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Development of Performance Using Phase Change Material in VCR System

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Abstract

The main aim of this paper is to enhance the coefficient of performance in the vapour compression refrigeration system (VCRS) by using phase change material. The phase change materials are solid, liquid, and vapour. Water is the most natural example of a substance that we use almost every day applications in all three phases; what is common to these three phases is that the water molecules remain unchanged, meaning that ice, water, and steam all have the same chemical formula as H_2O. The refrigeration system is a freezing system that uses two types of refrigerants having different boiling temperature points. They run through their own independent freezing cycle and are joined by a device called a heat exchanger. A refrigeration system is introducing the pump in the place of the heat exchanger with PCM based refrigerator. In this system temperature, it brings down up to -20^{o}c, reduces power consumption and To retain cooling effect for a long period of time without power supply and finally refrigeration system the refrigeration effect can be increased by 28% as compared to a single system for producing -20^{o}C in the cold storage.

Keywords*: - Vapour compression refrigeration system, Phase change material, Temperature*

INTRODUCTION

Refrigeration is the process of maintaining the temperature of the space below that of the surrounding temperature. Generally, refrigeration work is done by using a mechanical process or by means of electrical work. By using electrical work, we will run almost all refrigeration process. A refrigerating system which cool or maintain a body at a temperature below that of surrounding temperature refrigerating machine which will either cool or maintain a body at a temperature below that of surrounding temperature. The machine R absorbs heat Q_1 from a cold body at temperature T_o and with the aid of work input W_{in} from external agency and rejects heat Q2 to the surroundings at higher temperature T_2.

Methods of Refrigeration: Refrigeration utilizes several methods of providing differential temperature facilitating heat transfer between two bodies. Following are the various methods of refrigeration system. 1. Ice refrigeration 2. Dry ice refrigeration 3. Air expansion refrigeration. The primary and secondary refrigerants can be classified according to The Fluids suitable for refrigeration purposes. The Primary refrigerants are those fluids, which are used directly as working fluids, for example, in vapour compression and vapour absorption refrigeration systems. The primary refrigerants, when used in compression or absorption systems, these fluids provide refrigeration by undergoing a phase change process in the evaporator and condenser.

LITERATURE SURVEY

Before the invention of the household refrigerator, icehouses were used to develop cool storage for most of the year-round applications. Natural refrigeration is still used to cool foods for today applications. Especially On mountainsides, runoff from melting snow is a convenient way to cool drinks, and during the winter, one can keep milk fresh much longer just by keeping it in conditions of outdoors.

The history of artificial refrigeration had begun when Scottish professor William Cullen designed a small refrigerating system in 1755. The Cullen used a pump to create a partial vacuum other than a container of diethyl ether which then boiled, absorbing heat from the surrounding air. The experiment has even created a small amount of ice, but it had no practical application at that time.

The first practical system of vapor compression refrigeration machine was built by James Harrison and next to a British journalist who has immigrated to Australia. In 1856 patent was for a vapour compression system using ether, alcohol or ammonia refrigerants. He built a mechanical ice-making machine in 1851 on the banks of the Barwon River at Rocky Point in Geelong, Victoria, and his first commercial ice-making machine followed in 1854. And Harrison also introduced commercial vapour-compression refrigeration to breweries and meatpacking houses, and by 1861, a dozen of his systems were in operation.

The literature on low-temperature vapour compression refrigeration is usually focused on compound refrigeration systems. A study on the thermodynamic analysis of a 2-stage R134a refrigeration system with intercooling determined that the optimum interstage pressure is very close to the saturation pressure corresponding to the arithmetic mean of the condensing and evaporating temperatures and that most of the irreversibility losses steam from low Compression efficiency (Zubair et al., 1996). Another study on the performance of a 2-stage R22 refrigeration system with intercooling determined the effect of condensing, evaporating, refrigerated medium and environment temperatures on the system's irreversibility rate (Nikolaidis and Probert, 1998). Molenaar (1992) investigated the performance of a cascade refrigeration system using 2 different refrigerant couples, namely R502/R13 and R22/R23, to and a replacing couple with a lower ozone-depleting potential for R502/R13. A cascade heat pump system used for providing a hot water stream and utilizing R12 refrigerant was developed and experimentally analyzed in another study (Hasegawa et al., 1996).

