International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 03 | March - 2023 Impact Factor: 7.185 ISSN: 2582-3930

A Performance Enhancement of Household Refrigerator using Phase Change Materials (PCMs)

Dr. Vilas A. Pharande[1], Shrinath Arun Desai [2],

[1] Principal, Arvind Gavali College of Engineering, Maharashtra, India

2 P.G. Student, Department of Mechanical Engineering, Arvind Gavali College of Engineering, Maharashtra, India

---***---

Abstract - In this study, a household refrigerator with ceiling type evaporator is considered to equip it with CTES system by using PCM. 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. Different approaches have been used to improve the thermal performance of these systems by integration of PCM. A number of studies have focused on the application of PCM at evaporator for cold storage. So we are doing experimental investigation to improve energy efficiency of household refrigerator by introducing a new phase change material.

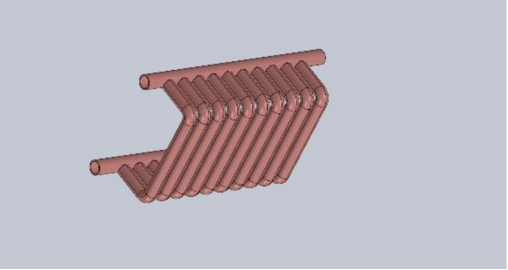
***Key Words*:** Thermal Energy Storage, Phase Change Material, Household Refrigerator, COP.

1.INTRODUCTION

At present industrialization and also standard of living is increasing rapidly. Almost all appliances or devices working for this growth consumes large amount of electricity.[1] Quarter of residential electricity is consumed by the household refrigerator because it is widely use home appliance due to continuous operation[2,3]. A rising global attention and speedily increasing cost of electricity is turning towards renewal energy sources. Most of the existing forms of renewable energy on earth are not continuous. Wind power plants can only generates power when there is enough wind. Same in case of solar power station, in this stations heat can only be collected when sun is shining. So the disordering between demand and supply takes place. To beat this problem 'energy storage' is an important approach mainly there are three ways to store the thermal energy. 1) Sensible heat storage 2) latent heat storage 3) chemical heat storage.[4] In today world, sensible heat storage technique is used largely in double molten salt tank concept. On the other hand, latent heat storage method becoming interesting alternatives due to high storage density and constant temperature.[5,6] In latent heat storage method heat is released or absorb during the phase transformation of PCMs from one form to another at constant temperature.[7]

In this work, experimental analysis of household refrigerator with copper and steel casing filled with eutectic PCM. In this, refrigerator compartment is surrounded by the tubular PCM heat exchanger for increasing compressor cut-off time and reducing energy consumption of refrigerator

2. CAD MODEL OF TRAY



[FIG 1: CAD MODEL OF COPPER TRAY]

[FIG 2: CAD MODEL OF STEEL TRAY]

3. EXPERIMENTAL SETUP

Conventional vapour compression single door household refrigerator was selected for this work. Two trays of metal tubes are Designed. Evaporator of the refrigerator is covered with a single tray at a time which is filled with PCM. This PCM is mixture of ethylene glycol and water. Thermal conductivity of PCM is 0.26W/m-K whereas thermal capacity is 2400 J/kg-K. Whole experimental setup includes regular refrigerator, two metal trays, four thermocouples, two pressure gauges.

Modified circuit with gauges shown in (fig 3) pressure gauges are used at inlet as well as at outlet of the compressor to measure the pressure of evaporation and condensation. Four thermocouples are used to measure the temperature of evaporator, condenser, cabin, compressor.

[Fig -3: Experimental setup]

[Fig 4: Copper Tray]

[Fig 5: Steel Tray]

4. EXPERIMENTAL PROCEDURE

Household refrigerator with PCM tray was tested at same operating conditions in case of copper tray as well as in case of steel tray. The experiment was carried out in room which was maintained at constant temperature of 240C by using air-conditioning system. Temperatures of evaporator, pressure of compressor inlet and outlet were tested. To further investigate the operating characteristics, the evaporator midpoint temperature, compressor outlet temperature and condenser outlet temperature were also measured. Evaporator midpoint temperature is the temperature at the midpoint of evaporator.

