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Experimental Investigation of the Performance of a Vortex Tube with Conical Control Valve

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Abstract

The Vortex tube (Ranque-Hilsch type/ RHVT) is a simple device used to obtain both cold and hot gas streams simultaneously from a compressed gas. The obtained cold gas is widely used in many low temperature commercial applications. In this work, the performance of the vortex tube was examined experimentally by studying the effects of inlet pressure variations, conical valve opening percentage, tube diameter and hot gas tube length on the thermal performance of the tube. Four tubes with diameters 14, 21, 25 and 32 mm with four hot exhaust gas lengths; 25, 50, 75 and 100 cm were tested experimentally and the obtained data were analyzed. It was observed that the 75 cm length of the hot side length, gives the maximum coefficient of performance for RHVT, as well as the maximum cold temperature reduction, either with or without insulation. Furthermore, the thermal performance of the RHVT was optimum for the two inner diameters; 14 and 21mm. This indicates that, when the ratio of hot side length to inner diameter (Lh/D) lies between 36 and 50, then the thermal performanmce of the RHVT is optimum and is highly recommended, which agrees with the results published in previous studies and invesitigations.

Keywords: Vortex tube, Conical control valve, experimental, performance;

1. Introduction

The Ranque-Hilsch vortex tube (RHVT) is a simple mechanical device operating as a refrigerating and heating apparatus that generates both hot and cold gas streams simultaneously from compressed air without utilizing any moving parts. The cold gas stream will be used in many industrial and commercial applications. Historically, the vortex tube was observed many decades ago, by Ranque [1] in 1933, and Hilsch [2] in 1947. Its principle of operation is based on the separation of a single compressed air stream with a uniform temperature into two streams (hot and cold), as it can be seen from Figure 1. Such a phenomenon is referred to as the temperature (or energy) separation effect, Figure 2. These figures show the operating principle and flow directions of the RHVT.

In Figure 3, a schematic diagram, is shown, to indicate the geometrical parameters of a given RHVT, i.e.; the inner diameter and length for cold and hot sides, orifice and nozzle diameters.

The vortex tube consists mainly of inlet tangential nozzles, vortex chamber or (hot side tube), cold orifice plate and control valve as shown. Basically, the vortex tube consists of one inlet in which the pressurized air is tangentially injected through a nozzle in the vortex chamber and exhausts on the right and left ends, as shown in Figures 1 and 2. The fraction of the air that leaves the vortex tube in the two directions is controlled by the conical valve. Due to the tangential injection, the velocity of air has significantly high rotational component in the chamber and splits into two streams; hot stream which exhausts at the right side periphery, and cold stream that exhausts at the left part of the tube. The vortex tube is a mechanical device and it operates as a refrigeration unit without any moving parts, no electricity or chemicals parts are needed, low cost, maintenance free, small and lightweight, adjustable temperature range, and no response time to reach the cold temperature, provided that compressed air is available. The geometrical parameters are: the vortex tube inlet diameter, cold orifice diameter, inlet nozzles diameter and number, conical control valve angle, cold tube length and hot tube length. When high pressure air enters into the vortex chamber through one or more tangential nozzles, a strong vortex flow is created and is split into two regions, the first one is the high temperature air near the boundary of the tube which leaves circumferentially through the conical valve, while the other one is the low temperature air that leaves through the cold orifice.

The principle of operation of the vortex tube, was first discussed by Ranque and Hilsch in 1933 and 1947,

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respectively. Ranque [1] noticed that the air entering tangentially into a pipe exits from one outlet at a lower temperature and from the other outlet at a higher temperature than the inlet flow temperature. Hilsch [2] studied on the Ranque's findings and performed experimental and theoretical studies on the vortex tube gas flow to improve its efficiency. He worked on spiral flow using smoke visualization inside a vortex tube in which inner wall is covered by oil. Some researchers have been able to explain the principle of operation of the vortex tube numerically, due to the complexity of modeling the Rangue-Hilsh vortex tube mathematically. Due to its practical importance, the performance of the vortex tube, has been the subject of numerous numerical and experimental investigations over the years [3- 26]. A review of the relevant literature can be found in e.g. [28, 29]. The present work is intended to report the results obtained experimentally to study the performance of a vortex tube by measuring the temperatures and the mass flow rates, for 10 samples of vortex tubes with different lengths and diameters at different values of inlet pressure, which ranges from 1-4 bars [27]. The goal of this work is to present the results obtained experimentally, and to study the effect of the physical parameters of the vortex tube: hot tube diameter and length, percentage of conical valve opening, inlet pressure and insulation, on the thermal performance such as, cold temperature separation and coefficient of performance of the vortex tube. Based on the results and investigations presented in [27], it was concluded that the inner diameter of the vortex tube is one of the most important factors that affect its performance, since any increase in vortex tube inner diameter, will result in a decrease in its coefficient of performance and cold temperature reduction. In general, the results indicate that 20% of conical valve opening has produced maximum cold temperature reduction at all inlet pressures regardless of the geometrical parameters of hot tube, and 10% of conical valve opening has caused the vortex tube to operate at the maximum coefficient of performance. It is very necessary to mention that results also reflect the fact that, increasing inlet pressure causes the cold temperature reduction to increase regardless of the percentage of conical valve opening.

As mentioned before, the RHVT, is a very simple mechanical device and can be used as a refrigerating system, unlike the traditional air conditioning systems [30]

In light of the above review, the objective of this work is to study experimentally the performance of a vortex tube with conical control valve. The interest here, will be on studying and analyzing the thermal performance of the vortex tube, i.e.; coefficient of performance, reduction in ambient temperature and effect of insulation. Moreover, the performance will be thouroghly analyzed for different values of : inner diameters, hot and cold sides lenghths, conical control valve opening, and inlet pressures.

