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Performance Improvement of Vapour Compression Refrigeration System with Phase Change Material

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ABSTRACT

Efforts to increase energy efficiency of refrigeration system shall directly reduce energy consumption. The phase change material stores the latent heat, this latent heat is utilize for heat leak from evaporator cabinet. Phase change material (PCM) is a new approach to improve the performance of refrigeration system. The refrigeration system has been tested with different PCMs Eutectic solution of melting point 0 to -5°C respectively. The three phase change materials has been tested and the observation for temperature stability has been tested, also the effect of phase change material on COP of the system has been tested. Experimental results show that when compressor is cut off the system with PCM maintains the desired temperature than without PCM. Also the COP is high if PCM is used than without PCM .In this study it shows that using phase change materials in refrigeration system is vary energy saving method.

Keywords: *PCM, Eutectic solutions, VCR, COP*

1. INTRODUCTION

The most alarming environmental disorder namely "Global Warming" refers to the rising temperature of Earth's atmosphere and ocean and its projected continuation. The heat from the Sun is entrapped in the Earth and thus increases the temperature of the atmosphere by Greenhouse Effect. Refrigeration system is directly and invisibly responsible for Global Warming problem. Also in developing countries like India there exist a wide spread general problem of frequent power cuts, which gives rise to spoilage of perishable items such as medicine and food due to lack of a passive cold retention system. moreover, there exist the pressing need of the hour to incorporate eco friendly practices from the grass root level, while at the same time conserving energy and increasing efficiency. Increasing the energy efficiency of refrigeration device is thus an important issue in terms of energy savings. Many countries have introduced labelling programs and minimum energy efficiency standards. Number of investigations have been carried out in the recent years to develop technical options for improving the energy performance of refrigeration system.

To overcome this problem Phase change material plays vital role. Phase change material (PCM) melts within a narrow temperature range, and absorbs a large amount of energy while changing state, thus minimizing the rise in the evaporator cabin temperature. PCM with a suitable phase change temperature may be used to provide thermal capacity to maintain suitable cabinet temperature during power failure. In the evaporator cabin, heat transfer from the refrigerated area to evaporator is mainly by natural convection and radiation with a low air-side heat transfer coefficient. Adding a layer of phase change material on outer side of the evaporator is a cheap and efficient solution, which results in an enhancement of the global heat transfer at the evaporator due to the conduction inside the PCM. [1]

Although the power consumption of individual refrigerators seems to be low today, these home appliances still have a large potential for energy saving because of their vast number. They have an almost complete market potential and they operate continuously thought the year. In recent years , the power consumption of household refrigerators has been reduced considerably by the manufacturers, who responded to market pressure due to the bold labeling of energy efficiency that is prescribed in many countries. For further reduction of power consumption ,both cooling load and conservation of electric energy to cooling capacity can be optimized.

Azzouz et al. (2008) in this paper studies the effect of adding a phase change material (PCM) slab on the outside face of a refrigerator evaporator. A dynamic model of the vapour compression cycle including the presence of the phase change material and its experimental validation is presented. The simulation results of the system with PCM show that the addition of thermal inertia globally enhances heat transfer from the evaporator and allows a higher evaporating temperature, which increases the energy efficiency of the system. The energy stored in the PCM is yielded to the refrigerator cell during the off cycle and allows for several hours of continuous operation without power supply

Eduard Oro et al. (2012) studied the thermal performance of freezers using phase change materials. A commercial PCM was selected with a melting temperature of 18 °C, which is contained in 10 mm thick stainless steel panels placed at different locations in the freezer. During 3 hours of electrical power failure, the use of PCM maintained the freezer temperature 4 to 6 °C lower and that of the frozen products remains at acceptable levels for much longer time. With frequent door openings the benefit of the PCM is evident when the temperature of the cabinet is near the melting temperature of the PCM.

Mohammed M. Farid et al. (2004) works on latent heat storage and provides the information about the classes of phase change materials (PCMs) for use in energy storage. Paraffin waxes and hydrated salts are the classes given in this paper. It is given that the advantages of PCM encapsulation are providing large heat transfer area. The various phase change material applications for heat storage are also given in this paper. The different applications in which the phase change method of heat storage can be applied are also reviewed in this paper. The problems associated with the application of PCMs with regards to the material and the methods used to contain them are also discussed. A.C. Marques et al. (2014) investigated the design and operation of a thermal storage refrigerator. Firstly the analysis of compressor is carried out which shows larger compressor gives higher efficiency but more start/stop events, which reduces overall efficiency. The high cooling capacity output of larger compressor is stored in a phase change material (PCM), reducing the number of on/off cycles. Numerical modelling and experimental validation is carried out using a prototype thermal storage refrigerator with PCM. The results showed that the addition of a 5 mm PCM slab into the refrigerator allowed for 3 to 5 hours of continuous operation without a power supply. The numerical model was found to be in good agreement with the experimental results, with the error between the simulation and tests below 5% for most experiments.

