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Performance Enhancement of Mini Refrigerator with Phase Change Materials

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ABSTRACT

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are a kind of latent heat storage units. The use of latent heat storage is especially suited to the storage of energy to prolong food preservation time and also use the excessive stored energy to improve the refrigerator cooling cycle by its release at appropriate time. The principle of latent heat storage using phase change materials (PCMs) can be incorporated into a thermal storage system suitable for using refrigerators. Also, there is an increase in the coefficient of performance of the system. So, our primary objective is to design a working model of the compact refrigerator of suitable capacity incorporating the concept of PCM. Some of the applications are that they are used in thermal energy storage, conditioning of buildings, medical applications and automobiles.

1. INTRODUCTION

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES is classified mainly into latent heat storage material and sensible heat storage material. Phase change materials (PCM) are ''Latent'' heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or ''Phase.'' Initially, these solid–liquid PCMs perform like conventional storage materials, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. A large number of PCMs are known to melt with a heat of fusion in any required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic considerations and easy availability of these materials has to be kept in mind. The PCM to be used in the design of thermal-storage systems should passes desirable thermo physical, kinetics and chemical properties.

2. VAPOR COMPRESSION CYCLE

The vapor-compression 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 environment. All such systems have four components: a compressor, a condenser, a Thermal expansion valve (also called a throttle valve or Tx Valve), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapour and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes.

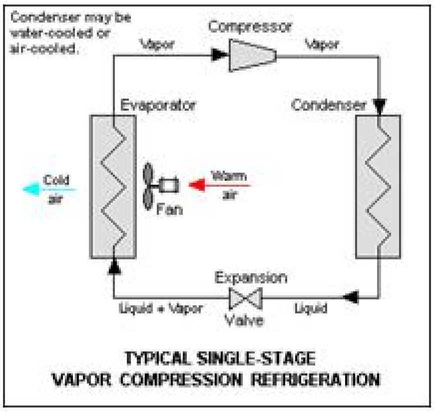


Fig. 1 Vapour compression Cycle

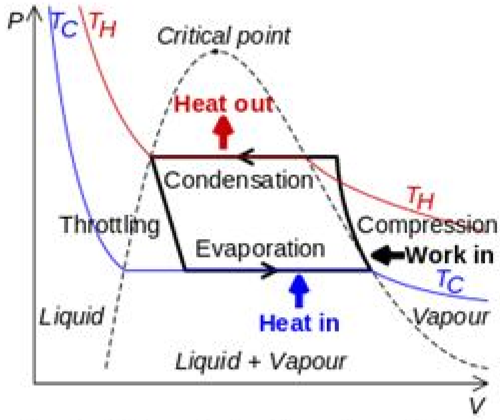


Fig. 2 P-V graph of refrigeration cycle

2.1 Refrigeration cycle with PCM

In our refrigerator, inside the evaporator section we have enclosed few pouches of Phase Change Materials and the remaining components like compressor, condenser and the expansion valve are left untouched.
We have used an inorganic PCM called as HS 01 N which is purchased from a company called PALSKEM, based in Mumbai. Here, we have used 5 pouches of PCM, each weighing 200 grams.