5. METHODOLOGY

Household refrigerator with PCM tray was tested at same operating conditions in case of copper tray as well as in case of steel tray. The experiment was carried out in room which was maintained at constant temperature of 240C by using air-conditioning system. Temperatures of evaporator, pressure of compressor inlet and outlet were tested. To further investigate the operating characteristics, the evaporator midpoint temperature, compressor outlet temperature and condenser outlet temperature were also measured. Evaporator midpoint temperature is the temperature at the midpoint of evaporator.

6. CALCULATIONS

For COP

Find COP for refrigerator Without PCM and with PCM (by using Steel tray and Copper tray)

Refrigeration system works on simple vapour compression system. Refrigerant used R134a

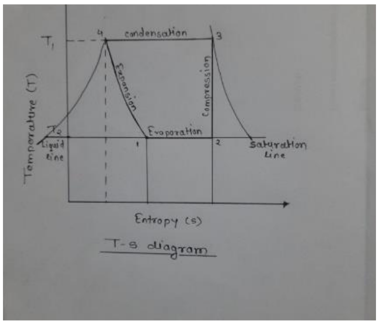
$$COP = \frac{Heat\ extracted\ or\ refrigerating\ effect}{Work\ done} = \frac{h_2 - h_1}{h_3 - h_2} = \frac{h_2 - h_4}{h_3 - h_2}$$

Without PCM

Evaporator temperature is -5°C and condenser temperature is 26

The following data from p-h chart for refrigerant R134a

Pressure, bar	Temperature, °C	Enthalpy, KJ/Kg		Entropy, KJ/Kg K	
		Liquid	Vapour	Liquid	Vapour
2.4	-5	44.7	247.3	0.1783	0.9347
7	26	88.8	265.1	0.3324	0.9200



T-S diagram without PCM

Here,

h_{f_2}=44.7, h_{fg_2}= 247.3 s_{f_2}= 0.1783 s_{fg_2}= 0.9347

h_{f_4}= 88.8 h_3= 265.1 s_{f_4}=0.3324 s_{g_3}=0.9200

$$s_{f_2} + x_2 * s_{fg_2} = s_{g_3}$$

$$0.1783 + x_2 * 0.9347 = 0.9200$$

$$x_2 = 0.8$$

$$h_2 = h_{f_2} + x_2 * h_{fg_2}$$

$$h_2 = 44.7 + 0.8 * 247.3$$

$$h_2 = 242.54$$

$$COP = \frac{h_2 - h_1}{h_3 - h_2} = \frac{242.54 - 88.8}{265.1 - 242.54} = 6.81$$

With PCM (Steel Tray)

Evaporator temperature is -3.9°C and condenser temperature is 26

The following data from p-h chart for refrigerant R134a

Pressure, bar	Temperature °C	Enthalpy, KJ/Kg		Entropy KJ/Kg K	
		Liquid	Vapour	Liquid	Vapour
2.5	-3.9	46.8	248.2	0.1834	0.9340
7	26	88.8	265.1	0.3324	0.9200

Here,

h_{f_2}=46.7, h_{fg_2}= 248.1 s_{f_2}= 0.1834 s_{fg_2}= 0.9340

h_{f_4}= 88.8 h_3= 265.1 s_{f_4}=0.3324 s_{g_3}=0.9200

$$s_{f_2} + x_2 * s_{fg_2} = s_{g_3}$$

$$0.1834 + x_2 * 0.9340 = 0.9200$$

$$x_2 = 0.8$$

$$h_2 = h_{f_2} + x_2 * h_{fg_2}$$

$$h_2 = 46.7 + 0.8 * 248.3$$

$$h_2 = 245.4$$

$$COP = \frac{h_2 - h_1}{h_3 - h_2} = \frac{245.4 - 88.8}{265.1 - 245.4} = 7.95$$

With PCM (Copper tray)

