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PEFORMANCE ENHANCEMENT OF DOMESTIC REFRIGERATOR USING PHASE CHANGE MATERIALS MIXED WITH NANO FLUID

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Abstract*—This paper investigates about the performance enhancement of domestic refrigerator using phase change materials(PCM) mixed with Nano fluids inside the evaporator. A u shaped PCM box is used to contain the PCM mixed with Nano fluid around the evaporator. The box is made of aluminium sheet as it is a good conductor of thermal energy. This system has been tested with water and NaCl solution mixed with 1 and 2% of Copper oxide (CuO) Nanofluid. Nano fluid enhance the ability of PCM to store more thermal energy. It has been found that during the operation of compressor the PCM mixture was cooled first by conduction process as it is very close to the evaporator. Then PCM mixture exchanges energy with the load in the refrigerator cabin. The stored thermal energy in PCM mixture was yielded to the refrigerator cell during off cycle and allows several hours of continuous operation without power supply. It has been observed that the performance of domestic refrigerator has improved by 19-78 %. The experimental studies with water and NaCl mixed with CuO Nanofluid has confirmed that there was an 78 % increase in the coefficient of performance and compressor off time also increased.

***Keywords*— Domestic refrigerator, Phase change material, Nano fluid, Coefficient of Performance, Thermal energy storage**

I. INTRODUCTION

The domestic refrigerators are the most extensively used appliances in the present day fast growing technology and it is consuming large amount of total world energy. In this situation improving the performance of refrigerator is an important issue in view of energy savings. Many researchers in the field of refrigeration and air conditioning are involving themselves to develop different technical options for enhancing the energy efficiency of household refrigerators. On this regard, following are the technical options:

1.To improve the performance of the compressor
2. Using heat exchangers which have very high effectiveness.
3.To decrease heat loss by the utilization of good insulating material

In the domestic refrigerator, if it is switched on, the refrigerant in the evaporator coil takes the cabinet heat. During the off mode of the compressor, the temperature inside the evaporator cabinet starts rising due to heat released from the materials inside the refrigerator, due to heat inleak from atmosphere. This on and off makes temperature fluctuations (temperature rapidly rise and fall) inside the evaporator cabinet which ultimately decrease the quality of the fresh items. One of the above three must be employed to increase the quality of fresh items and for Preservation of food, medicine in a country which has more power cuts. Among them improving the efficiency of heat exchanger (condenser and evaporator) has got attention in the recent years. So, Thermal energy storages were used in this work. The thermal energy storages like Phase Change materials(PCM) have excellent characteristic of constant temperature in course of absorbing or releasing energy.

***A. PHASE CHANGE MATERIAL*:** Phase change material capable of storing large amount and releasing large amounts energy due to its high latent heat of fusion. Heat can be absorbed or released when it is changed from the solid to liquid and vice versa.

***B. NANO FLUIDS*:** Nano fluids had grabbed much attention from the past few years. These are prepared from the Nano sized particles which were dispersed in the base fluid. The base fluid can be selected based on the requirements of research. Mixing of these in varied proportions in a fluid improves the properties of the fluid. There is a difficulty in the stability of the Nano particles in the Nano fluid this can be overcome by using suitable surfactant.

II. LITERATURE REVIEW

The works which had done on the domestic refrigerator earlier falls under two categories: Some focussed on performance enhancement and the other on the reduction of power consumption.

Azzouz et al.(2005) has established a mathematical model of the vapour compression refrigeration cycle with existence of PCM and showed its experimental justification. The results of this model show that the using of PCM increase the heat transfer from the evaporator and consent to a higher evaporating temperature which ultimately increases the energy efficiency of the system as compared to without PCM.

Rezaur Rahman(2013) from Khulna university of engineering and technology, Bangladesh had investigated on the performance improvement by using water as phase change material . his experiments shown that incorporating water as PCM around the evaporator has 50-60% increase in the performance.

Easwaran nampoothiry k(2016) from saintgits college of engineering had worked on the performance improvement by using ethylene glycol as PCM around the evaporator. His experiments had shown that there is a 5 to 19% increase in the performance.

V.S.Hajare and B.S.Gawali(2015) from SITCOE, yadraw had investigated on the study of latent heat storage using Nano mixed phase change materials. He experimented by making PCM capsule mixed with TiO2 Nano particle and taking solar water heater as a thermal energy storage. This resulted that mixing of Nano fluid with PCM had given excellent absorbing and releasing energy at constant temperature.

