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Effect of Changing Cone Valve Diameter on the performance of Uni-Flow Vortex Tube

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***Abstract*— In this study the optimum design and performance of the uni-flow vortex tube used as cooling and heating device at high efficiency is investigated experimentally. Strenuous attempts were made to reach minimization of the uni-flow vortex tube size and achieve high separation energy. The experimental investigating was carried out on a vortex tube rig especially designed for the present study covering all tests. A study was made on the effect of varying the cone valve diameter (d_c= 14,12,10,8, and 6mm) on the performance of uni –flow vortex tube using two nozzles with constant nozzle diameter (d_n = 6.5 mm) and varying the pressure of the inlet air ($P_{iabs)}$ as well as cold air mass ratio(Y) within the ranges (P_{iabs} = 2-6 bar)and (Y =0 – 1)consecutively . The experiments showed an optimum design of uni-flow vortex tube that gave high energy separation at cone valve diameter (d_c= 12mm) for four vortex-tube diameters:(D=30, 20, 15mm and taper). As for the vortex tube with (D = 10 mm), the cone valve diameter that gave high energy separation was (d_c= 8 mm) with a number of nozzles (N = 2), (d_n= 6.5 mm).**

***Index* Uni-Flow Vortex, Tubes, performance analysis, Energy Separation.**

I. INTRODUCTION

Vortex tube is a device that enables the separation of hot and cold air when compressed air flows tangentially into the vortex chamber through inlet nozzles. Separating cold and hot air by using the principles of the vortex tube can be applied to industrial applications such as cooling equipment in CNC machines ,refrigerators, and cooling suits .The vortex tube is well-suited for these applications because it is simple ,compact ,light ,quiet, and does not use Freon or other refrigerators. Besides, it has no moving parts and does not break or wear and therefore requires little maintenance. [1]

Generally, the vortex tube can be classified into two types. One is the counter- flow type and the other one is the parallel uni-flow type ,as shown in Fig(1, a and b) [2,3].

Martynovskij and Alekseev (1957)[4] found that the best performance for vortex tube obtained when the (40 < L/D < 50), and this value is similar to the value set by the Hilsch [3]which was(L/D=50) and gave the best thermal separation performance.

Parulekar (1961) [5] carried out a practical study of a short vortex tube which included a number of models i.e., straight, convergent , and divergent to reach optimum design for the vortex tube. The biggest drop in temperature was obtained when using divergent tubes with short dimensions (16 mm) and (18 mm). He came to the conclusion that theoretically it was possible to build another vortex tube sot that the cold air outside of the first vortex tube entered second vortex tube to get more temperature drop.

Al-Abriy (1995) [6] made another practical study of laboratory vortex tube (Type Hilton Co. Manufacture) to see the effect of increasing the number of nozzles tangent on the performance of counter vortex tube and test a number of nozzles (N=1 to 8) and pressure ranging between (3-7)bar for different ratios of the mass cold air to the total air (Y =0 - 1). The results reached at showed that the optimum number of nozzles was (N=8) and (d_c=0.8mm) diameter yielding maximum difference in temperature and maximum value of the coefficient of performance and Refrigeration.

Ahlborn and Groves, S. (1997) [7] used a new probe (novel pitot probe) to measure the velocities in counter vortex tube diameter (D=25mm) to study the performance of secondary flow in vortex tubes. They concluded that the amount of cold air in the center of vortex tube was greater than the amount of cold air emerging from the end of the cold air and thus concluded that there were swirling secondary losses inside the mean swirls causing a back flow movement through the slot cold air (Cold end).

Al-Nasser, A.K. (2001)[8]studied the effect of air temperature laboratory vortex tubes (Hilton Co. type) on the coefficient of performance of vortex tube by changing the inside air temperature using electric heaters placed in the way of entering air ranging from (20-60 C^0), with a pressure ranging between (2-5 bar) , ratios of the mass cold air to the total air (Y =0-1). He found out that increasing the degree of entering air minimized the difference between entering cold and hot air. This led to an increase in the coefficient of performance.

