Comparison of a Conventional Domestic Refrigerator with a PCM Encapsulated Refrigerator

Abhilash A, Adarsh Murali Menon, Anirudh K
UG Scholar,
Department of Mechanical Engineering,
Nehru College of Engineering and Research Centre
Pampady, Thrissur, India

Aby Kurian M
Assistant Professor,
Department of Mechanical Engineering
Nehru College of Engineering and Research Centre
Pampady, Thrissur, India

***Abstract*— Renewable energy systems have always attracted research scholars especially in past few decades due to over exploitation and large scale depletion of non-renewable energy sources. Conservation of energy resources have paved way for improving energy storage and conversion systems. The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing energy in the form of thermal energy. PCM materials have large amount of heat energy stored in them in the form of latent heat. The heat energy associated with PCM is green energy and is a natural phenomenon. The latent heat of the PCM can be utilized for various thermal energy storage applications. It possess the advantages of high-energy storage density and the isothermal nature of the storage process. Recent researches are going on about the applications of PCM in heat pumps, air conditioning and refrigeration, green house buildings, solar engineering, and spacecraft thermal control applications. This paper conducts experiment and summarizes the investigation and analysis of the thermal energy storage systems incorporating PCMs for use in refrigeration systems. The Efficiency of Refrigerator was enhanced and improvement in the quality of food is obtained. Results can be improved with different combination PCM materials or different design of PCM encapsulation which ensures more heat transfer.**

Keywords*— *Latent Heat Storage, Phase Change Materials (PCM), Thermal Energy Storage Systems (TES), Refrigerator.

I. INTRODUCTION

Renewable energy systems are getting large importance due to continuously increasing fossil fuel prices and increase in the amount of greenhouse emissions. This leads to effective utilization of the renewable source of energies. Direct solar radiation is most suitable renewable energy available in all parts of world. Scientists all over the world are in search of new and effective way of utilizing available renewable energy sources. One of the main important area of research is to develop the energy storage methods finding efficient and economic energy storage aid is like finding new renewable resource. The storage of energy in one form and converting the energy to required form is great challenging area of research for today's scientists. Storing energy not only balances the supply and demand required but also plays in important role in conserving energy by increasing the performance and reliability of the system. It will also lead to reduced amount of fuel consumption and thus saving the fossil fuels by limiting the wastage and reducing pollution and greenhouse emissions.

One of prospective clean energy technique of storing thermal energy is by the use of phase change materials (PCMs). Storage of energy as thermal energy in Phase changing materials is a new research area it has large interest among technologists. Prior to the large-scale practical application of this technology, it is necessary to resolve numerous problems at the research and development stage. Thermal energy can be stored in many ways in a material depending on its nature. It can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or as a combination of these. The storage capacity of the LHS system with a PCM depends on its latent heat of fusion. Phase change materials (PCM) are ''Latent'' heat storage materials. Latent heat is the 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.'' These solid–liquid PCMs perform like conventional storage materials, they absorb heat as changing phase from solid to liquid and their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature.

The main objective of this work is to utilize the latent heat of PCM for Thermal Energy Storage applications and also to conduct an experimental investigation on the application of Phase Change Materials as Thermal Energy Storage Systems (TES).

In the conventional household refrigerator the compressor works in on /off mode. The refrigerant absorbs the heat from the cabinet during compressor on mode. Actually during the off mode of the compressor or when the power failure happens which is very common nowadays the temperature inside the evaporator cabinet starts rising. The rise of temperature inside the cabinet of a refrigerator is due to the heat entering from atmosphere and also heat released by food materials kept inside it. If PCM is encapsulated in the cabinet it will take most of the heat by changing its phase from solid to liquid. Thus whole heat entering to cabinet or the heat released by the food particles is absorbed by the PCM for its Phase change. Hence there will not be any rise in the temperature inside cabinet till whole of the PCM melts and thus it maintains a constant temperature until the melting process is completed. Thus for a certain period of time (until the PCM melts completely) the temperature inside the cabinet can be maintained during the off cycle of the compressor which ultimately prolonged the off cycle. This ensures less thermal distortion of materials and greater refrigerator efficiency with less cost.

