International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

Experimental Analysis of Space Cooling Using Refrigeration System Creating Vacuum

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Abstract **In today's world, human comfort is one of the most important need. Refrigeration and air conditioning devices were developed to fulfill this need. But the refrigerant used in refrigerator and air conditioner is very harmful for our environment. Many refrigerant used such as CFCs or which contain chlorine atoms, damages ozone layer day by day. Chlorine oxide present in the CFCs, reacts with ultraviolet rays from the sun and splits into Cl (chlorine) and O (oxygen) atoms. One CFCs molecule breaks one lakhs ozone molecules [23]. Therefore, many new refrigerant replaced CFCs but they have their own harmful effects for environment.**

In this paper, system is based on the steam jet refrigeration system and water used as a refrigerant. The steam jet is replaced by vacuum pump, which creates same effect as steam jet. The aim of this paper is to find the coefficient of performance and analyses the application of vacuum cooling technique to the cooling of water and show the pressure effect on cooling time, temperature decrease and vice-versa. Also find out the limitation of cooling of water and the cooling of air cooler with this refrigeration system. Experimentally we have found that the maximum degree of cooling of water in 1 hour was 10°C. After 1 hour rate of cooling decreases drastically and takes much more time to cool than the previous hour.

***Keywords* — *Vacuum cooling, refrigeration, vacuum chamber, water refrigerant, heat exchanger, air cooling*.**

I. INTRODUCTION

The term 'refrigeration' is used for the process of extracting heat from a space. It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings. In other words, the refrigeration means a continued extraction of heat from a body, whose temperature is already below the temperature of its surroundings. The subject of refrigeration has evolved out of human need for food and comfort, and its history dates back to centuries

In this paper, system is based on the steam jet refrigeration system and water used as a refrigerant. And the steam jet is replaced by vacuum pump, which creates same effect as steam jet is produced. So, the requirement of thermo-compressor and main condensers are removed and cost of the system is decreased.

Such a system has been discussed by Sukumar et al [1], Hande Mutlu Ozturk et al [3], Karl McDonald et al [9] in various areas but they did not analyse the variation of pressure, temperature and time with cooling of water and the limitations of the system. So aim of this paper is to analyse the application of vacuum cooling technique to cool water and this cooled water is used in heat exchanger to cool air. This paper shows the effect of pressure on cooling time, temperature decrease and vice-versa. The COP of the system is found out and limitation of cooling of water and the cooling of air is discussed.

II. WORKING PRINCIPLE OF VACUUM REFRIGERATION SYSTEM

The basic idea behind vacuum refrigeration system is to decrease the boiling point of water by creating vacuum in the vacuum chamber. The simple mechanism of vacuum refrigeration system is shown in the fig. 1:

