Hany Ahmed et al. experimentally investigated various effect of Nozzle Numbers (2, 3 and 6 with aspect ratio 1.6 and inner diameter of 7.5mm)on Performance and found that he higher effect of nozzle number is for 3 in number nozzle [26]

Abbas Moraveji et al. carried out investigation using CFD analysis for finding the effects of 1 to 5 in number of inlets, tube length and diameter of cold outlet on temperature and flow rates passing through the vortex tube are investigated. They conclude that the passing flow rate from a cold outlet is increased as its diameter increase and by increasing the length of the vortex tube, the passing mass flow rates from the cold and hot cross sections slightly increased and slightly increased, respectively. Also, the temperatures at both outlets decreased as the number of inlets increased. [27]

Hitesh R. Thakare et al. experimentally investigated and carried out CFD analysis to study vortex tube. They found that for both insulated and non-insulated condition, temperature separation increases with increase in inlet pressure. [28]

M. Attalla et al. experimentally investigated effect of two identical counter flow vortex tubes in series and parallel arrangement on thermal performance and found that higher cop of refrigeration can achieved with series and higher cop of heat pump can be achieved using parallel arrangement of the vortex tubes. [29]

S.E. Rafiee et al. carried experiments and 3D CFD analysis to investigate effects of different shapes of hot control valves namely spherical, plate, cone and truncated cone to find heat transfer and energy separation inside a counter flow vortex tube. They found that by decreasing distance between the stagnation point and the control valve the cooling capability can reaches the maximum value and in the case of spherical, increasing the injection pressure has different effect on cooling ability compared to other valves. Furthermore, cooling capability can be assumed approximately independent of the slots number in the case of spherical, while, cooling capability depends extremely on the slots number in the case of truncated cone. [30]

Volkan Kirmaci et al. carried exergy analysis to find thermal performance using different nozzle material experimentally and came to conclusion that steel is best suited and has the highest value of temperature gradient for air as a working fluid among other tested nozzle materials like fibreglass and aluminium [31]

Davood Majidi et al. examined different Cascade arrangements of Vortex Tubes (VTs) for Highest Thermal Separation and performance and proposed its optimal arrangement of the three vortex tubes and a double-pipe helical heat exchanger that gives the highest performance. [32]

Mohammad O. Hamdan et al. carried out experimental investigation for different geometrical parameters to evaluates the effect of inlet pressure on the performance of the vortex and found that higher the inlet pressure, the greater the temperature difference and there is a maximum value where performance starts to deteriorate due to inlet nozzle choking. They also concluded that optimum length between 66 mm and 158 mm, an optimum diameter between 9 mm and 26 mm and a tapering angle smaller than 4° for greater performance.[33]

Anatoliy Khait et al. analysed method of local entropy generation first time in a double-circuit vortex tube for its study. They suggested factors to be optimized in the first place are decrease of the vortex tube diameter, or installation of a rod in the centre of the vortex tube, modernization of the main nozzle and the turbulization of the additional flow which may help to redistribute entropy production and enthalpy growth rate.[34]

Experimental Investigation was carried out to find Thermal Performance of Parallel Connected Vortex Tubes with Various Nozzle Materials like polyamide plastic, aluminium and brass as nozzle materials. Result shown for operating parameters like inlet pressure range 150 kPa – 550 kPa with 50 kPa increment, Orifices having 2, 4 and 6 nozzle numbers, length – diameter ratios (L/D) of the vortex tubes are 14and the cold mass fractions are 0.36 noted that the maximum performance was obtained with aluminium nozzles with nozzle number 6 at 550 kPa inlet pressure.[35]

III. CONCLUSIONS

Here Ranque- Hilsch vortex tube is discussed and available literature are reviewed to find influence of different performance parameters most likely geometrical which would help selecting Vortex Tube for various applications are.

L/D ratio in range of 4.5 to 45.

Nozzle material: steel

Surface roughness values up to 6.264 μm

Number of orifices preferably 3,

Arrangement in cascade applications like series for refrigeration application and paralle for heat pump like applications.

Though numerous information is available in literature regarding above content it is suggested that modern simulation tools like CFD and precise measurement technology during actual experimentation may become counterpart and complementary to each other to reach on an ultimate conclusion.