C. Marques, et al. [1] investigated the performance improvement provided by a phase change material associated with the evaporator in a domestic refrigerator. The heat release and storage rate of encapsulated ice, used as the thermal energy storage material, has been investigated numerically. The mathematical model for phase change is based on the enthalpy method and the governing equations were discretized on a fixed grid using the finite difference method.

Rezaur Rahman et al. [2] investigated the performance improvement provided by a phase change material associated with the evaporator in a domestic refrigerator. They stated that the heat release and storage rate of a refrigerator depends upon the characteristics of refrigerant and its properties. The usage of PCM as TS will help to improve the COP (Coefficient of performance) of new refrigeration cycle by introducing a new sub cooling routine. The analysis of the experiment exemplifies the improvement of the system coefficient of performance considerably

Chetan Tulapurkar et al. [3] explains the method and design of a novel Dual evaporator based domestic refrigerator with Phase Change materials (PCM) which provide thermal storage (TS) is presented .The usage of PCM as a TS will help to improve the COP (Coefficient of performance) of new refrigeration cycle by introducing a new sub cooling routine. This improvement by sub cooling can be done for single evaporator refrigeration system or with even a dual evaporator system for a refrigerator / freezer combination. Because of prolonging of the compressor off time by using the latent heat of energy of the PCM we can have better food quality due to lower hysteresis cycles of on/off for a given period of operation .

Md. Imran Hossen Khan, et al.[4] shows the effect of phase change material (PCM) on temperature fluctuation inside the evaporator cabinet of a household refrigerator. The experiment has been done at different thermal loads with two different PCMs (Water and Eutectic solution (90% H2O + 10% NaCl) of melting point 0 ° C and -5 ° C respectively). The PCM is placed around the five sides of the evaporator cabinet in which the evaporator coil is immersed. The experimental results with PCM confirm the notable reduction of the fluctuation of the cabin temperature at lower load but at higher load this effect is not so significant. Between two PCM, the reduction of temperature fluctuation for Eutectic solution is better than water PCM. This reduction of temperature fluctuation ultimately improves the food preservation quality of the refrigerator.

Piia Lamberg, et al.[5] states through paper to obtain physical validation of the numerical results produced using FEMLAB. This validation was obtained through a comparison of experimental data and numerical results. The numerical methods studied were an enthalpy method and an effective heat capacity method. An ensemble of experimental PCM storages, with and without heat transfer enhancement structures, was designed and constructed. The numerical predictions calculated with FEMLAB simulation software were compared to experimental data. Both numerical methods gave good estimations for the temperature distribution of the storages in both the melting and freezing processes.

Application phase change material (PCM) could be a nice option for reducing temperature fluctuation inside the evaporator cabinet. A phase change material (PCM) is a latent heat thermal energy storage system. These PCM melts and solidifies at a certain temperature. During the phase change time the material is capable of storing and releasing large amounts of heat energy. There is no artificial energy associated with the thermal energy storage using PCM.

II MATERIALS AND METHODS

PCMs latent heat storage can be achieved through any of the solid-solid, solid-liquid, solid-gas, and liquid-gas phase change. However, the only phase change used for PCMs is solid-liquid change. Initially, the solid-liquid PCMs behave like sensible heat storage materials; their temperature rises as they absorb heat. When PCMs reach the temperature at which they change their phase they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from -5 ºC up to 190ºC. Within the human comfort range between 20-30 ºC, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

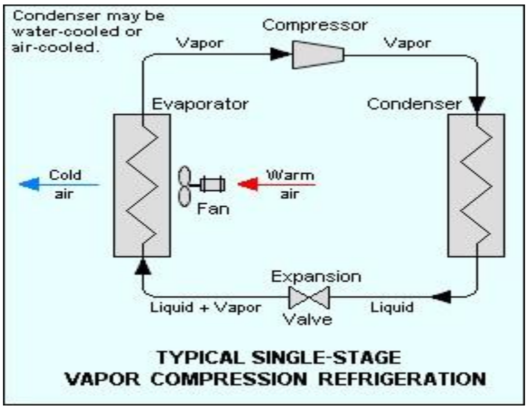


Figure Typical Single Stage Vapor Compression Refrigeration

The salient components of vapor compression refrigeration system used in Indian cold storage system are: evaporator, compressor, condenser and manually operated expansion valve. A typical schematic diagram of the refrigeration system is shown above.