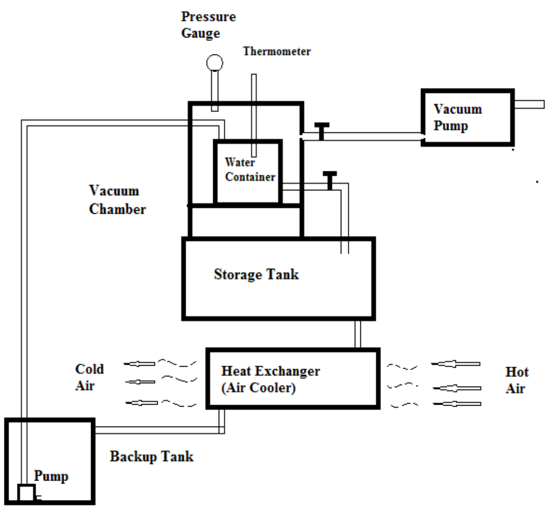


Fig. 1: Schematic diagram of Vacuum Refrigeration System

 DOI : 10.18231/2454-9150.2018.0909

ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

Water is stored in the vacuum chamber under atmospheric pressure. Vacuum pump creates low pressure (below atmospheric pressure) in the chamber. Due to low pressure water boils below its normal boiling point (100^{o}C). During boiling it takes heat from itself and is vapourised. During this process water is cooled in the vacuum chamber. This cooled water passes through the pipe and stored in the storage tank. From the storage tank cooled water is supplied to the heat exchanger due to head. In heat exchanger, water passes through the helical coil copper tube and air blows over the tube in the opposite direction. During this process the air is cooled by water. At the outlet of the heat exchanger we get cooled air and hot water. And this hot water is supplied to the backup tank which maintains water level in the vacuum chamber. The Experimental setup is shown in fig. 2 and its schematic diagram is shown in fig. 3.

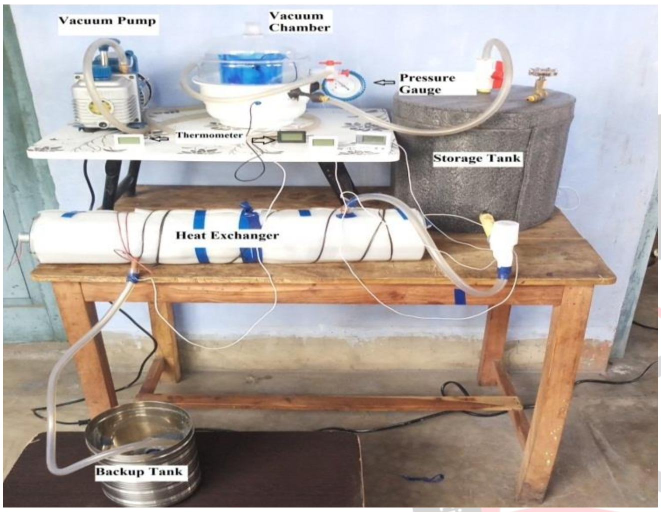


Fig. 2 Actual Setup of Vacuum Refrigeration System

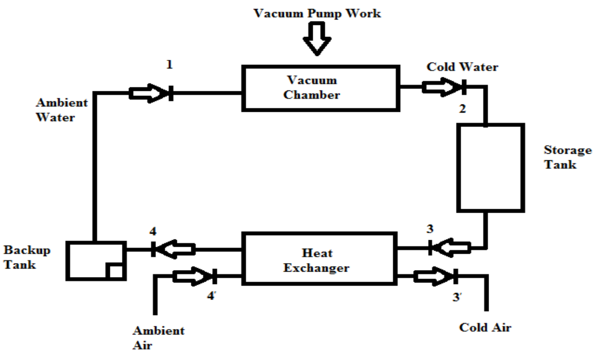


Fig. 3 Schematic Diagram of Vacuum Refrigeration System

II.I Design of Vacuum Refrigeration System

Many operational and physical factors contribute to the refrigerator performance. Since the aim is to build an eco-friendly system and at the same time make a simple system to facilitate the study, steam jet system has been eliminated. Main component of the system are:

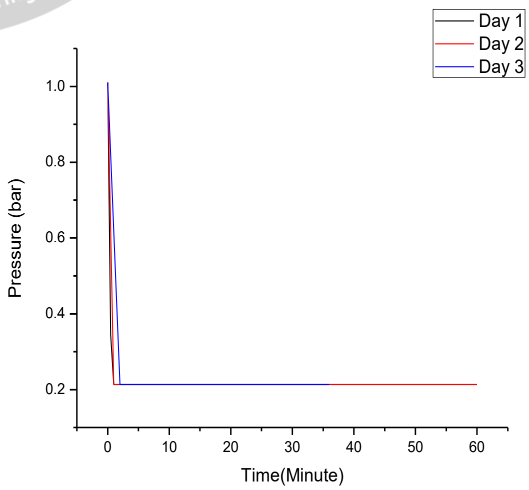
- Vacuum pump
- Vacuum chamber
- Water container
- Storage tank
- Backup tank
- Pump
- Heat exchanger
- Thermometer
- Pressure gauge