The effect of evaporating temperature on the performance of a cascade system using R22/R23 refrigerants were also examined (Cho et al., 2001). Kanoglu (2002) performed an exergy analysis of cascade refrigeration. A system consisting of 3 individual cycles and used for natural gas liquefaction. Kilicarslan (2004) presented the experimental performance of a cascade refrigeration system using R134a in both lower temperature and higher-temperature cycles and relying on a water stream to exchange heat between the cycles.

As seen from the literature survey outlined above, a thorough comparison of the experimental performances of single-stage and cascade refrigeration systems has not been made yet. Therefore, the main objective of this study is to compare the performance characteristics of these systems using R134a as the working fluid, while the secondary objective is to investigate the effect of using a refrigerated condenser water stream on the performance of a refrigeration system. For this purpose, 2 experimental plants were developed and instrumented. These plants employ a refrigeration cycle serving as a base unit for each system, a bench-top cooling tower and another refrigeration cycle serving as a higher-temperature unit for the cascade system.

The performance of the experimental single-stage system using 3 different types of condensers, namely air-cooled, water-cooled and evaporative condensers, was presented in a previous study (Hosoz and Kilicarslan, 2004). In the present study, the single-stage operation was achieved using only a water-cooled condenser. The base unit and higher-temperature unit of the cascade system were thermally connected to each other by means of a water stream. Each refrigeration system was tested by varying refrigeration capacity in the base unit and the water flow rate passing through the condenser of the base unit. Then, the performance characteristics of both systems, namely condensing and evaporating temperatures, refrigerant mass flow rate, compressor power, coefficient of performance (COP), compressor discharge temperature, compressor volumetric efficiency and the ratio of compressor discharge to suction pressures, were determined and compared with cop values.

PHASE CHANGE MATERIAL

A phase change material (PCM) is a substance that can store or release significant amounts of heat energy by changing its phase from liquid to vapor or vice versa. It has already been proven that the incorporation of PCM with refrigeration systems improves the energy efficiency as well as the quality of frozen food. The idea to use phase change materials (PCM) for the purpose of storing thermal energy is to make use of the latent heat of a phase change, usually between the solid and the liquid state. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes. The successful usage of PCMs is, on the one hand, a question of a high energy storage density, but on the other hand, it is very important to be able to charge and discharge the energy storage with thermal power that is suitable for the desired application.

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid by using its heat capacity. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

Latent heat storage uses the latent heat of the material to store thermal energy. Latent heat is the amount of heat absorbed or released during the change of the material from one phase to another phase. Two types of latent heat are known, latent heat of fusion and latent heat of vaporization. Latent heat of fusion is the amount of heat energy absorbed or released when the material changes from the solid-state to the liquid state or vice versa, while latent heat of vaporization is the amount of thermal energy is absorbed or released when the material changes from the liquid phase to the vapour phase or vice versa.

