PERFORMANCE ANALYSIS OF COLD ENERGY STORAGE USING PHASE CHANGE MATERIAL

R.Karthikeyan1*, Dr.P.Thangavel2
1 Assistant Professor, Kongu Engineering College, Department of Mechanical Engineering, Perundurai, Erode,Tamilnadu, India.
2 Associate Professor, Kongu Engineering College, Department of Mechanical Engineering, Perundurai, Erode,Tamilnadu, India.

Abstract. Refrigeration is a method of extracting heat from low-temperature reservoir and shifting it to a high-temperature reservoir. The energy consumed by the refrigerator is increased day by day due to the changes in the standard of living and quick industrialization. In household appliances, the domestic refrigerator is the most energy consuming devices due their continuous operation. Efforts have been made in many countries to boost the COP of the refrigerators and reduce the energy consumption in the compressor. The above problems are rectified by using of Phase Change Material (PCM) in the domestic refrigerators. Due to the fact that over a large number of freezing / melting periods, PCM must be chemically and thermally stable. In the case of thermal energy storage in refrigerators, the PCM must be applicable and the choice of PCM in refrigeration systems is an important issue. The use of PCM in the evaporator segment minimizes compressor dome temperature fluctuations and provides stable conditions against changes in thermal loads. The main objective of the present research is to investigate the household refrigerator using Phase Change Material. The experimental results showed important impacts on the performance of the system, the on-off compressor cycle and the reduction in electricity consumption. The results showed that 0.69 % increase in COP, 1.8 % decrease in compressor work and 6.7 % increase in refrigerator Effect. The dome temperature is reduced to 3.91% when compared to without PCM in the evaporator.

Keywords: Phase Change Material (PCM), Refrigerating Effect, Co Efficient of Performance, Compressor work, Evaporator, Household Refrigerator, Vapour Compression Refrigeration System, Dome Temperature.
1. Introduction

Refrigeration is a method of extracting heat from and shifting it to a high-temperature reservoir from a low-temperature reservoir. The heat, magnetism, electricity and lasers are used to drive the heat transfer work. The applications of the refrigeration are refrigerators, air – conditioning, cryogenic applications and freezers. The air-conditioning systems are designed reversible to the heat pump that use the outlet temperature in the cooling process. Jonathan Cofre – Toledo (2003) et al. describes the use eutectic phase change material i.e., combination of ammonium chloride and PLUSICE E-10. They have used ammonium chloride at 19.5%. Their concentrations and thermal storage values are determined by phase shift, and their heat capacity. The density values are considered at the temperature of 20 °C. The material for phase change is located parallel to the aluminium tubes. On either side of the evaporator, two rows of six tubes are mounted parallel to the evaporator tubes with self-locking nylon cables. In freezing food, the average temperature is decreased to 37.2% and 56.9% 19.5 wt. % aqueous solution of NH4Cl.

Subhanjan Bista (2008) et al. Explain the benefit of using phase change material in condenser compressor and evaporator sections to reduce the amount of power supplied. In this they have used both the organic, eutectic and inorganic phase change materials separately at different times and analyzed the power consumption. Organic phase change materials like n-Tetradecane, Paraffin (C14) and inorganic phase change materials like Hexadecane + tetradecane (2:3–0:1 by volume) and Octadecane + docosane and eutectic phase change materials like LiClO3·3H2O or water. By applying these different phase change materials show improvement in system performance and in reducing noise of the refrigerator. It also helps to keep the items stored in times of power outages. Yusufoglu (2009) et al. used two different kind of phase change material in two different models of refrigerator to optimize the compressor on/off time. They have increased the surface area of the condenser in the design to increase the effect of phase change material. They used distilled water in their first model of the refrigerator behind the evaporator. In the second refrigerator model the circulated
cold air in the evaporator through tubes. The result shows 9.4% saving in energy by using 950 grams of phase change materials used in the evaporator. R. Elarem (2005) et al. used the ICE PCM are filled in the entire evaporator of twelve U-type tubes. The change in temperature range of 4 °C is produced by using the above mentioned phase change material. The results show that 8 % increase in COP and 12 % decrease in the power consumption by using the new PCM in the refrigerator when compared to base type refrigerator.

