Comparative study between Vortex Tube Refrigeration System and regular Air Conditioner: Experiment

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Abstract

Refrigeration plays an important role in developing countries, primarily for the food preservation, medicinal activities, and for the air conditioning. Conventional refrigeration systems are using Freon and CFC's as refrigerant. As this chemicals are the main cause for depletion of ozone layer, extensive work is going on alternate refrigeration projects.Thermal separation flow studied and preliminary tests suggest that with the increase in technological advancements, vortex tube refrigeration can be effectively used in place of conventional refrigeration systems. In this paper, comparative study has been done on regular air conditioner and environment friendly refrigeration system. A model is designed and constructed, in the laboratory, for the experiment on the vortex cooling system incorporating the thermoelectric module. Test parameters are the cold fraction from 0 to 1 and an inlet air pressure of 4 bars. The results show that the COP of vortex tube refrigeration system is less than the regular Air conditioner but it can be used as a cooling medium for spot cooling at thermal machinery, cutting tool, electronic enclosure and vest cooling. In the mining where the working environment may be uncomfortable and inconvenient to construct conventional cooling system, vortex cooling has proved to be useful.

Keywords: Refrigeration; Vortex tube; Efficiency; Cooling capacity

Introduction

A vortex tube is a thermal device that can produce hot and cold air streams continuously and simultaneously using only a compressed air source. Air is commonly used as a working medium in the vortex tube; hence, the vortex cooling is an environmentally friendly system. Other benefits of vortex cooling are fast cooling, short time producing a low temperature stream, and no moving parts thus little requirement for maintenance. The device is also called Ranque-Hilsch tubes and Ranque-Hilsch vortex tubes, named after the people who invented and published significant research on the vortex tube. Several studies presented the finding on the unique energy separation phenomena in the vortex tube. Compressed gas at higher pressure than atmospheric enters the tube inlet passing through radial nozzles into the swirl or vortex generation chamber where it creates a high speed flow with thousands of rotations per second. Two different airstreams produced then flow along the tube where a high temperature stream is found at outer region while a low temperature stream is observed at the central region as shown in Fig.1.

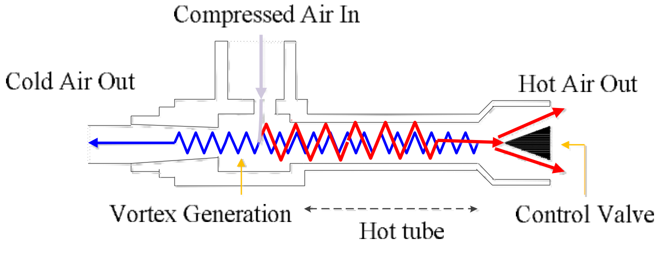


Fig.1. Counter-current flow type of vortex tube

Nowadays, the most widely used application of refrigeration are for air conditioning of homes and commercial buildings, and refrigerating edible items in homes and restaurants . The use of refrigerators in kitchen for storing fruits and vegetables has allowed adding fresh salads to the modern diet year round, and storing fish and meats safely for long periods. By using vortex tube refrigeration system, both hot and cold effects can be produced without any harmful effects to the environment.

Based on experimental study, temperatures of the flow stream inside the vortex tube were measured using small thermostat [1]. This found that an expansion of a centrifugal field is the main cause of energy separation which regards to the turbulent eddies and adiabatic contraction. Another study showed that a vortex braid is formed and results in the viscous heating to the gas near the vortex chamber wall at the same time the adiabatic cooling of gas near the axis of the tube [2]. There is a supporting statement on the heat transfer and turbulent flow model in which the acceleration and viscous resistance created by a high speed rotation of the flow effect to the variation of the fluid pressure. This has caused the energy separation [3]. Another study presented the finding of secondary flow that contributed to the energy transfer between the two difference flow streams as a result of the energy separation effect [4]. The secondary circulation flow was enclosed in the primary vortex flow and moved the backflow from the core region to peripheral region which carried the energy from a cold to a hot flow.

