EXPERIMENTAL INVESTIGATION FOR PERFORMANCE ENHANCEMENT OF HOUSEHOLD REFRIGERATOR USING PHASE CHANGE MATERIAL

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Abstract- A phase change material is a substance that can store or release significant amounts of heat energy by changing its phase from solid to liquid vice versa. It has already been proven that incorporation of phase change material with refrigeration systems improves the energy efficiency as well as the quality of the frozen food. However, the attachment of phase change material system with the refrigeration system is a challenging task in different aspects such as PCM thickness, quantity of PCM, PCM phase change temperature selection for optimizing energy consumptions of refrigeration systems are the main concerns of today's researches. Implementation of the Cold Thermal Energy Storage system is one of the effective ways to reduce energy consumption. In this study, a household domestic refrigerator with ceiling type evaporator is considered to equip it with cold thermal energy storage system. According to ASHRAE standard, the temperatures are ranges for the household refrigerator is between 274 and 280 K, and hence water is used as phase change material. Owing to the low thermal conductivity of water impact of the extended surface in the container was investigated. The experimental results of charging and discharging process show the good consistency with the numerical results. Furthermore, it is obtained that using finned cold thermal energy storage system, would reduce compressor's energy consumption about 17.4% per day.

Keywords – Cold thermal energy storage, Phase change material, Latent heat storage, Thermal energy storage system, Heat transfer surface, Latent cold thermal energy.

I. INTRODUCTION

Domestic refrigerators the most commonly used household appliances. These appliances are consuming the more residential electricity throughout the year. In china we can see that the residential electricity usage is about 30 to 40%. Hence, enhancing the energy efficiency of domestic refrigerator is the major issue. We can overcome this issue up to some extent by improving the coefficient of performance of a domestic refrigeration system. We can also reduce the power consumption, by using water as a phase change material in refrigeration system.

Introduction to Phase Change Material:

The materials which are having the capability of storing and releasing the energy when phase transformation occurred are called phase change materials. As the material changes its phase from solid to liquid, energy is absorbed from its local while remaining at a constant temperature. The energy which is absorbed by the material performs to increase the energy of the constituent molecules and their vibrational position. At the diffuse temperature the atomic bonds breakup and the materials progression from a solid to liquid. During solidification process the material transfer energy to its local and the molecules lose energy, position.

Types of PCMs:

There are three types PCMs are, they are

(A) Organic PCMs
(B) Inorganic PCMs
(C) Metal and Metal alloy PCMs

II. LITERATURE REVIEW

The invention of the refrigeration system in the modern world is one of the admirable works which helps to increase the comfort levels of mankind. The great invention makes nature to help us according to our requirements, anyhow increases in energy predicament and ecological pollution, which drives to acceleration of atmospheric temperature. R&AC sector is the major contributor for this issue because they are the major energy taking devices due to their continuous usage. In today's world, the most energy consuming appliances are household refrigerators and are utilizing a major part of the entire universal energy. According to the Liu et al the energy utilization of refrigerators are nearly 15% to 20% of electricity utilization whereas in Malaysia 26% of electricity was consumed. Usage of the PCM as a LHTES system would be the latest alternative for achievement improving of the domestic refrigerator by improving evaporator heat transfer, decreasing efficiency losses of the compressor. In our project work the performance improvement of the domestic refrigerator has been studied in detail. The performance enhancement of the domestic refrigerator is determined by the phase change material box volume, geometry, assimilation, and position. The design of PCM containing chamber is the main challenge for developing refrigeration system. Different shapes of phase change material compartment were used in the previous papers such as rectangular slab or circular slab at different positions of the refrigeration system.

Performance of refrigeration system in accordance with PCM position:

The installation of PCM with domestic refrigerator is a vigorous work. Phase change material can be installed at anywhere among the condenser or evaporator else in the storage chamber. It is known by the study of previous research papers data, which gives the placing of phase change material at evaporator will gives the improvement of the coefficient of performance, at the same time the ON time of compressor also decreased with longer compressor off time. Which will also give fluctuations in the compartment temperature with varying thermal loads. According to the Azzouz et al. [1] constructed the system with phase change material keep retain the compressor off time from 28.5–32.6% and autonomy of 4.7–8.5h. The stable working of compressor and its periodicity ultimately cuts off temperature fluctuations inner the storage compartment and resulting in approximately constant warmth for better food quality.