A phase-change material (PCM) is a substance with a high heat of fusion which, on 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 classified as latent heat storage (LHS) units. PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid-gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation.

Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from −5 up to 190 °C. Within the human comfort range between 20– 30 °C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

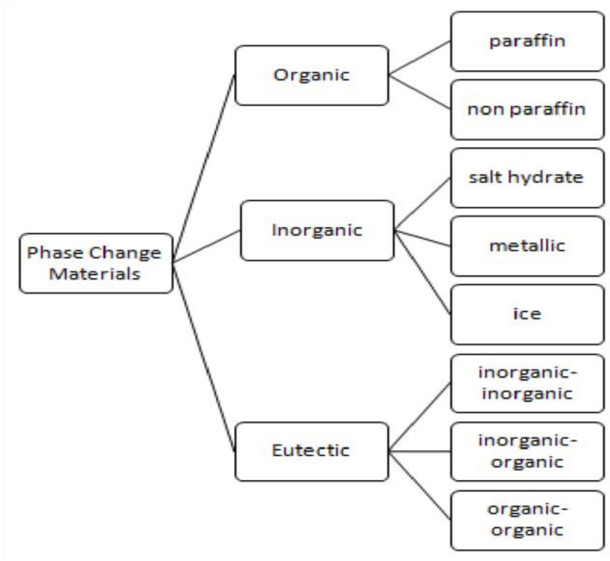


Figure: Classification of PCM

The phase changing material used for the experiment was Formic acid.

Formic acid (also called methanoic acid) is the simplest carboxylic acid. Its chemical formula is HCOOH or HCO_2H. It is an important intermediate in chemical synthesis and occurs naturally, most notably in ant venom. Its name comes from the Latin word for ant, *formica*, referring to its early isolation by the distillation of ant bodies.

Formic acid is color-less. It is miscible with water and also in most polar organic solvents. But is somewhat soluble in hydrocarbons. It have a highly pungent, penetrating odor at room temperature. In the vapor phase, it consists of hydrogen-bonds rather than individual molecules. This compound also forms a low-boiling azeotrope with water (22.4%) and liquid formic acid also tends to supercool.

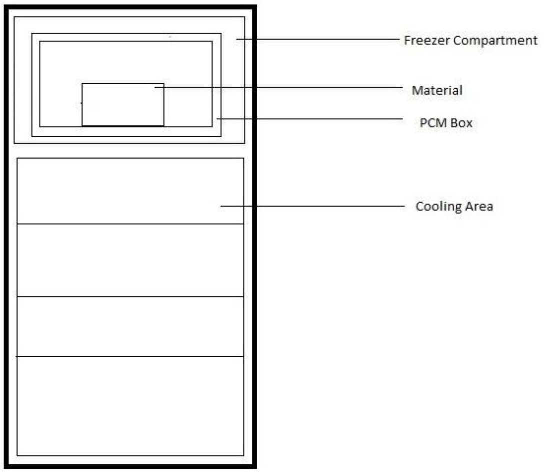


Figure: Schematic arrangement of Experimental Setup.

III. EXPERIMENT METHODOLOGY

The Experiment consisted of 2 stages lasting 4-6 hours each. First stage was completed without using PCM. Second stage with Formic acid as PCM. Experimental procedure is described below in detail. The experiment was scheduled on consecutive days to ensure less effect due to climate and the experiment timing were strictly followed to obtain any deviation. The weather details are also noted.

Stage 1: Without PCM

Weather Conditions for Day 1

- Average Atmospheric Temperature : 31.8 °C
- Weather Conditions : Clear, Sunny
- Humidity : 33%
- Maximum Temperature (Day) : 32.8°C (01:45 P M)
- Minimum Temperature (Day) : 30.6°C (10.15 A M)

The experiment started at sharp 10:00 hrs. and temperature rise of domestic refrigerator before encapsulating PCM and material temperature was noted. The detailed procedure is described below.

1. The anodized aluminium box was cleaned.
2. 250ml of water was poured into the anodized aluminium box by using a measuring flask.
3. The nob of the digital thermometer was inserted into the box through the nob hole and was immersed in the water.
4. This box was kept in the refrigerator for cooling purpose at 10:00 a.m.
5. At 11:00 a.m. the final temperature of the cooled water was noted using the digital thermometer.

