International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Experimental Investigation and Performance of Vortex Tube Refrigeration

Dr. Ajoy Kumar

Principal, Chhatrapati Shivaji Maharaj Institute of Technology, Panvel, University of Mumbai, India

Abstract: ***The simultaneous release of hot air at one end & the cold air at the other end of the same tube by using compressed air, made the Pulse tube refrigeration system very interesting. After proper design and fabrication, the present vortex tube is tested in the laboratory by providing compressed air from a reciprocating air compressor having specification of FAD=13.608 m^3/hr. Co-efficient of performance, (c.o.p.) and Adiabatic efficiency, (η_{adia}) have been achieved as 0.1075 and 10.75%.Moreover, temperature of coldest and hottest air were recorded as -6 ^{0}C and 63^{0}C respectively.***

Keywords: Vortex tube, Refrigeration, Cooling, Nozzle, Adiabatic efficiency.

1. Introduction

The vortex tube has been a scientific curiosity ever since a French metallurgist, Gorge Joseph Ranque[1] (Patented in 1932) followed by German scientist Rudolph Hilseh[2] (1946). So, the vortex tube is also called as Ranque or Hilseh tube. Vortex tubes also seem to work with liquids to some extent, as demonstrated by Hsueh and Swenson[3] in a laboratory experiment where free body rotation occurs from the core and a thick boundary layer at the wall. Air is separated causing a cooler air stream coming out the exhaust hoping to chill as a refrigerator. In 1988 R.T.Balmer[4] applied liquid water as the working medium. It was found that when the inlet pressure is high, for instance 20-50 bar, the heat energy separation process exists in incompressible (liquids) vortex flow as well. Note that this separation is only due to heating; there is no longer cooling observed since cooling requires compressibility of the working fluid. Despite the simplicity of vortex tube's geometry, the energy separation phenomenon is quite complex and this has lead to the publication of several, semi-conflicting theories regarding its operation. Some researchers have suggested that energy is transferred as work due to viscous shear between a fast moving, inner core and a slower moving outer annulus that is characteristic of a free vortex (e.g. Lewins et al., 1999). Other researchers have described internal, refrigeration cycles associated with fluid motion due to turbulent eddies (Hartnett et al., 1957), sound waves (Kurosaka, 1982), Göertler vortices (Stephan et al., 1983), and secondary circulation (Ahlborn et al., 2000). In this paper the behavior of the vortex tube is modeled more simply as a nozzle in series with a counter flow heat exchanger, an idea originally attributed to Sheper (1951). Later on, the improvement in the vortex tube has been made by many more on these models which can be found in recent review articles [5, 6].

The present paper deals with the performance and testing of vortex tube designed in the college laboratory. The present status of theory of counter flow type vortex tube as shown in Fig.1, states that fresh air, before it has traveled very far in the tube, succeed in forming an almost free vortex in which the angular velocity or rpm is low at the periphery and vary towards the center .But friction between the layer of air under takes to reduce all the air to the same down and outer layers to speed up as the vortex. At the same time, because the center of vortex is much colder than the outside, heat flows towards the center, but not as rapidly as the works flows. The inner air is originally cooled by its kinetic energy to the outer gas by friction without receiving as much heat energy in return. The outer gas in turn receives more kinetic energy that it loses heat energy, and this kinetic energy eventually gets converted into internal energy through friction in the hot end of the tube.

2. Experimentation

The present set –up excluding compressor part has been shown in Fig.2.After proper design and fabrication, the present vortex tube is tested in the laboratory by providing compressed air from a reciprocating air having specification of FAD=13.608 m^3/hr, cylinder size and stroke =70 × 50 × 85 mm and compressor speed of 925 rpm .The test was conducted under the following effects:

1) Effect of cold friction on temperature drop of the air for constant inlet pressure.
2) Effect of inlet air pressure on temperature drop of the inlet air for constant cold fraction.
3) Effect of cold fraction on the refrigerating effect for constant inlet pressure.

3. Design Analysis and Manufacturing

3.1 Design of Nozzle

For good cooling effect, it is essential that air suit should form the vortex at sonic velocity. Hence, the entry passage of air in the nozzle is designed for sonic velocity condition of air.

