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Performance Improvement of a Domestic Refrigerator by using PCM (Phase Change Material)

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PERFORMANCE IMPROVEMENTOFADOMESTICREFRIGERATORBYUSINGPCMPHASECHANGE MATERIAL

Strictly as per the compliance and regulations of:

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Abstract- The paper investigates the performance improvement provided by a phase change material associated with the evaporator in a domesticrefrigerator. The heat release and storage rate of a refrigerator is depends upon the characteristics of refrigerant and its properties. Theusage of PCM as TS will help to improve the COP (Coefficient of performance) of new refrigeration cycle by introducing a new sub coolingroutine. The analysis of the experiment exemplifies the improvement of the system coefficient of performance considerably. Using water asPCM and for a certain thermal load it is found that the coefficient of performance of the conventional refrigerator increased by 55-60%.This improvement by sub cooling can be done for single evaporator refrigeration system. Because of prolonging of the compressor off timeby using the latent heat of energy of the PCM capsulated ice, used as the thermal energy storage material, has been investigatednumerically. We can have better food quality due to lower hysteresis cycles of on/off for a given period of operation.

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I. Introduction

The most alarming environmental disorder namely "GlobalWarming" refers to the rising temperature of Earth'satmosphere and ocean and its projected continuation. Theheat from the Sun is entrapped in the Earth and thusincreases the temperature of the atmosphere by Green houseEffect. Refrigeration system is directly and invisiblyresponsible for Global Warming problem. For the typicalhome of the early 1990s, a frost-free refrigerator or freezerwas the second most expensive home appliance to operatebesides the water heater. Appliance makers were requiredto include labels listing an estimate of the annual cost ofrunning each appliance so consumers could compare costsand energy usage.[1]

A refrigerator (colloquially fridge) is a common householdappliance that consists of a thermally insulatedcompartment and a heat pump (mechanical, electronic, orchemical) that transfers heat from the inside of the fridge toits external environment so that the inside of the fridge iscooled to a temperature below the ambient temperature ofthe room. [2]

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Domestic refrigerators are among the most energydemanding appliances in a household due to their continuous operation. [3]

The domestic refrigerator is one found in almost all thehomes for storing food, vegetables, fruits, beverages, andmuch more. [4]

Materials that can store thermal energy reversible over along time period are often referred to as latent heat storagematerials. [5]

II. Objectives

The objectives of the performance improvement of thedomestic refrigerator by using the phase change material(PCM) are given below,

a) To fabricate the experimental set up by modifyingthe domestic refrigerator with PCM basedrefrigerator.

b) To observe the effects of phase change material(PCM) in compressor effect on COP.

c) To observe the difference on the Coefficient ofperformance (COP) of the refrigerator cycle withPCM and without PCM.

III. Overview of Phase Change Material (PCM)

PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change.However, the only phase change used for PCMs is thesolid–liquid change.

Thermal Energy Storage through Phase Change materialhas been used for wide applications in the field of airconditioning and refrigeration especially at industrial scale.[6]

A *phase-change material (PCM)* is a substance with ahigh heat of fusion which, melting and solidifying at acertain temperature, is capable of storing and releasinglarge amounts of energy. [7]

Even though the thermal conductivity of phase changematerials (PCM) is usually not high, it is sufficient toenhance the global heat transfer conditions of an evaporatorwith air as external fluid and natural convection as heattransfer mechanism. [8]

IV. Vapor Compression Refrigeration Cycle (Without PCM)

The vapor-compression uses a circulating liquid refrigerantas the medium which absorbs and removes heat from thespace to be cooled and subsequently rejects that heatelsewhere. Figure depicts a typical, single-stage vaporcompressionsystem. All such systems have fourcomponents: a compressor, a condenser, a Thermalexpansion valve (also called a throttle valve or Tx Valve),and an evaporator. Circulating refrigerant enters thecompressor in the thermodynamic state known as asaturated vapor and is compressed to a higher pressure,resulting in a higher temperature as well. [9]