Evaporator temperature is -3.2°C and condenser temperature is 26

The following data from p-h chart for refrigerant R134a

Pressure, bar	Temperature °C	Enthalpy, KJ/Kg		Entropy KJ/Kg K	
		Liquid	Vapour	Liquid	Vapour
2.6	-3.2	47.5	248.6	0.1885	0.9333
7	26	88.8	265.1	0.3324	0.9200

Here,

h_{f_2}=47.5, h_{fg_2}= 248.6 s_{f_2}= 0.1885 s_{fg_2}= 0.9333

h_{f_4}= 88.8 h_3= 265.1 s_{f_4}=0.3324 s_{g_3}=0.9200

$$s_{f_2} + x_2 * s_{fg_2} = s_{g_3}$$

$$0.1885 + x_2 * 0.9333 = 0.9200$$

$$x_2 = 0.8$$

$$h_2 = h_{f_2} + x_2 * h_{fg_2}$$

$$h_2 = 47.5 + 0.8 * 248.6$$

$$h_2 = 246.3$$

$$COP = \frac{h_2 - h_1}{h_3 - h_2} = \frac{246.3 - 88.8}{265.1 - 246.3} = 8.30$$

For Power consumption

Power consumption by refrigerator without PCM and with PCM (Steel tray and Copper tray)

We observe that normal running time of compressor for 1 hr. is 23 mins

Hence for 24 hrs running time of compressor time = 552 min = 9.2 hrs

Power input (for 1 hr) = 160 watts

Hence the power required for day (9.2 hrs)= 160*9.2= 1472 Wh = 1.472 KWh

For year, 1.472*365= 537.28KWh

For year total power consumed by refrigerator is **538** KWh

By using Phase Change Material (with steel and copper tray)

PCM with steel tray

We observe that, by using PCM with steel tray the running time of compressor for 1 hr. is 19.5 mins

Hence for 24 hrs running time of compressor time = 468 mins = 7.8 hrs

Power input (for 1 hr) = 160 watts

Hence the power required for day (7.8 hrs)= 160*7.8= 1260 Wh = 1.26 KWh

For year, 1.26*365= 460KWh

For year total power consumed by refrigerator is **460** KWh

PCM with copper tray

We observe that, by using PCM with copper tray the running time of compressor for 1 hr. is 18.9 mins

Hence for 24 hrs running time of compressor time = 454 mins = 7.6 hrs

Power input (for 1 hr) = 160 watts

Hence the power required for day (7.6 hrs)= 160*7.6= 1216 Wh = 1.216 KWh

For year, 1.216*365= 443.84KWh

For year total power consumed by refrigerator is 444 KWh

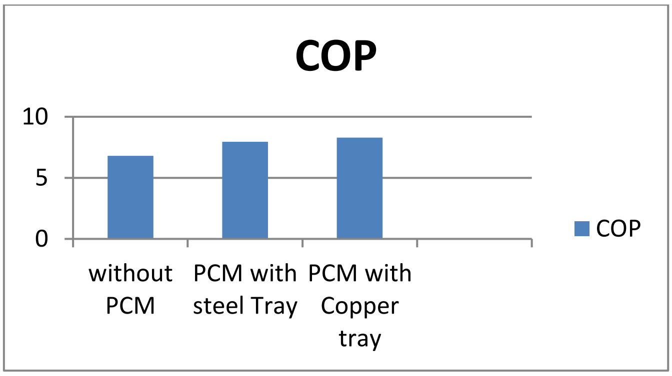
7. EXPERIMENTAL RESULTS

For COP

PERCENTAGE IMPROVEMENT IN COP

Sr. no			COP	% increase in COP
1	Without PCM		6.81	_
2	PCM	Steel tray	7.95	15
		Copper tray	8.30	18