From above mentioned discussion it is clear that a very few experimental works of performance improvement of household refrigerator by PCM has been done. also it is clear that performance of system is improved when PCM is used.

1. Types of phase change material

1. Organic phase change compounds:

Organic phase change materials are chemically stable, avoid super cooling, noncorrosive, non-toxic and they have high latent heat of fusion.

i. Paraffin's

paraffin waxes CH3(CH2)nCH3 have low cost. and have a reasonable thermal storage density of 120 up to 210 kJ/kg. Paraffin's are available from approximately 20 up to about 70°C i.e. wide range of melting temperatures, they are chemically inert, have a low vapour pressure in the melt and they avoid phase segregation.

ii. non-paraffin's

The non-paraffin organics include fatty acids, esters, alcohols and glycols i.e. wide range of section. They are three times costlier than paraffin's but they have good melting and freezing point.

2. Inorganic phase change compounds:

Inorganic PCMs in general have a rather high heat of fusion, good thermal conductivity, are cheap and non flammable. However, most of them are corrosive to most metals, undergo super cooling and undergo phase decomposition. Most common inorganic PCMs are hydrated salts. Hydrated salts are attractive materials for thermal energy storage due to their high storage density of about 240 kJ/kg, their relative high thermal conductivity of about 0.5 W/(mK) and their reasonable cost compared to paraffin waxes.

3. Eutectics:

Eutectic mixtures or eutectics, i.e. a mixture of multiple solids in such proportions that the melting point is as low as possible, have in general sharp melting points and its volumetric storage density is slightly higher than that of organic compounds. However, limited data are available on their thermal and physical properties.

i. organic organic
ii. inorganic-inorganic
iii. inorganic-organic eutectics.

2. EXPERIMENTAL WORK

The schematic diagram of system is shown in figure (1)

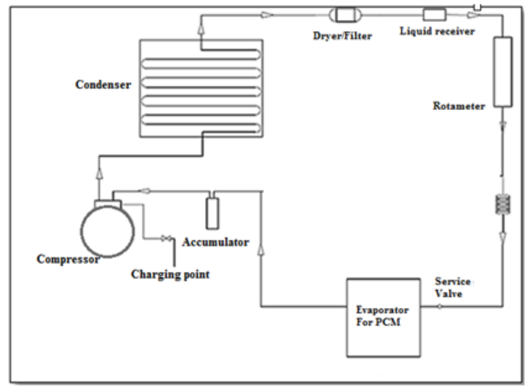

Figure 1 Schematic layout of the experimental setup

The two phase change materials are tested these are as follows

PCM	Percentage by weight	Melting point (°C)	Latent heat kJ/kg	Theoretical time
KNO_3	9.7	-2.8	296	2 hr 26 min
Na_2SO_4	12.7	-3.6	285	2 hr 22 min
NaCl	8	-5	289	2 hr 24 min

Compressor

A hermetic compressor 0.3 TR capacity is fixed on rigid foundation with help of rubber bushes to avoid vibrations. Process line is used for evacuation and charging the system. Suction line of compressor is brazed to suction main coming from system. Discharge line is connected to the condenser inlet using copper brazing. The actual setup is shown in figure (2).

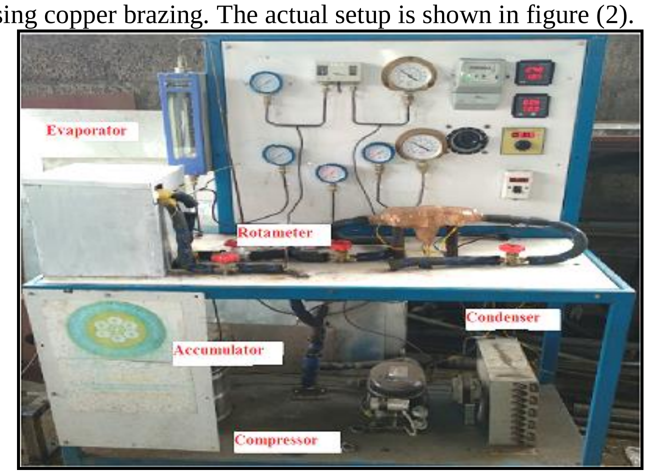

Figure 2 Developed experimental setup

Evaporator

Evaporator is shell and coil dipped evaporator. The inner vessel contains mono ethylene glycol. Outer vessel contains the PCM. The PCM is placed between inner and outer vessel. The glass wool is used for insulation.

Type = Dipped coil evaporator .