6. Now the refrigerator was switched off and the temperature rise was noted at equal intervals of time.
7. Finally the temperature fall was tabulated.

Stage 2: With Formic Acid as PCM

Weather Conditions for Day 2

- Average Atmospheric Temperature : 32.0 °C
- Weather Conditions : Clear, Sunny
- Humidity : 32%
- Maximum Temperature (Day) : 33.0°C (02:00 P M)
- Minimum Temperature (Day) : 31.2°C (10.30 A M)

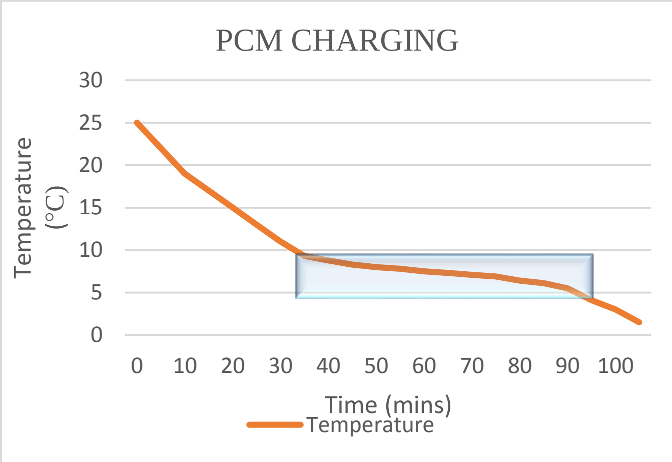
The second stage of experiment was on Day 2 using PCM encapsulated box placed inside the material. Same time schedule as that of previous day is maintained. Experiment procedure is as follows.

1. The anodized box was cleaned by using water and was dried.
2. 300ml of formic acid was poured into the hollow space in the anodized aluminium box by using a 300ml measuring cylinder.
3. 250ml of water was poured into the anodized aluminium box by using a measuring flask.
4. The nob of the digital thermometer was inserted into the box through the nob hole and was immersed in the water.
5. Also nob of another digital thermometer was inserted into the box through the nob hole and was immersed in the PCM layer.
6. PCM was allowed to charge. The PCM material temperature is noted and charging curve is plot.
7. This anodized aluminium box was then kept in the refrigerator for cooling purpose.
8. Experiment was started at 10:00am, water was allowed to cool for a certain interval of time and then the refrigerator was switched off.
9. Temperature was noted at every interval of time from both the digital thermometers and the result was tabulated.

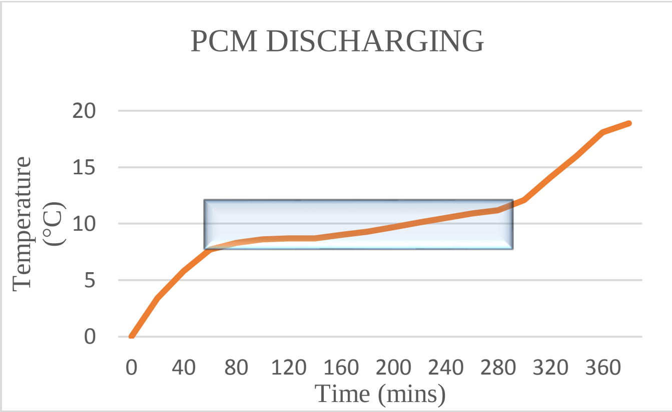
Material is kept inside PCM box. The double walled PCM box contains formic acid in between and the box. The box is made of anodized aluminium to ensure maximum heat transfer and not to react with acid.

IV. RESULTS AND DISCUSSION

The graph showing charging and discharging of PCM is plotted below. Shaded portion indicates the Phase Change of the PCM.