Most of the investigations cited above were focused on the heat transfer in the latent heat storage system. There are very few studies that have been reported in the literature on the behaviour of a refrigerator coupled with a phase change material mixed with Nano fluids as a slab applied on the entire area of the evaporator.

III. OBJECTIVE

The main objectives of this work are given below:

1. Fabricating the PCM box around the evaporator with aluminium sheet of 5mm thickness in a domestic refrigerator.
2. Incorporating PCM mixed with Nano fluid in a U-shaped box around the evaporator with 1 and 2 % Nanofluid
3. Observing the effects of PCM on the performance of refrigerator i.e., COP by conducting the experiments.
4. Comparing the results of the experiments done using with and without PCM mixed Nano fluid

IV. EXPERIMENTAL SETUP

A conventional household refrigerator is used in the modified form with PCM box located behind the evaporator cabinet to carry out the necessary experiments. The experimental set up comprised with a refrigerator, pressure gauge, energy meter, thermocouple, phase change material box

1) Cabinet : Internal volume, 12.5L
2) Evaporator : Mode of heat transfer - Free convection
Material of the coil/tube - Copper tube
Length of cabin-30cm
Breadth of cabin-20cm
Height of cabin-13cm
3) Condenser : Mode of heat transfer
Material of the coil/tube: Steel and wire tube
4) Compressor : Hermetic reciprocating compressor,
LG NR45LAEG 220-240V, 50Hz
5) Expander : Capillary tube (Internal diameter 1 mm)
6) On/off control
7) Refrigerant : 1,1,1,2-Tetrafluoroethane (R-134a)

Temperatures at various locations (compressor, evaporator and cabinet) are measured with digital thermocouples. Two pressure gauges are used to measure the evaporation and condensation pressures at the inlet and outlet of the compressor.

PCM inclusion in the system affects the evaporation and condensation pressures. Since evaporation and condensation processes are examples of a phase change process, the pressure change in these components are negligible (unless refrigerant superheating or sub cooling takes place in the evaporator or condenser, respectively). Therefore, only two pressure gauges are normally used for measurement in these components. Pressure gauges are fitted at the low pressure and high pressure sides of the refrigerator and as shown in the figure 1.

Fig.1 Experimental test rig and setup

A U-Shaped box is fabricated and is fitted inside the evaporator cabin to contain the phase change material. It is fitted in such a way that it is fully in contact with the evaporator coils. The box is made of aluminium sheet with a thickness of 5mm. The fabricated model of the box is shown in figure 2.

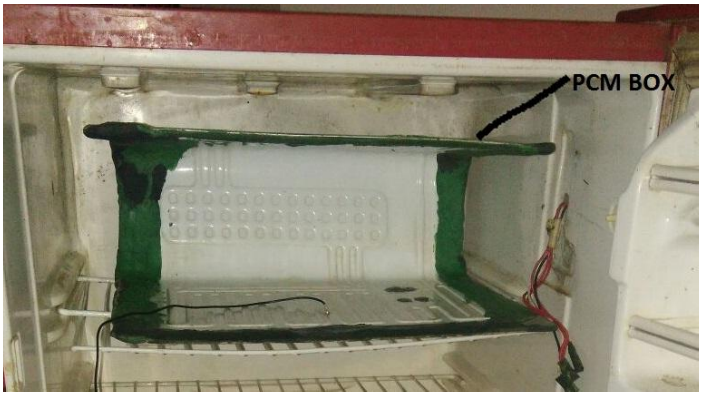

Fig 2. Fabricated PCM box fitted around the cabin

The system is also connected to the energy meter for recording the energy consumption for the refrigerator.

V. WORKING OF REFRIGERATOR WITH AND WITHOUT PCM

A. ***WITHOUT PCM****:* when the refrigerator is switched on the refrigerant from the compressor with high pressure and temperature enters the condenser where the temperature drop occurs then in the form of liquid state the refrigerant enters the expansion valve i.e., capillary tube where the drop-in temperature takes place at constant enthalphy then the refrigerant with low temperature and pressure enters the evaporator. In evaporator refrigerant exchanges thermal energy with the load in the cabin and gains some heat from the cabin then enters in to compressor in the form of liquid with low pressure. This cycle continuous.