Volume flow rate of air entering the compressor to nozzle chamber is given as:

$V = A_n v$

Where, A_n =Total cross sectional area of the nozzle in m^2

V = Velocity of air in m/s

$P_1 V_1 = mRT_1$

P_1=Inlet pressure of air to the compressor in N/m^2
= 94725.36 N/m^2

T_1 = Ambient temperature in K= 28+273= 301 K

V_1= FAD= 0.00378 m^3/S

Therefore, m= 0.004125 Kg/s
$P_2V = mRT_2$
Since compressed air is received in the receiver and then admitted to the nozzle, its temperature T_2 of the compressed air going from the receiver to tube is 35^0 C.
P_2= Air delivery pressure = 6 Kgf/cm^2
V= 0.0025793m^3/s = $(\gamma RT_2)^{0.5}$ = $(1.4 \times 287 \times 308)^{0.5}$
= 351.7874 m^3/s

A_n = V/v = 0.00000733217 m^2
Where v= velocity of air in m/s
Since 6 flutes are provided on the nozzle,
Area of one flute = 0.00000122 m^2
Let the breadth (b) = height (h)
Therefore, B= h = 1.1055 mm
For assuring sonic velocity we take
B= h= 1.0 mm
Dimensions of various parts are fixed as per following empirical relations:

1) **Inner diameter of warm tube :**
   D=3.3 (A_n)
   =3.3*(0.000011105) =11mm

2) **Orifice diameter**
   D_c= 0.396D =0.396 (11)
   D_c= 43.56 mm

3) **Length of warm tube**
   L=13 D =13 (11)
   L=143 mm

4) **Aperture angels for hot & cold ends**
   $a_{n} = a_n = 3^o$

4. Sample Calculation Regarding Vortex Tube Performance

1) Cold air temperature ($T_{c)}$ = -6^0 C
2) Hot air temperature (T_h) = 63^0 C
3) Inlet air temperature (T_i) = $28^{0\,C}$

Drop in air temperature
(T_C) = (T_i) – (Tc) = {28-(-6)} = 34^0C

Rise in temperature of air
(T_H) = (T_h)- (Ti) = (63-28) = 35^0C

Cold Fraction (u) = [(T_h) - (T_i)] / [(T_i) – (T_c)] = 0.5072
Cold fraction = m_c / m_i --------------------- (1)
FAD= 0.00378 m^3/sec = 13.608 m^3//hr
$P_i V_i = m_i R T_i$
m_i = (94725.36 x 13.608)/(287 x 301 x 3600)
= 0.004145 Kg/s

From Eqn. 1
m_c = 0.002092Kg/s
m_i= m_c +m_h
m_h =(m_i-m_c)= (0.004125- 0.002092)
=0.002033 Kg/s

4.1 Refrigerating effect (Q_c) = $m_c C_p T_c$
= 0.002092*1.005*10^3 *34= 71.4836 Watt

4.2Co-efficient of performance (C.O.P.) = Q_C/ W_c --(2)
Where,W_c= work consumed by compressor
= [n/(n-1)]($P_i V_i$)[$(P_2/P_1)^{(n-1)/n}$ -1] --------(3)

P_1 = pressure of air supplied to the compressor in N/m^2 = 94725.36 N/m^2
P_2 = pressure of air discharged by the compressor in N/ m^2= 600000 N/m^2
V_i = volumetric flow of air supplied to compressor in m^3/s= 0.00378 m^3/s
n= polytropic index= 1.01237
Hence, W_c= 664.45 Watt
C.O.P.= 0.1075

4.3 Adiabatic efficiency of the vortex tube

Vortex tubes have lower efficiency than traditional air conditioning equipment [7]. They are commonly used for inexpensive spot cooling, when compressed air is available.
C.O.P. = η_{adia}.[$(P_a/P_i)^{(\gamma-1)/\gamma}$]
0.0175= $[1.013/0.9472]^{0.4/1.4}$ η_{adia}
η_{adia} = 10.5%

5. Results and Conclusion

As a result, the following are obtained as given under:

Co-efficient of performance, (C.O.P) =0.1075
Adiabatic efficiency, η_{adia} = 10.5%

S.N	Pressure of air supplied to vortex tube (Bar)	Cold exit temp. ^{0}C	Hot exit temp. ^{0}C
1	6	-6	63
2	5	-3	62.5
3	4	-1	61.3
4	3	2	59
5	2	5	57

So for the working and performance of vortex tube is discussed .However , there is every possibility to improve the low COP of vortex tube which may enable the wide use of it in industries for the purpose of cooling of cutting tools, air –craft refrigeration, air suits, cooling of turbine blades and year round air conditioning etc.

