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Improvement in COP of Domestic Refrigerator Using Phase Change Material

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Abstract: Domestic refrigerators are among the most widely used household appliances and a great portion of energy is used by these systems. Reduction of temperature fluctuation and enhancement of system performance is the main reason of using phase change materials (PCMs) in refrigeration systems. The aim of this work is to improve the thermal performance of refrigerator using phase change materials (PCMs) under door openings and electrical power failure. The PCM is located around the evaporator tube coil in order to improve its efficiency and to provide a storage capacity allowing several hours of refrigeration without power supply. The system has been tested with water and with a eutectic mixture. The analysis of the results shows a significant improvement of the performance compared to a conventional system.

Keywords: COP, Evaporator, Phase Change Material, Refrigerator.

1. INTRODUCTION

Nowadays, almost every household uses at least one refrigeration system for domestic food preservation. Thus, even small performance enhancement of these appliances brings huge amounts of energy saving. Generally, energy consumption of a refrigerator depends upon its components efficiency, ambient temperature, thermal load, door openings, set-point temperature in its compartment, and refrigerant type. Hence, performance enhancement of refrigeration systems covers a vast research area since each part of the system has its own technical complexity. Nevertheless, most of the ideas applied to refrigeration systems lie in three major categories: development of energy-efficient compressors, enhancement of thermal insulation, and enhancement of heat transfer from heat exchangers, i.e. condenser and evaporator. Due to the high latent heat, integration of PCM at evaporator side of a refrigerator could prolong the compressor OFF time.

2. LITERATURE REVIEW

Most of the work has done on the enhancement of heat transfer rate in evaporator section with use of phase change material at evaporator section.

K.Azzouz ,D.Leducq, D.Gobin [1] studied the effect of adding a phase change material (PCM) slab on the outside face of a refrigerator evaporator. A dynamic model of the vapor 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.

E. Oro´ , L. Miro[2] Food transport and storage at low temperatures is a matter worldwide due to changes of the dietary habits and the increasing of the population. The issue of improving food storage applies at different applications such as commercial freezers or refrigerated trucks. The aim of this work is to improve the thermal performance of commercial freezers using phase change materials (PCMs) under door openings and electrical power failureDuring 3hr of electrical power failure, the use of PCM maintained the freezer temperature4-6 ℃ 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

Abhilash A, Adarsh bMurali Menon [3] worked on the Comparison of a conventional domestic refrigerator with a PCM encapsulated refrigerator. PCM materials have large amount of heat energy stored in them in the form of latent heat. The heat energy associated with PCM is green energy and is a natural phenomenon. This paper conducts experiment and summarizes the investigation and analysis of the thermal energy storage systems incorporating PCMs

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for use in refrigeration systems. The efficiency of refrigerator was enhanced and improvement in the quality of food is obtained. Results can be improved with different combination PCM materials or different design of PCM encapsulation which ensures more heat transfer.

Chetan Tulapurkar, Pradip Radhakrishnn Subramaniam[6]showed that incorporating phase change materials (PCM) is a new approach to improve the performance of refrigerators. In this study, they have tested four different PCMs in two different refrigerator models. Compressor ON/OFF time was optimized and better energy efficiency was achieved. Economic analyses show that using PCMs in household refrigerators is clearly a cost effective method that saves energy and reduces harmful emissions. Adding PCM in the enclosures helps to maintain a homogeneous temperature distribution. Heat is gained from door openings and/or from thermal loads in the refrigerator. This leads to a reduction of usable cabinet volume, and more energy consumption to re-freeze the PCM packages. On the other hand, more homogeneous temperature maintained by PCMs leads to reduction of the ON time of the compressor.

3. OBJECTIVES

The objective of performance improvement of domestic refrigerator using phase change material are:
1. To fabricate the refrigerator with PCM based evaporator.
1. To observe the difference of the COP of refrigerator cycle with and without using PCM at evaporator section.

Overview of Phase Change Material:
A phase-change material (PCM) is a substance with a high latent heat of fusion which melts and solidifies at a certain temperature and is capable of storing and releasing large amounts of energy. Even though the thermal conductivity of phase change materials (PCM) is usually not high, it is sufficient to enhance the global heat transfer conditions of an evaporator.

VCRS (With and without PCM)
The vapor-compression refrigeration system uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. The main heat transfer part is done via convection method between evaporator coil and the space to be refrigerated. In conventional system the heat releasing environment for evaporator is usually air but using a Phase Change Material (PCM) surrounding the evaporator coil work as a liquid or solid medium to release the heat. PCM is touched with the evaporator coil the stored heat energy of PCM will be extracted by the refrigerant through conduction method. The conduction transfer is faster than the natural convection heat transfer. In the conventional refrigerator the cabinet heat is extracted by the refrigerant through natural convection. So the PCM will improve the heat transfer performance of the evaporator.

4. EXPERIMENTAL SETUP

The followings are the major technical specifications of the refrigerator.
1. Cabinet: -Internal volume= 0.165 cubic meter

2. Evaporator: -
Mode of heat transfer= Free convection and conduction.
Material of coil or tube= aluminium tube.

3. Condenser: - Mode of heat transfer= Free convection.
Material of the tube= steel and wire tube.

4. Compressor: Model No.: GVF30AA
Evaporating Temperature: -25° C
Condensing Temperature: 70° C
Displacement: 5.12 CC/ Rev
Motor type: RSCR
Nominal voltage range: 187V~276V at 50Hz

5. Expansion device: Capillary tube

6. On/Off control and self-defrost.

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

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Fig 1 : Fabrication of refrigerator unit with measuring devices.