II.II Experimental Procedure

1.5L of water is poured into the water container. Both inlet and outlet valves of water supply to vacuum chamber are closed and the suction valve of the vacuum pump is made to be opened. The initial pressure of the chamber and the temperature of the water are noted. After that the vacuum pump is started. Pressure of the vacuum chamber and temperature of the water are noted for 1 hour at every 30 seconds interval for first day, at every 1 minute interval for second day and at every 2 minutes interval for third day. With this information, COP of the vacuum chamber has been calculated. Initially water is filled in the water container and after starting the vacuum pump, water in the vacuum chamber is started to cool. After getting the desired temperature of water, valve of the vacuum pump gets closed and valve of storage tank (19^{o}C) gets opened. Now water is allowed to flow in storage tank. In this way when desired water level in the storage tank that is 10L is achieved, our whole system starts working in cyclic manner. Now water is allowed to flow from the storage tank to counter flow heat exchanger. Inlet and outlet temperatures of water and air of the heat exchanger are noted at every 30 seconds for 15 minutes. The water is coming from the heat exchanger is stored in the backup tank due to water head. The stored water is pumped to vacuum chamber with the help of circulating pump.

III. OBSERVATION

Graph 1: Vacuum chamber pressures vs. time

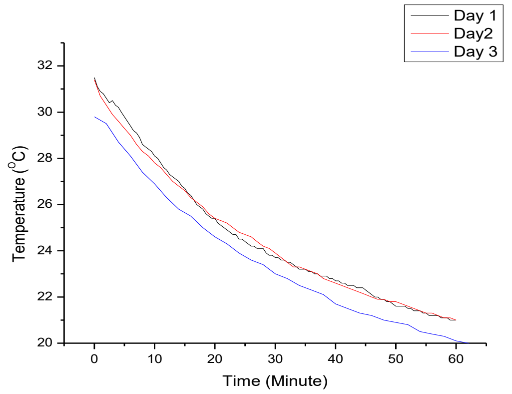


Above graph 1 shows the variation of vacuum chamber pressure with time for three consecutive days. At initial stage, atmospheric pressure is present in the vacuum chamber. Within 1 minute its pressure decreased to .213bar and it is constant throughout the experiment. Maximum

 DOI : 10.18231/2454-9150.2018.0909

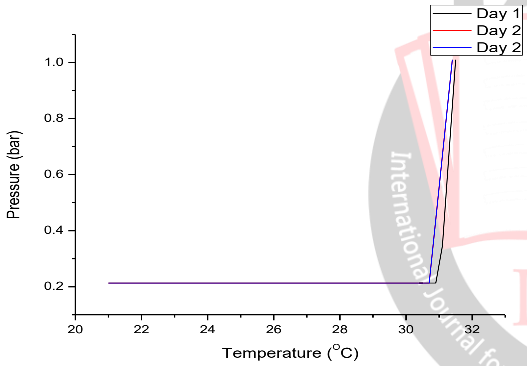
degree of cooling occurs at this constant pressure. We found that the pressure inside the vacuum chamber becomes constant at .213bar due to limited capacity of vacuum pump. If we use high capacity of vacuum pump then the rate of cooling become increase.

Graph 2: Water temperatures vs. time



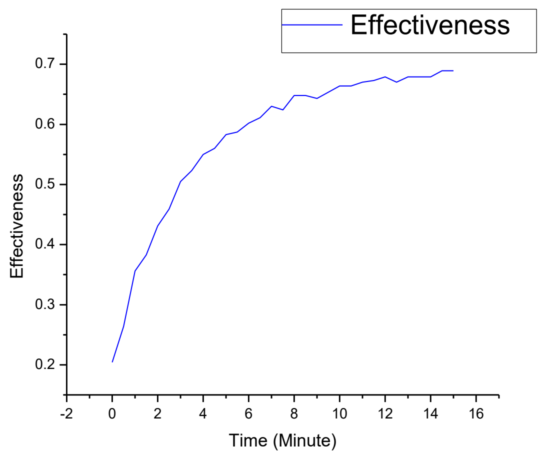
The variation of temperature with time of three consecutive days shows in the graph 2. The rate of temperature drop is approximately similar in three days. Rate of cooling mainly depends on the pressure of vacuum chamber.