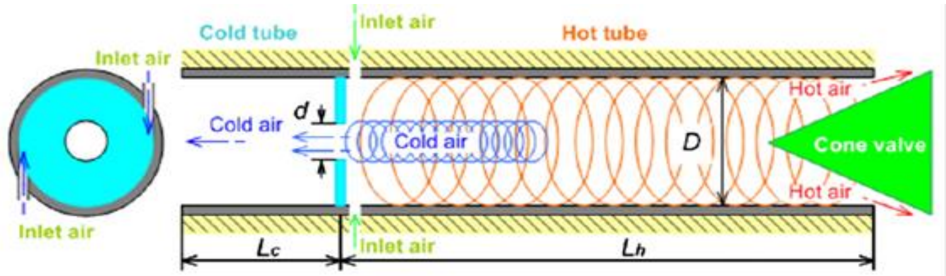

Figure 1. Air flow directions inside counter-flow type tube (Eiamsa-ard et al, 2010)

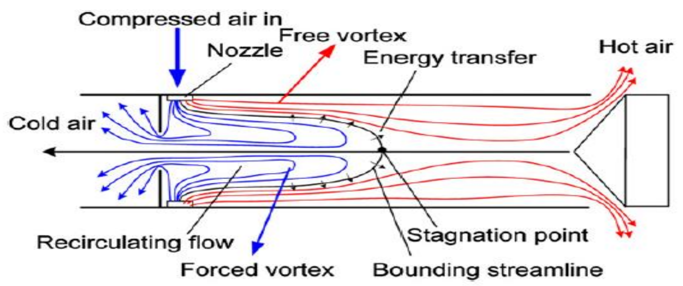

Figure 2. Stagnation point on vortex tube (Im and Yu, 2012)

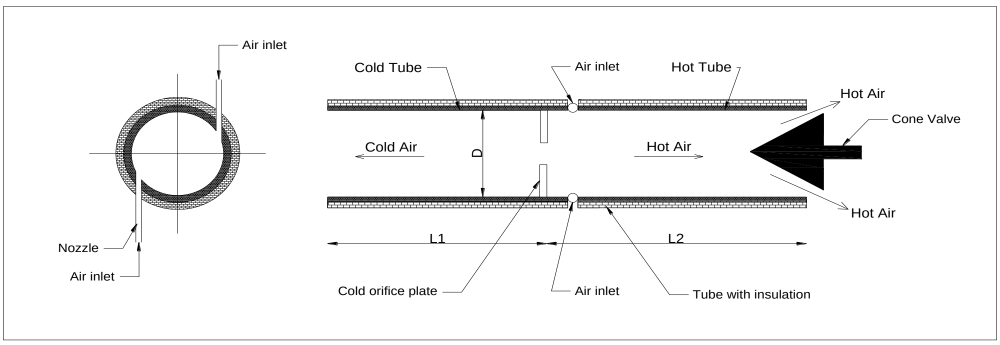

Figure 3. Schematic diagram of a general vortex tube (front and side views)

2. Experimental set-up description

The experimental setup of the vortex tube under consideration is shown in Figure 4. The test rig consists of a frame to hold the tube and a sliding type conical control valve

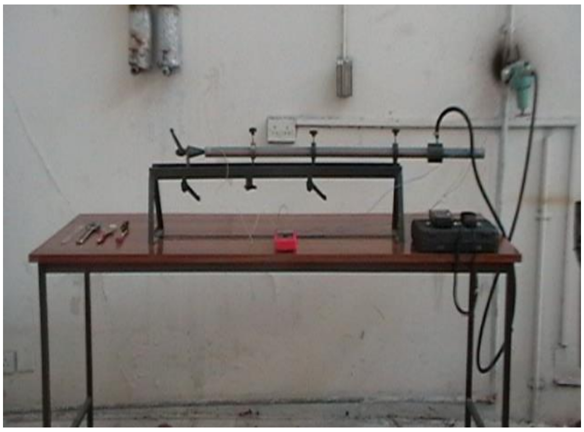

Figure 4. The Test rig used in the study

In this work, an Anemometer and three thermocouples were used to measure, respectively, the mass flow rates and temperatures at the inlet and two exits (hot and cold). The thermocouples of K-type located directly downstream at the inlet, hot and cold flows to measure temperatures by connecting them with a digital multi-meter type (TC-100).

The installed pressure gage on the main supply line (compressed air) was used to measure the pressure of the inlet air stream, i.e. the compressed air that is tangentially injected via the nozzle to the vortex chamber, and the target pressure was set by adjusting the regulation valve of the main supply line. In addition, on the vortex tube, a conical flow control valve was fixed at the end of the hot tube to control the mass flow rate of the hot stream (mass fraction), which in turn regulate also the cold stream mass fraction. The conical valve is fabricated in a very simple way and fixed on the mainframe of the test rig. It moves horizontally and a linear scale is used to calculate the percentage of the opening at the hot airside. Also, clamps are mounted on the steel frame to fix the vortex tubes during the experiments. As can be seen from the figure, the steel frame can be used to hold any vortex tubes individually during the experiment, to prevent any movements and vibrations resulted from the high pressures at the inlet. This steel frame has been designed to match all vortex tubes used regardless of their lengths and diameters. Ten vortex tubes made from Chlorinated polyvinyl chloride (CPVC) with different diameters were fabricated and used. The dimensions and geometrical parameters of these tubes are given in Table (1).

3. **Experimental results**

During the experiments, for a given vortex tube, the input air pressure was regulated through the supply valve and varied from 1 to 4 bar with an increment of 0.5 bar. In order to minimize the errors encountered in the measurements, the following procedure has been followed in all tests and for all vortex tubes. For a given inlet pressure, the steady-state condition was obtained first by obtaining a steady record for the temperature on both sides (hot and cold).