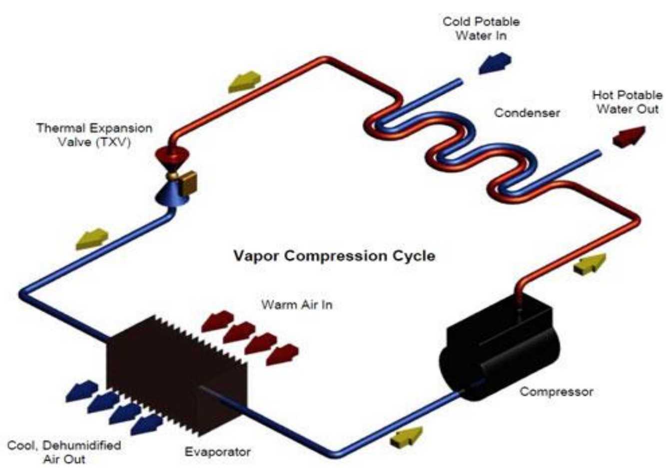

Figure 1 : Vapor compression refrigeration system

V. Using PCM as Latent Heat Storage System

In the conventional household refrigerator the compressorworks in ON/OFF mode. The refrigerant of the evaporatorcoil takes the cabinet coil takes the cabinet heat duringcompressor ON mode. If PCM is used in the cabinet then itwill take most of the heat by changing its phase from solidto liquid. The temperature is constant until the meltingprocess in finished. Moreover, if the PCM is touched withthe evaporator coil the stored heat energy of PCM will beextracted by the refrigerant through conduction methodduring compressor on mode. The conduction transfer isfaster than the natural convection heat transfer. In theconventional refrigerator the cabinet heat is extracted by therefrigerant through natural convection. So the PCM willimprove the heat transfer performance of the evaporatoralso.

A mathematical model of parallel plate's field with a phasechange material that absorbs heat from the flow of warmmoist air was developed and validated. In this study, effectsof the design and the operating condition on theperformance of the system are discussed only for themelting process and the interaction with the refrigerationsystem is not studied.[10]

VI. Working Mechanism of Vapor Compression Refrigeration with PCM

In the model with mechanism showing below the followingassumptions have been made:

a) The thermo physical properties of the materials areconstant with temperature.
b) The solidification/melting processes are slowenough to consider that heat transfer in the solidand liquid phase is in quasi steady-state.
c) The thermal resistance of the evaporator and thethermal contact resistance between the Evaporatorand the PCM are neglected.
d) Vapor compression cycle is considered to be in thesteady-state.

The liquid PCM passed through a coil or any path whichsurrounds the whole evaporator. The evaporator chamber iscovered with another box which has the passage or storagecavity for PCM. When the compressor On-state is on actionthe liquid PCM releases the heat and become solid and therefrigerant takes the heat. Evaporator and PCM box (tocover the evaporator and food cabinet) are shown in thefollowing figure.

Figure 2 : Step 1 Conventional Evaporator

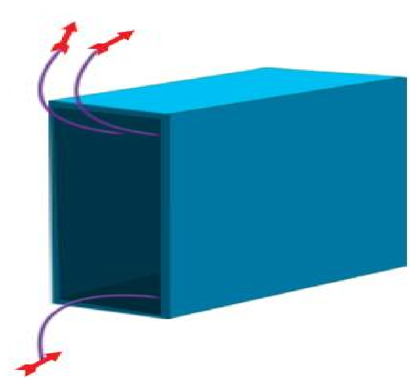

Figure 3 : Step 2 PCM box with PCM passage

When the compressor is in off-state the temperature rises inthe evaporator or food cabinet by placing new foods oropening the door of the refrigerator. When this heat rises inthermostat temperature the compressor starts again andconsumes electricity. In such condition the surroundedPCM takes the extra heat by convection from the foodcabinet keep it far from the thermostat temperature. Thiscertainly increases the off-state of the compressor thusreduces power consumption and increase compressor andcondenser life. Heat releases from the PCM to becomeSolid and covering food cabinet to consume heat in Off-stateare shown in the following figure.