Inner diameter of vessel = 15 cm

Outer vessel diameter = 20 cm

Phase change material is filled in the gap between outer vessel and inner vessel and cooling coils are dipped in anti freezing solution.

Condenser

Finned type air cooled condenser of air conditioner is used for the system. It has 3 rows running from top to bottom in parallel. This arrangement is made so as to cool the compressor head. A pressure gauge is installed in discharge line to measure the discharge pressure of refrigerant before entering the condenser.

parameter of air cooled finned tube type

a) Mode of heat transfer= Free convection
b) Linear length of the coil= 4.1m
c) Internal and external diameter of the tube= 8.82 mm and 9.52 mm respectively.
d) Material of the tube= steel and wire tube.

Refrigerant =1, 1, 1, 2-Tetrafluoroethane (R-134a)

Capillary of size of 1.5 m length is installed for evaporator coil using brazing.

Experimental result for VCR

Sr. No.	Load	Condenser				Evaporator				Evaporator
	(W)	Inlet temp.	Outlet temp.	Sat. Press.	Sat. temp.	Inlet temp.	Outlet temp.	Sat. Press.	Sat. temp.	bath temp.
1	0	77	33	130	39.3	-13	-13	9	-15	-12
2	152	78	33	133	40.1	-12	-8	10	-14	-10
3	244	78	34	137	41.1	-11	-5	12	-12	-8
4	358	77	33	140	41.9	-9	2	14	-10	-4
5	505	78	34	152	44.7	-8	5	18	-7	2

3. RESULTS AND DISCUSSION

Sample theoretical calculations for temperature stability with PCM

PCM	Percentage by weight	Melting point (ºC)	Latent heat kJ/kg	Theoretical time
KNO_3	9.7	-2.8	296	2 hr 26 min
Na_2SO_4	12.7	-3.6	285	2 hr 22 min
NaCl	8	-5	289	2 hr 24 min

i. Potassium Nitrate (KNO_3) ,9.7% wt

From Figure it is shows that after 130 minutes the evaporator bath temperature changes from -2.2 ºC to 1.2 ºC. For potassium nitrate as a PCM its temperature changes from -2.5 ºC to 0 ºC after 130 minutes. similarly, for same temperature intervals, without using PCM, the bath temperature changes from -2.1 to 8.3 ºC. Table is given in figure

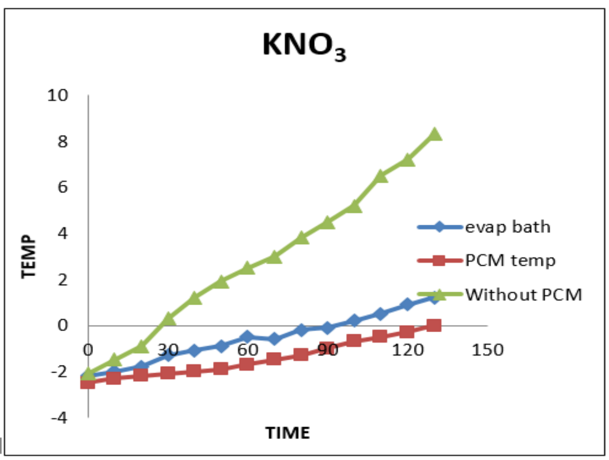

Figure 3 Temp vs. time for Potassium Nitrate (KNO_3)

ii. Sodium Chloride (NaCl), 8%

After 180 minutes the evaporator bath temperature changes from -5 ºC to 1.2 ºC. For potassium nitrate as a PCM its temperature changes from -5.8 ºC to 0.1 ºC after 180 minutes. similarly, for same temperature intervals, without using PCM, the bath temperature changes from -4.2 to 7 ºC. It is shown in figure .

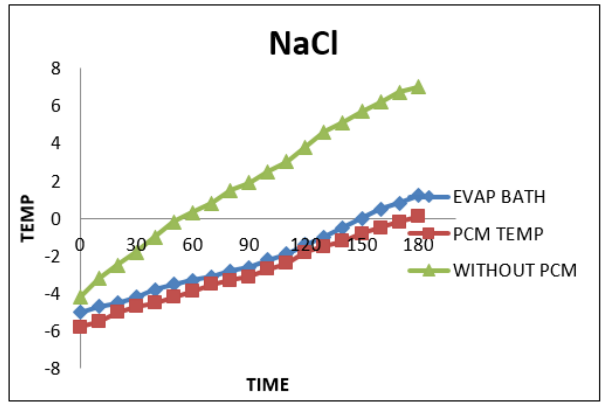

Figure 4 Temp vs. time for Sodium Chloride (NaCl)

iii. Sodium Sulphate Na2SO4

After 160 minutes the evaporator bath temperature changes from -3.8 oC to 1 oC. For potassium nitrate as a PCM its temperature changes from -4 oC to - 0.1 oC after 160 minutes. similarly, for same temperature intervals, without using PCM, the bath temperature changes from -3.6 to 6.2ºC. It is shown in figure.