1. The repeatability of all results was examined, re-measuring the temperatures at hot and cold sides, for some inlet pressure values.
2. The ambient temperature was recorded before each test and run.
3. All steps mentioned above were repeated in all tests conducted on all 10 vortex tubes, regardless of the diameter and length of the tube under consideration.

In the following table (2), some temperature measurements at hot and cold sides, for a given vortex tube (14 mm inner diameter, 100 cm length and 10% conical valve opening) are presented.

The cold and hot tempartures are measured for three values of inlet pressure, form 1.5 bar to 2.5 bar. For each set of data, the average value is calculated, and the absolute errors, were estimated with respect to the average value of each temperature measurement.

The temperature records shown in the table, indicate that, the percentage of errors varies from 1 % to 6%. Other results but not shown here for the sake of brevity, have indicated that the maximum absolute errors for inlet pressure and flow rates were; 5 % and 6.5 %, respectively. It could be concluded that the variations and the percentages of errors are very little small and can be neglected, which is acceptable in any experimental work. As mentioned before, for a given vortex tube, i.e. one of the tubes listed in Table (1), first the inlet pressure is set to 1 bar, which is the minimum value of pressure. While the cold and hot air streams temperatures are measured as well as the mass flow rate at the inlet and at the hot and cold sides, at a given value of the conical valve opening. For each vortex tube and at a given percentage of conical valve opening, the procedure is repeated for different values of inlet pressure, i.e. by increasing the inlet pressure by 0.5 bar. As an example, in Table (3) below, results of the vortex tube No. 4 from table (2) are shown for 10% conical valve opening.

Table 1. Dimensions of geometrical parameters employed in the study

Sample Number	Hot Tube		Cold Tube		Orifice Diameter (mm)	Nozzles Diameter (mm)
	Inner Diameter (mm)	Length (cm)	Inner Diameter (mm)	Length (cm)		
1	14	25	14	20	7.0	3
2		50				
3		75				
4		100				
5	21	25	21		10.5	
6		50				
7		75				
8		100				
9	25	100	25		12.5	
10	32	100	32		16	

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4. Discussion of the Results

Since the conical valve is mounted on the hot side exhaust tube, it was noticed that when the conical valve is fully closed, all inlet air will escape from the cold side in the form of unsteady air currents at different temperatures, which is an expected behavior. On the other hand, when the conical valve is completely opened, all the compressed air will exhaust from the hot side, and the ambient air also goes inside from the cold side due to pressure drop formed by the tangential movement "circulation " of the injected compressed air into the vortex tube. Thus, the effect of the percentage of conical valve opening on the vortex tube operation and performance was investigated in this work. The opening was gradually increased by 10% in each step. For a given percentage of opening and inlet pressure, the temperatures and anemometer reading were recorded, and the corresponding mass flow rates were calculated.

4.1. Effects of conical valve opening on temperature difference

In Fig. 5, the temperature difference between inlet and cold side air stream (Ti-Tc) versus inlet pressure, for different values of conical valve opening (10%, 20%, 30% and 40%) is presented. The tested vortex tube was of 14 mm inner diameter and 100 cm hot tube length. While Fig. 6 presents the effect of tube opening on the coefficient of performance of the vortex tube expressed as percentage ratio to maximum possible coefficient of performance that may be obtained by Carnot ideal cycle (or second law efficiency). It was found that the coefficient of performance ratio decreases with the increase of conical valve opening for all inlet pressures, which means that coefficient of performance is maximum at 10% opening, corresponding to cold volume flow rate of (0.27 - 0.34) m^3/min. While the maximum cold air temperature difference for same vortex tube occurred at 20% of conical valve opening, regardless of inlet pressure value, which corresponds to cold volume flow rate of (0.11 - 0.15) m^3/min. For this vortex tube, the maximum cold temperature difference recorded was 17.1 °C at 4.0 bar inlet pressure and 20% conical valve opening, with coefficient of performance of 2.1%. The maximum second law coefficient of performance was only 5.3% with 7.9 °C cold temperature difference at inlet pressure of 1.5 bar and 10% conical valve opening.

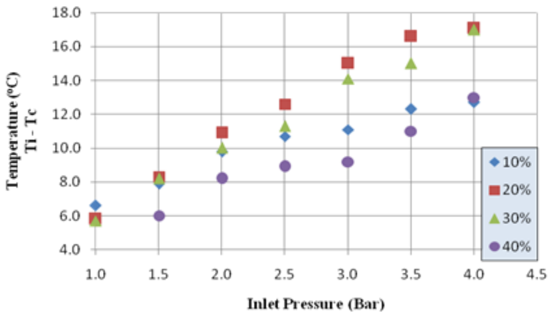

Figure 5. Temperature differences versus inlet pressures for a vortex tube of 14 mm inner diameter and 100 cm hot tube length for different values of conical valve opening

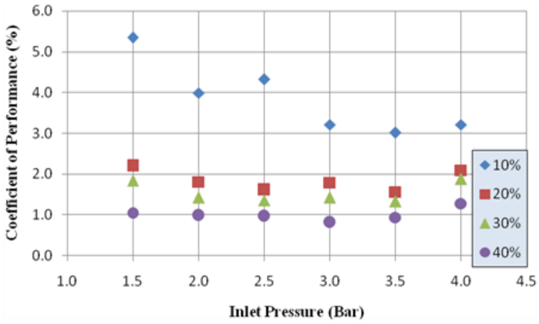

Figure 6. Coefficient of performance versus inlet pressures for a vortex tube of 14 mm inner diameter and 100 cm hot tube length for different conical valve opening

Figure 7 shows the results obtained by operating a vortex tube of 21 mm inner diameter and 100 cm hot tube length, for this vortex tube the cold temperature difference is largest at 20% of conical valve opening only for inlet pressures larger than 2.0 bar or in other words; for cold mass fraction between (0.07 - 0.10) m^3/min.. Note that this vortex tube needs more than 4.0 bar inlet pressure to operate at more than 30% of conical valve opening.