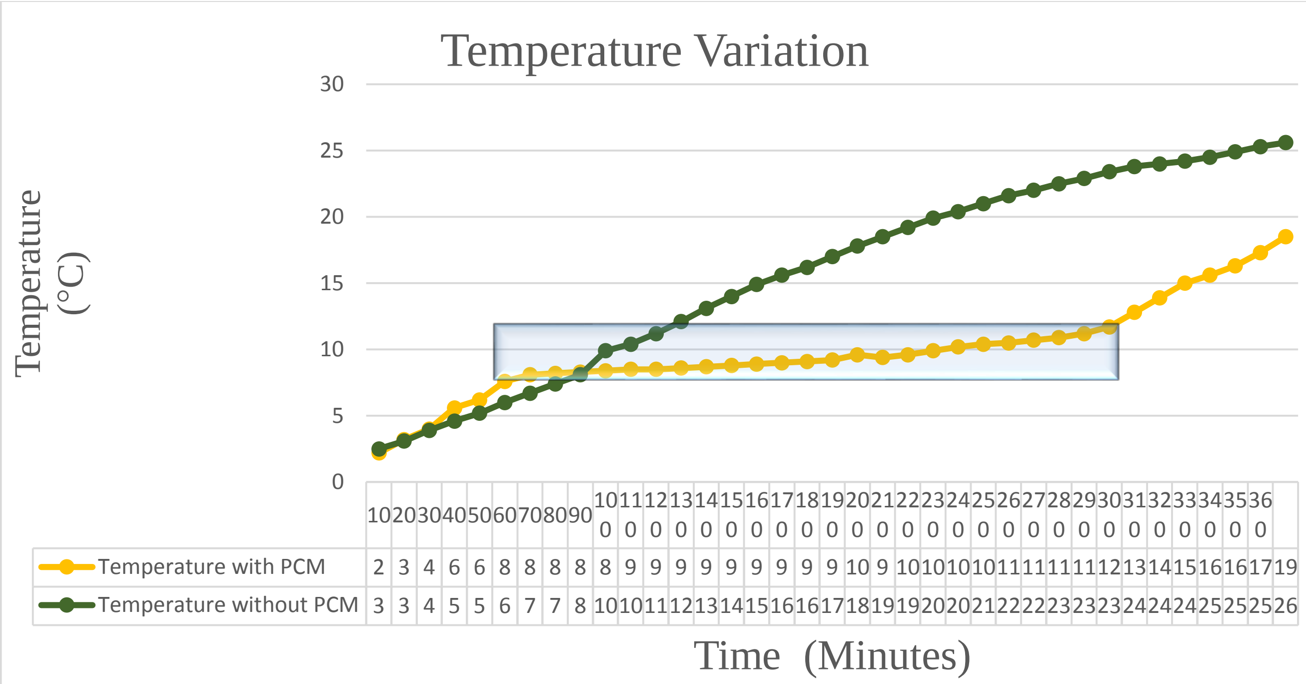
Graph: PCM Charging



Graph: PCM Discharging

Stage 1 that is temperature of material without PCM is indicated in graph with green line and yellow line indicates the temperature of material with formic acid as PCM as obtained in stage 2.is shown in the graph above. The blue shaded portion indicate the Melting point range of PCM. The green line has a steady normal increase of temperature as power went off. But yellow line at beginning increase steadily and later attains a constant range from 7°C to 11°C, this is the melting point range of the PCM and during this PCM material absorbs the Latent heat required for the Phase change and hence the temperature of the material remains the same.

One good aspect of the test results was that the food temperatures were more stable for fresh food and freezer during the on / off cycling of the PCM based refrigerator in comparison . The efficiency was increased by 29% with an increase of 2 hrs 20 minutes instead of normal 5hrs without PCM.



Graph : Temperature Variation with and without PCM

V. CONCLUSION

Experimental tests have been carried out to investigate the temperature fluctuation inside the evaporator cabin a household refrigerator using phase change materials at same thermal loads.

Use of PCM in a household refrigerator decreases the fluctuation of the cabinet temperature. The reduction of temperature fluctuation between two PCM, however depends on the latent heat capacity and the properties such as melting point of PCM. At higher load more amount of PCM is required for significant change.

This reduction of temperature fluctuation ultimately improves the food preservation quality of the refrigerator.In the blue shaded portion of the graph phase change occurs of PCM Formic acid.Hence the heat entering is absorbed by the Formic acid and no heat is theoretically given to material. Temperature of material changes only after PCM absorbs whole of its heat required and changes phase completely. Hence a prolonged time is obtained. This is more effective in the case of usual powercuts during which the PCM helps in reducing the temperature fluctuations for material thus preserving the quality of material.

Flutuation of temperature due to freequent powercuts can be thus reduced and this leads to less thermal distortion in the food materials and good quality of food preserved. The refrigerator Efficiency was strongly affected by the refrigerator heat load and compressor cooling capacity which draws less power.

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