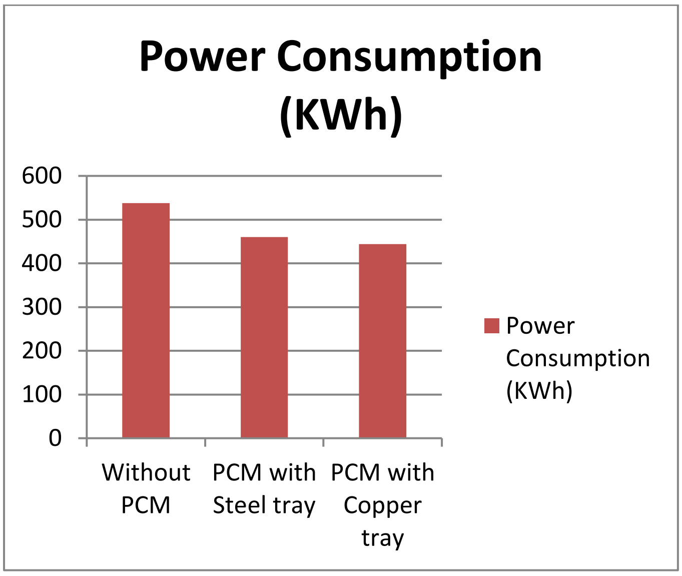
PERCENTAGE IMPROVEMENT IN COP



For power consumption

POWER CONSUMPTION (for year)

SR. NO.			Power consumption (in KWh)	% of reduction in power consumption
1	Without PCM		538	_
2	PCM	Steel tray	460	14.50
3		Copper tray	444	17.47



8. CONCLUSIONS

Here we increased COP value of refrigerator by using Phase Change Material which located at evaporator of refrigerator. R134a refrigerant used in refrigerator. Experiment perform in 3 steps 1. Without using PCM (normal condition) 2. Using PCM with steel tray and 3. Using PCM with copper tray. The results shows that COP value increases when temperature of evaporator increase. For steel tray COP of refrigeration system is 7.95 which is 15 % greater than COP of normal condition where as for the copper tray COP of refrigeration system is 8.30 which is 18 % greater than normal condition.

Under the stable operating condition refrigerator, the energy consumed by refrigerator is 538 KWh for year. After the use of Phase Change Material consumption rate is decreased. For steel tray energy consumption is 460KWh while for copper tray is 444 KWh for year. Comparing with normal condition 14.50% and 17.47% energy consumed by respective steel and copper tray.

Copper tray is more efficient than steel tray. PCM reduce fluctuations in temperature and gives more stability to evaporator for variant load on evaporator. As increased in evaporating temperature the COP of cooling system of refrigerator is improved. We improved Coefficient of Performance and reduce power consumption of household refrigerator by easy and cheap way. Both trays are easy to handle, removable and refilling Phase Change Material.

REFERENCES

1. S.E. Hosseini, M.A. Wahid, Hydrogen production from renewable and sustainable energy resources: promising green energy carrier for clean development, Renew.Sustain. Energy Rev. 57 (2016) 850–866, https://doi.org/10.1016/j.rser.2015.12.112.

2. Joybari, M.M., Haghighat, F., Moffat, J., Sra, P., 2015. Heat and cold storage using phase change materials in domestic refrigeration systems: The state-of-the-art review. Energy Build. 106, 111–124.

3. A.P. Simard, M. Lacroix, Study of the thermal behaviour of a latent heat cold storage unit operating under frosting conditions, Energy Convers. Manag. 44 (2003) 1605-1624.

4. S. Bakhshipour, M.S. Valipour , Y. Pahamli, Parametric analysis of domestic refrigerators using PCM heat exchanger 2017

5. E. Risueno, A.Faik, J. Rodríguez-Aseguinolaza, P. Blanco-Rodríguez, A.Gil, M. Tello and B. D'Aguanno. Mg-Zn-Al eutectic alloys as phase change material for latent heat thermal energy storage. https://doi.org/10.1016/j.egypro.2015.03.193

6. Haoxin Xu, Jia Yin Sze, Alessandro Romagnoli, Xavier Py. Selection of Phase Change Material for Thermal Energy Storage in Solar Air Conditioning Systems. https://doi.org/10.1016/j.egypro.2017.03.898

7. D.J. Malan, R.T. Dobson, F. Dinter. Solar thermal energy storage in power generation using phase change material with heat pipes and fins to enhance heat transfer. https://doi.org/10.1016/j.egypro.2015.03.176