Figure 8 below gives a good view about the effect of conical valve opening on the coefficients of performance. Although coefficient of performance is higher at 10% of conical valve opening with cold volume flow rate fraction between (0.16 - 0.18) m^3/min., it drops down with increasing inlet pressure. On the contrary, the coefficient of performance increases with increasing inlet pressure at 20% of conical valve opening, and it is almost negligible for 30% of conical valve opening.

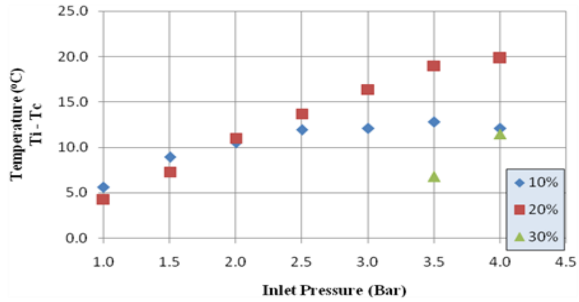

Figure 7. Cold temperature differences versus inlet pressures for a vortex tube of 21 mm inner diameter and 100 cm hot tube length for different conical valve opening.

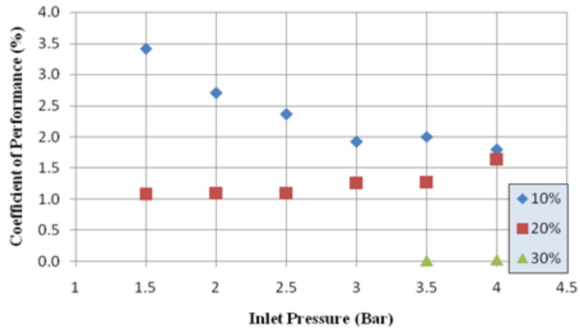

Figure 8. Coefficient of Performance versus inlet pressures for a vortex tube of 21 mm inner diameter and 100 cm hot tube length for different conical valve opening.

The maximum temperature drop in this vortex tube equals to 19.8 °C which occurred at 4.0 bar inlet pressure and 20% of conical valve opening, the coefficient of performance in this case is 1.6%. The maximum coefficient of performance is 3.4% with cold temperature difference equals to 8.9 °C which was recorded at 1.5 bar and 10% of conical valve opening.

The third tested vortex tube was of 25 mm inner diameter and 100 cm hot tube length. The maximum cold temperature difference was 16.3 °C with 0.5 % coefficient of performance ratio at 4.0 bar at 20% of conical valve opening. On the other hand, the maximum coefficient of performance was 0.7% with 4.6 °C cold temperature difference at 1.5 bar and 10% of conical valve openings. Those results are shown in Figures 9-10.

The last tested Vortex tube was of 32 mm inner diameter and 100 cm hot tube length. It operated properly under inlet pressures below 4.0 bar when the percentage of conical valve opening was below 10%. For larger openings, pressures more than 4.0 bar were needed to operate it. So that, it produced a maximum cold temperature difference of 10.6 °C with maximum coefficient of performance of 0.5% at 4.0 bar inlet pressure and 10% of conical valve opening.

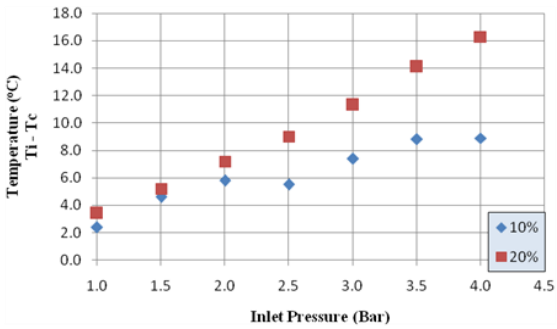

Figure 9. Cold temperature difference versus inlet pressures for a vortex tube of 25 mm inner diameter and 100 cm hot tube length for different conical valve opening.

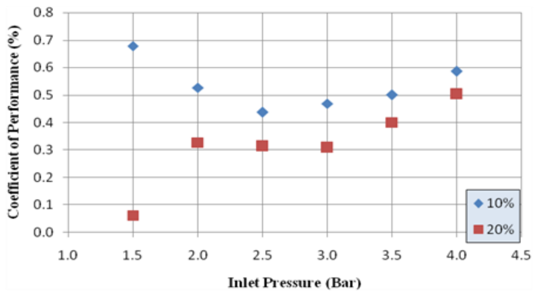

Figure 10. Coefficient of Performance versus inlet pressures for a vortex tube of 25 mm inner diameter and 100 cm hot tube length for different conical valve opening.

Based on above, it may be stated that the coefficient of performance for any vortex tube is maximum at conical valve opening of 10%, while the cold temperature deference is maximum at 20% valve opening for all inlet pressures as shown in table 4.

4.2. Effect of inlet pressure

The inlet flow pressure has been investigated. Figures 11-13 show the variations of cold air temperature difference versus the conical valve opening for different inlet pressures. It may be concluded that increasing the inlet pressure causes the cold air temperature difference to increase, as a result of increasing inlet angular momentum or centrifugal force, i.e. mixing rate. It is important to note that there is critical percentage of conical valve opening for each vortex tube which depends on tube's diameter. At this percentage, the cold temperature differences starting to decrease regardless of inlet pressures. For further details see table 5.