B. ***WITH PCM:*** The operation of the refrigerator with PCM is same as that of the without PCM. The only difference is, in the evaporator the thermal energy of the refrigerant is first exchanged by the PCM in the PCM box as it is very close to the evaporator then the PCM exchanges energy with the load in the cabin. During the compressor off time the latent heat stored in the PCM is yielded to the refrigerator cabin thus reducing the temperature fluctuations inside the refrigerator.

VI. SELECTION OF PCM AND NANOFLUID

The PCM's used in the system are selected basing on the thermal conductivity, cost, latent heat capacity, corrosion resistant. By considering all these parameters the PCM's used in this system were water and NaCl solution as these two were easily available at low cost and have good latent heat capacity.

The Nanofluids selected basing on the thermal conductivity of the Nano particles and cost. Nano fluids were prepared by dispersing Nano particles in the base fluid by two step method. The base fluid can be selected basing on the fluid in which the mixture will be done. Here the both water and NaCl solutions were water based. so, water was taken as base fluid. Nano powders were dispersed in to the base fluid using ultrasonic agitation or magnetic force agitation and citrate was used as stabilizing surfactant. By considering these parameters copper oxide(CuO) Nanofluid.

The observations were taken in different proportions of nanofluid in the following manner:

1. Refrigerator without PCM with and without load.
2. Refrigerator with water as PCM with and without load. (200ml)
3. Refrigerator with water mixed with 1% of Nanofluid as PCM with and without load. (200mlwater+2ml of nanofluid)
4. Refrigerator with water mixed with 2% of Nanofluid as PCM with and without load. (200mlwater+4ml of nanofluid)
5. Refrigerator with NaCl as PCM with and without load
6. Refrigerator with NaCl mixed with 1% of Nanofluid as PCM with and without load. (200mlwater+2ml of nanofluid)
7. Refrigerator with NaCl mixed with 2% of Nanofluid as PCM with and without load. (200mlwater+4ml of nanofluid)

VII. OBSERVATIONS

The observed readings during the operation were tabulated below:

TABLE I
OBSERVATIONS OF REFRIGERATOR WITHOUT PCM WITHOUT LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Rseading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	31.1	31.9	0.27	8.61	30.5	6165.45
2	1.30	33.1	39.1	0.7	14	25	6165.45
3	3.02	34.2	40.6	0.7	14.8	20	6165.45
4	3.42	34.5	40.9	0.7	14.8	15	6165.45
5	4.10	34.8	41.1	0.7	14.8	10	6165.45
6	4.30	35.1	41.5	0.7	14.8	5	6165.46
7	5.00	35.1	41.5	0.7	14.8	0	6165.46
8	5.35	35.0	41.6	0.5	14.1	-5	6165.46

TABLE II
OBSERVATIONS OF REFRIGERATOR WITHOUT PCM WITH LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	30.2	3.08	0.5	9.3	31.3	6165.46
2	4.32	33.3	38.9	0.5	13.78	25	6165.46
3	6.02	33.6	40.2	0.5	13.78	20	6165.47
4	8.09	33.4	40.7	0.5	13.78	15	6165.47
5	10.12	34.1	41.8	0.6	12.05	10	6165.47
6	12.45	35.0	40.9	0.4	12.05	5	6165.47
7	18.30	35.1	41.6	0.4	12.05	0	6165.48
8	27.42	35.2	41.6	0.3	12.05	-5	6165.48

TABLE III
OBSERVATIONS OF REFRIGERATOR WITH WATER AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(^oC)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(^oC)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	29.8	30.9	0.4	8	30.2	6165.48
2	2.56	31.1	35.6	0.5	12	25	6165.48
3	6.42	32.8	38.3	0.6	12	20	6165.48
4	9.00	33.2	39.1	0.6	12	15	6165.49
5	10.50	33.6	40.1	0.7	13	10	6165.49
6	13.10	34.1	41.1	0.8	14	5	6165.49
7	15.16	34.2	42.2	0.8	14	0	6165.49
8	17.18	34.4	42.6	0.7	13	-5	6165.49