REFERENCES

[1] Ranque,Georges "Method And Apparatus For Obtaining From Alpha Fluid Under Pressure Two Currents Of Fluids At Different Temperatures" Patent (USA) United States Patent 1,952,281 lens.org/176-757-402-179-355,(1934)

[2] Hilsch R. "The use of the expansion of gases in a centrifugal field as cooling process." Review of Scientific Instruments; 18(2), pp.108–113, February 1947

[3] Y. Soni and W. J. Thomson "Optimal Design of the Ranque-Hilsch Vortex Tube." Journal of Heat Transfer Vol. 97(2), pp.316-317, (1975)

[4] Jeffery Lewins and Adrian Bejan "Vortex Tube Optimization Theory" Energy (24), pp. 931–943, (1999)

[5] G. F. Nellis and S. A. Klein "The Application of Vortex Tubes to Refrigeration Cycles" Purdue University, School of Mechanical Engineering International Refrigeration and Air Conditioning Conference. Paper 537, pp.1-9, (2002)

[6] Upendra Behera, P.J.Paul, S.Kasthurirengan, R.Karunanithi, S.N.Ram,K.Dinesh and S.Jacob "CFD analysis and experimental investigations towards optimizing the parameters of Ranque–Hilsch vortex tube" International Journal of Heat and Mass Transfer Vol. 48(10), pp. 1961–1973, (2005)

[7] Pongjet Promvonge and Smith Eiamsa-ard "Investigation on the Vortex Thermal Separation in a Vortex Tube Refrigerator" Science Asia (31), pp.215-223, (2005)

[8] N.F.Aljuwayhel,G.F.Nellis and S.A.Klein "Parametric and internal study of the vortex tube using a CFD model" International Journal of Refrigeration Volume 28, Issue 3,pp.442-450, May 2005

[9] Orhan Aydın and Muzaffer Baki "An experimental study on the design parameters of a counter flow vortex tube" Energy (31), pp.2763–2772, (2006)

[10] H.M.Skye,G.F.Nellis and S.A.Klein "Comparison of CFD analysis to empirical data in a commercial vortex tube" International Journal of Refrigeration Volume 29, Issue 1,pp. 71-80, January 2006

[11] Y.T.Wu, Y. Ding, Y.B.Ji, C.F.Ma and M.C.Ge "Modification and experimental research on vortex tube" International Journal of Refrigeration (30), pp.1042-1049, (2007)

[12] Smith Eiamsa-ard and Pongjet Promvonge "Review of Ranque –Hilsch effects in vortex tubes" Renewable and Sustainable Energy Reviews (12), pp. 1822–1842, (2008)

[13] Saeid Akhesmeh, Nader Pourmahmoud and Hasan Sedgi "Numerical Study of the Temperature Separation in the Ranque-Hilsch Vortex Tube" American J. of Engineering and Applied Sciences Vol.1(3) ,pp.181-187, (2008)

[14] Yunpeng Xue and Maziar Arjomandi "The effect of vortex angle on the efficiency of the Ranque–Hilsch vortex tube" Experimental Thermal and Fluid Science (33), pp.54–57, (2008)

[15] M. Yilmaz,M. Kaya, S. Karagoz and S. Erdogan "A review on design criteria for vortex tubes" Heat Mass Transfer (45), pp.613–632, (2009)

[16] BurakMarkal ,OrhanAydin and MeteAvci "An experimental study on the effect of the valve angle of counter-flow Ranque–Hilsch vortex tubes on thermal energy separation" Experimental Thermal and Fluid Science Volume 34, Issue 7,pp.966-971, October 2010

[17] Nader Pourmahmoud and Abdol Reza Bramo "The Effect Of L/D Ratio On The Temperature Separation In The Counter Flow Vortex Tube" IJRRAS Vol.6(1), pp.60-68, (2011)

[18] H. Khazaei, A.R. Teymourtash and M. Malek-Jafarian "Effects of gas properties and geometrical parameters on performance of a vortex tube" Scientia Iranica B Vol.19 (3), pp.454–462, (2012)