Current Development of Phase Change Material Placed Domestic Refrigeration System:

As on date so many experimental investigations are performed, to develop a PCM based domestic refrigerator. The quantity of phase change material and position of phase change material gives the COP of domestic refrigeration system. Below table gives the summary of the present studies are given in the below Table.1.

Table.1. Current development of domestic refrigeration system with phase change material

No	*Reference*	*Area of Connection of PCM*	*PCM Box material*	*Size of PCM Box*	*Types of PCMs*	*Result Tested*
1	*Azzouz et al*	*Between the evaporator section and the back side of the evaporator*	*Plexiglas*	*5and 10mm thickness*	*Eutectic and water*	*Compressor on-off run, pressure, evaporation temperature and COP.*

		section.				
2	*Afroz and Khan*	*Evaporator coil was immersed inside the PCM and placed behind the part of evaporator chamber.*	*Galvanized iron plate*	*0.03m^{3}and 0.04m^3*	*Water and eutectic*	*COP, evaporation temperature and pressure, compressor on–off cycling.*
3	*Gin et al*	*Phase change material used as a slab in each wall inside the evaporator chamber*	*Anodized aluminum plate*	*25mm diameter*	*Aqueous ammonium chloride solution*	*Energy enhancement, temperature fluctuations*
4	*Wang et al*	*Used as an additional heat exchanger with evaporator*	*Expanded natural graphite*	*Paraffin*		*Energy efficiency and co-efficient of performance.*

III. METHODOLOGY

For the experimental setup, a domestic refrigerator is having the dimensions of 50×60×105 cm^{3}and walls with thickness of 3.7 cm. The household refrigerator consists of freezer cabin at the top and refrigeration chamber below the freezer cabin. The Thermal Energy Storage system has two PCM cubic containers that are of 1×24×17.6 cm^{3}size and are placed on either sides of the evaporator and another with a specification of 1×34.8×17.6 cm^3 is placed under evaporator cabin that are made out of aluminum plates which are 1.2mm thick. Referring ASHRAE standard [2], it is accepted that refrigerator's environment is held between 1-5 °C, where we used pure water as phase change material. The Thermal conductivity and Latent thermal energies of melting water are 0.59 W/m. K and 334kJ/kg. In such arrangement, air is abstained from direct contact with cold evaporator surfaces at the top and both sides hence the evaporator cools down and also in turn freezes the water inside the PCM containers which then absorbs the energy in the form of heat from the refrigerator's cabin through free convection. The average temperatures of the cabin are shown in Fig.1.

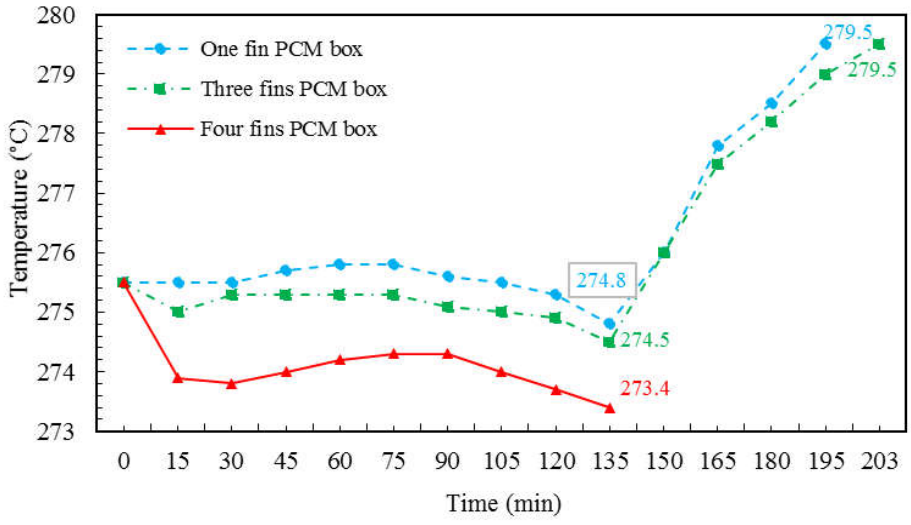

Figure.1. The cabin average temperature with different PCM container configurations

The experimental setup consists of a 16 feet conventional refrigerator, container with PCM, two six channel data acquisition system with ten thermocouples, whose detailed characteristics are illustrated in Table.2.