Development of Refrigeration System with a PCM box:

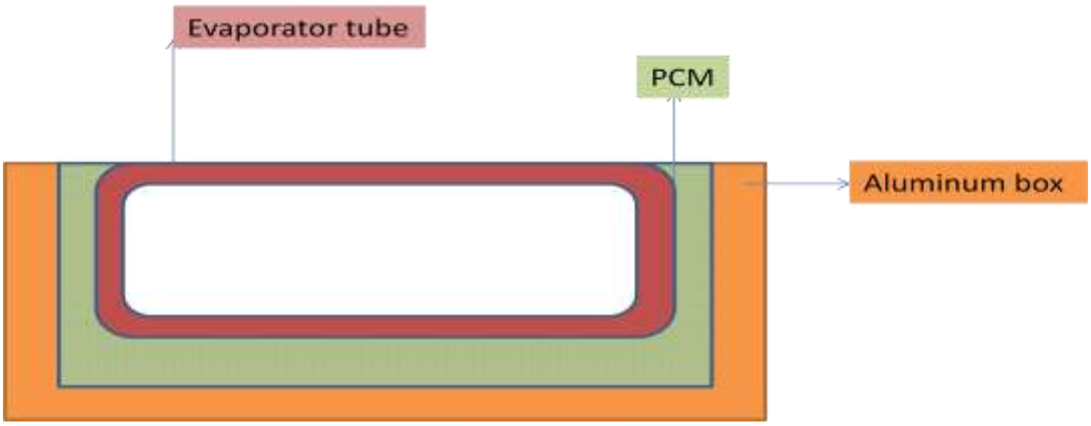

Fig 2 : The evaporator is placed inside the PCM box. PCM is in between the outer side of evaporator and inner side of PCM box.

Data collection and calculation:
COP - Coefficient of performance;   Mf - Mass flow rate of refrigerant;

Tci and Tco - Temperature at inlet and outlet of condenser ;

Tei and Teo - Temperature at inlet and outlet of evaporator;

h1 - Enthalpy at outlet of evaporator;   h2 - Enthalpy at outlet of compressor;   h3 - Enthalpy at inlet of evaporator

For the tables below – Mass of refrigerant = 1 lph & load = 0 watt

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Reading without using PCM:

Time	Mref (lph)	Pcond (bar)	Pevp (bar)	Tci (℃)	Tco (℃)	Tei (℃)	Teo (℃)	h1(kJ/kg)	h2(kJ/kg)	h3(kJ/kg)	COP
9:00	1	9.6	2	49	38	-9	-2.8	378	439	251	3.24
9:15	1	9.6	2	48	38	-10	-2.8	378	439	252	3.26
9:30	1	9.6	2	49	39	-9	-2.9	377	439	251	3.26
9:45	1	9.6	2	48	38	-10	-2.9	377	438	252	3.25
10:00	1	9.6	2	49	39	-10	-3.8	377	438	251	3.24
10:15	1	9.6	2	48	38	-9	-3.9	378	439	252	3.26
10:30	1	9.6	2	49	39	-10	-2.8	377	438	251	3.24
10:45	1	9.6	2	48	38	-10	-2.8	377	438	251	3.25
11:00	1	9.6	2	49	39	-10	-2.9	378	439	251	3.24

Reading with water used as a PCM:

Time	Mref (lph)	Pcond (bar)	Pevp (bar)	Tci (℃)	Tco (℃)	Tei (℃)	Teo (℃)	h1(kJ/kg)	h2(kJ/kg)	h3(kJ/kg)	COP
9:00	1	10.2	2.9	50.1	40.2	-8.5	-3.9	396	446	232	4.67
9:15	1	10.3	2.8	50.1	40.1	-8.5	-3.8	397	445	231	4.69
9:30	1	10.2	2.8	50.2	40.0	-8.6	-3.9	397	446	232	4.71
9:45	1	10.3	2.9	50.1	40.5	-8.5	-3.9	396	445	232	4.70
10:00	1	10.2	2.9	50.1	40.3	-8.6	-3.8	395	446	231	4.71
10:15	1	10.3	2.8	50.2	40.1	-8.5	-3.9	395	445	231	4.69
10:30	1	10.2	2.9	50.2	40.3	-8.6	-3.8	397	445	232	4.68
10:45	1	10.4	2.8	50.2	40.2	-8.5	-3.9	395	446	233	4.69
11:00	1	10.3	2.9	50.1	40.1	-8.5	-3.8	395	446	233	4.71

TABLE 4.1

Step 1 : Percentage of COP improved for the use of Phase Change Material (PCM)

$$= \frac{4.67 - 3.24}{3.24} \times 100 = 44.13$$

Step 2 : Percentage of COP improved for the use of Phase Change Material (PCM)

$$= \frac{4.69 - 3.26}{3.26} \times 100 = 43.86$$

5. CONCLUSION

Use of water as PCM imposes a great impact on COP improvement. Using water as PCM, it is found that the 39-44% COP improvement has been achieved by the PCM in respect without PCM in conventional refrigerator.

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