Figure 1

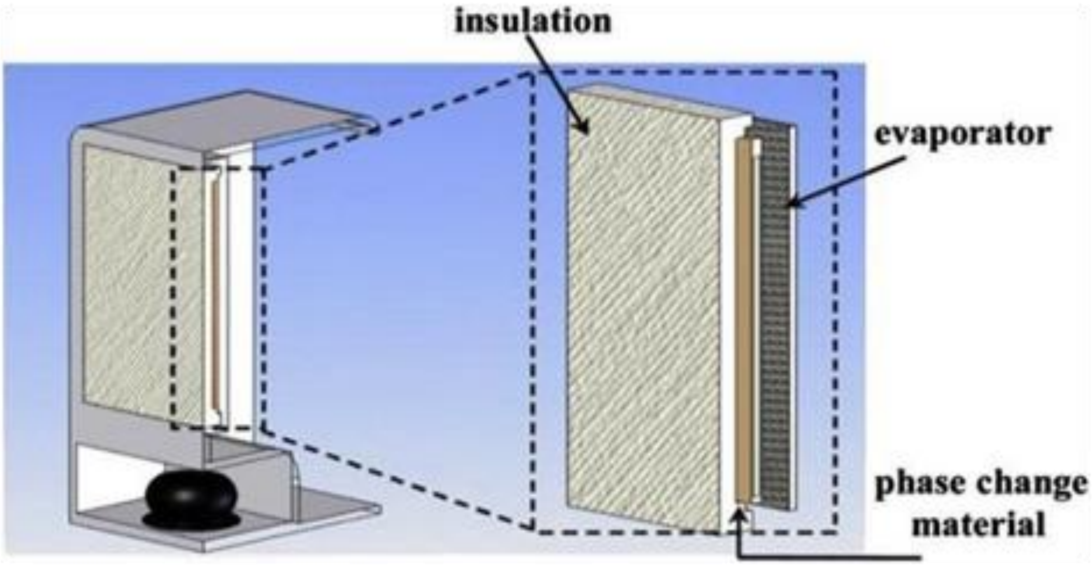

Figure 2

Phase changes happen as the temperature change. All substances can exist in three different states: they are solid, liquid, and vapour. Water is the most natural example of a substance that we use almost every day applications in all three phases. For the water, the three phases have received different names - making it a bit confusing when using it as a model substance. The solid phase we call ice, the liquid form we just call water, and the vapour form we call steam. What is common to these three phases is that the water molecules remain unchanged, meaning that ice, water, and steam all have the same chemical formula as H_2O.

PCMs are preferred due to their large-scale availability and low-cost investment. Salt hydrates (M_nH_2O), Eutectics, Hygroscopic materials ethylene glycol.