The fluid flow characteristic in vortex tube was studied using computational methods [6]. This indicated the areas of high and low air temperatures. It also presented the area where the secondary flow occurred. The advantage of a computational method is clearly less expensive when considering the installation cost for the test rig and the cost of all measuring instruments. A review of computational flow models was presented [7]. The computational fluid dynamic codes were employed for the study on vortex tube performance and thermal separation effect. Real dimensions were referred in the simulation model which aimed to optimize the tube performance and operating condition. One subject of the vortex tube remains to be debated among researchers in this field is the theory on the energy separation phenomena.

1. ASSUMPTIONS

The following assumptions were made for the ease of calculation:-

1. The entire system is insulated and the process are adiabatic.
2. The outlet pressures are equal to atmospheric pressures.
3. The cold end diaphragm and hot end conical valve does not absorb any heat.
4. The flow is turbulent.

2. Experimental Setup

A vortex tube made of stainless steel from AiRTX is used. The counter current vortex tube has one inlet, line vertically, and two outlets, line horizontally, located at the opposite end. The dimension of the vortex tube is measured and illustrated in table 1.

Detail	Dimension(mm)
Tube diameter (inlet)	7.5
Hot outlet diameter	15.2
Cold outlet diameter	19.1
Generation chamber (outside diameter)	27.8
Hot tube length	68.9

Table 1. Vortex tube dimension

Experimental description

A test rig is designed and constructed in the laboratory where a compressed air outlet is located. Ambient air is compressed by the compressor. A pressurized air flows into an air storage tank then goes to the pressure regulator, to control an inlet air pressure, for the test condition. The vortex tube, counter current flow type, is employed in the test for the baseline system. The vortex tube is later modified and combined with thermoelectric module at the hot tube section which aims to increase the system efficiency by reducing the temperature of hot tube surface. An inlet compressed air goes to the radial nozzles that generate thousands of rotation of the flow then separates into two different temperature airstream and exit the tube at different ends. Temperature is measured by thermocouple at an inlet and the two outlets of the vortex tube. Variable cold and hot air flow rate can be adjusted by turning the needle valve at the end of the vortex tube. To measure air flow rate, variable area flow meters are installed at the vortex tube outlets.

The thermoelectric module was tested prior to install at the hot tube section of the vortex tube, in which the heat flow is controlled at constant temperature on one side as seen in Fig.3. At the same time, the other side of thermoelectric module is surrounded by ambient air. Voltmeter and ammeter were used to measure voltage and current generated by thermoelectric module. This experiment is done with due respect of all the assumptions being taken by our team and under the critical conditions.

Empirical model

Measured temperature and air flow rate are used to determine the vortex cooling capacity and efficiency.

The vortex cooling capacity can be determined

$$Q_c = \dot{m}_c\, c_p\left(T_{in} - T_c\right) \qquad (1)$$

where c_p is a specific heat at constant pressure (kJ/kg.K),

$\dot{m}_c$ is a cold air mass flow rate (kg/s),

T_{in} and T_c are an inlet air temperature (K) and a cold air temperature (K) respectively.

The cold mass fraction, CF, is the ratio of a cold air mass flow rate to a total inlet air flow rate.

$$CF = \dot{m}_c / \dot{m}_t \qquad (2)$$

The isentropic efficiency of a vortex cooling system can be calculated

$$\eta_s = \Delta T_c / \Delta T_s$$

where ΔT_s is an isentropic temperature difference (K), P_a and P_{in} are atmospheric and inlet air pressure (N/m^2) respectively and c_v is a specific heat at constant volume (kJ/kg.K).

3. Figures and Tables

Fig 1 : Actual variable Flow meter

Fig 2 : Actual Vortex Tube

Calculations

1. Pressure Range = (4-5 bar)
2. Temp. Difference of cold end (ΔT) = 19.1
3. Temp. Difference of hot end (Δt) = 19.7
4. T(atm) = T(inlet) = 26.7 °C
5. Discharge (d) =6.38*10-5 m3/s
6. Mass Flow Rate (m) =4.47*10-4 kg/s
7. Cooling Effect (q) = 8.72 W
8. Heating Effect (Q) =3.91 W

