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Investigation on Performance Parameters of Vapour Compression Refrigeration System by Incorporating Phase Change Materials

Dr. K.Dilip Kumar[1], T.Ayyappa[2], and Dr. K.Vijay Kumar[3]

[1] Associate Professor: Dept. of Mechanical Engineering, LBRCE, Mylavaram, India. Email: dilip_011@yahoo.co.in
[2] M.Tech Student : Dept. of Mechanical Engineering, LBRCE, Mylavaram, India. Email:ayyappa.thota4u@gmail.com
[3] Professor: Dept. of Mechanical Engineering, LBRCE, Mylavaram, India. Email: pjoel2013@gmail.com

Abstract

Efforts to increase energy efficiency of refrigerators shall directly reduce energy consumption in vapour compression refrigeration system. Incorporating phase change materials (PCM) is a new approach to improve the performance of refrigerators. This paper presents the results of experimental tests carried out to investigate the performance of household refrigerator using a three types phase change materials (PCM), which have low melting points. These are Eutectic salt solutions, paraffin C14 wax, and ethylene glycol. The PCMs is locates the back side of the evaporator. In this study we are comparing between the simple VCR system, PCM equipped VCR system. Performance parameters like actual C.O.P, refrigeration effect, theoretical C.O.P, capacity of the system are compared .From this study among all three types of PCMs ethylene glycol equipped VCR systems gives better results than simple VCR system. The increment in the PCM equipped VCR system parameters than simple VCR system is actual C.O.P is 4.2%, refrigeration effect rate is 19.8%, capacity of the system 11.6%, theoretical C.O.P 14.2% Economic analyses shows that using PCMs in household refrigerators is clearly a cost effective method that saves energy and reduces harmful emissions.

1. INTRODUCTION

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 penetration and they operate continuously throughout the year. The largest share of the electrical power consumption by private households in the OECD member states is caused by refrigeration (IEA, 2003). In Germany this share is about 20%, translating to about 7% of the total national electric power consumption (Barthel et al., 2005). 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. Nowadays, energy efficiency has become the decisive criterion for the consumer upon appliance replacement decisions (Faberi et al., 2007). For a further reduction of power consumption, both cooling load and the conversion of electric energy to cooling capacity can be optimized. The according technical developments can be divided into three categories:

1) Improvement of casing and door: By using polyurethane foam, which has long become standard, instead of polystyrene insulation, which has been common up into the 1980s, the cooling load was reduced by about 30%. Similar additional progress can be achieved through the application of e.g. vacuum insulated panels, but they are hardly used due to their high production cost in this price sensitive segment (Philipp, 2002). However, a simple increase of the polyurethane insulation thickness is mostly not effective because of the reduced net storage volume.

2) Improvement of compressor efficiency: The application of variable speed compressors enables for a transition from their common intermittent operation by on/off control towards a continuous and variably controlled operation. Less friction losses, a higher evaporation and a lower condensation temperature as well as a reduction of losses associated with the pressure equalization during compressor off times can be achieved. These effects may lead to a reduction of power consumption by up to 30% (Binneberg et al., 2002). However, variable speed compressors are usually not used in simple household refrigerators because of their substantially higher costs.

3) Improvement of heat transfer performance of evaporator or condenser: The maximum efficiency of cooling processes is determined by the difference between evaporator and condenser temperature. Reducing the condenser temperature resp. raising the evaporator temperature by 1ºC typically leads to a power consumption that is reduced by about 2.4%. E.g., enlarging the effective heat transfer surface area of condenser or evaporator by approximately50% reduces the power consumption by 6% or 10%, respectively (DKV, 1985). Another option is to use ventilators for the improvement of the convective heat transfer.

However, the power consumption of such ventilators themselves must be put in relation to the overall performance gain (Roth, 2008).

The use of thermal heat storages, which is discussed in the present study, falls into the third category. Phase change materials (PCM) can absorb large quantities of heat at almost constant temperature. Thereby, temperature fluctuations can be reduced, which is interesting for numerous applications.

2. EXPERIMENTAL SETUP.

In this present study of investigation we fabricated vapour compression refrigeration system, which have the components like compressor, condenser, evaporator, expansion valve, and filter. All these are circuited with copper tubes of diameter 7mm by brazing process. In this test rig we used measuring devices like pressure gauge, T-Type thermocouples with indicator ammeter, voltmeter. In this experimental test rig we used to charge the refrigerant R134a after evacuating the test setup. The lubricant used in the compressor is R134a PAG oil. The lubricant oil should match the refrigerant within the system.

