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Improving Performance of vapour compression refrigeration system by using PCM in evaporator

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ABSTRACT

This present study presents the solidification behaviour of water based PCM (Phase Change Material), surrounded in an evaporator coils by using copper. The PCM was prepared by Propane-1, 2-diol and Ethane-1, 2-diol with volume fractions of 22.85% and 25% in de-ionized (DI) water as the base PCM. The solidification experiments was conducted the with and without the PCM at surrounding bath temperature of -11˚C and 0˚C respectively. The presence of Propane-1, 2-diol and Ethane-1, 2-diol acted as nucleating agent that caused appreciable reduction in the sub cooling. It is a possible energy saving is 20-25% in the CTES (Cold Thermal Energy Storage) using the PCM. Hence the proposed system will be a new thing for performance improvement of a cold storage.

KEY WORDS: Refrigeration system, Phase Change Material (PCM), Cold Thermal Energy Storage, Coefficient of Performance, Energy Saving.

1. INTRODUCTION

The uses of PCM enhances the rate of heat transfer and hence improve the COP (Coefficient of Performance), of refrigeration that in conventional refrigerator compressor efficiency improves by increase in compressor displacement for single speed compressor (Pere Moreno, 2014). The method proposed to take advantage of high cooling capacity of large compressor with PCM to increase the refrigerator autonomy i.e. off-cycle period, without power supply, from a few minutes to several hours (Fuxin Niu, 2013). The effect of ambient temperature can be minimized by fitting vacuum insulated panels into the cabinet walls. They offer twice the level insulation of polyurethane foam and result in an increased refrigerator storage volume (Rezaur Rahman, 2013). The main reasons preventing the use of this technology are related to reliability over lifespan and high manufacturing and disposal costs (Azzouz, 2009). PCM in evaporator and to analyse the effect of PCM on compressor running time to evaluate the saving in power consumption of compressor (Mehling, 2008).

The energy consumption for the refrigerators is affected by several factors, such as the ambient temperature, product loading and number of door openings, thermostat setting position and refrigerant migration during the compressor it will be off (Imran Hossaen Khan, 2013). The effect of ambient temperature can be minimized by fitting vacuum insulated panels into the cabinet walls. As compared to polyurethane foam they offer twice the level of insulation which also results in an increased refrigerator storage volume (Barreneche, 2013). The main reasons preventing the uses of this technology are related to less reliable over lifespan and high disposal and manufacturing costs (Oro, 2012). It will be increase the efficiencies of refrigerators for aqueous salt solutions are the main PCM (Azzouz, 2008).

Preparation Of Water Based PCMS: The PCMs were prepared by a small amount of Propane-1, 2-diol and Ethane-1, 2-diol in water using a one-step method. The Propane-1, 2-diol and Ethane-1, 2-diol was used for water based PCMs with a volume fraction of 22.85% and 25% in each sample. Propane-1, 2-diol is used for fabric industry, and polyethylene terephthalate resins (PET) used in bottling process. Table.2 shows the properties of PCM 2. The Propane-1, 2-diol and Ethane-1, 2-diol is separately mixed with DI water and continuously stirred for 30 min. Several single-step methods have been arrived for PCM preparation. This process is familiar as VEROS (Vacuum Evaporation onto a Running Oil Substrate). But prime problem is that only low vapour pressure fluids are compatible with such a process

Table.1. Properties of PCM 1 (22.85% of Propane-1, 2-diol + 77.15% of DI water)

IUPAC ID	Propane-1,2-diol
Chemical formula	$C_3H_8O_2$
Molar mass	76.10 $g.mol^{-1}$
Density	1.036 g/cm^3
Freezing point	-11˚C
Solubility in water	Miscible

Table.2. Properties of PCM 2 (25% of Ethane-1, 2-diol + 75% of DI water)

IUPAC ID	Ethane-1,2-diol
Chemical formula	$C_3H_6O_2$
Molar mass	62.07 g.mol^{-1}
Density	1.1132 g/cm^3
Freezing point	-11˚C
Solubility in water	Miscible