Xi Guo (2008) et al. have prepared composites with expanded PCM of graphite stabilised paraffin and wood/polyethylene. The simple and efficient stable PCMs are formed by the base PCMs are mixed with porous material. The result indicated that the Thermal Energy Storage (TES) composites have the good thermal capacity when compared to the Refrigerant. D. Shikalgar Niyaj (2010) et al. explains the use of propane as refrigerant rather than R134a. The positive result shows that COP of the system was increased by incorporating the Phase Change Material (PCM) in the evaporator in addition to provide the cooling to the material. Depending upon the thermal load, the refrigerator was tested with Ethylene Glycol. The running time of the compressor per cycle was decreased and the co efficient of the performance was increased when R290 as a refrigerant. The selected refrigerant is equal to R134a and the torque of the compressor was reduced. The life time of the compressor was increased due to the reduction in torque of the compressor.

Kun Du (2012) et al. observed that the energy storage is maximum which leads to store more heat of fusion when compare to conventional energy system. The latent heat storage is the alternate method for the conventional structure. The phase change material is coated inside the evaporator backside. The compressor inlet and outlet temperature varied from -20°C to 200°C was measured by the application of the phase change material.

Suxin Qian (2014) et al. The performance of refrigerator was reviewed with and without PCM. In this refrigerator, the new design of refrigerated space which is positioned after the condenser. The selected PCM is N-Octadecane and blending temperature of 27.5 °C. The refrigerator COP was increased to 9.58% due to the lower temperature of condenser. The system performance was increased due to the modified design and refrigerant properties. Malik Muhammad Umair (2019) et al. analyzes the performance of the refrigerator and reported that the system performance was increased and leakage of the refrigerant was reduced due to the energy storage in the organic phase change material. The energy produced on or after the organic phase change material is maintaining the shape stability. The performance of the system was increased and work input to the compressor was reduced.

Kin Yuen Leong (2019) et al. use the nano-particles for the upgrading of energy storage capacity of the refrigerator. The phase change material having the capacity to release or store the latent heat that is used for maintaining the cooling. The effectiveness of the substance was lowered due to the lower energy storage capacity of the substance. The energy storage capacity of the substance was improved by the mixing the nano particles to the refrigerant. As a result, the effectiveness of the substance was increased.

Vapor-compression refrigeration is the cycle that used in the all refrigerators and air conditioning. The latent heat of vaporization is the one of the technique used in the domestic refrigerator which refrigerant flowing through tubes. It is often used in domestic refrigerators and vehicle air conditioning, large refrigerated or frozen food and meat storage plants, refrigerated trucks and railway vehicles. In this refrigeration cycle, the heat is removed from the low temperature source and rejected into a high temperature sink by the external power source. This is the application of second law of thermodynamics. The main problem behind the refrigerators is the energy consumed by the compressor was high and also lower performance. The above problem is rectified by the employ of phase change material in the refrigerator. The phase change material stores the energy when energy is excessive and release the energy when required.

The main objective of the research work is to improve the performance of the refrigeration system and reduce the energy consumption in the refrigerator using phase change material in the evaporator.

2. **Methodology**

The below figure 1 describes about the methodology of the work. The initial task in the project is to create a model of the refrigeration system. The literatures about the research done in the field of refrigeration are studied. The phase change material is selected based on the temperature ranges. The PCM is selected and then incorporated in the evaporator section and
subjected to analysis. The results obtained through analysis are checked and verified. The report is prepared using the obtained results from the analysis and concluded.

**Figure 1**: Proposed methodology
2.1. Experimental detail

The figure 2 shows the experimental setup of the refrigeration system. The refrigeration system consists of a (1/5 HP) compressor, condenser, expansion valve, evaporator, plywood, aluminium paper and phase change material in liquid state. The components are fixed in their locations through welding at some places and riveting at other locations. The refrigerant used is R134a and it made to cycle inside the modal. The equipment needs external power supply for its function so external source is applied. The equipment is placed where temperature can be controlled and readings were taken at the same location.