Table 1: Properties of refrigerant R134a

Physical properties	**HCF-134a**
Boiling point	-26.3ºc
Freezing point	-103.3 ºc
Critical density	515.3 kg/m^3
Critical temperature	213.9 ºc
Critical pressure	4060kpa
Heat capacity(liquid)	1.34 kj/kg.k
Heat capacity(vapour)	0.9 kj/kg.k

Table 2: Properties of lubricant PAG oil

Lubricant oil	SP10
Lubricant type	PAG
Specific gravity	1.046
Colour(astm)	L 0.5
Kinetic viscosity	47.73
Flash point(ºc)	243
Pour point(ºc)	< -50
Falex load test(lbs/in^2)	1300
Critical solubility point(ºc)	76

Test carried on VCR without PCMSs into the evaporator. Then a small place is chosen to arrange the phase change materials around the evaporator, and this small place should be 10 mm as in the introduction. The phase change materials are ethylene glycol, paraffin C14 wax, eutectic salt solution. The above PCMs are selected due to their close melting point to the evaporator temperature of test rig. These phase change materials melting points are -13ºc, 6ºc, -6.6ºc respectively.

Figure 1: Vapour compression refrigeration test rig

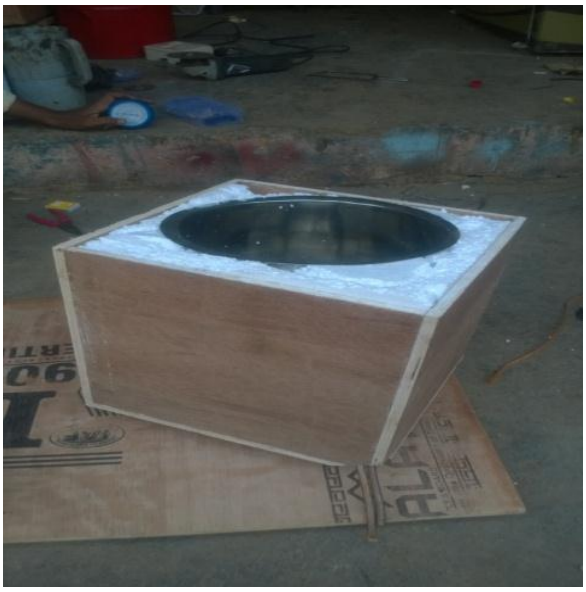


Figure 2: PCM container around the evaporator

After conducting the test on VCR without PCM, Again the test is repeated with different PCMs choosing in a sequential order i.e eutectic salt, paraffin C14 wax, and ethylene glycol. Readings are noted from different measuring devices which are attached to the system.

2.1 Calculations:
From the pressure measuring device only gauge pressure is measured convert that into absolute pressure.
Absolute pressure = gauge pressure + atmospheric pressure.

$P_{abs} = p_{gauge} + p_{atm}$

1) Refrigeration effect

The amount of heat taken by the refrigerant in the evaporator is called refrigerant effect.

Refrigerant effect = $m_w c_p (dT)$ ……………………………...……(1.1)

2) Actual C.O.P

It is the ratio of refrigerant effect to the power consumed by the compressor.

$$C.O.P_{actual} = \frac{h_1 - h_4}{h_2 - h_1}$$ ………………….…………(1.2)

3) Capacity of VCR system(TR) = $\frac{\text{refrigerant effect/min}}{210}$ ……………......(1.3)

4) Mass flow rate ($\dot{m}$) kg/s = $\frac{\text{refrigerant effect/s}}{h_1 - h_4}$ …..................(1.4)