Nyaz (2009) [9] used the artificial neural network (ANN) on a mathematical model to see the effect of length on diameter (L/D) and the effect of the cold end of the tube diameter (d_c) as well as (Y),pressure on the performance of vortex tubes .The practical results and the results (ANN) were found to be in harmony with his work. The aim of the research is to reduce the size of the uni-flow vortex tube with high separation energy.

II. THORETICAL ANALYSIS

Applying mass fraction to vortex tube system:

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$m_i=m_c+m_h$ …………………….. (1)

Cold mass fraction(Y),give the friction of inlet gas passing through the old side for vortex tube.

$$Y = \frac{mc}{mi} \qquad (2)$$

From the first law analysis of vortex [10]

$h_i= Yh_c +(1-Y)h_h$ ……………. (3)

Generally, the flow velocities at the exit of long vortex tube are small and their influence on enthalpy can be neglected [10].Here, air is used as the working gas and applying ideal gas equation:

$C_pT_i=YC_pT_c+(1-Y)C_pT_h$ ……….(4)

Re-arranging equation (4)

$$Y = \frac{(Ti-Th)}{(Tc-Th)} \qquad (5)$$

Cold air temperature difference

$\Delta T_c =T_i-T_c$ ………(6)

The vortex tube can be used as a refrigeration device when the cold pipe wall is used to reduce the temperature or as a heating device when the hot pipe is used to increase the temperature of an enclosure. If the system was assumed to be steady, then from the first law of thermodynamics[11].

$$C.O.P = \frac{\Delta Hc}{W} \qquad (7)$$

Where ΔH_c is obtained from

$\Delta H_c= m_cC_p(T_i-T_c)$ …………(8)

ΔH_c is equal to the heat that is transferred to the cold stream though the cold pipe wall from some source and (W) in the present case is work done to compress the air from atmospheric pressure and temperature to the inlet conditions of the tube.

The C.O.P of the vortex tube is defined as the ratio of the actual cooling effect to the work input to the air-compressor ,by substituting the actual cooling effect of the vortex tube (Q_r), in equation (8) one get:

$Q_r =m_cC_p(T_i-T_c)$ …………….(9)

The adiabatic (isentropic) efficiency of vortex tube is defined as:

$$\eta = \frac{Actual\ cooling\ effect\ obtained\ in\ vortex\ tube}{Ideal\ cooling\ effect\ possible\ with\ adiabatic\ expansion} \qquad (10)$$

III. EXPERIMENTAL WORK

The Schematic diagram of the experimental setup is shown in figure (3) Laboratory system designed and manufactured to fulfill the requirements of uin-flow vortex Tube test .The compressed working fluid supplied from the compressor passes through pressure tank, then the working fluid is introduced tangentially into the uni vortex tube where it is expanded and separated into hot and cold air stream. The cold stream in the central region flows out of the tube in the central orifice of cold end tube, while the hot stream in the outer periphery annulus leaves the exit of the hot end tube .The inlet pressure and the outlet cold gas pressure was measured with Borden Gauge. The temperatures of the inlet and outlet flows were measured with thermocouples. The mass flow rate of the inlet fluid was measured using rotameters.

IV. RESULTS AND DISCUSSION

The optimum design of uni flow vortex tube and parallel flow mainly depends on the diameter of the cone valve where the hole vent through cone movement during the opening and closing of the cone identifies the performance vortex tube and directly affects the isentropic efficiency, performance, and capacity, figure (2).

A. Effect of cone valve diameter on Isentropic efficiency

Increase in the cone valve diameter affects isentropic efficiency value for deferent pressures. Isentropic efficiency increase with increase in cone valve diameter to reach better diameter (d_c=12 mm) and for vortex tubes (No.1,2,3,and 4),(Table 1). From figure(4) it is clear that the upper value of isentropic efficiency occurs at diameter (d_c= 12 mm)for vortex tubes(1,2,3and 5),and the highest values of isentropic efficiency occurs at diameter (d_c=12 mm)for tubes (No.1,2,3 and 5).The best results obtained was at vortex tube(No.2)at (Y=o.323)and the highest inlet pressure value was at (P_{iabs} =6 bar).Besides, the efficiency increased with the increase in tube diameter for each umi-flow vortex tube and reaching highest value at (d_c= 12 mm) and then decreases.