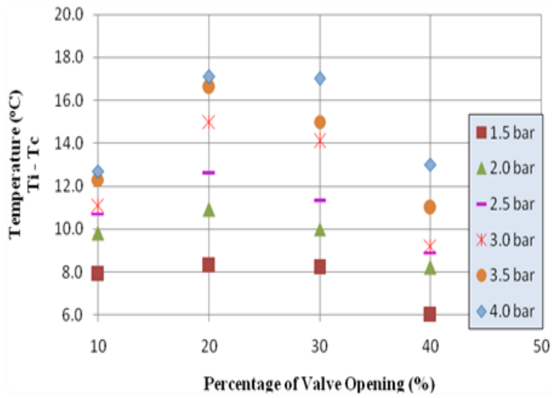

Figure 11. Cold temperature differences versus percentages of conical valve opening for different inlet pressures at a vortex tube of 14 mm inner diameter and 100 cm hot tube length

Table 2. Absolute Errors in temperature measurements (14 mm inner diameter, 100 cm length and 10% conical valve opening)

Trial Number	Cold temperature (°C)	Error (%)	Hot temperature (°C)	Error (%)
Inlet Pressure equals to 1.5 bar:				
1	9.8	2.97	23.5	1.29
2	10.4	2.97	23.4	0.86
3	10.3	1.98	23.0	0.86
4	9.9	1.98	22.9	1.29
Average	10.10	2.475	23.2	1.075
Inlet Pressure equals to 2.0 bar:				
1	8.1	5.19	23.6	1.25
2	7.3	5.19	23.4	2.0
3	7.4	3.89	24.2	1.25
4	8.0	3.89	24.4	2.09
Average	7.7	4.540	23.9	1.647
Inlet Pressure equals to 2.5 bar:				
1	6.0	4.76	23.6	2.88
2	6.5	3.17	24.0	1.23
3	6.6	4.76	24.7	1.64
4	5.9	6.35	24.8	2.05
Average	6.3	4.76	24.3	1.950

Table 3. Results for vortex tube, with a hot tube of 14 mm inner diameter and 100 cm length at 10% of conical valve opening and ambient temperature 18.5 (ºC).

Inlet Flow			Cold Flow		Hot Flow	
Pressure (Bar)	Temperature (ºC)	Flowrate (m^3/min.)	Temperature (ºC)	Flowrate (m^3/min.)	Temperature (ºC)	Flowrate (m^3/min.)
1.0	18.2	0.600	11.6	0.170	20.1	0.430
1.5	18.0	0.800	10.1	0.230	23.2	0.570
2.0	17.5	1.000	7.7	0.270	23.9	0.730
2.5	17.0	1.200	6.3	0.410	24.3	0.790
3.0	15.9	1.600	4.8	0.460	24.4	1.140
3.5	15.2	1.900	2.9	0.520	24.6	1.380
4.0	14.7	2.000	2.0	0.620	25.5	1.380

Table 4. Summarize of the critical values resulted from analyzing the effects of conical valve opening.

Vortex tube diameter (mm)	**Maximum cold temperature difference ΔT_c (ºc)**					**Maximum cold Coefficient of performance ratio COP_c (%)**				
	Max. ΔT_c	**Opening percent (%)**	**Cold mass fraction**	**Inlet pressure (bar)**	**COP_c**	**Max. COP_c**	**ΔT_c**	**Opening percent (%)**	**Cold mass fraction**	**Inlet pressure (bar)**
14	17.1	20	0.150	4.0	2.1	5.3	7.9	10	0.288	1.5
21	19.8	20	0.100	4.0	1.6	3.4	8.9	10	0.163	1.5
25	16.3	20	0.038	4.0	0.5	0.7	4.6	10	0.063	1.5
32	10.6	10	0.061	4.0	0.5	0.5	10.6	10	0.061	4.0

Table 5 . Critical percentages of conical valve opening for different vortex tube diameters

Vortex tube diameter (mm)	Critical percent of opening conical valve (%)
14	21 – 24
21	16 - 19
25	13 - 15

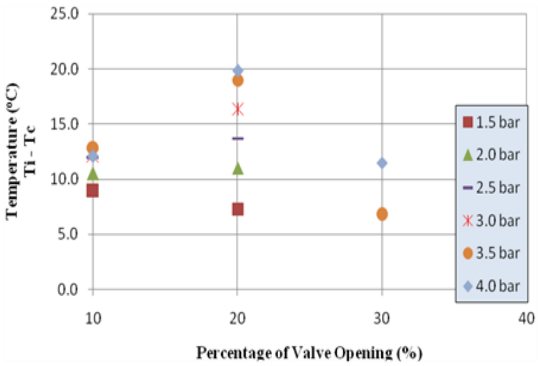

Figure 12. Cold temperature differences versus percentages of conical valve opening for different inlet pressures at a vortex tube of 21 mm inner diameter and 100 cm hot tube length.

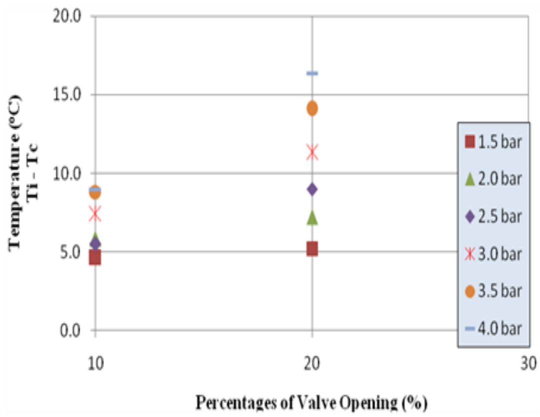

Figure 13. Cold temperature differences versus percentages of conical valve opening for different inlet pressures at a vortex tube of 25 mm inner diameter and 100 cm hot tube length.