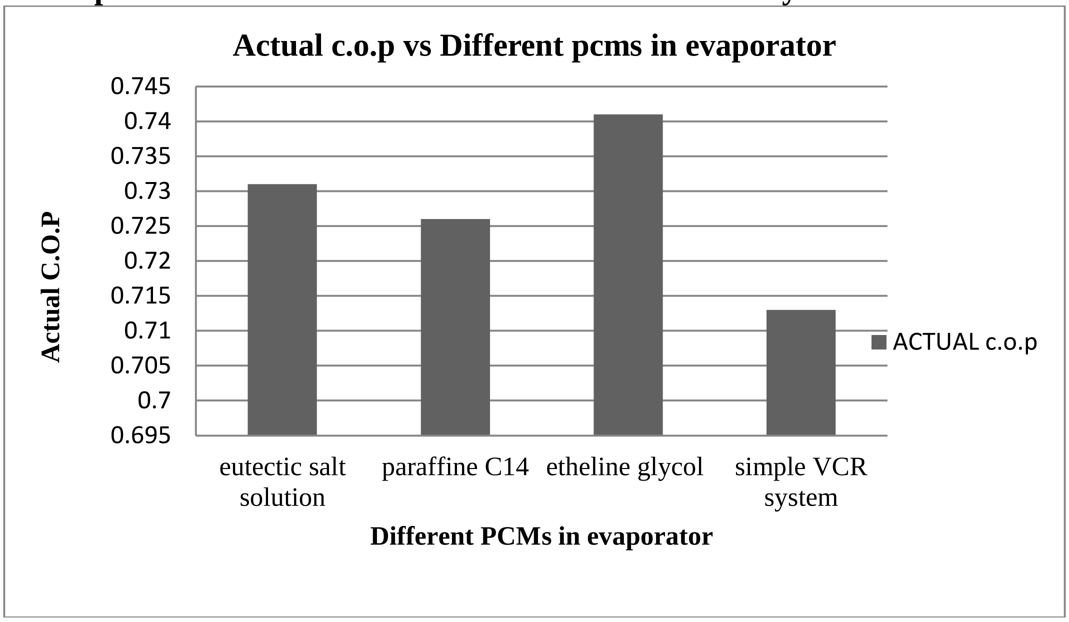
5) Power consumption by the compressor (p) = volts *amps (V*I) (j/s)…...(1.5).
6) Energy input o the compressor = power *time = p*t (kj) …………....(1.6)

Table 3: of calculation for PCM equipped VCR system.

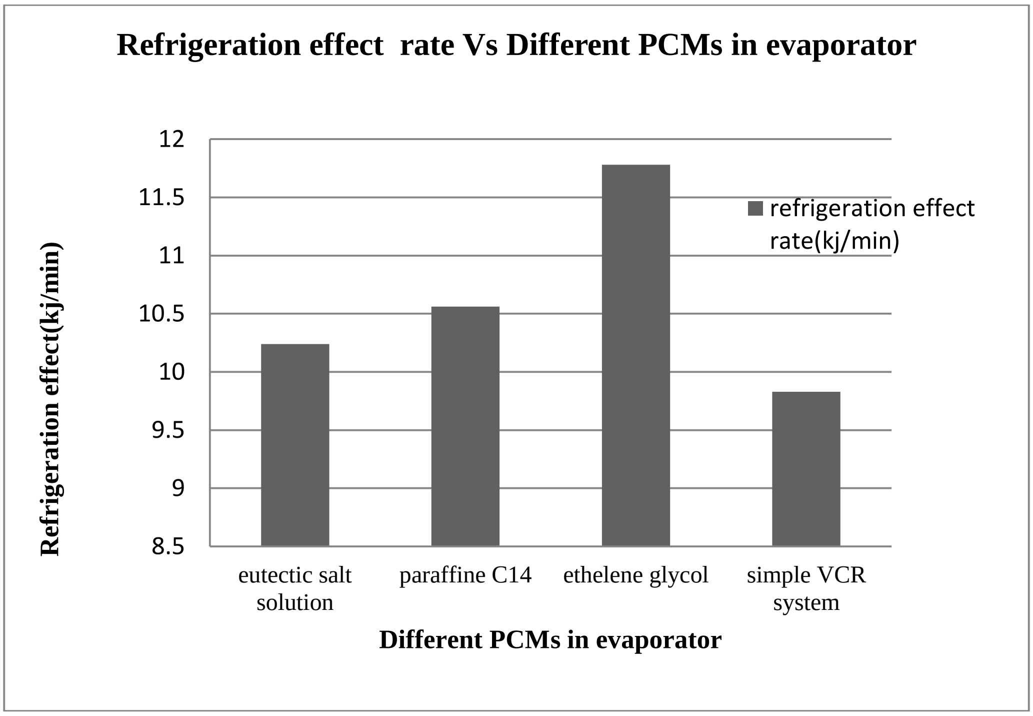
	Eutectic salt solution(10% NaCl+,90% water)	paraffin c14 wax	ethylene glycol
Actual C.O.P	0.731	0.726	0.7413
Refrigeration effect rate(kj/min)	10.24	10.56	11.78
Power consumption(j/s)	230	230	230
Theoretical C.O.P	3.137	3.14	3.64
Mass flow rate(kg/sec)	0.00185	0.00124	0.00126
Capacity of system(TR)	0.04815	0.0513	0.05225