B. Effect of cone valve diameter on the coefficient of performance

The increase in diameter valve cone led to increase coefficient of performance and reached highest values when (d_c=12 mm)for all vortex tubes except vortex tube (No.2),(Table 1)while the best diameter was (d_c=8 mm).

C. Effect of cone valve diameter on the Refrigeration Capacity

Figures (5,6) show the effect of change valve cone diameter for each vortex tube on values of refrigeration capacity(Q_r) for (Y= o.323)and (Y=0.712) ,where the results showed that the best uni-flow vortex tube was (No.2) at diameter (d_c=12mm) reaching the highest values ,while the diameter (d_c=14),had a less impact than (d_c=12mm).This also applies to the uni-flow vortex tubes(No.1,2,3 and 5),except vortex tube(No.4), (Table 1)where the best diameter was (d_c=8mm)

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giving less results compared with rest vortex tubes.

V. CONCLUSION

The main conclusions drawn from this research are as follows:

1-Vortex Tubes No.2 (Table 1) (L=400 mm, D=20mm , d_c= 12 mm)gives lower temperature for cold air reached (T_c= -3o.6 C^0) at (Y=0.313)and highest hot temperature reached (T_h=14.5 C^0) at (Y=0.823).

2-Isentropic efficiency and coefficient of performance (C.O.P)for uni-flow vortex tube increases with the cold air mass ratio (Y) at (Y=0.5-0.7)and this corresponds to the counter vortex tube. The vortex Tube No.2 at cone valve diameter (d_c=12mm) for inlet pressure (P_{iabs} =6 bar),gave the highest values for isentropic efficiency, reaching (η =24%) at (Y=0.724).

3-The Refrigeration Capacity for vortex tube increases in proportion to the mass cold air ratio (Y).The the highest value reaches (Y=0.6-0.8)it also increases with increase in the value of inlet air pressure. Meanwhile,the vortex tube No.2 at (d_c=12 mm) ,with inlet air pressure(P_{iabs} =6 bar),give highest values for refrigeration Capacity, reaching (Q_r=1380 Watt) at (Y=0.704).

4- Diameter cone valve controls the performance of uni-flow vortex Tube. When there is an increase in the diameter it causes an increase the thermal performance for all vortex tubes reaching a climax at (d_c=12 mm).

5- The diameter cone valve (d_c=12 mm) gives highest values of (Δ T_h)and (Δ T_c) and coefficient of performance, as well as refrigeration Capacity.

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Nomenclature

C.O.P	Coefficient of performance
C_p	Specific Heat Capacity (kJ/Kg.k°)
D	Inner diameter of vortex tube (mm)
d_c	Diameter of cold end orifice (mm)
d_h	Diameter of hot end outlet (mm)
h	Enthalpy(kJ/Kg)
L	Length of vortex Tube (mm)
L/D	(Length /inner diameter) of the vortex tube
m_i	Mass flow of inlet air (kg/s)
m_c	Mass flow of cold air (kg/s)
m_h	Mass flow of hot air (kg/s)
N	Number of nozzles
p_{iab}	Absolute air pressure
Q_r	Refrigeration capacity(watt)
T_o	Temperature at the nozzle outlet(C^0)
T_c	Temperature of cold air(C^0)
T_i	Temperature of the inlet air(C^0)
T_h	Temperature of hot air(C^0)
ΔT_c	Temperature difference of cold air(T_C-T_I)(C^0)
ΔT_h	Temperature difference of hot air (T_h-T_0)(C^0)
Y	Cold mass fraction

Greek Letters

η	Efficiency

Subscripts

i	inlet conditions
c	cold conditions
h	hot conditions
o	outlet conditions

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TABLE(1)Details of Uni- flow Vortex Tubes tested