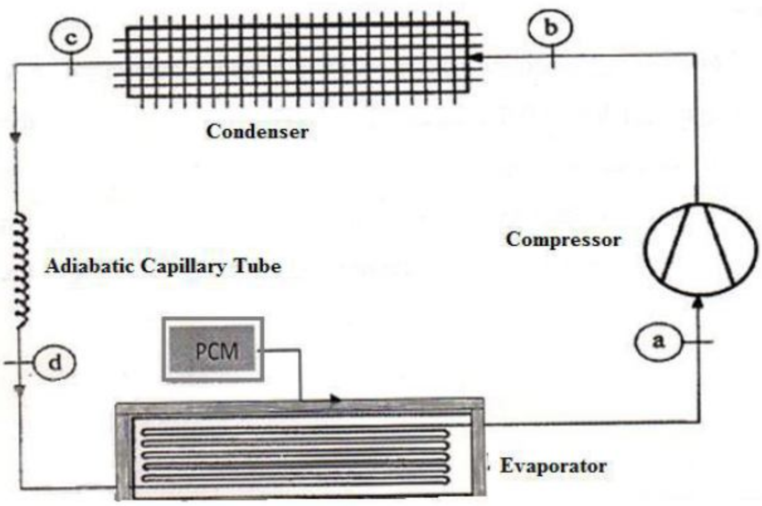


Fig 3. Vapour compression cycle with PCM

3. PROPERTIES OF PHASE CHANGE MATERIAL USED IN EXPERIMENT:

The Phase change material which we are using here is an inorganic salt which is called as HS 01 N, which is purchased from PALSKEM. This particular PCM are available in pouches form of specific size. PCM pouches are placed on the sides of the refrigerator wall. Properties and details of pcm is tabulated below.

Description of PCM:

Material	HS 01 N
Operating Range	-5 to 5
Density	1,100 kg/m^3
Latent heat	290 kJ/kg

Specifications of PCM Pouches:

Particulars	Specifications
Length	125 mm
Width	150 mm
Thickness	17 mm

The PCM pouches are then encapsulated within the evaporator and also the sides of the refrigerator.

Fig .4 HS01N Phase change material

4. EXPERIMENTAL SET UP

The experimental setup consists of a domestic refrigerator of 50 litres capacity designed to work with the refrigerant R-134a which has four main components –

1) Compressor
2) Condenser
3) expansion coil or the capillary tube
4) evaporator which is also called as the cooling coil, where the cooling takes place.

This experimental setup consists of the conventional vapour compression refrigeration machine in which proper instrumentation systems are attached such as the pressure gauges and the thermocouples to measure the pressure and the temperature

Our main objective in this experiment is to calculate COP in various time interval with and without phase change material

In our experimental setup we are going to use two vacuum pressure gauges which will give the pressure in condenser and evaporator respectively. Two different Pressure gauges are used in our experimental setup. Low pressure gauge (max reading 10 bar or 150psi) is attached in the outlet pipe of the evaporator (inlet of compressor) to obtain the pressure in evaporator. High pressure gauge (max reading 20 bar or 280 psi) is fixed in the inlet pipe of condenser to measure the condenser pressure. This experimental setup also consists of two J type thermocouple and a temperature controller which helps us in reading the temperature on a digital display. Thermocouples, attached with temperature sensor, are used to find out respective temperature of compressor inlet pipe and condenser outlet pipe. By using the values obtained with help of pressure gauges and thermo couple, we can plot the values on a R-134a P-h chart.

Fig .5 Digital Temperature controller

Fig.6 Inside of the refrigerator

Fig.7 Back of refrigerator

Fig.8 PCM in the refrigerator.

Tabulation of experimental values

Refrigerator is switched on and values are tabulated.

Notation:

P_1= evaporator outlet pressure. (bar)
P_2=condenser pressure. (bar)
T_1=compressor inlet temperature
T_3=condenser outlet temperature

Sl.no	Time	Evaporator Inlet pressure P_1(bar)	Condenser Outlet Pressure P_2(bar)	Compressor Inlet Temperature T_1(c)	Condenser Outlet Temperature T_3(c)
1	10:00	0.8	9.5	25	25
2	10:10	0.8	10.25	26	29
3	10:20	1	12	27	31
4	10:30	1.1	13.2	28	22
5	10:40	1.1	13.5	28	33
6	10:50	1.2	13.75	28	34
7	10:60	1.2	14.25	29	34
8	11:00	1.2	14.25	31	34
9	11:10	1.2	14.25	31	35
10	11:20	1.2	14.25	31	35