3. RESULTS AND DISCUSSIONS.

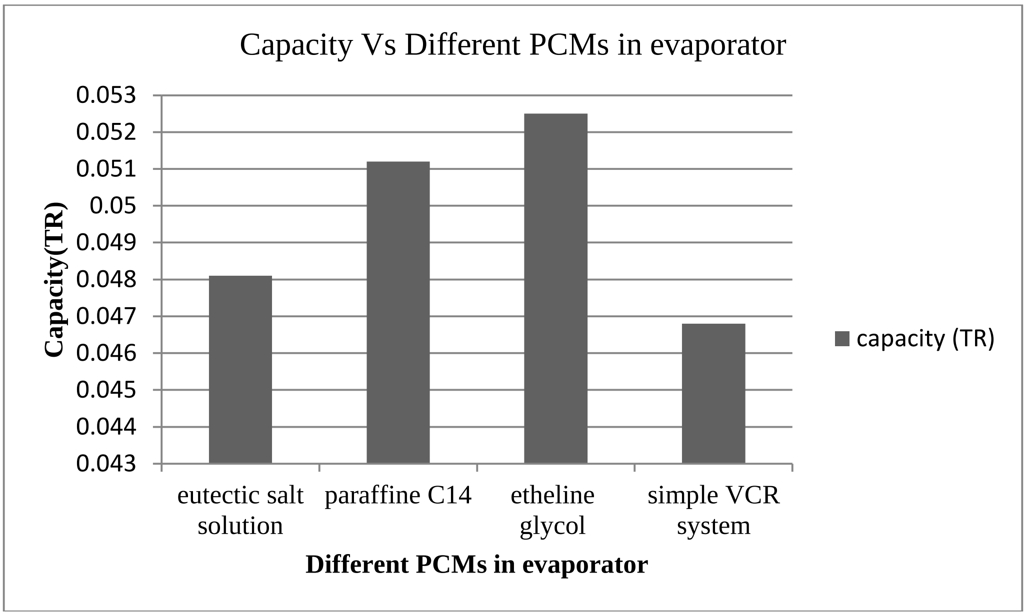
3.1 Comparison Of actual C.O.P for PCM enabled V.C.R system



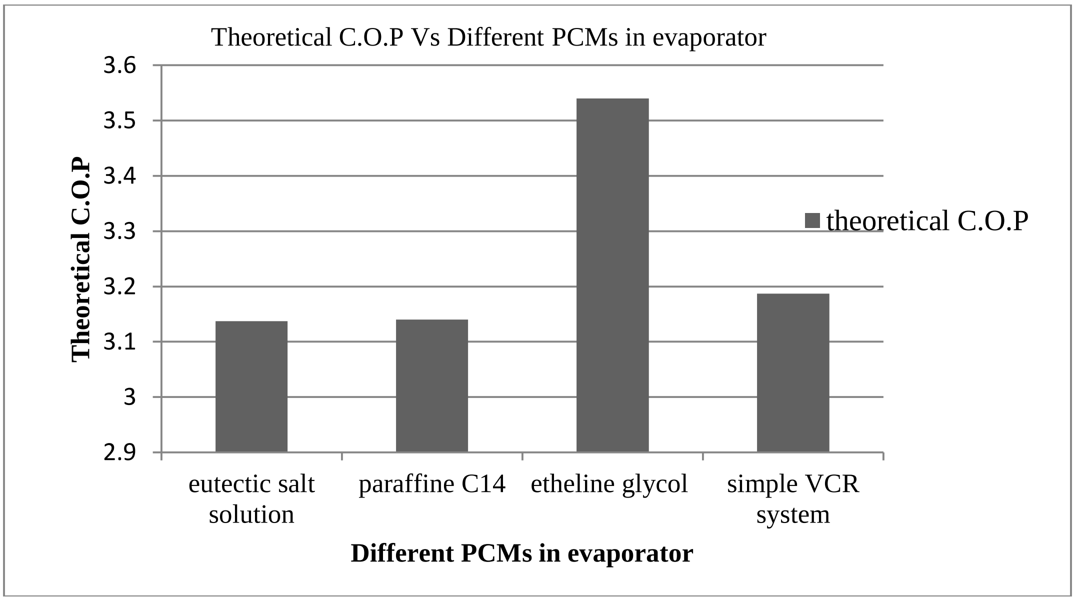
3.2 Comparison of refrigerant effect rate for PCM enabled V.C.R system