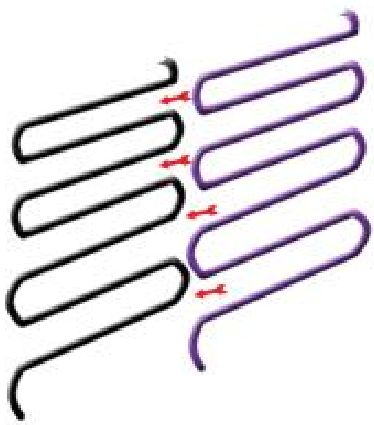

Figure 4 : Step 3 Heat releases from PCM (Compressor On)

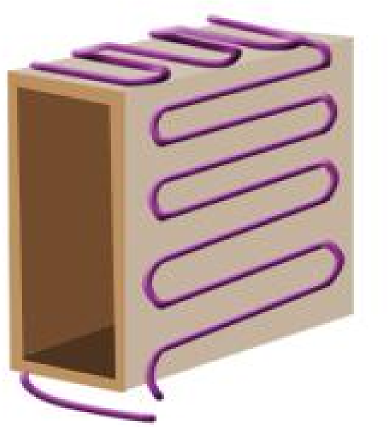

Figure 5 : Step 4 Heat taken from the food

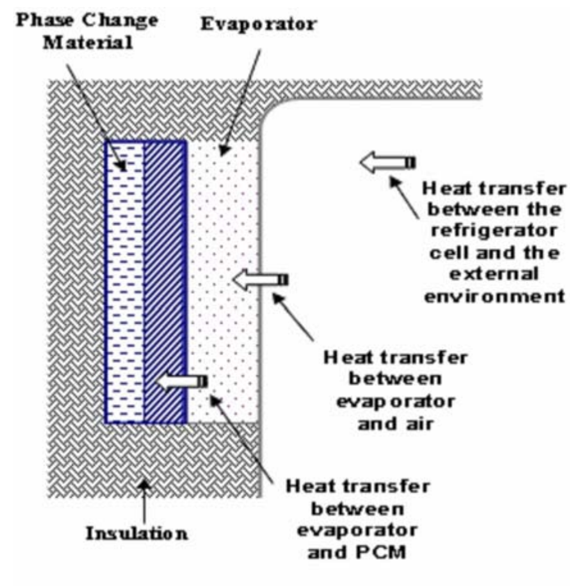

Figure 6 : Schematic Model of the refrigerator with PCM

VII. DATA COLLECTION AND RESULT

The following data have been collected for each test run atthe steady state condition of the system.

- P_1= Compressor suction/Evaporator outletpressure(bar)
- P_3=Evaporator Inlet Pressure(bar)
- T_1= Compressor suction Temperature (˚C)
- T_2=Compressor discharge/condenser Inlet
- Temperature(˚C)
- T_3=Condenser Outlet Temperature(˚C)
- T_4=Evaporator Inlet Temperature(˚C)
- t=Time

Table 1 : Experimental Data without Phase Change Material (PCM)

Time Reading taken	Evaporator inlet Pressure P_1 bar	Condenser outlet Pressure P_3 bar	Compressor inlet Temp T_1 ° C	Compressor outlet Temp T_2 ° C	Condenser inlet Temp T_3° C	Condenser outlet Temp T_4° C
11.10 am	0.27	9	26	50	33	17
11.25 am	0.4	8.5	27	53	36	17
11.40 am	0.44	9	26	58	37	19
11.55 am	0.47	9.5	27	61	37	18
12.1 pm	0.51	10	27	65	39	21
12.25 pm	0.34	10.2	26	67	38	19
12.40 pm	0.44	10.2	22	72	41	18
12.55pm	0.44	10.2	22	72	39	18
1.10 pm	0.57	10.4	20	72	41	19
1.25 pm	0.57	10.6	20	72	42	19

Table 2 : Experimental Data with Phase Change Material

Time Reading taken	Evaporator inlet Pressure P_1 bar	Condenser outlet Pressure P_3 bar	Compressor inlet Temp T_1 ° C	Compressor outlet Temp T_2 ° C	Condenser inlet Temp T_3° C	Condenser outlet Temp T_4° C
10.00 am	0.44	11	30	56	48	22
10.15 am	0.61	11.5	31	59	49	23
10.30 am	0.68	12.4	33	63	53	25
10.45 am	0.78	12.8	34	65	58	27
11.00 am	0.98	14	35	68	59	30
11.15 am	1.02	15.5	35	70	57	32
11.30 am	1.02	15.5	35	73	58	33
11.45 am	1.02	15.5	35	75	62	33
12.00 Pm	1.09	16	34	77	62	32
12.15 pm	1.09	16	34	77	61	32

Table 3 : COP found in each test run without and with PhaseChange Material (PCM)