Table 2. Temperature Difference

Sr. No.	Pressure Range (bar)	Inlet Temperature (˚C)	Hot End Temperature (˚C)	Cold End Temperature (˚C)
1.	4-5	26.7	46.4	7.6
2.	3-4	26.7	40.2	13.3
3.	2-3	26.5	34.1	16.1
4.	1-2	26.5	30.3	18.2

Table 3. Cooling Effect

Sr.No.	Pressure Range (bar)	Discharge (m3/s)	Temperature Difference	Cooling Effect (W)
1.	4-5	$6.38*10^{-5}$	19.1	8.72
2.	3-4	$5.24*10^{-5}$	16.2	5.23
3.	2-3	$4.44*10^{-5}$	13.4	2.43
4.	1-2	$3.61*10^{-5}$	9.7	1.07

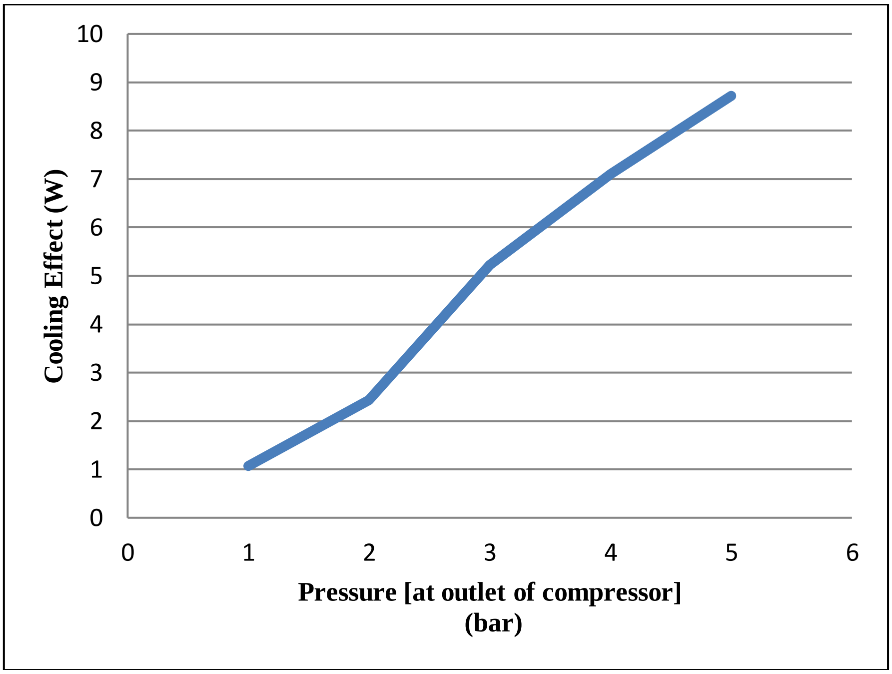
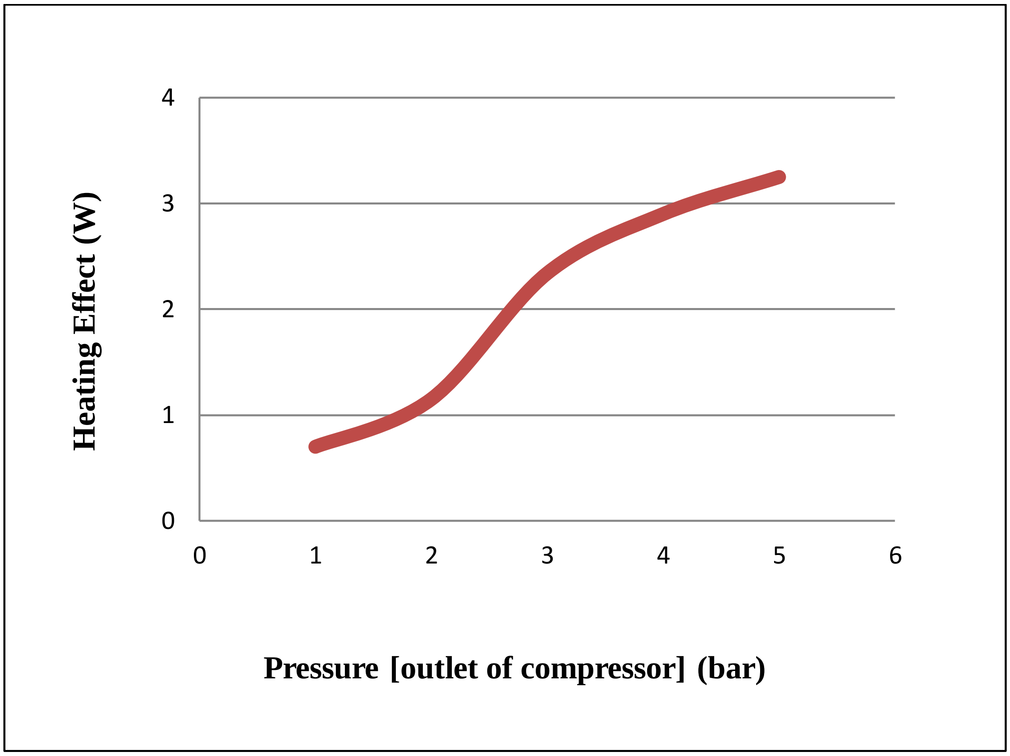
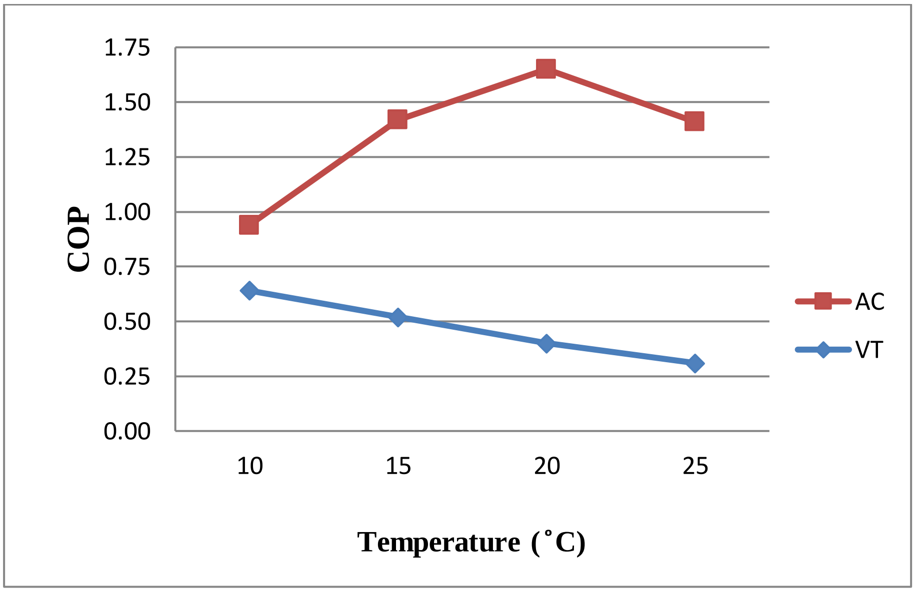