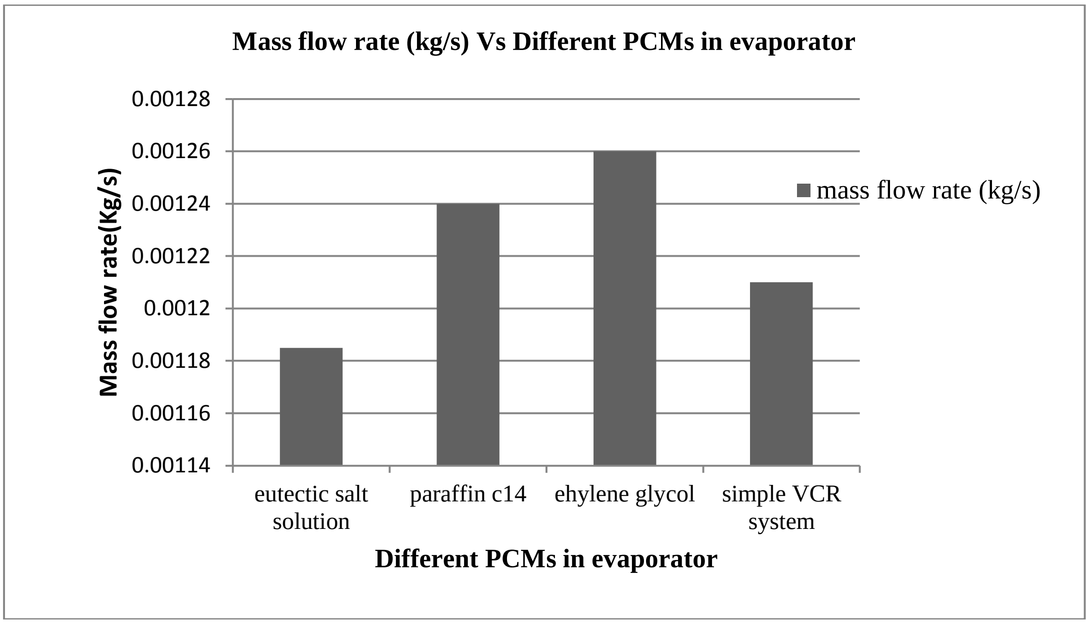
3.3 Comparison of capacity for PCM enabled V.C.R system



3.4 Comparison of Theoretical C.O.P for PCM enabled V.C.R system



3.5 Comparison of mass flow rate for PCM enabled VCR systems.



From the above all graphs ethylene glycol gives the better comparative performance parameters than any other phase change materials. By using the PCMs in the VCR systems decrease the fluctuation in the evaporator temperature. The reduction in temperature fluctuation improves the refrigeration effect. Ethylene glycol is better among the others while comparing with other. Because it has high latent heat capacity, low melting point (melting point -12.9ºc), thermal conductivity is more than paraffin wax and eutectic salt solution. From the above investigation ethylene glycol optimising the performance parameters, they are actual C.O.P, Theoretical C.O.P, and capacity of system, refrigeration effect rate, and mass flow rate.

CONCLUSION

The experimental study of a household refrigerator equipped with a latent storage unit on the unused face of the evaporator shows an enhancement of the system performance and a reduction of the temperature fluctuations in the refrigerated cell. Performance results and cold storage capacity measurements have been obtained from all three PCMs and compared with the original system without storage, ethylene glycol has 11.64% higher than the simple VCR system. The results indicate that the response of the refrigerator to the addition of PCM and its efficiency are strongly dependent on the thermal load. By comparing the all actual C.O.Ps ethylene glycol gives 4.8% increase of the coefficient of performance, depending on the thermal load. Refrigerant effect is also more for the ethylene glycol that is 19.8% is more than conventional VCR system, eventually theoretical C.O.P is also more but these phase change materials incorporation is not a good idea for higher thermal loads, some design modifications is needed. The economic and environmental analyses carried out show that PCM incorporation in refrigerators is beneficial for end-users, national economies, and for the global environment.

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