On the contrary, the coefficient of performance is increasing with decreasing inlet pressure up to critical percentages of conical valve opening. This is clearly shown in Figures 14 - 16 below.

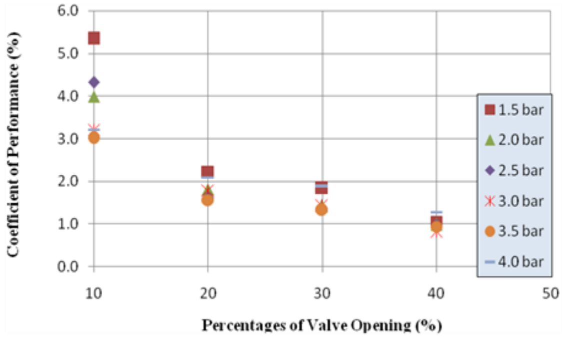

Figure 14. Coefficients of Performance versus percentages of conical valve opening for different inlet pressures at a vortex tube of 14 mm inner diameter and 100 cm hot tube length.

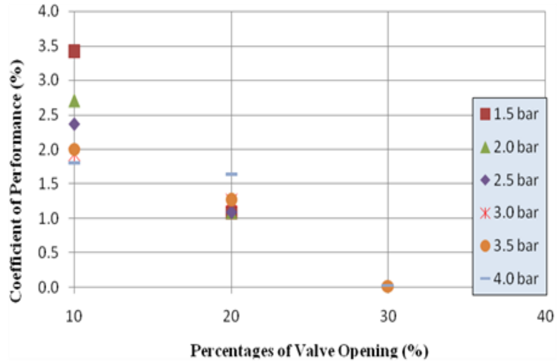

Figure 15. Coefficients of Performance versus percentages of conical valve opening for different inlet pressures at a vortex tube of 21 mm inner diameter and 100 cm hot tube length.

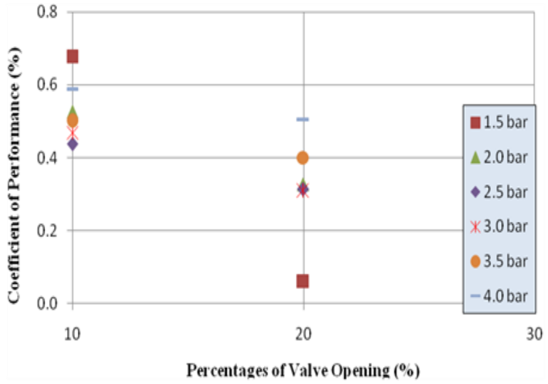

Figure 16. Coefficients of Performance versus percentages of conical valve opening for different inlet pressures at a vortex tube of 25 mm inner diameter and 100 cm hot tube length.

4.3. Effect of vortex tube diameter

Previous studies have indicated that a very small diameter of the vortex tube would offer considerably higher back pressures. Therefore, the tangential velocities between the periphery and the core would not differ substantially due to the lower specific volume of air (still high density), while the axial velocities at the core region are high. This would lead to low diffusion of kinetic energy which means low temperature separation. On the other hand, a very large tube diameter would result in lower overall tangential velocities both at the core and at the peripheral region, which would produce low diffusion of mean kinetic energy and also low temperature separation. In order to be able to study the practical effect of vortex tube diameter on its operation, we have taken 4 vortex tubes with different inlet diameters (14, 21, 25, and 32 mm). The results are shown in Figures 17-20

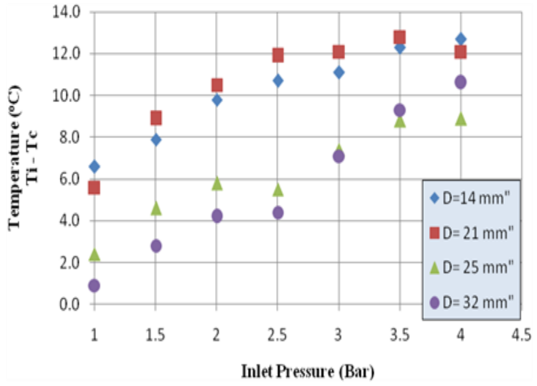

Figure 17. Cold temperature differences versus inlet pressures at 10% of conical valve opening for deferent vortex tube inner diameters.

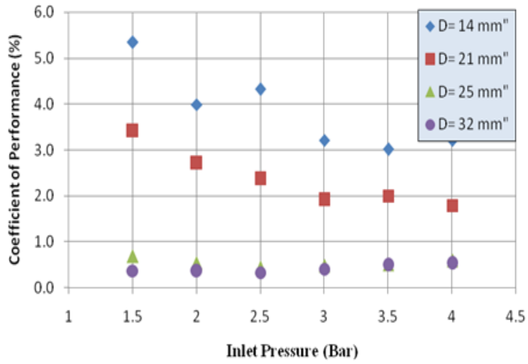

Figure 18. Coefficients of Performance versus inlet pressures at 10% of conical valve opening for deferent vortex tube inner diameters.

It is generally shown in Figures 17-18 that any increase in inner diameter of vortex tube will decrease the cold temperature deference and the coefficient of performance simultaneously. As counter to this rule, vortex tube with 21 mm inner diameter has introduced the best cold temperature differences during our experiments.

4.4. Effect of Hot tube length

In order to study the effect of length on the performance of the vortex tube, the hot tube lengths for two samples have been changed. Therefor vortex tubes with inner diameters equal 14 and 21 mm were used and their hot tube lengths were also changed to 25, 50, 75 and 100 cm.