Table.2. Common place details of the equipment

Equipment		*Properties*
Refrigerator	*Dimensions*	*50×60×105 cm3*
	Power rate	*149 Watts*
Container with PCM	*Dimensions*	*1×24×17.6 cm3*
	Thickness	*1.2 mm*
	Material	*Copper*
Thermocouples	*J type*	

The three finned PCM container of aluminum plates (1.2mm thickness) provided fine heat transfer between phase change material, evaporator emerge during charging time, between cabin's air, PCM during discharging. An opening at the bottom of PCM container helped in injection of PCM and two slits at the front surface to mount thermocouples at two different levels to measure temperature of PCM. Similarly, two aluminum plates on either side of the cabin has a hole for injection and two provisions for thermocouple mounting. During the discharge cycle, the compressor gets turned off and temperature inside the cabin tends to increase. The warm air which is lower density raises up to the level of PCM containers and the cold air with higher density settle at the bottom of refrigerator. The warm air archive CTE from phase change material container thus turning the solidified PCM into liquid and this exchange of heat continues up until all the solid is converted into liquid and the cabin reaches at a mean temperature which is a highest permissible point set in the ASHRAE standard [2]. It is worthy to note that the evaporator cabin was closed and the air in it was kept secluded from the rest of the refrigerator cabin. Operation of refrigerator and CTES systems were assessed by measuring the temperatures of air and PCM at various points with the help of ten J type thermocouples with and accuracy of ±0.5°C for PCM and air, respectively.



Figure.2. The arrangement of PCM and thermocouples inside the refrigerator

IV. RESULTS AND DISCUSSION

Initially 2.35°C temperature was adopted. And the surface temperature of the evaporator was established to -5 °C for the CTC of phase change material. After 2 hours 30 minutes the phase change material frozen totally at the same time the compressor was turned off at this instant. As far as pretend compressor-off, evaporator emerges acts as an established emerge without mounting any position on the evaporator. Hence, at the end of phase change material liquid to solid state, the cold TESS maintains the refrigerator to normal low warmth. As we can see that, the cabin mean temperature was discharged from 2.35°C to 1.85°C during liquid to solid process. Afterward, in the without charging time, the cabin warmth increased to near the highest temperature at 6.35°C during30 minutes. Throughout this period, a solid PCM couldn't change to the liquid phase as per the mean temperature of phase change material at the end of the discharging period at -2.05°C. In this experiment water is used as a phase change material, which has the phase change temperature -0.15°C. Hence, to have solid to liquid phase change process the PCM should contain minimum of -0.15°C temperature.

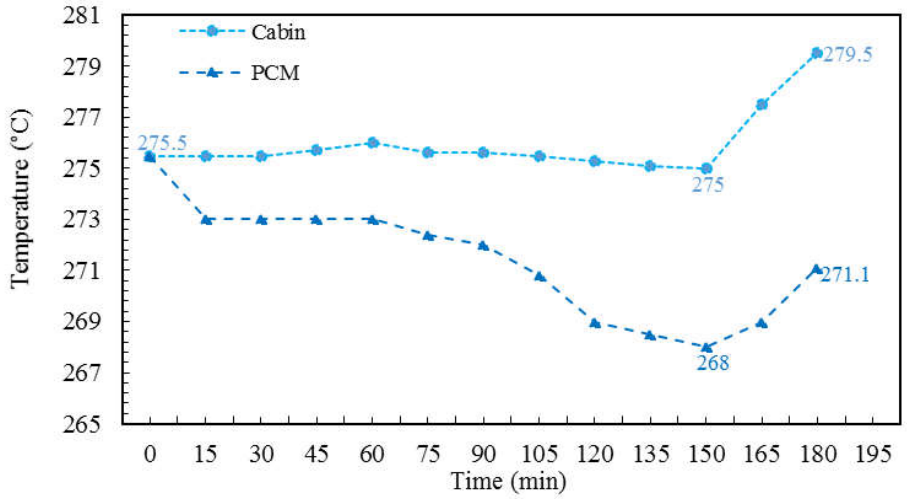

Figure.3. The numerical simulation result for simple PCM container

The experimental tests are attained in two sections:

1. Initially the normal working of domestic refrigerators power ratio was determined because which continues the cabin temperature in the established point. After the completion power ration, the working period of the domestic refrigerator was examined.