[19] Mahyar Kargaran and Mahmood Farzaneh –Gord "Experimental Investigation the effects of orifice diameter and tube length on a vortex tube performance" International Journal of Recent advances in Mechanical Engineering Vol. 2(3), pp.1-12, (2013)

[20] Mohammad O. Hamdan ,Basel Alsayyed and Emad Elnajjar "Nozzle parameters affecting vortex tube energy separation performance" Heat Mass Transfer Vol.49(4), pp 533-541, (2013)

[21] R.S.Mourya and Kunal Y Bhavsar "Energy and Flow Separation In Vortex Tube Numerical Investigation" ISSN : 2319 – 3182, International Journal on Theoretical and Applied Research in Mechanical Engineering Vol.2(3),pp.25-32, (2013)

[22] B.Sreenivasa kumar reddy and K.Govindarajulu "Air Cooling in Automobiles" ISSN : 0975-5462 , International Journal of Engineering Science and TechnologyVol.5(2), pp.341-348, (2014)

[23] Mahmood Farzaneh-Gord and Meisam Sadi "Improving vortex tube performance based on vortex generator design" Energy Vol.72(1), pp. 492–500, (2014)

[24] R.Madhu Kumar and N.V.V.S.Sudheer "Performance Improvement of Ranque-Hilsch Vortex Tube by Varying inside Surface Roughness of Hot Tube" ISSN 2348 – 7968 ,International Journal of Innovative Science, Engineering & Technology, Vol.1(4), pp.297-302, (2014)
[25] Sudhakar Subudhi and Mihir Sen "Review of Ranque–Hilsch vortex tube experiments using air" Renewable and Sustainable Energy Reviews Volume 52,pp.172-178, December 2015
[26] Hany Ahmed, M. Salem Ahmed, M. Attalla & A. Abo El –Wafa "Experimental investigation of the effect of nozzle numbers on Ranque–Hilsch vortex tube performance" Experimental Heat Transfer Volume 30, 2017 Issue 3
[27] Abbas Moraveji and Davood Toghraie "Computational fluid dynamics simulation of heat transfer and fluid flow characteristics in a vortex tube by considering the various parameters "International Journal of Heat and Mass Transfer Volume 113,pp.432-443, October 2017
[28] Hitesh R.Thakare and Ashok D.Parekh "Experimental investigation & CFD analysis of Ranque–Hilsch vortex tube" Energy Volume 133,pp.284-298, 15 August 2017
[29] M.Attalla,HanyAhmed,M. SalemAhmed and A. AboEl-Wafa "Experimental investigation for thermal performance of series and parallel Ranque-Hilsch vortex tube systems" Applied Thermal Engineering Volume 123, pp. 327-339, August 2017
[30] S.E.Rafiee and M.M.Sadeghiazad "Experimental and 3D CFD investigation on heat transfer and energy separation inside a counter flow vortex tube using different shapes of hot control valves" Applied Thermal Engineering Volume 110,pp. 648-664, 5 January 2017
[31] Volkan Kirmaci, Hüseyin Kaya, Ismail Cebeci "An experimental and exergy analysis of a thermal performance of a counter flow Ranque–Hilsch vortex tube with different nozzle materials" International Journal of Refrigeration Volume 85,pp. 240-254, January 2018
[32] Davood Majidi,Hashem Alighardashi and FatolaFarhadi "Best vortex tube cascade for highest thermal separation" International Journal of Refrigeration Volume 85,pp. 282-291, January 2018
[33] Mohammad O. Hamdan, Salah-A.B. Al-Omari and Ali S. Oweimer "Experimental study of vortex tube energy separation under different tube design" Volume 91,pp. 306-311, February 2018
[34] Anatoliy Khait , Alexander Noskov , Vladimir Alekhin and Vincenzo Bianco "Analysis of the local entropy generation in a double-circuit vortex tube" Applied Thermal Engineering Volume 130,PP. 1391-1403, 5 February 2018
[35] Hüseyin Kaya, Fahrettin Günver, Volkan Kirmaci "Experimental investigation of thermal performance of parallel connected vortex tubes with various nozzle materials" Applied Thermal Engineering Volume 136, pp. 287-292, 25 May 2018