TABLE IV
OBSERVATIONS OF REFRIGERATOR WITH WATER AS PCM WITH LOAD

S.No	Time (min)	Temperature(^oC)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(^oC)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	30.6	31.1	0.4	9.3	31.2	6165.49
2	4.12	35.8	42.4	0.6	10	25	6165.49
3	6.00	37.3	44.3	0.7	14	20	6165.49
4	8.12	38.6	46.3	0.8	15	15	6165.49
5	11.50	39.5	49.9	0.9	16	10	6165.50
6	15.13	39.4	50.1	0.9	16	5	6165.50
7	25.10	39.9	51.2	0.7	17	0	6165.50
8	30.00	40	52	0.5	14.4	-5	6165.50

TABLE V
OBSERVATIONS OF REFRIGERATOR WITH WATER MIXED WITH 1% NANO FLUID AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(^oC)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(^oC)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	28.2	28.8	0.5	9	29.6	6165.50
2	1.58	29.6	33.6	0.7	11	25	6165.51
3	3.53	31.8	37.1	0.8	12.2	20	6165.51
4	4.30	33.0	38.8	0.9	13.5	15	6165.51
5	6.20	33.33	39.9	1	14	10	6165.51
6	9.15	34.5	41.8	1	14	5	6165.51
7	10.12	35.3	44.6	0.9	13.2	0	9165.52
8	12.19	35.2	45.9	0.8	13.0	-5	6165.52

TABLE VI
OBSERVATIONS OF REFRIGERATOR WITH WATER MIXED WITH 1% NANO FLUID AS PCM WITH LOAD

S.No	Time (min)	Temperature(^oC)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(^oC)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	29.7	30.8	0.5	9.6	31.0	6165.52
2	6.00	32.0	36.3	0.8	13	25	6165.52
3	8.45	32.6	38.0	0.9	14	20	6165.52
4	12.30	32.7	38.3	1	14	15	6165.53
5	14.45	32.7	39.1	0.7	13.0	10	6165.53
6	16.23	33.2	40.4	0.7	12.5	5	6165.53
7	25.23	32.8	40.3	0.6	11	0	6165.53
8	32.20	32.6	40.7	0.5	10.4	-5	6165.54

TABLE VII
OBSERVATIONS OF REFRIGERATOR WITH WATER MIXED WITH 2% NANO FLUID AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm²)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	28.1	29.6	0.5	9.6	28	6165.68
2	2.10	28.8	33.1	0.6	9.7	25	6165.68
3	4.43	30.8	36.3	0.7	10	20	6165.68
4	6.30	31.7	37.3	0.8	11	15	6165.68
5	7.53	32.7	38.1	0.9	11.5	10	6165.68
6	9.45	32.9	39.2	1	12	5	6165.69
7	11.30	33.6	40.2	0.9	12.5	0	6165.69
8	14.30	34.4	42.1	0.8	12	-5	6165.69

TABLE VIII
OBSERVATIONS OF REFRIGERATOR WITH WATER MIXED WITH 2% NANO FLUID AS PCM WITH LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm²)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	29.7	30.8	0.5	9.6	31.0	6165.70
2	3.20	32.0	36.3	0.7	10	25	6165.70
3	6.10	32.6	38.0	0.9	11	20	6165.70
4	8.1	32.7	38.3	1.0	13	15	6165.70
5	14.30	32.7	39.1	1.0	14	10	6165.71
6	19.00	33.2	40.4	1.0	14.8	5	6165.71
7	25.20	32.8	40.3	0.8	13	0	6165.71
8	31.16	32.6	40.7	0.8	12	-5	6165.71

TABLE IX
OBSERVATIONS OF REFRIGERATOR WITH NACL AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm²)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	30.5	31.3	0.5	11	30	6165.71
2	1.10	31.2	34.0	0.8	11.5	25	6165.71
3	2.09	33.3	35.8	0.9	12	20	6165.71
4	3.00	34.2	38.9	0.9	13	15	6165.71
5	5.15	35.1	39.2	1.0	13	10	6165.71
6	6.10	35.2	40.1	1.0	13.2	5	6165.71
7	7.19	35.3	42.1	1.0	13.4	0	6165.71
8	8.10	35.4	43.2	1	13.5	-5	6165.71