Figures 19 - 20 below show the results of changing the hot tube length in a vortex tube of 14 mm inner diameter under 40% of conical valve opening. It is clearly seen that lengths 50 cm and 75 cm have produced the best performance regardless of the inlet pressures.

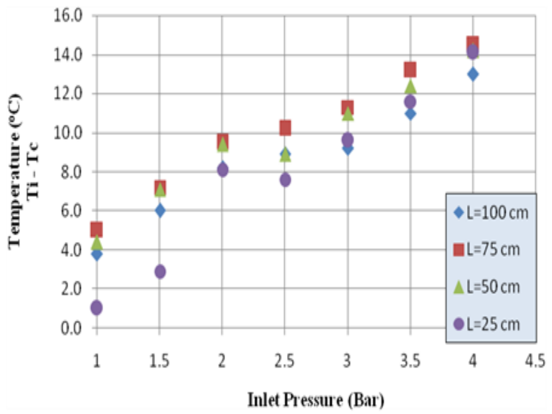

Figure 19. Cold temperature differences versus inlet pressures at 14 mm inner diameter vortex tube and 40% of conical valve opening for deferent hot tube lengths.

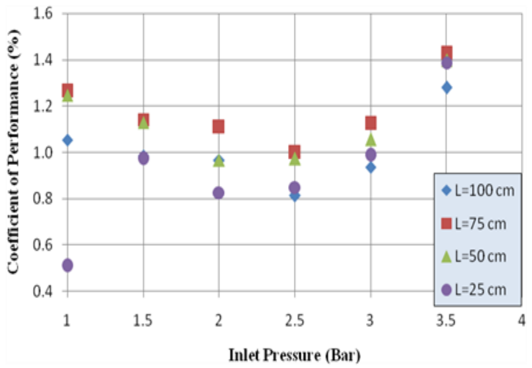

Figure 20. Coefficients of Performance versus inlet pressures at 14 mm inner diameter vortex tube and 40% of conical valve opening for deferent hot tube lengths.

Figures 21 - 23 below show the results for another vortex tube of 21 mm inner diameter operating at 20% of conical valve opening to prove the conclusions. It is clear here that hot tube length between 75 cm and 100 cm is too suitable for this vortex tube diameter.

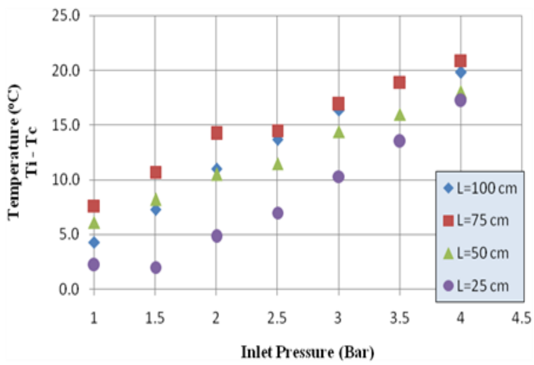

Figure 21. Cold temperature differences versus inlet pressures for a vortex tube of 21 mm inner diameter operated at 20% of conical valve opening for deferent hot tube lengths.

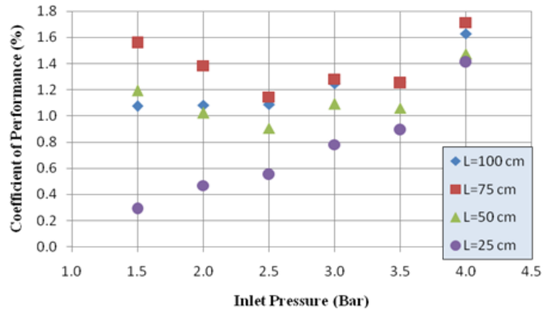

Figure 22. Coefficients of Performance versus inlet pressures for a vortex tube of 21 mm inner diameter operated at 20% of conical valve opening for deferent hot tube lengths.

As a result, using vortex tube with (L_h/D) ratio between 36 and 50 has been recommended, but using ratio equal to 36 is cost-saving - with maintaining the same level of performance - specially for vortex tubes operating at inlet pressures of more than two bars.

4.5. Effect of insulation

Figures 23-28 show the relationship between inlet pressures, temperature differences at the two exits and coefficients of performance for vortex tubes of inner diameters 14 and 21 mm operating with and without insulation. The non-insulated vortex tube provided a higher cold temperature reduction compared to the insulated one by about 2 degrees. This is due to the transition heat that has been prevented from escaping to the surroundings by the insulation being acquired by cold and hot streams.

This result has been proved in Figures 25-26 by showing the increase in hot temperature of the hot stream using insulated tube. The coefficient of performance decreases slightly with using insulation, this is clearly seen in Figures 27- 28 below.

In addition to what mentioned above, the insulation effect becomes more obvious with the increase of hot tube diameter and length due to the increase in the heat exchanging area insulated.

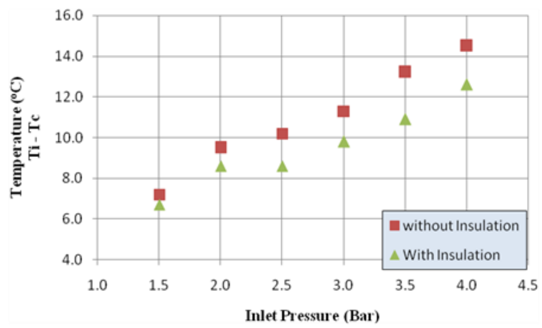

Figure 23. Cold temperature differences versus inlet pressures for a vortex tube of 14 mm inner diameter and 75 cm hot tube length operated at 40% of conical valve opening with and without insulation.