Table:1 Initial reading Without PCM

Sl.no	Time	Evaporator Inlet pressure P_1(bar)	Condenser Outlet Pressure P_2(bar)	Compressor Inlet Temperature T_1(c)	Condenser Outlet Temperature T_3(c)
1	10:00	0.6	8.5	29	29
2	10:10	0.62	8.75	28	29
3	10:20	0.75	9.25	28	29
4	10:30	0.75	9.25	27	30
5	10:40	0.825	9.25	26	30
6	10:50	0.85	9.25	25	30
7	10:60	0.85	9.25	25	30
8	11:00	0.85	9.25	25	30
9	11:10	0.85	9.25	25	30

Table:2 Initial reading With PCM

4.1 Procedure to plot the graph:

Graph plot is one of the important steps to calculate COP. We need to use table1 and table 2 for plotting the graph. Graph is plotted on p-h diagram for R134a. At first two constant pressure lines need to be drawn by taking evaporator pressure (P_1) and condenser pressure (P_2). Constant temperature line at T_1(compressor inlet emp) need to be located and the intersection point of constant T_1 line and constant P_1 line should be marked as point 1. As compression process is isentropic, constant entropy line from point 1 is taken in consideration. Intersection point of constant entropy line and constant P_2 line is marked as point 2. Similarly point 3 is marked by taking the intersection point of constant T_3(condenser outlet temp) and constant P_2 line. Expansion process is constant enthalpy process so a straight line perpendicular to X axis is drawn from point 3 to meet constant P_1 line at point 4. After plotting all the points corresponding enthalpy (h) values are noted in table3 and table 4. Below shown is a model graph.

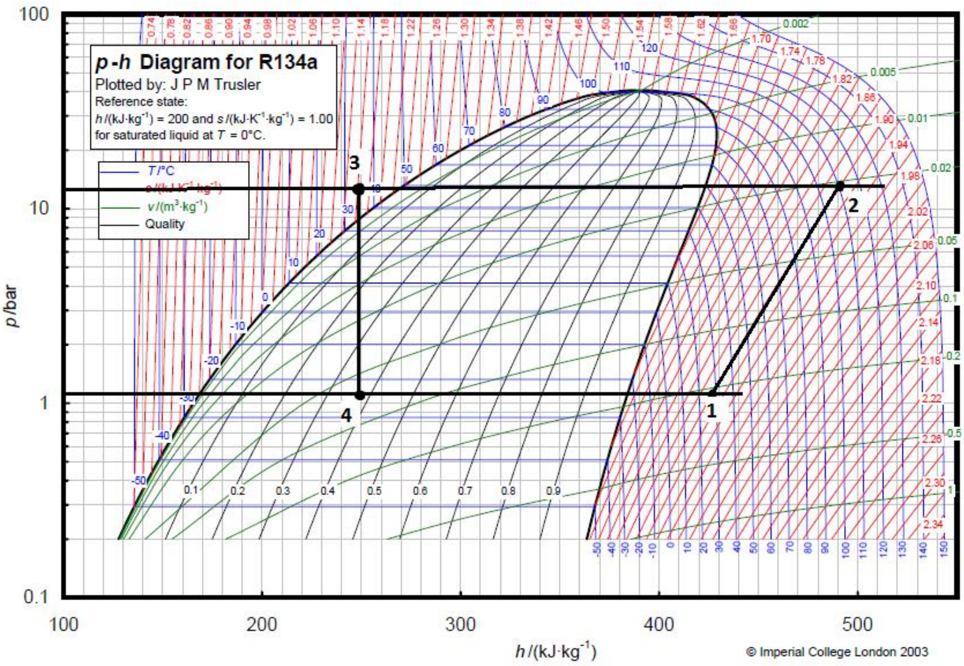


Fig.9 R-134 a Chart

Without PCM:

Sl. no	Time	P_1(bar)	P_2(bar)	T_1(c)	T_3(c)	h_1 ($Kj.kg^{-1}$)	h_2 ($Kj.kg^{-1}$)	h_3($Kj.kg^{-1}$)
1	10:00	0.8	9.5	25	25	420	480	238
2	10:10	0.8	10.25	26	29	422	484	239
3	10:20	1	12	27	31	425	488	240
4	10:30	1.1	13.2	28	22	428	492	240
5	10:40	1.1	13.5	28	33	430	498	242
6	10:50	1.2	13.75	28	34	432	503	242
7	10:60	1.2	14.25	29	34	434	506	250
8	11:00	1.2	14.25	31	34	434	506	250
9	11:10	1.2	14.25	31	35	434	506	250