TABLE X
OBSERVATIONS OF REFRIGERATOR WITH NACL AS PCM WITH LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm²)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	30.5	34	0.5	11	31	6165.72
2	2.10	32.3	35.8	0.8	11.5	25	6165.72
3	4.09	34.2	38.9	0.9	12	20	6165.73
4	6.00	36.7	40.2	0.9	13.5	15	6165.73
5	10.17	39.3	45.2	1.0	13.9	10	6165.73
6	13.13	39.1	79.3	1.0	13.9	5	6165.73
7	15.20	39.3	50.2	1.0	14.0	0	6165.73
8	20.13	39.2	50.2	1.1	15	-5	6165.74

TABLE XI
OBSERVATIONS OF REFRIGERATOR WITH NACL MIXED WITH1 % NANO FLUID AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	30.5	33.2	0.5	9.6	30	6165.75
2	1.20	33.2	37.8	0.6	10.0	25	6165.75
3	3.90	35.3	39.1	0.7	10.2	20	6165.75
4	4.00	36.4	39.8	0.8	10.8	15	6165.76
5	5.15	38.9	42.2	0.8	11.0	10	6165.76
6	6.15	40.2	45.6	0.8	11.2	5	6165.76
7	7.0	42.2	47.2	0.9	12	0	6165.76
8	8.19	42.5	52.0	0.9	13	-5	6165.76

TABLE XII
OBSERVATIONS OF REFRIGERATOR WITH NACL MIXED WITH 1 % NANO FLUID AS PCM WITH LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	31.6	32.8	0.5	9.2	28.8	6165.77
2	3.00	34.3	38.9	0.5	10	25	6165.77
3	5.50	36.2	39.9	0.6	10.2	20	6165.77
4	8.19	38.2	40.5	0.7	10.5	15	6165.78
5	12.08	38.2	42.2	0.8	10.6	10	6165.78
6	14.08	39.1	45.1	0.9	11.0	5	6165.78
7	18.10	39.2	46.0	0.9	11.2	0	6165.78
8	21.10	39.1	50.2	0.9	11.3	-5	6165.79

TABLE XIII
OBSERVATIONS OF REFRIGERATOR WITH NACL MIXED WITH 2 % NANO FLUID AS PCM WITHOUT LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	29.3	35.1	0.7	8.0	30	6165.80
2	3.36	35.4	37.8	0.8	8.2	25	6165.80
3	5.45	37.2	39.6	0.9	8.5	20	6165.81
4	7.0	38.5	40.8	1.0	9.2	15	6165.81
5	8.12	39.0	42.8	1.3	9.5	10	6165.81
6	8.59	39.5	45.9	1.4	10.1	5	6165.81
7	9.40	40.1	48.2	1.4	10.2	0	6165.81
8	10.12	40.2	51.1	1.3	10.2	-5	6165.81

TABLE XIV
OBSERVATIONS OF REFRIGERATOR WITH NACL MIXED WITH 2 % NANO FLUID AS PCM WITH LOAD

S.No	Time (min)	Temperature(°C)		Pressure(KgF/Cm^2)		Evaporator Cabin Temperature(°C)	Energy Meter Reading(KwH)
		Compressor Inlet(T_1)	Compressor Outlet (T_2)	Compressor Inlet (P_1)	Compressor Outlet (P_2)		
1	0	29.2	31.2	0.5	8.0	30	6165.83
2	3.36	32.3	36.2	0.8	8.5	25	6165.83
3	5.45	35.9	39.2	0.9	9.2	20	6165.84
4	9.0	36.8	40.1	1.0	9.7	15	6165.84
5	11.15	37.9	42.3	1.1	10.9	10	6165.84
6	15.13	38.8	45.3	1.2	11.1	5	6165.85
7	18.19	38.9	48.7	1.3	11.2	0	6165.85
8	21.23	391	51.2	1.3	11.3	-5	6165.85

VIII. SAMPLE CALCULATIONS

For determining the Coefficient of performance of a refrigerator with above observations can be done in the following way:

Using R134a refrigerant PH chart the enthalphies at different points can be obtained as shown in the figure:

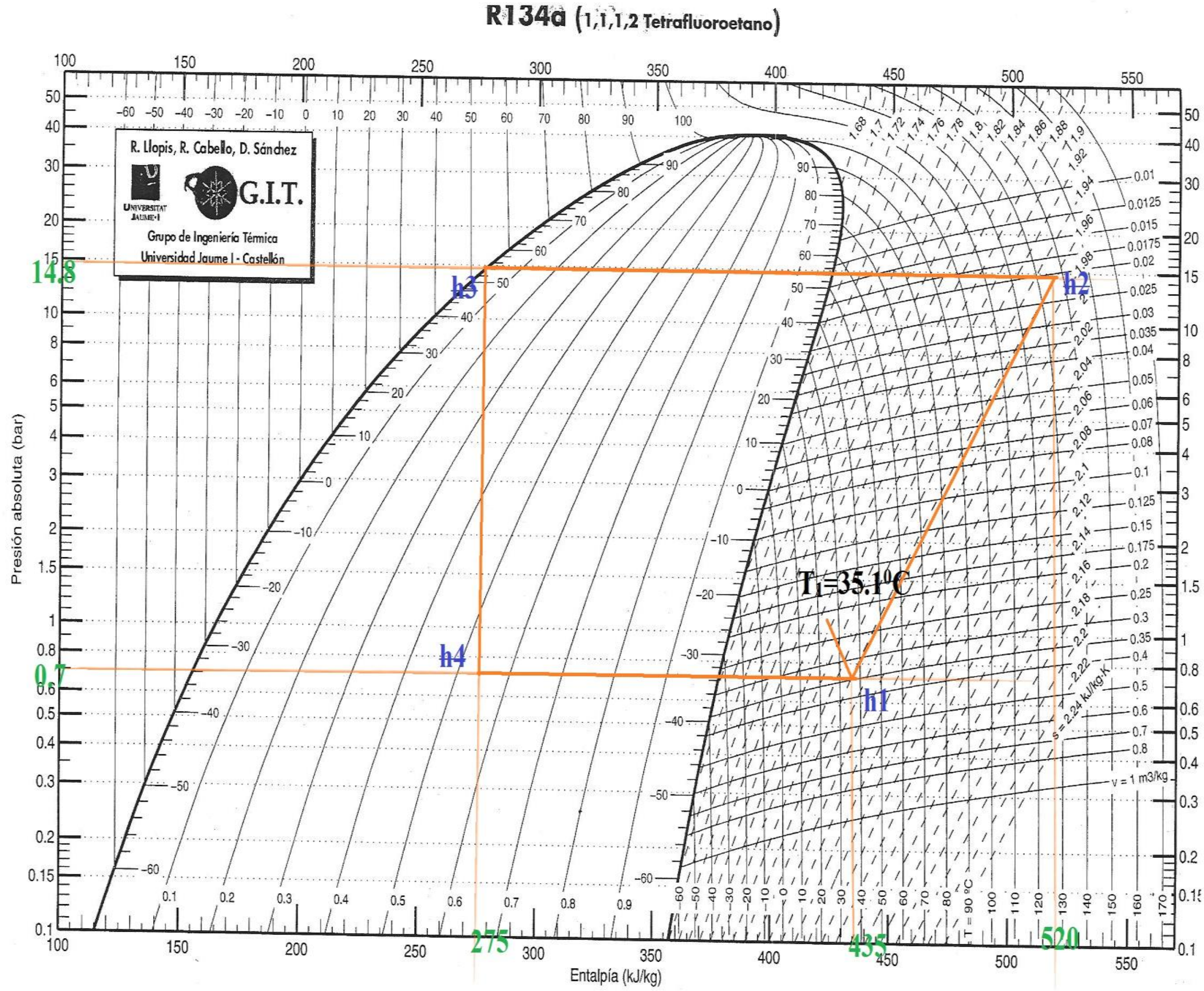

Fig.3 R134a Chart

The pressure and enthalpy diagram was drawn from the observations at 5^0C of the table I i.e., by considering the pressures at inlet of compressor and by taking compressor inlet temperature, point 1 had been located. Then following the constant entropy line, the point 2 had been located at outlet pressure. Point 3 had located on the outlet pressure line where it meets the saturation curve. Point 4 located is located by simply dropping the point 3 downwards (constant enthalphy) line on to the inlet pressure line.

h_1= enthalphy at compressor inlet(KJ/KG)

h_2= enthalphy at compressor outlet(KJ/KG)

h_3= enthalphy at condenser outlet(KJ/KG)

h_4= enthalphy at evaporator inlet(KJ/KG)