2. EXPERIMENTAL SETUP

A VCRS (Vapour Compression Refrigeration System) as shown in Fig.1, for the Schematic layout of VCRS cold storage is used to perform the experiment and to evaluate the performance of Phase Changing Material. As evaporator tubes are surrounded with PCM by using copper for a good thermal contact with tubing. PCM around the tubes to avoid possible air gaps have high thermal conductivity. The thickness of the PCM is 0.004 m and the PCM occupying a volume of 0.983 kg was used for experimental investigation. The PCM surrounded the copper coil of evaporator because it will increase the contact area of PCM with evaporator coil and maximum heat will be transferred via conduction. Due to this arrangement heat transfer rate is higher in conduction as compared free convection and heat transfer losses will be reduced. The experiments were carried out initially without PCM at 0˚C and the power consumption of compressor is evaluated. Again this experiment is repeated with PCM (Propane-1, 2-diol and Ethane-1, 2-diol) at -11˚C and the power consumption of compressor is evaluated. Then the results are compared and best recommended solution is evaluated. The PCM will absorb the energy and stores the energy by changing its phase during power cuts or off peak time the PCM will releases its energy and maintains the cold cabin at constant require temperature.

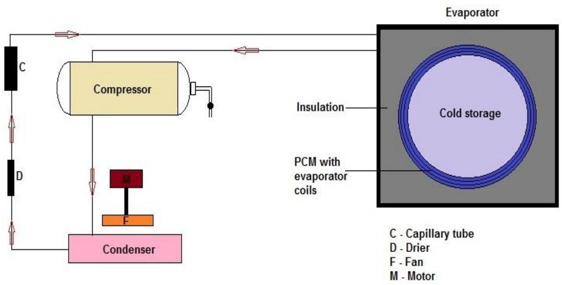

Figure.1. Schematic layout of VCRS cold storage

3. RESULTS AND DISCUSSION

Transient temperature variation of PCMs during Solidification: Fig.2 (a, b) shows the transient temperature variation of PCM at the surrounded in an evaporator coils by using copper, when the temperature of the surrounding heat transfer fluid was maintained at -11˚C. The Variation of evaporator temperature for PCM it has been observed from Fig.2 (a), that the sensible cooling of all the PCM was nearly at a constant rate. The without PCM the temperature of the surrounding heat transfer fluid was maintained at 0˚C. The Variation of evaporator temperature for without PCM it has been observed from Fig.2 (b), and by the experiment power consumption of the compressor is evaluated which is 0.35 KWh per hour for one hour of continues operation.

In this experiment the compressor works only during freezing cycle. So from all these data total power consumption is calculated and % of saving of compressor power is evaluated with comparison of experiment of without PCM. The recommended temperature of evaporator or storage depends on the type of the food products or any other storage material.

The PCM with different proportionate should be mixed with water to get the desired melting point of the mixture. This melting point should be slightly below the recommended temperature in evaporator or storage.

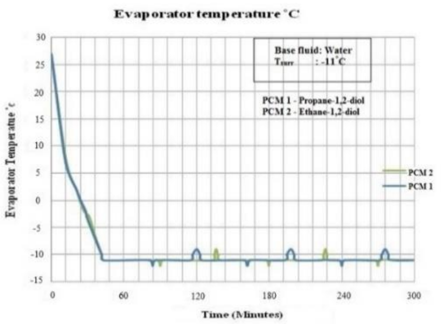

Figure.2 (a). Variation of evaporator temperature for PCM

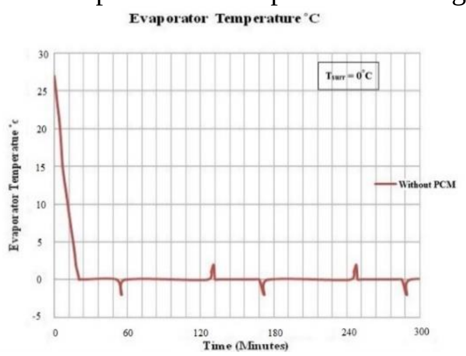

Figure.2 (b). Variation of evaporator temperature for without PCM

Co-efficient of performance: The co-efficient of performance of a refrigerating cycle is an expression of the cycle efficiency and is stated as the ratio of the heat absorbed in the refrigerated space to the equivalent heat energy supplied to the compressor. The Performance test on refrigeration test it has been observed from Table.3.

$$COP_{Carnot} = \frac{T_C}{T_H - T_C}$$

Where, T_C - Saturation temperature of refrigerant corresponding to P_1 (K), T_H - Saturation temperature of refrigerant corresponding to P_2 (K).

$$COP_{Theorectical} = \frac{h_1 - h_4}{h_2 - h_1}$$

Where, h_1 - enthalpy of refrigerant at inlet of compressor (kJ/kgk), h_2 - enthalpy of refrigerant at outlet of compressor (kJ/kgk), h_4 - enthalpy of refrigerant at evaporator inlet (kJ/kgk).

$$COP_{Actual} = \frac{m \times c_p \times (t_2 - t_1)}{(X_1 - X_2) \times 3600}$$

Where, m - mass of water in chiller (12 kg), C_p -specific heat of water (4.187 kJ/kg), t_1 - initial temperature of water in chiller, t_2 - Final temperature of water in chiller, x_1 – initial energy meter reading, x_2- final energy meter reading.