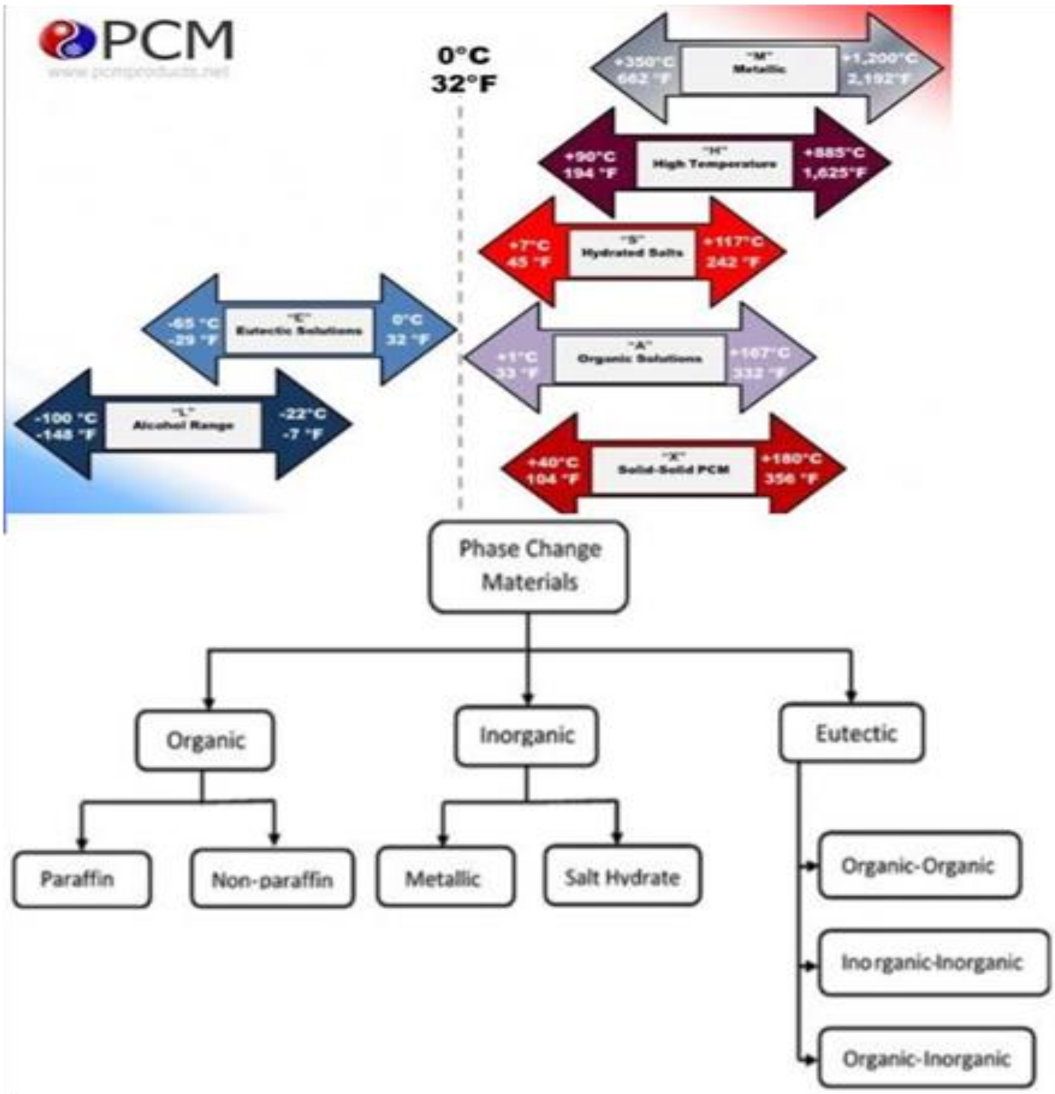

Figure 3

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EXPERIMENTAL SETUP

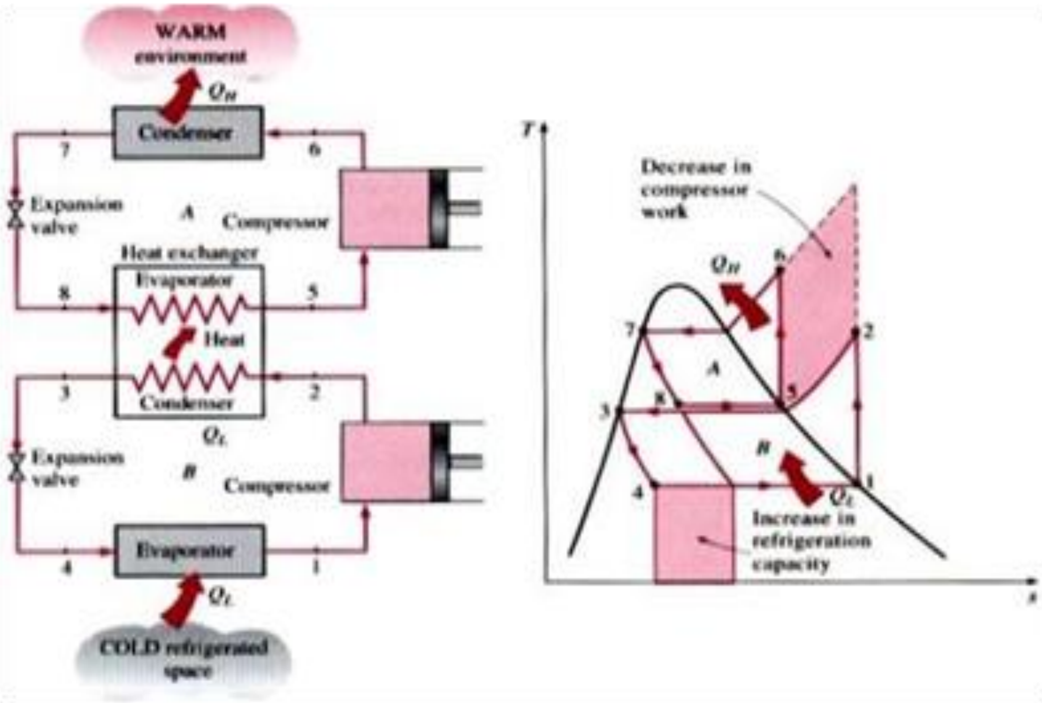

Figure 4

A two-stage cascade refrigeration system uses two types of compressor devices; they run individually with different refrigerants, connected among them so that the evaporator of the first cycle used for cooling of the second cycle condenser (i.e., the evaporator with the first unit cools the condenser of the second unit). In practice, an alternative approach using a common capacitor with a booster circuit to provide two separate temperature limits of the evaporator. See above **figure 4**.

In the present work, a parametric study with a fixed mass flow rate in a low-temperature circuit and varying different parameters such as evaporator temperature, condenser temperature and temperature difference in cascade condenser have conducted to determine the effects of these parameters on system performance. The analysis is done by making general assumptions so as to simplify the analytical procedure; these are as follows.

a) Negligible change in kinetic and potential energy.
b) Isenthalpic expansion of refrigerant in the expansion valve.
c) Negligible pressure and heat loss/gain in the pipe or other components
d) The compressor process is irreversible and adiabatic.

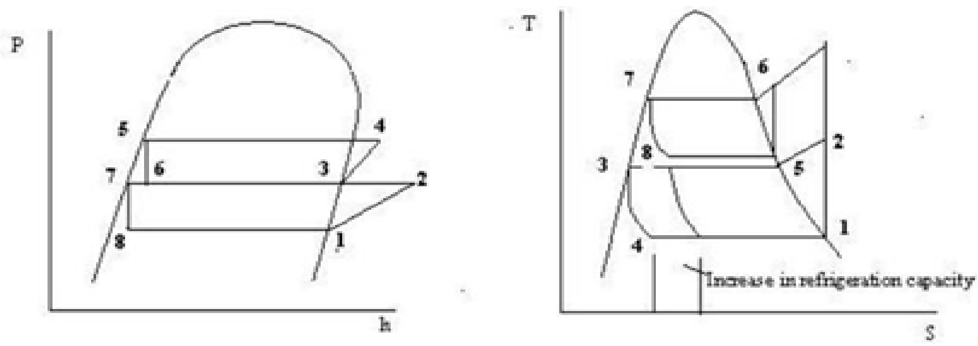

Figure 5

Advantages of Cascade Systems

- In a cascade system using different refrigerants, so that it is possible to select a refrigerant that is best suited for that different temperature range. In the manner of Very high or very low pressures can be avoided for extending.