6. Current Applications

Commercial vortex tubes are designed for industrial applications to produce a temperature drop of up to 71 °C (127 °F). With no moving parts, no electricity, and no Freon, a vortex tube can produce refrigeration up to 6,000 BTU/h (1,800 W) using only filtered compressed air at 100 PSI (6.9 bar). A control valve in the hot air exhaust adjusts temperatures, flows and refrigeration over a wide range [8].
Vortex tubes are used for cooling of cutting tools (lathes and mills), both manually-operated and **CNC** machines) during machining. The vortex tube is well-matched to this application: machine shops generally already use compressed air, and a fast jet of cold air provides both cooling and removal of the "chips" produced by the tool.

This completely eliminates or drastically reduces the need for liquid coolant, which is messy, expensive, and environmentally hazardous.

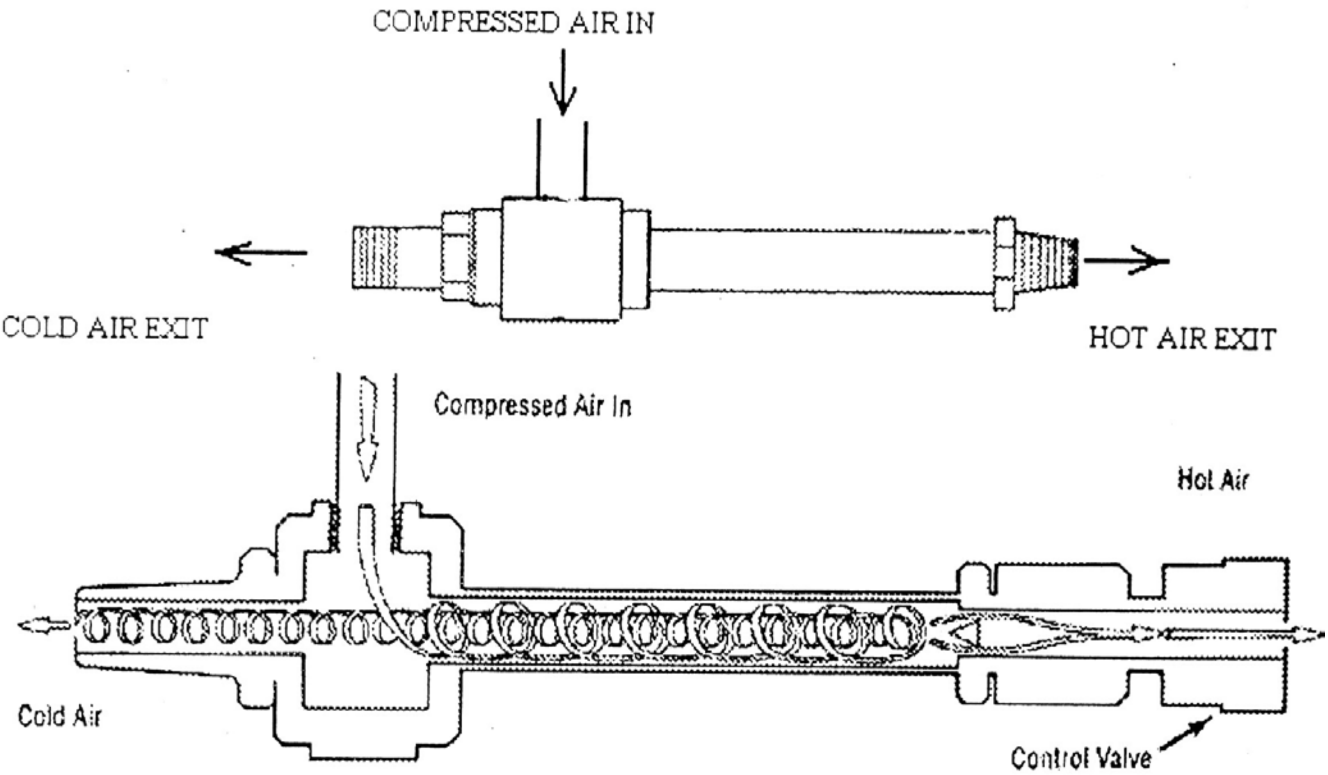


Figure 1: Principle of Operation

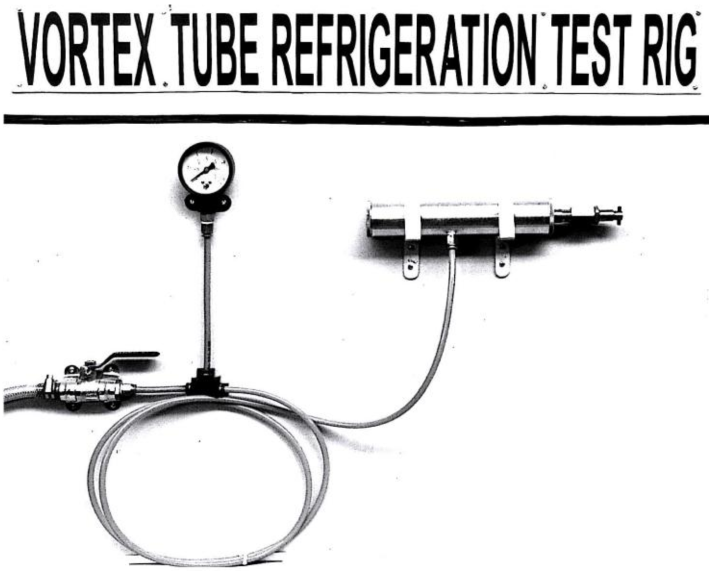
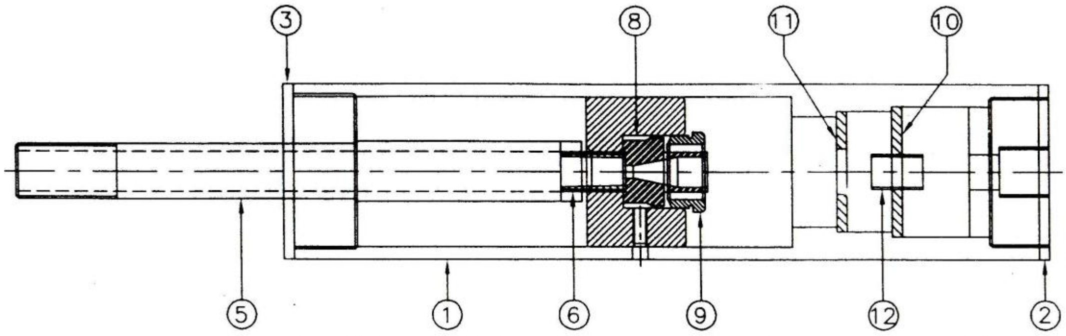


Figure 2: Experimental set-up



SR. NO.	DESCRIPTION	MATERIAL	QTY.	REMARKS
12	SILENCER	ALUMINIUM	01	PRESS FIT
11	DEFLECTOR-2	ALUMINIUM	01	PRESS FIT
10	DEFLECTOR-1	ALUMINIUM	01	PRESS FIT
09	NUT	ALUMINIUM	02	
08	NOZZLE	BRASS	03	
07	NOZZLE HOLDER	ALUMINIUM	02	
06	TAPERED BUSH	BRASS	01	PRESS FIT
05	WARM TUBE-TPR	BRASS	01	
04	WARM TUBE-ST	BRASS	01	
03	TUBE END OUTER	ALUMINIUM	01	
02	TUBE ADAPTER	ALUMINIUM	01	
01	OUTER TUBE	MILD STEEL	01	
01	OUTER TUBE	ALUMINIUM	01	