2. After completion of the initial test, the performance of the domestic refrigerator was analyzed by installing the CTESS. Throughout this procedure the phase change material storage time, charging and discharging processes were examined. By considering the thermocouples measured values, the behavior of the CTESS was plotted its working cycles.

By the completion of the first cycle, the time taken for the PCM to freeze completely was 135 minutes and at the end of second cycle it was reduced to 52 minutes. Based on these outcomes and the placing positions of the thermocouples, we come to know that 25 % of the PCM got melted at the end of the all discharging stages. For the next cycle during charging process the phase change material

needs only 52 minutes to freeze remained liquid. For the next charging and discharging cycles were taken same time as previous cycles took. This shows that at the end of the charging there is no alter in the volume of PCM available for discharging process. To calculate the volume of the melted PCM during every discharging period, thermocouples were mounted at the different places in the phase change box. As seen in the fig.4, the average temperature of the PCM reached to its melting point by the completion of the discharging period.

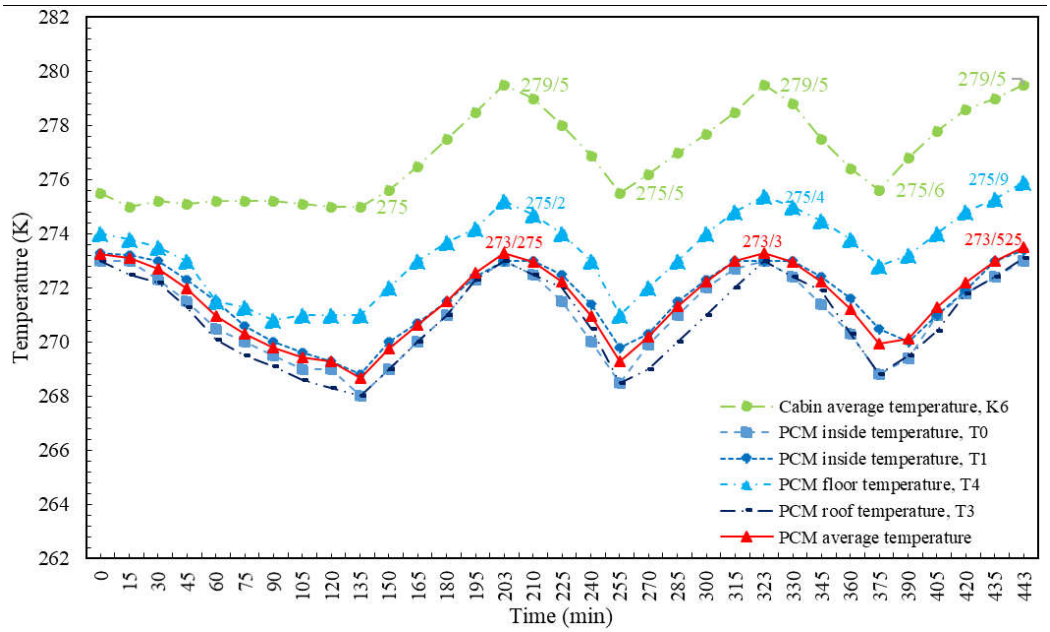

Figure.4. Trends of temperatures during charging and discharging in the experimental investigation.

The purpose of the conducting the experiment is to know the working period of the compressor as well as to have highest energy saving by using fins in cold thermal energy storage systems. Generally, compressor wants to work for 11 minutes in an hour to keep the cabin in normal condition. When the compressor is not in working condition then the cabin temperature increased to 4.15°C, and then reduces to 1.15°C, the compressor starts to work. For the first time of charging and discharging when the cold thermal energy storage system was used the cabin warmth was raised to 6.35°C, to reduce this warmth to normal 1.85°C the compressor needs to work for more than 11 minutes. By using of CTESS, as we can see that the total working period of the compressor was decreased. According to the experimental outcomes, the difference in the time taken by the compressor with CTES system and without CTES system was observed. When the cold thermal energy storage system was used during a day, the time taken for the compressor in which CTES system used shown 3.566 hours and the system without CTES shown 4.316 hours. By this comparison we can conclude that, by using CTESS reduces the working time of the compressor about 45 minutes per day.