Refrigeration effect= h_1-h_4 =435-275=160 KJ/KG

Work done by the compressor= h_2- h_1=520-435=85 KJ/KG

Coefficient of performance of refrigerator(COP) = (Refrigeration effect)/(Compressor work)

=160/85

=1.88

In the same way for every table the COP is calculated. The COP of different observations are tabulated below:

TABLE XV
COP OF REFRIGEARTOR WITH DIFFERENT TYPES OF PCM'S

S.No	Different Cases Of Refrigerator	Coefficient Of Performance (COP)	
		Without Load	With Load
1	Without PCM	1.88	1.7368
2	With water as PCM	2.26	2.066
3	With water mixed with 1%Nano fluid as PCM	2.461	2.361
4	With water mixed with 2% Nano fluid as PCM	2.69	2.538
5	With NaCl solution as PCM	2.53	2.432
6	With NaCl solution mixed with 1% Nano fluid as PCM	2.88	2.723
7	With NaCl solution mixed with 2% Nano fluid as PCM	3.27	3.1

IX. RESULTS

The experiments were conducted using different percentages of Nano fluids as PCM's as discussed above to evaluate the performance improvement of domestic refrigerator. The main aim of this work was to investigate the COP of domestic refrigerator as it is closely related to the refrigeration capacity and compressor work done. PCM's used in this system directly affect the performance of the refrigerator based on the difference in their melting point and latent heat storage capacity.

The following table shows the percentage increase in the COP using different PCM's :

TABLE XVI
PERCENTAGE INCREASE OF COP WITH DIFFERENT TYPES OF PCM'S WITHOUT LOAD

S.No	Different Cases Of Refrigerator	COP	% Increase Of COP
1	Without PCM	1.88	-
2	With water as PCM	2.26	20.2
3	With water mixed with 1%Nano fluid as PCM	2.461	30.9
4	With water mixed with 2% Nano fluid as PCM	2.69	43
5	With NaCl solution as PCM	2.53	34
6	With NaCl solution mixed with 1% Nano fluid as PCM	2.88	53
7	With NaCl solution mixed with 2% Nano fluid as PCM	3.27	73

TABLE XVII
PERCENTAGE INCREASE OF COP WITH DIFFERENT TYPES OF PCM'S WITH LOAD

S.No	Different Cases Of Refrigerator	COP	% Increase Of COP
1	Without PCM	1.736	-
2	With water as PCM	2.066	19
3	With water mixed with 1%Nano fluid as PCM	2.361	36
4	With water mixed with 2% Nano fluid as PCM	2.538	46
5	With NaCl solution as PCM	2.432	40
6	With NaCl solution mixed with 1% Nano fluid as PCM	2.723	56
7	With NaCl solution mixed with 2% Nano fluid as PCM	3.1	78

Above all PCM's the NaCl solution mixed with 2% Nano fluid has higher COP because NaCl has a lower phase change temperature. NaCl solution starts change its phase at -5^{o}C while water at 0^{0}C. when mixed with Nano fluid its phase change temperature has again lowered. As a result, NaCl mixed with Nano fluid stores more latent heat by phase change than other PCM's. During compressor off mode the latent heat stored in the PCM was transferred to the refrigerator cabin through conduction process very fast and avoid the temperature fluctuations inside the evaporator.
The average compressor on time per cycle is significantly reduced for the system with PCM with respect to without PCM and this reduces the energy consumption of the system.
Based on the results, the addition of PCM prolongs the compressor OFF time and enhances the COP of the system. Based on the result 19-78% enhancement of COP can be achieved by the application of PCM inside the evaporator cabin. The amount of enhancement mainly depends on the ambient temperature and the type of PCM used. PCM at evaporator increases evaporation temperature initially which in turn increase compressor inlet temperature. Thus, the performance of a system equipped with PCM at evaporator side is somewhat limited by high condensation temperature. A PCM equipped refrigerator has a smaller ON-time ratio as well as higher COP. These two results are most important for the enhancement of the system. Thermal storage by PCM at evaporator keeps compartment cold for longer periods of time. In case of power failure, the thermal storage compensates the heat gain through the compartment walls.