Number of observation	COP found in Vapor compression Refrigerator Without PCM	COP found in Vapor compression Refrigerator With PCM
1	6.12	9.85
2	5.55	9.42
3	6.12	9.45
4	5.5	9.04
5	5.13	9
6	6.78	9
7	5.1	9
8	5.11	8.91
9	5.02	8.82
10	5.02	8.91

a) *Effect of PCM on Coefficient of Performance (COP)*

- *At step 1*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} \text{ [9]} = \frac{410-230}{445-410} = 5.78$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{435-232}{455-435} = 10.25$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{10.25-5.78}{5.78} \times 100\% = 77.33\ \%$$

- *At step 2*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{420-220}{456-420} = 5.55$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{430-232}{451-430} = 9.42$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.42-5.55}{5.55} \times 100\% = 69.7\%$$

- *At step 3*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{422-226}{454-422} = 6.12$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{433-232}{433-453} = 9.45$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.45-6.12}{6.12} \times 100\% = 54.41\ \%$$

- *At step 4*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{425-218}{462-425} = 5.5$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{434-235}{456-434} = 9.04$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.04-5.5}{5.5} \times 100\% = 64.36\ \%$$

- *At step 5*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{427-232}{465-427} = 5.13$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{434-236}{456-434} = 9.00$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.00-5.13}{5.13} \times 100\% = 75.43\ \%$$

- *At step 6*

$$COP_{WITHOUT\ PCM} = \frac{h1-h4}{h2-h1} = \frac{420-226}{458-420} = 5.10$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{436-238}{458-436} = 9.00$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.00-6.78}{6.78} \times 100\% = 19.5\ \%$$

- *At step 7*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{420-226}{458-420} = 5.10$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{438-240}{460-438} = 9.00$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{9.00-5.10}{5.10} \times 100\% = 76.47\%$$

- *At step 8*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{427-232}{466-427} = 5.11$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{438-242}{460-438} = 8.91$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM)

$$= \frac{8.91-5.11}{5.11} \times 100\% = 74.36\ \%$$

- *At step 9*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{426-225}{466-426} = 5.02$$

$$COP_{WITHPCM} = \frac{h1-h4}{h2-h1} = \frac{438-244}{460-438} = 8.82$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM) $= \frac{8.82-5.02}{5.02} \times 100\% = 75.69\%$

- *At step 10*

$$COP_{WITHOUTPCM} = \frac{h1-h4}{h2-h1} = \frac{426-225}{466-426} = 5.02$$

$$COP_{WITH\ PCM} = \frac{h1-h4}{h2-h1} = \frac{442-246}{464-442} = 8.91$$

Percentage of COP improved for the use of Phase ChangeMaterial (PCM) $= \frac{8.91-5.02}{8.91} \times 100\% = 77.49\ \%$

VIII. Discussion

Experiments were carried out under certain thermal loadswith water as PCM. Here the effect PCM in certainquantities in this case 5 liters at certain thermal loads on theperformance parameter of house hold refrigerator. Thenumber of compressor on-off cycle within a certain periodof time for different PCMs and without PCM can bepointed up. Use of water as PCM imposes a great impact onCOP improvement at certain thermal loads. Using water asPCM and certain thermal load it is found that the 55-60%COP improvement has been achieved by the PCM inrespect without PCM in conventional refrigerator.

During the compressor running the refrigerant takes thechamber heat byfree convection in case of without PCM,which is slower heat transfer process in respect toconduction process. But PCM most of the heat in thecabinet is stored in the PCM during compressor runningtime. Since the conduction heat transfer process is fasterthan the free convection process the cooling coil
temperature does not require dropping very low to maintaindesired cabinet temperature. As result the evaporator worksat high temperature and pressure with PCM. Moreover, dueto high operating pressure and temperature of theevaporator the density of the refrigerant vapor increases, asa result the heat extracted from the evaporator by the fixedvolumetric rate compressor is higher than without PCM.

IX. Conclusion

Experiment tests have been carried out to investigate theperformance improvement of a household refrigerator usingtwo different phase change materials of different quantitiesat different loads. The following calculation have beendrawn-

a) In case of without PCM and with PCM the COP ishigher at low thermal load while it decreases withit decreases with the increase of thermal load.

b) Depending on the PCM and the thermal loadaround 55-60% COP improvement has beenachieved by the PCM in respect to without PCM.

c) Use of PCM decreases the fluctuation of thecabinet temperature. At higher load this effect isnot so significant.

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