![Photographic view of the working model](image)

**Figure 2:** Photographic view of the working model
2.2. Experimental Procedure

The experiment is connected to the power supply and the process begins with the compression of R134a refrigerant with the compressor, the refrigerant in the vapour phase gets compressed and the temperature of the refrigerant reaches super saturation temperature and also the pressure of the refrigerant increases. Then the refrigerant with high temperature and high pressure moves to the condenser and then the condensing of the refrigerant takes place. The condensation process decreases the temperature of the refrigerant and does not cause any change in pressure. The refrigerant with high pressure and low temperature moves inside the expansion valve and the pressure suddenly decreases and also the temperature because of the sudden change in volume. Now with low pressure and temperature the refrigerant enters into the evaporator and absorbs the heat inside and comes out of the evaporator. The refrigerant emits cold energy by absorbing heat energy in every cycle. The phase change material is placed inside the evaporator so during each cycle the phase change material absorbs the cold energy and solidifies and when the temperature is reached the compressor cut off takes place and the working stops. When the temperature of the evaporator increases the compressor is cut on and cycle continues and the cooling takes place. During the cut-off the phase change material emits the cold energy by absorbing the heat energy and liquefies. Because of the phase change material action the compressor cut-on time is increased. So when the compressor work is reduced so the power consumption is reduced.

2.3. Selection of PCM

The selected phase material is the savE® OM03 and is used in the refrigerator. The phase change material is organic material which stores the energy in the shape of suppressed temperature and release the power once necessary. The phase change material which store the heat without change in the material and compound properties of the substance. The freezing and melting temperature of the savE® OM03 organic material are 3.0°C and 4.0°C

The Table 1 shows the Properties of Organic Phase change materials.

| S.NO | Property                        | Value  |
|------|---------------------------------|--------|
| 1.   | Melting Temp (°C)               | 4.0    |
| 2.   | Freezing Temp ( °C)             | 3.0    |
| 3.   | Latent Heat (kJ/kg)             | 229    |
| 4.   | Density of Liquid (kg/m3)       | 835    |
| 5.   | Solid Density (kg/m3)           | 912    |
| 6.   | Liquid Specific Heat (kJ/kgK)   | 1.91   |
| 7.   | Solid Specific Heat (kJ/kgK)    | 1.76   |
| 8.   | Thermal Conductivity of Liquid (W/mK) | 0.146  |
| 9.   | Thermal Conductivity of Solid (W/mK) | 0.224  |
| 10.  | Base Material                   | Organic|

3. Results and Discussion

As per the analysis the phase change material is placed in the evaporator. The phase change material solidifies at -5 degree. The readings obtained in the systems with and without PCM are compared. The performance of the system is increased and power consumption is decreased by using PCM in the evaporator.
3.1. **Effect on Compressor Cut-Off With and Without PCM**

The Figure 3 shows the time versus compressor outlet temperature and of compressor cut-off cycle in the definite period was noted. The difference in the cut-off conditions show that the cut-off of the refrigerator model with PCM takes place before the cut-off of the model without PCM. The Cut off cycle with PCM is lesser than that of exclusive of PCM. As a consequence, the compressor mode is extended off. The cut-off cycle was reduced certain period of time.

![Figure 3: Effect of compressor cut off](image-url)
3.2. Effect on Co-efficient of Performance With and Without PCM

Fig 4 shows the comparison between co-efficient of performance of the refrigerator with model PCM and without PCM. As shown in the figure the co-efficient of performance of the model with PCM is more when compared with the refrigerator model without PCM. This is because of the cold energy stored in the PCM during every cycle of the refrigerant flow that emits the cold energy stored during the cut-off time so the performance is increased. As the results showed using PCM, the COP is increased by 6.7% than the usual system without using PCM and based on the quantity of PCM, the COP value is increased.
3.3. Effect on Refrigerator Effect with and without PCM

![Figure 5: Effect on Refrigeration effect](image)

The Figure 5 explains the comparison between the amount of refrigeration effect produced by the refrigerator model with and without PCM. The refrigerating effect and COP are directly proportional to each other. As seen in the figure the refrigeration effect produced by the system with PCM is more when compared with the system without PCM. The reason behind this is the PCM stored in the evaporator section stores the cold energy and emits it back when there is a difference in the evaporator section. As the results showed, using PCM the refrigeration effect increased by 0.69% than the usual system which is modeled without using PCM.

3.4. Effect on Compressor Work with and without PCM

![Figure 6: Effect on Compressor work](image)

The Figure 6 explains the difference in compressor work takes during the cycles of refrigeration systems designed without PCM. The difference shows the system designed with PCM shows reduced
in compressor work while the compressor without PCM is more. The reason for reduction of compressor work is the prolonged compressor cut off – on time. The compressor cut off – on time is reduced due to the placing of PCM in the evaporator. As the results showed using PCM, the compressor work decreased by 1.8% than the usual system.