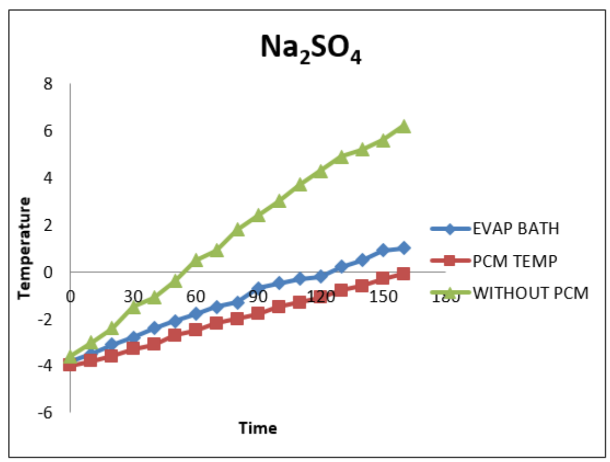

Figure 5 Temp vs time for Sodium Sulphate (Na_2SO_4)

Comparative output of PCM's

with PCM's there is increasing evaporator working temperature and corresponding saturation pressures shown in table. And there is increase in theoretical COP of system with PCM's. It is shown in below table.

Comparative output of PCM's

	Without PCM	KNO_3	NaCl	Na_2SO_4
Condenser inlet temperature t_1 (°C)	78	79	80	79
Condenser outlet temperature t_2 (°C)	34	36	34	35
Evaporator inlet temperature t_1 (°C)	-9	-7	-8	-8
Evaporator inlet temperature t_2 (°C)	-1	2	1	0
Heater Load on Evaporator (W)	505	510	502	505
Sat. Condenser Pressure (psi)	152	158	154	156
Sat. Condenser Temp.(°C)	44.7	46.1	45.2	45.6
Sat. Evaporator Pressure (psi)	14	17	15	16
Sat. Evaporator Temp.(°C)	-10.4	-7.8	-9.5	-8.6
(COP)Theoretical	3.19	3.4	3.34	3.37

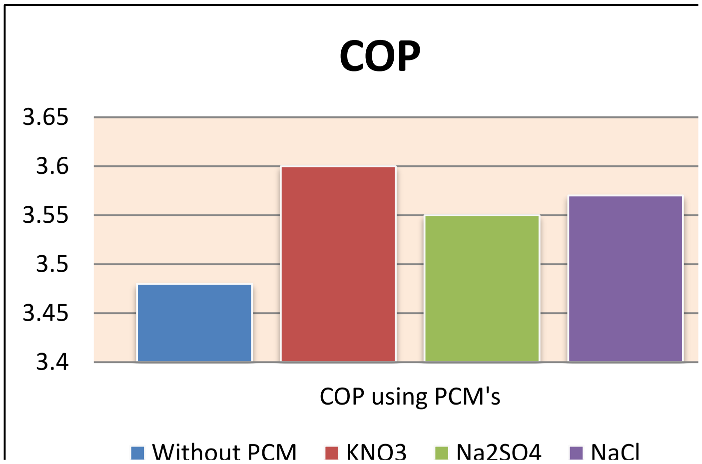

Figure 6 Compression of COP with and without PCMF

Figure shows the refrigeration cycle change with (Na_2SO_4) as a PCM in comparison to without PCM on the p–h diagram. From this diagram we can observe that the evaporating temperature and pressure is higher for PCM as compared to without PCM which ultimately increase the heat transfer rate of evaporator. During the compressor running time the refrigerant takes the chamber heat by free convection in case of without PCM, which is a slower heat transfer process with respect to conduction process. For that reason the operating temperature of the cooling coil drops very low to maintain the desired cabinet temperature. But with PCM most of the heat in the cabinet is stored in the PCM during compressor on time and this heat is extracted by the refrigerant through conduction during compressor running time. Since conduction heat transfer process is faster than the free convection process the cooling coil temperature does not require dropping very low to maintain desired cabinet temperature. As a result the evaporator works at high temperature and pressure with PCM.

4. CONCLUSION

Based on experimental readings, following conclusions can be made

1. Longer Compressor OFF time with PCM was achieved thus improving the stability of the system
2. Less fluctuations in temperature of cabinet was observed ,due to this desired temperature is maintained in the cabinet.
3. Higher evaporator temperature and pressure with PCM than without PCM which ultimately increase the heat transfer rate of evaporator.
4. COP of system is higher with PCM than without PCM.

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