One more important feature observed with PCM incorporated refrigerator was, when the refrigerator door is opened during power outage, the hot ambient air enters in to the cabin, an ordinary refrigerator with well insulation cannot go back to colder temperature after air exchange. However, when PCM used at evaporator absorbs heat from the cabin air due to its phase change nature and doesn't allow cabin to temperature rise quickly.
Graph below shows the variation of evaporator temperature with time during the compressor off time with and without PCM's.

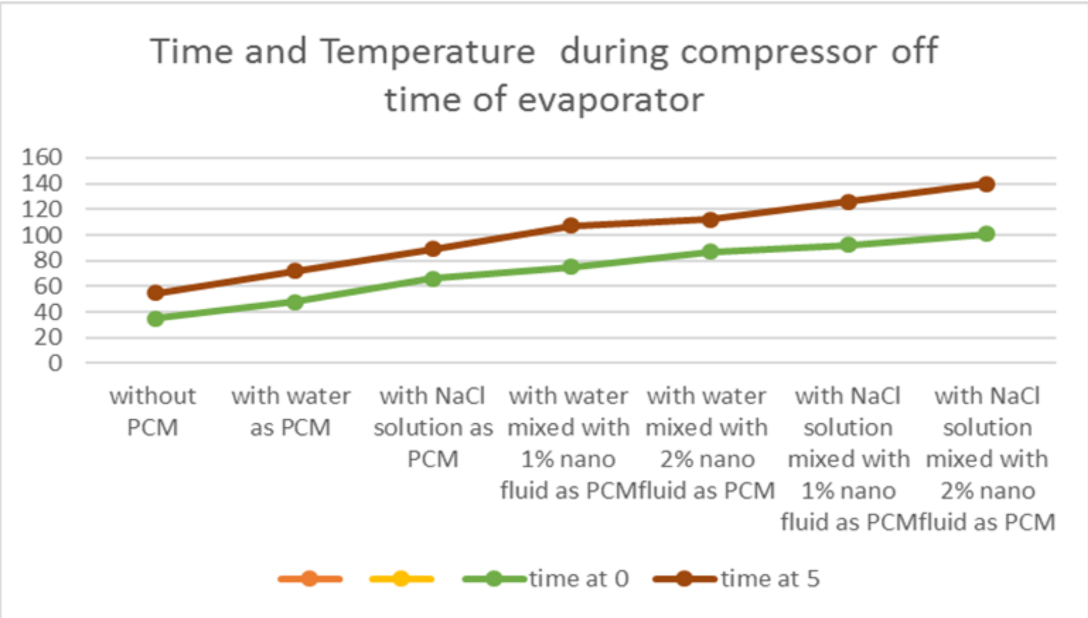

Fig 4. Time taken by the evaporator to maintain 5^{0}C during compressor off time

From the above graph , it was observed clearly that temperature fluctuations with PCM incorporated refrigerator was low when compared to without PCM. Mixing of nano fluid in the phase change material enhanced its thermal storage capacity thus keeps the evaporator cabin cool for a longer time. From the graph, it was observed that the compressor off time for Nano mixed PCM is high.

X. CONCLUSIONS

The experimental study of a domestic refrigeration system with phase change materials mixed with Nano fluids shows the enhancement of the performance of the system and reduction of power fluctuations in the evaporator cabin. Depending on the amount of Nano fluid mixed, maximum of 78% of performance has been increased when compared with without PCM. The integration of 200ml of PCM inside the evaporator cabin maintains the desired temperature of 5^{o}C for maximum of 140 min with NaCl solution mixed with 2% of Nano fluid during the compressor off time.
It has been observed that addition of Nano fluid in to the PCM not only enhanced the thermal storage capacity of PCM but also increased the conduction of heat transfer from the evaporator to PCM in addition to the convective heat transfer to the air.

The experiments results suggested that NaCl solution mixed with 2% Nano fluid would need to be employed in the domestic refrigerators to reduce the temperature fluctuations inside the evaporator and to maintain the required temperature.

So, from all these results it has been noticed that PCM mixed with nanofluid can be utilized in remote areas where power cuts are high. It is very useful to preserve medicines as they need to preserve at low temperatures. The low temperatures can be easily employed by the PCM mixed with Nano fluid incorporated system with power fluctuations. Installing PCM box in the domestic refrigerator can improve the freshness of the load kept in the cabin during power loss.

PCM mixed with Nano can be very effective in a country which has more power cuts.

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