Graph 3: Vacuum chamber pressures vs. water temperature



Graph 3 shows the variation of pressure with temperature drop. We have seen that the large temperature drop occurs at .213bar.

Graph 4: Time vs. Effectiveness



Graph 4 shows the variation of effectiveness of heat exchanger. Effectiveness is increased with decreasing the outlet temperature of air (T_3'). After 15 minutes, the outlet temperature of air becomes nearly equal to the inlet temperature of cooled water in the heat exchanger. Due to this, effectiveness of heat exchanger becomes constant after 15 minutes.

IV. RESULT AND DISCUSSION

The aim of this analysis is to determine the effect and limitation of vacuum cooling on the water. The effect of the cooling of water depends on the vacuum pressure. The variation of water temperature depends on the pressure of air in the vacuum chamber during the vacuum cooling is measured while the results are given in graph 3(In three different day conditions). As can be seen in the graph 1, after 2 minutes (approx.) the air pressure in the vacuum chamber becomes constant and equal to .213bar during the cooling period. Temperature of the water decreases during vacuum cooling by .2°C (average value) every 2 minutes, as can be seen in graph 2.

The experiments were carried out with 1.5 L of water at a time and some amount of water is lost during the cooling process due to evaporation, is considered negligible. When the chamber pressure is equal to the saturated pressure at the local temperature, water starts to boil in the vacuum chamber and the evaporation of the water causes cooling. These experiments were carried out for 1 hour in a day and the maximum degree of cooling found in 1 hour was 10°C. After 1 hour rate of cooling decreases drastically and takes more time cool than previous hour. Some temperature drop occurs in the system through pipe, chamber wall, storage tank etc. during the experiment. So the temperature of water at the storage tank was 20.1°C. Counter flow heat exchanger is used to cool ambient air. When cooled water is supplied to the heat exchanger it cools ambient air temperature to 24°C within 15 minutes and the average effectiveness of the heat exchanger is found 0.575, as can be seen in graph 4.

Therefore, overall COP of the system is found that 0.711. The system COP is low as compared to commercial refrigeration system but it has a lot of advantages. Here refrigerant used is eco-friendly as it does not produce any harmful impact on our environment. It has negligible global warming potential and ozone depletion potential.

V. CONCLUSION

In this study, analysis of vacuum cooling refrigeration system to cool air has been carried out based on the experimental values. The following conclusions may be drawn from the experimental results of the present analysis:

➢ The vacuum cooling is a fast cooling method with high COP [4]. But the present experiment has been done with ¼ HP vacuum pump, so the vacuum chamber pressure becomes constant after 2 minutes and equal to 0.213 bar.

 DOI : 10.18231/2454-9150.2018.0909

The temperature of the water gradually decreases with the rate of 0.1^{o}C per minute and it gives 10^{o}C of cooling per hour. After 1 hour, rate of cooling of water decreases due to constant vacuum pressure in the chamber. We can use high power vacuum pump to get high rate of cooling by dropping air pressure in the chamber.

➢ In this experiment pressure is the most important factor for cooling effect. So, some leakage problem may be occurs during experiment. And some heat losses also occur so we need to use good insulating material over the system components.

➢ The calculated effectiveness of air cooler (heat exchanger) is found 0.575. The temperature drop of ambient air of 6^{o}C is achieved by this heat exchanger.

➢ The COP of vacuum cooling refrigeration system is found to be 0.711. The low COP can be compensated with the eco-friendly nature of the system as it free from toxic refrigerant.

➢ This system does not contain compressor, evaporator and condenser, so it is cheap from conventional refrigeration system.

➢ This system can be recommended in domestic room cooling, cold storage and food processing industry with the main objective of being eco-friendly.

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