Table:3 Enthalpy values without PCM

With PCM:

Sl.no	Time	P_1(bar)	P_2(bar)	T_1(c)	T_3(c)	h_1 ($Kj.kg^{-1}$)	h_2 ($Kj.kg^{-1}$)	h_3($Kj.kg^{-1}$)
1	10:00	0.6	8.5	29	29	430	490	242
2	10:10	0.62	8.75	28	29	431	492	243
3	10:20	0.75	9.25	28	29	433	494	244
4	10:30	0.75	9.25	27	30	433	494	245
5	10:40	0.825	9.25	26	30	434	492	243
6	10:50	0.85	9.25	25	30	426	488	242
7	10:60	0.85	9.25	25	30	426	490	242
8	11:00	0.85	9.25	25	30	426	490	242
9	11:10	0.85	9.25	25	30	426	490	242

Table:4 Enthalpy values with PCM

4.2 Calculations:

Coefficient of performance without PCM

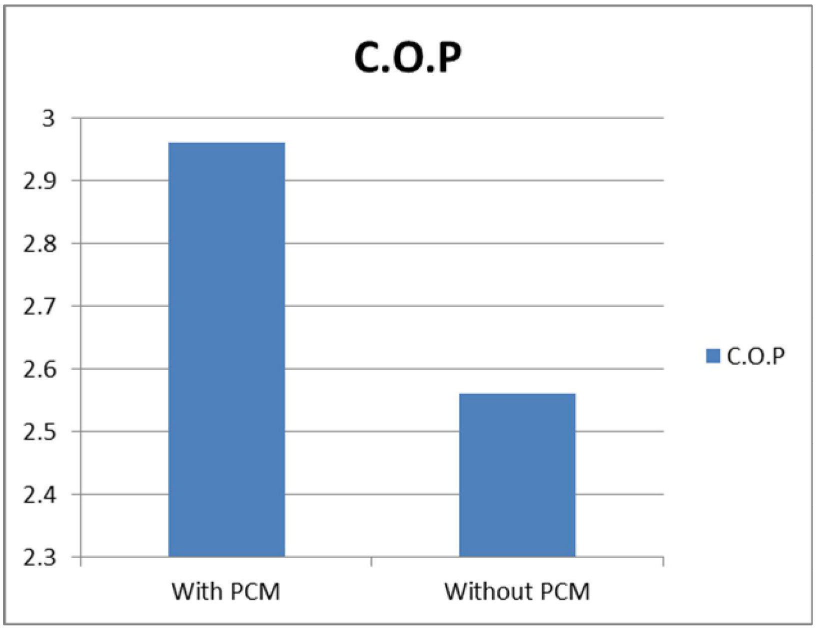
$$COP=\frac{h_1 - h_4}{h_2 - h_1} = \frac{434-250}{506-434} = 2.55$$

Coefficient of performance with PCM

$$COP=\frac{h_1 - h_4}{h_2 - h_1} = \frac{426-242}{488-426} = 2.96$$

Percentage Calculation: % increase in COP = $\frac{final\ COP - initial\ COP}{initial\ COP} \times 100$

$$= \frac{2.96-2.55}{2.55} = 16.07\%.$$



5. CONCLUSION

Experimental tests have been carried out to find the performance improvement of a household refrigerator with and without using Phase Change Materials.

- The COP using PCM is found out to be 2.96
- The COP without using PCM is found to be 2.56

There is a 16.07% increase in the COP using 1 kg of HS 01N PCM.
Hence the results proved that the coefficient of performance is found more in a refrigerator using PCM compared to without using PCM. Depending on the load and no-load conditions the COP changes and shows a significant improvement using Phase Change Materials.

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