Table 4. Heating Effect

Sr.No.	Pressure Range (bar)	Discharge (m3/s)	Temperature Difference	Heating Effect (W)
1.	4-5	$2.77*10^{-5}$	19.7	3.91
2.	3-4	$2.22*10^{-5}$	17.2	2.34
3.	2-3	$1.80*10^{-5}$	15.7	1.15
4.	1-2	$1.38*10^{-5}$	4.8	0.7



Comparison of Coefficient of Performance



Conclusion

A model of the Vortex Tube refrigeration system is described that incorporates the physics and operating mechanism. The model is faithfully reproducing a limited set of data if two dependent and empirical parameters are adjusted. An experimental study on the temperature separation in the Vortex Tube has been carried out and this research finding can be summarized as follows –

1. Temperature difference increases with increase in Inlet Pressure.
2. Efficient working point of the existing design is at a cold mass fraction 0.64 for an inlet pressure of 5 bar.
3. The increase of the number of inlet nozzles led to higher temperature separation in the Vortex Tube.
4. Using the tube with insulation to reduce energy loss to surroundings gave a higher temperature separation in the tube than that without insulation around 2-3°C for the cold tube and 2-5°C for the hot Tube.
5. The performance of a regular air conditioner found to be more effective than vortex tube refrigeration system .Although it can be used where conventional cooling with air conditioner is not possible.

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