V. CONCLUSION

The paper is a manifestation to observe the consequence of improvement of HTS of CTES system experimentally. Based on results obtained from Omid Ghahramani Zarajabad, Rouhollah Ahmadi [3], fin and finless construction of phase change material containers were considered. As per the results, a phase change material container with fin could increase discharge period and in turn decrease

charge period in comparison to a finless container. The most essential outcome is that the phase change material with finned container be capable of fuse in direction of discharge point, thus releasing LCTE. To gauge the digital outcomes an experimental setup of household refrigerator was used with the finned PCM container & 10 J type thermocouples were used to measure temperatures inside and outside the refrigerator. The time required for phase change material to freeze completely, and to maintain the cabins warmth in the STC were obtained by the experimental outcomes. Thermocouples were mounted at different levels to analyzed melting volume of phase change material and for that reason temperatures at discharge time were analyzed. The results obtained showed that 25% of PCM was melted and hence this proportion of PCM accounts for the heat capacity of Cold Storage Thermal Energy system and hence led to the electrical energy consumption. Referring to the compressor's power rating, a figure of 40kWh/year was obtained as the energy savings per refrigerator, i.e. 17.4% of energy reductions were estimated that can show positive effects over environment as well as economy. This could reduce conventional energy consumption.

REFERENCES

[1] K. Azzouz D. Leducq and D. Gobin, Performance enhancement of a household refrigerator by addition of latent heat storage, Int. J. Refrig. 31 (2008) 892–901.

[2] American society of heating, refrigeration and air conditioning engineers, ASHRAE Refrigeration Handbook, ASHRAE, Publications, Atlanta.210.

[3] O.G. Zarajabad, R. Ahmadi, Employment of finned PCM Container in a Household Refrigerator as a cold Thermal Energy Storage System, Thermal Science and Engineering Progress (2018).

[4] B. Gin, M. M. Farid and P. K. Bansal, refrigerator of door opening and defrost cycle on a freezer with phase change panels, Energy Converts. Manage. 2698–2706.

[5] E. O. Prim, Improvement of thermal performance of commercial freezers using phase change materials, Master's Thesis, University of Lleida, Spain (2011).

[6] A. C. Marques, G. F. Davies, J. A. Evans, G. G. Maidment and I. D. Wood, Theoretical modeling and experimental investigation of a thermal energy storage refrigerator, Energy 55 (2013) 457–465.

[7] D. Onyejekwe, Cold storage using eutectic mixture of NaCl/H2O: An application to photovoltaic compressor vapor freezers, Solar Wind Technol. 6 (1989) 11–18.

[8] G. Cerri, A. Palmieri, E. Monticelli and D. Pezzoli, Identification of domestic refrigerator models including cool storage, Proc. 20th Int. Cong. Refrig., Washington, 2003.

[9] A. Marques, G. Davies, G. Maidment, J. Evans and I. Wood, Novel design, and performance enhancement of domestic refrigerators with thermal storage, Appl. Therm. Eng. 63 (2014) 511–519.

[10] M. I. H. Khan and H. M. M. Afroz, Diminution of temperature actuation inside the cabin of a household refrigerator using phase change material, Recent Adv. Mech. Eng. 3 (2014) 43–52.

[11] F. Wang, G. Maidment, J. Missenden and R. Tozer, The novel use of phase change materials in refrigeration plant. Part 3: PCM for control and energy savings, Appl. Therm. Eng. 27 (2007b) 2893–2901.

[12] A. Jakobsen, Energy optimization of refrigeration systems: The domestic refrigerator — A case study, Conventional Refrigeration Systems Using PCM: A Review 1630007-15 Int.

[13] M. J. P. Janssen, J. A. D. Witt and L. J. M. Kuijpers, Cycling losses in domestic appliances: An experimental and theoretical analysis, Int. J. Refrig. 15 (1992) 152–158.

[14] W. L. Cheng and Y. X. Dong, Numerical analysis of a novel household refrigerator with shape-stabilized PCM (phase change material) heat storage condensers, Energy 59 (2013) 265–276.

[15] M. I. H. Khan and H. M. M. Afroz, Experimental investigation of performance improvement of household refrigerator using phase change material, Int. J. Air Cond. Refrig. 21 (2013a) 1350029-1–8.