- In this system, migration of lubricating oil from one compressor to the other compressor is prevented.

- The saving of energy is more because the system allows the use of refrigerants that have suitable temperature limits characteristics for each of the higher-temperature side and the lower-temperature side.

- It allows, especially for stable ultra-low-temperature operation.

- The running cost of this system is inexpensive.

- Repair and maintenance is easy.

Description of the Setup: The test rig is a cascade refrigeration system. This test rig mainly consists of compressors, condenser, expansion devices, cascade condenser, evaporator, water pump and PCM. This cascade refrigeration system is generally divided into two vapour cycles. These two vapour cycles are run individually; the cycles are

1. Higher temperature cycle
2. Lower temperature cycle

Higher temperature cycle

- In a high-temperature cycle, the high-pressure gas from the compressor flows through an oil separator where the compressor lubricant oil and refrigerant are separated, and oil is fed back to the compressor.

- The high-pressure refrigerant from the compressor entering into the air-cooled condenser.

- The condenser is cooled by a fan, which is run by compressor. In condenser, the high-pressure vapour refrigerant is converted into high-pressure liquid refrigerant due to latent heat of evaporation.

- This high-pressure liquid refrigerant is entering into the expansion device; in the expansion device, the throttling process will take place the pressure is reduced as a condenser to evaporator pressure.

- The low-pressure liquid refrigerant is entering into the evaporator, where the liquid refrigerant takes the heat from the refrigerated space and converts it into vapour.