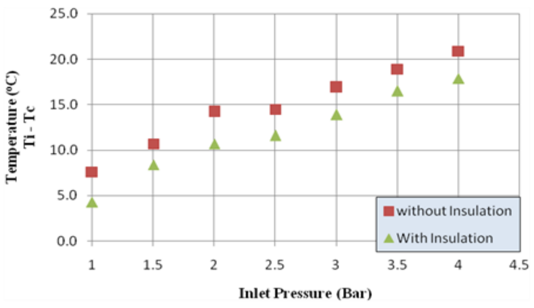

Figure 24. Cold temperature differences versus inlet pressures for a vortex tube of 21 mm inner diameter and 75 cm hot tube length operated at 20% of conical valve opening with and without insulation.

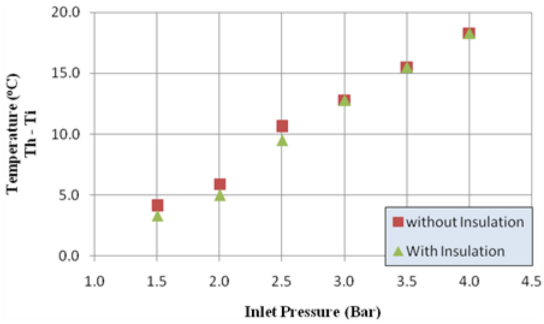

Figure 25. Hot temperature differences versus inlet pressures for a vortex tube of 14 mm inner diameter and 75 cm hot tube length operated at 40% of conical valve opening with and without insulation.

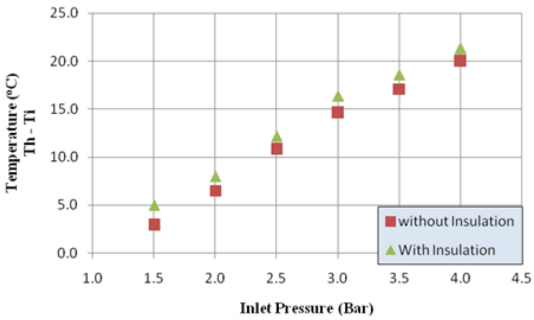

Figure 26. Hot temperature differences versus inlet pressures for a vortex tube of 21 mm inner diameter and 75 cm hot tube length perated at 20% of conical valve opening with and without insulation.

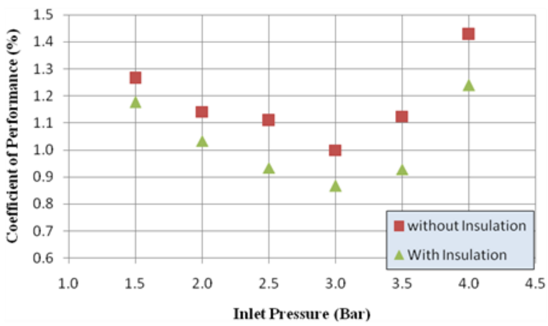

Figure 27. Coefficients of Performance versus inlet pressures for a vortex tube of 14 mm inner diameter and 75 cm hot tube length operated at 40% of conical valve opening with and without insulation.

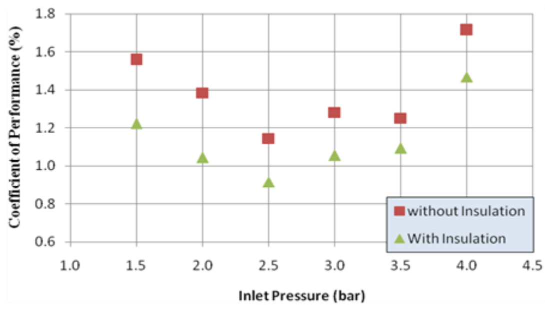

Figure 28. Coefficients of Performance versus inlet pressures for a vortex tube of 21 mm inner diameter and 75 cm hot tube length operated at 20% of conical valve opening with and without insulation.

5. Conclusions

The thermal performance of a vortex tube with conical control valve is studied experimentaly. Results were obtained for different values of: conical control valve opening, inner diameter of the vortex tube, hot and cold side lengths, inlet pressures and with and without insulation.

As a result of the presented study, it can be said that the inner diameter of vortex tube is one of the most important parameters that affect the tube performance; since any increase in vortex tube inner diameter produces a decrease in its coefficient of performance and cold temperature reduction. It was observed that the 75 cm length of the hot side length, gives the maximum coeffecint of performance for RHVT, as well as the maximum cold temperature reduction, either with or with out insulation. Moreover, the thermal performance of the RHVT, was optimum for the two inner diameters; 14 and 21mm.

This would indicate that, when the ratio of hot side length to inner diameter (Lh/D) lies between 36 and 50, then the thermal performanmce of the RHVT is optimum and it is highly recommended, which agrees with the results of published previous studies.

In general, it was found that 20% of conical valve opening produced maximum cold temperature reduction at all inlet pressures, regardless of geometrical parameters of hot tube, while 10% of conical valve opening has caused the vortex tube to operate at the maximum coefficient of performance. It is very necessary to mention that results also reflect the fact that, increasing inlet pressure causes the cold temperature reduction to increase regardless of conical valve opening.

It was found that conical valve opening is characterized by the following:

- It is inversely proportional to the inner diameter of the vortex tube.
- The vortex tube operates at maximum cold temperature reduction regardless of the inlet pressure at this range.
- At this range, the coefficients of performance converge to closed values.
- Increasing inlet pressure will decrease coefficients of performance up to these critical ranges and then the relation will be reversed, so that increasing inlet pressure will increase coefficients of performance.

The insulated vortex tube gave less energy loss to the surroundings than the non-insulated one, causing a higher hot temperature difference within the hot tube and lower cold temperature difference in the cold tube, giving a lower coefficient of performance.

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