Figure 3: Design of Vortex tube

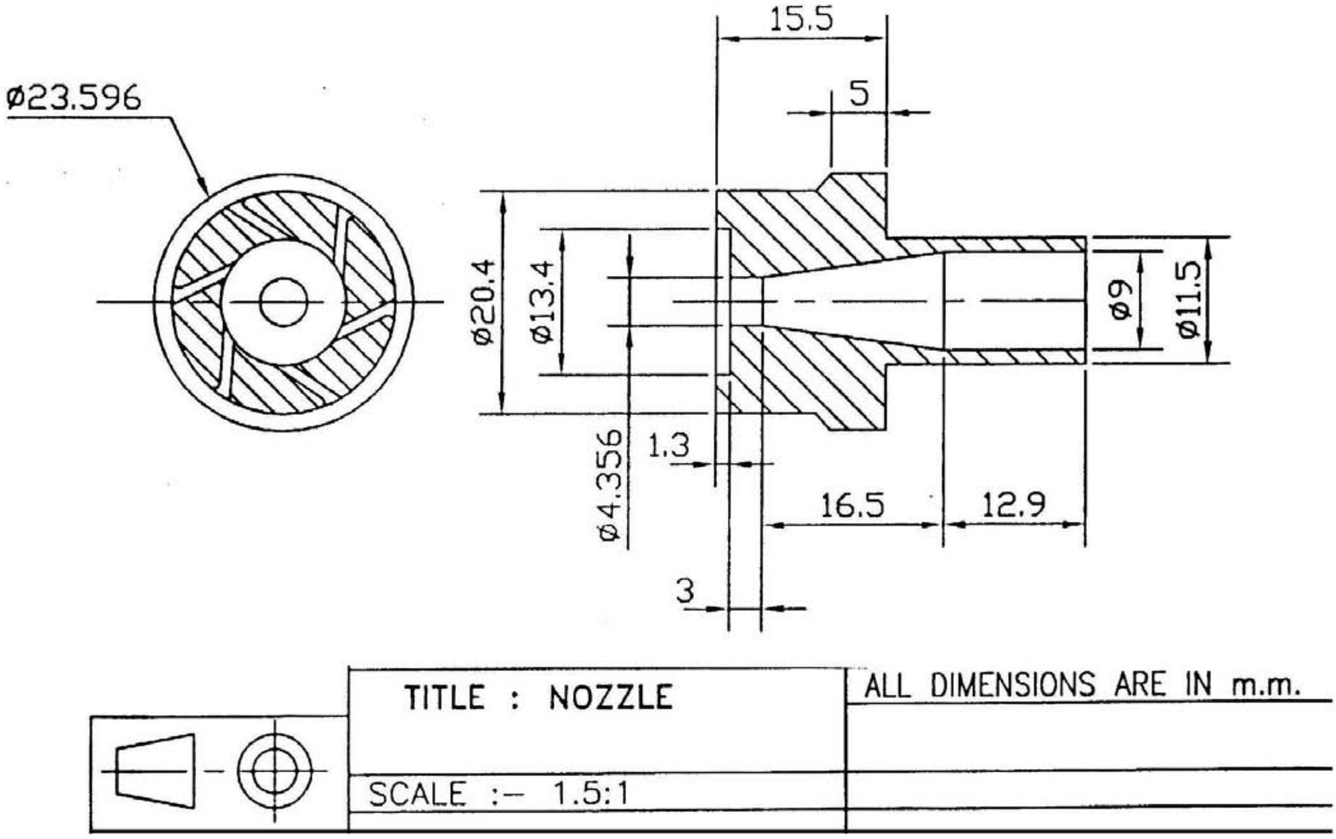


Figure 4: Design of nozzle

References

[1] Georges Joseph Ranque, "Method and apparatus for obtaining from a fluid under pressure two currents of fluids at different temperatures," U.S. Patent no. 1,952,281 (filed: December 6, 1932; issued: March 27, 1934).

[2] Hilsch, Rudolf (1947). "The use of the expansion of gases in a centrifugal field as cooling process". The Review of Scientific Instruments. **18** (2): 108–113. Doi: 10.1063/1.1740893. Translated from the original German article: Rudolf Hilsch (1946) "Die Expansion von Gasen im Zentrifugalfeld als Kälteprozeß" (The expansion of gases in a centrifugal field as a cooling process), **1**: 208–214.

[3] Samuel B. Hsueh and Frank R. Swenson,"Vortex Diode Interior Flows," 1970 Missouri Academy of Science Proceedings, Warrensburg, Mo

[4] R.T. Balmer. Pressure-driven Ranque-Hilsch temperature separation in liquids. Trans. ASME, J. Fluids Engineering, 110:161–164, June 1988.
[5] Xu, Y.; et al. (2010). "A critical review of temperature separation in a vortex tube". Exper. Therm. Fluid Sci. **34** (8):1367–1374. Doi: 10.1016/j.expthermflusci.2010.06.010.
[6] Eiamsa-ard, S.; et al. (2008). "Review of Ranque–Hilsch effects in vortex tubes". Renewable and Sustainable Energy Reviews. **12** (7): 1822–1842. Doi: 10.1016/j.rser.2007.03.006.
[7] Polihronov, J.; et al. "The maximum coefficient of performance (COP) of vortex tubes". Canadian Journal of Physics. **93**: 1279–1282. Doi: 10.1139/cjp-2015-0089.
[8] NewmanToolsInc. http://www.newmantools.com/vortex.htm

Author Profile

Dr. Ajoy Kumar completed his Bachelors and Masters in Engineering at B.I.T Sindri, and Ph.D at N.I.T. Jamshedpur. He is currently working as Principal at Chhatrapati Shivaji Maharaj Institute of Technology Panvel, University of Mumbai.