Table.3. Performance test on refrigeration test rig

S.NO	**Parameter**	**Without PCM**	**PCM 1 (Propane-1,2-diol)**	**PCM 2 (Ethane-1, 2-diol)**
1	Initial temperature of water t_1 (°C)	28	28	28
2	Final temperature of water t_2 (°C)	6	3.6	3
3	Initial energy meter reading of compressor x_1 (kWh)	432	442	446
4	Final energy meter reading of compressor x_2 (kWh)	432.3	442.27	446.26
5	Pressure of refrigerant at compressor inlet P_1 (lb/in^2)	20	22	23
6	Pressure of refrigerant at compressor outlet P_2 (lb/in^2)	160	160	160
7	Pressure of refrigerant before throttling P_3 (lb/in^2)	160	160	160
8	Pressure of refrigerant after throttling P_4 (lb/in^2)	20	22	23
9	Temperature of refrigerant at compressor inlet T_1 (°C)	15.5	15.8	16.2
10	Temperature of refrigerant at compressor outlet T_2 (°C)	58.4	60	60
11	Temperature of the refrigerant before throttling T_3 (°C)	38.2	38	40
12	Temperature of the refrigerant after throttling T_4 (°C)	5.3	5.3	5.6

The comparison of C.O.P of a refrigeration system for with and without PCM as shown in Fig.3. For purposes of comparison, the higher the COP the more efficient the system.

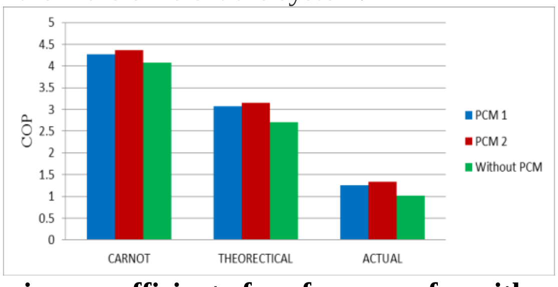

Figure.3. Comparison co-efficient of performance for with and without PCM

Energy saving potential using PCMs: It was interpreted the solidification behaviour of the PCM that there was a significant reduction in the solidification time, when the PCM was dispersed in water. In order to estimate the energy saving potential due to the presence of (Propane-1, 2-diol and Ethane-1, 2-diol) the PCM, the experimental result obtained with the PCM at T_{surr}= -11˚C was compared with that of the experimental results of without PCM at T_{surr} = 0˚C. It was found that the time for solidification of PCM at T_{surr}= -11˚C matched with the PCM containing volume fraction 22.85% and 25% (Propane-1, 2-diol and Ethane-1, 2-diol). Hence THE concluded that there is a possible energy saving it will be estimation of about 20-25% using the PCM in the CTES based chiller system as shown in Fig. 4.

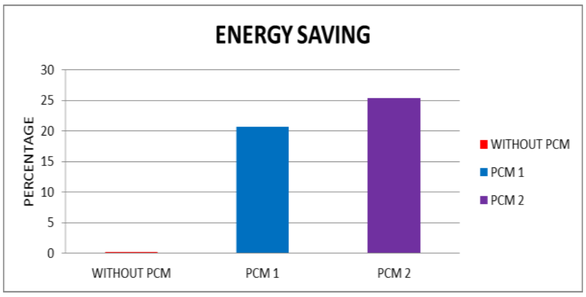

Figure.4. Variation in total energy saving for with and without PCM

4. CONCLUSIONS

The following conclusions have been obtain from the present experimental investigation on the solidification behaviour of water based PCM.

- The solidification time was considerably reduced for PCM. The PCM at the surrounding temperature of -11˚C and without PCM of 0˚C respectively due to its enhanced heat transport properties.
- The presence of high conductive (Propane-1, 2-diol and Ethane-1, 2-diol) acted as the nucleating agent to initiate the solidification in advance to that of PCM.
- The sub cooling was significantly reduced for the PCM containing minimum concentration of the Propane-1, 2-diol and Ethane-1, 2- diol.
- The sub cooling increased with increase in the concentration owing to the effects in the PCM.
- It is obtain there is an energy savings of 20-25% in the chiller with the CTES system using the PCM.

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