Chamber	D mm	L/D	L mm	Dn mm	Dc mm	Dhmm
Vortex tube No. 1	30	20	600	6.5	6 8 10 12 14	14 22 28
Vortex tube No. 2	20	20	400	6.5	6 8 10 12 14	14 22 28
Vortex tube No. 3	15	20	300	6.5	6 8 10 12	14 22 28
Vortex tube No. 4	10	20	200	6.5	8 6	14 22 28
Vortex tube No. 5 Taper	30 20	20	350	6.5	6 8 10 12 14	14 22 28

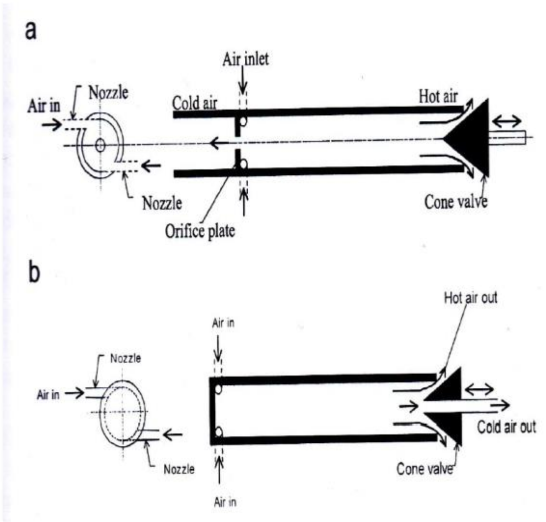


Figure (1) Basic operation of vortex tubes (a) Counter- flow vortex Tube (b) Uni-flow vortex Tube

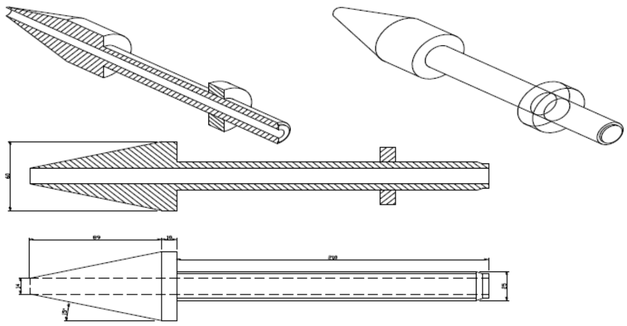
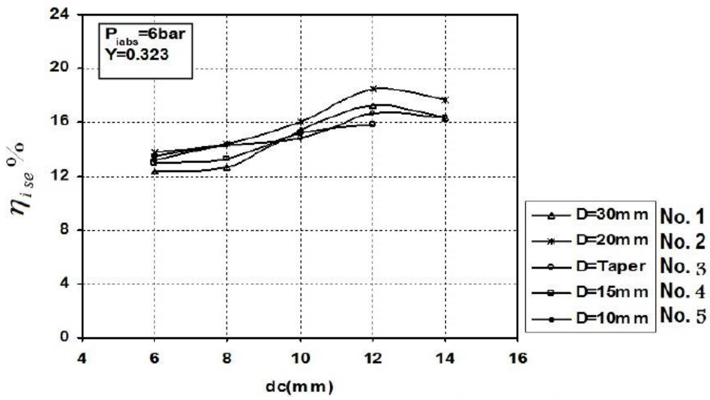
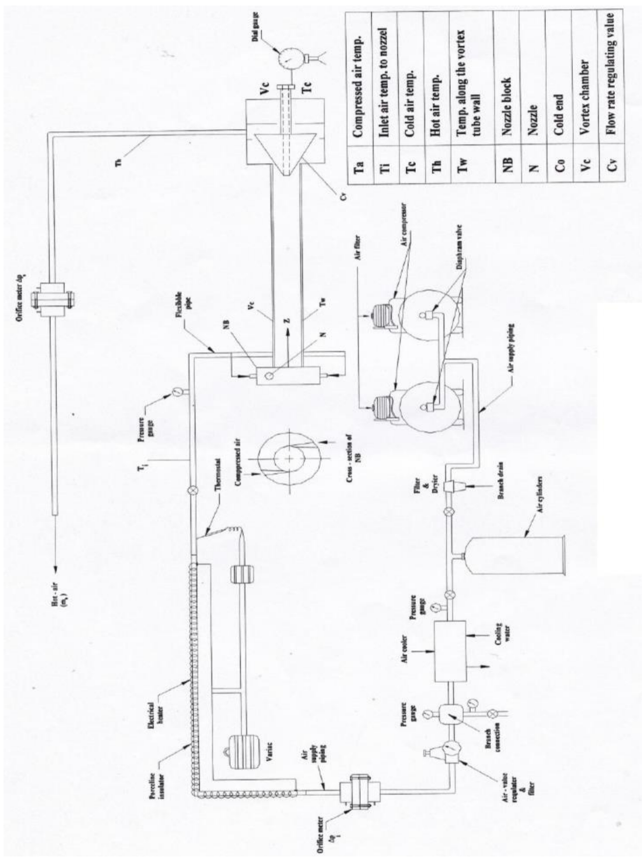