Lower temperature cycle

- The working process of the lower temperature cycle is the same as, the higher temperature cycle, but the differences are as follows.

- The lower temperature condenser is cooled by the higher temperature evaporator, which is achieved by keeping the pump between the higher temperature evaporator and lower temperature condenser.

- The pump can supply the refrigerated water, which is generated by a higher temperature cycle to the lower temperature cycle condenser, where the heat transfer takes places from refrigerant which is flowing in the coils to the cooling water, and this cooling water is converted into hot water, this hot water is again supplied to the higher temperature cycle evaporator by using a pump. So, in this way, the cold and hot water is supplied in between high-temperature cycle evaporator and lower temperature condenser by using a pump.

PCM

- In this system, ethylene glycol is used as a phase change material.

- The PCM is incorporated between the lower temperature evaporator coil and the refrigerated space.

- Initially, the PCM is in a liquid state; the refrigerant, which is flowing in a lower temperature evaporator, gives cooling to the PCM.

- The PCM can store this cooling for a long period of time and extract the heat from the refrigerated space.

RESULT AND SCOPE OF WORK

Without PCM

It is evident that the temperature is decreasing gradually with respect to time up to a temperature of -10^{o}C with a time of 3.6 hours; after that, for getting a temperature from -10^{o}C to 0^{o}C, it will take a time of only 1.9 hours.

Finally, without a PCM panel in cascade refrigeration system for getting a temperature from -20^{o}C to 0^{o}C, it will take a time of 5.5 hours totally.

With PCM

The relation between the Time Vs Temperature with PCM panel for cascade system. From the above graph, it is evident that the temperature is decreasing almost uniformly with respect to time from a temperature of -20^{o}C to 0^{o}C.

Finally, in cascade refrigeration system with PCM panel, for getting a temperature from -20^{o}C to 0^{o}C; it will take a time of 14.5 hours totally, with this, by using the PCM panel, we will retain the cooling effect for a long period of time.

Objectives

The objectives of the performance improvement of the cascade refrigeration system by using the phase change material (PCM) are given below,

- To fabricate the experimental set-up by modifying the cascade refrigeration system as introducing the pump in the place of heat exchanger with PCM based refrigerator.
- To bring down the system up to -20^{o}C.
- To reduce power consumption.
- To retain cooling effect for a long period of time without power supply.
- To compare the performance of single-stage cycle with a binary cycle.
- To observe the system with PCM and without PCM.

CONCLUSIONS

The desired working model of the cold storage plant of cascade refrigeration system with and without (PCM) phase change material is successfully designed and fabricated. And It is also successfully tested for working.

- From the experimentation, it is observed that in Cascade (Binary) refrigeration system, the refrigeration effect can be increased by 28% as compared to single system for producing -20°C in the cold storage.

- By using a cascade system, the actual work can be reduced by 21% as a compared single system for producing -20°C in cold storage.

- Experimental results show that the coefficient of performance (COP) of the cascade refrigeration system is higher than single refrigeration system.

- With phase change material (PCM), panels at the walls of cold storage can maintain the temperature for a long period of time.

- Experimental results show that for getting a temperature from -20°C to 0°C, without phase change, material takes a time of 5.5 hours, with phase change material, takes a time of 14.5 hours, with this, by using the PCM panel, we will retain the cooling effect for a long period of time as compared to without PCM.

- Reduction of a temperature in a cascade cold storage plant using PCM panels has observed that a reduction of 10°C approximately for every one hour.

- With phase change material, the COP can be increased around 10% to 20 % other than without PCM.

- With phase change material, the compressor work can be reduced by 15 % to 25 % as compared to without PCM.

- From the experiment, it is observed that the COP is maximum at 1.5 kg of thermal load while it decreases with the increase of thermal loads.

- It is understood that present-day, due to intermittent power supply and power crisis, it has become compulsory to have continuous cooling to the frozen items. It is also observed from the system that while the power supply is off, this method is the cheapest when compared to all other alternate power sources systems.

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