3.5. Effect on Dome Temperature with and without PCM

![Graph showing comparison of dome temperature between systems with and without PCM.](image)

The Figure 7 shows the comparison between the dome temperature produced during the compressor operation on both the systems with and without PCM. The interval between cut-off and cut-in condition the compressor work reduces due to the PCM in the evaporator. As a result, the dome temperature produced in the compressor system with PCM is 3.91 % less when compared with the system without PCM.

4. Conclusion

In household appliances, the domestic refrigerators are the most energy consuming devices. The energy consumed by the refrigerator and COP are the most challenging research in the refrigerators. The duration of the compressor cut off-on was long due to their lower energy storage capacity if the material. The above problem in the refrigerator is rectified by the bring into play of Phase Change Material (PCM) inside the refrigerator. The PCM is an organic material that is stored the energy when excess energy is produced and release the energy whenever required. The PCM of Liquid state to be made used to store the energy in the evaporator. The cold energy storage setup is analyzed a as per the plan. The thermal storage material be used to increase the COP, reduce the Energy Consumption and prolonged compressor cut off on time. The result shows that increase in COP by 6.7%, refrigeration effect by 0.69% and reduction in compressor work by 1.8%. The dome temperature in the compressor was reduced to 3.91 % when compared refrigerator without PCM.
References

[1] A. Abhat (1983), ‘Low temperature latent heat thermal energy storage heat storage materials’. (1983), pp. 313-332.
[2] Al-Abidi (2012), ‘The review of thermal energy storage for air conditioning systems renew. Sustain’. Energy Rev., 16 (8) (2012), pp. 5802-5819.
[3] Azzouz (2008), ‘Performance enhancement of a household refrigerator by addition of latent heat storage’. Int. J. Refrigeration., 31 (5) (2008), pp. 892-901.
[4] Azzouz (2009), ’The performance of household refrigerators with latent heat storage: an experimental investigation’. Int. J. Refrigeration”, 32 (7) (2009), pp. 1634-1644.
[5] S. Naik (2010), ‘Solar dryer with thermal energy storage systems for drying agricultural food products: a review. Renew. Sustain. Energy’ Rev., 14 (8) (2010), pp. 2298-2314.
[6] Bansal (2003), ‘Developing new test procedures for domestic refrigerators: harmonization issues and future r&d needs’ – a review. Int. J. Refrigeration., 26 (7) (2003), pp. 735-748.
[7] Cabeza (2011). ’Materials used as {PCM} in thermal energy storage in buildings’: a review. Renew. Sustain. Energy Rev., 15 (3) (2011), pp. 1675-1695.
[8] Cheng W.L. (2017), ‘Analysis of energy saving performance for household refrigerator with thermal storage of condenser and evaporator’. Energy Conversion. Management 132 (2017), pp. 180-188.
[9] W.-L. Cheng (2011), ‘A novel household refrigerator with shape-stabilized PCM (Phase Change Material) heat storage condensers’: an experimental investigation, Energy 36 (2011) 5797–5804, https://doi.org/10.1016/j.energy.2011.08.050.
[10] M.I.H. Khan (2016), ‘Conventional refrigeration systems using phase change material’: a review, Int. J. Air-Cond. Refrig. 24 1630007, https://doi.org/10.1142/S201013251630007X.
[11] V. Kumar (2016), ‘Energy Saving Using Phase Change Material in Refrigerating System Energy Saving using Phase Change Material in Refrigerating system’.
[12] G. Cerri (2003), ‘Identification of domestic refrigerator models including cool storage’, in: Int. Congr. Refrig., Washington, DC.
[13] Neto I de Marchi (2009), ‘Refrigerator COP with thermal storage’, Appl. Therm. Eng. 29 2358–2364
[14] A. Abhilash (2015), ‘Comparison of a conventional domestic refrigerator with a PCM encapsulated refrigerator’ 4 582–7.
[15] G. Sonnenrein (2015), ‘Copolymer-bound phase change materials for household refrigerating appliances’: experimental investigation of power consumption, temperature distribution and demand side management potential.
[16] C. Veerakumar (2016), ‘Phase change material based cold thermal energy storage: materials, techniques and applications’ - a review, Int. J. Refriger. 67 (2016) 271–289.