Figure (2) Valve cone used in Uni-flow Vortex Tube





Figuri(3)Schematic Diagram of Experimental Rig

Fig(4)Variation of cone valve diameter(d_c mm)with isentropic efficiency(η) for different uni-flow vortex tubes, inlet pressure(p_{iab} =6 bar)and air cold mass ratio (Y=0.323)

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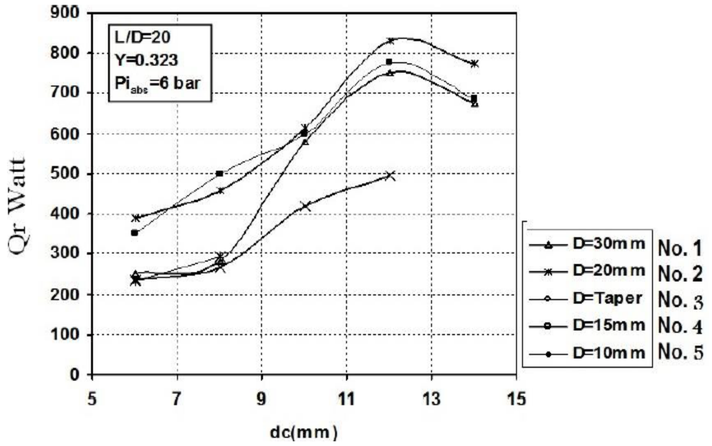

Fig (5) Variation of cone valve diameter (d_c mm)with Refrigeration capacity(Q_r) for different uni-flow vortex tubes, inlet pressure(p_{iab} =6 bar)and air cold mass ratio (Y=0.323)

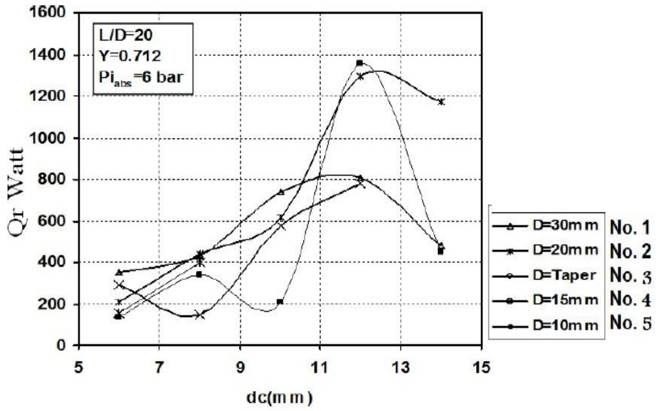

Fig (6)Variation of cone valve diameter(d_c mm)with Refrigeration capacity(Q_r) for different uni-flow vortex tubes, inlet pressure(p_{iab} =6 bar)and air cold mass ratio (Y=0.712)

He had received Bachelor in mechanical Engineering from –University of Technology/ Baghdad in 1979. Then he had received Higher diploma from University of Technology/ Baghdad in 1979. In 1983 he had received MSc. Degree from University of Technology/ Baghdad. In 2004 he had received PhD. In Mechanical Engineering from University of Technology/ Baghdad.

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