A Review on Phase Changing Materials (PCM) and Its Application to Conserve Energy in Refrigeration System

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Abstract- *This paper presents a review of cold thermal energy storage technologies. Latent heat thermal energy storage with phase change materials deserves attention as they provide high energy density and small temperature change interval upon melting/solidifying. A refrigerator is a common household appliance that found in almost all the homes for storing food, vegetables, fruits, beverages, and much more. Refrigerators are among the most energy demanding appliances in a household due to their continuous operation. The performance of refrigerator is improved by a phase change material (PCM) associated with the evaporator in a refrigerator system. As the PCM cool off, they subsequently release the stored heat while solidifying in the same fashion. The phase change takes place without a change in the temperature of the material. PCMs have always been viewed as a suitable candidate for off peak thermal storage, particularly for refrigeration systems, due to the high latent energy densities of these materials. The usage of PCM enhances the heat transfer rate thus improve the COP (Coefficient of performance) of refrigeration. For temperatures below 0 °C, usually water-salt eutectic solutions such as ethylene glycol and water mixture are used. The use of phase change materials to accumulate thermal energy in refrigeration system is a new solution to improve the performance of these appliances.*

Keywords- Phase change material (PCM), refrigeration, thermal energy storage, latent heat storage

I. INTRODUCTION

Refrigeration systems are directly or indirectly responsible for Global Warming problems which refer to the rise in temperature of Earth's atmosphere and ocean. During early 1990, after water heater a frost freezer was the second most expensive and energy consuming home appliance. It was compulsory for appliance makers to include labels which list an estimate of the annual cost of running the appliance so consumers could compare energy usage and costs.[1] A refrigerator is thermally insulated compartment and a heat pump which transfers heat from the inside of the refrigerator to its external environment so that the inside temperature of the fridge is below the ambient temperature of the room. Refrigeration systems are among the most energy demanding appliances due to their continuous operation.[2] The domestic refrigerator is generally found in each homes for storing fruits, vegetables, dairy products, beverages, and much more. Materials which can store thermal energy reversible over a longer time period are generally referred to as latent heat storage materials. They also help in heat transfer via conduction.

Now-a-days power cuts are often due to accidents or implementation of demand side management schemes to shift maximum power demand by the electricity supplier, or by the user to shift their electricity usage to off-peak pricing periods (electrical load shifting). It is important to maintain regulated temperatures inside the refrigeration system. Most frozen and chilled foods are sensitive to temperature fluctuations. A major heat load contribution is by heat penetrating the walls. The refrigeration system removes this heat load, but if there is a power failure, cooling is not provided to the stored product. Thermal Energy storage systems (TES) will use phase change materials (PCM) for storage of heat and cold at shifted time. Phase change material (PCM) melts within a narrow temperature range, and while in transition state absorbs a large amount of heat, thus rise in the refrigerator temperature is minimum. PCM with a suitable melting temperature may be used to provide thermal capacity for maintaining suitable recommended internal temperature during power failure. PCM may also be used in load shedding applications to shift electricity usage to an optimum time.

The energy consumption of refrigerators is affected by several factors, such as the ambient temperature, product loading and number of door openings, thermostat setting position and refrigerant migration during the compressor off-cycle. The effect of ambient temperature can be minimized by fitting vacuum insulated panels into the cabinet walls. As compared to polyurethane foam they offer twice the level of insulation which also results in an increased refrigerator storage volume. The main reasons preventing the widespread use of this technology are related to less reliable over lifespan and high disposal and manufacturing costs. Refrigerator energy losses resulting from refrigerant charge displacement e.g. due to off-cycle migration and on-cycle redistribution were estimated to be 11%. This energy loss can be prevented by fitting a liquid line solenoid valve to stop refrigerant migration from the condenser to the evaporator during the compressor off-cycle.

The compressor is the major energy user in a refrigerator, which accounts for more than 80 % of the total energy consumption of the appliance. Compressor manufacturers have recently developed variable speed compressors which adjust the refrigeration capacity in relation to the load by controlling the motor speed resulting in energy savings of up to 40%.[1] However this technology is still very expensive which limits its use in a market which is particularly price sensitive.

There are constant heat gains from the environment through the insulated walls and the front glass in commercial options. Door openings by the users are another source of heat gain. Here, warm and moist air from the outside environment exchanges with the cool dry internal air when the doors of the cold storage space are opened. This raises the temperature inside the storage space, and also brings in moisture. Moreover, it could occur without previous notice an electrical power failure, and therefore having the refrigeration system not running. Now-a-days power cuts are very often due to accidents, or could be due to implementation of demand side management schemes to shift power usage to avoid high loads by the electricity supplier, or by the user to shift their electricity usage to off-peak pricing periods (electrical load shifting) and it is important to maintain regular temperatures inside refrigerator. Most frozen and chilled foods are sensitive to temperature fluctuations. Thermal Energy storage systems (TES) will use phase change materials for storage of heat and cold at shifted time. Phase change material (PCM) melts within a narrow temperature range, and absorbs a large amount of energy while in the transition state, thus minimizing the rise in the refrigerator temperature. PCM with a suitable melting temperature may be used to provide thermal capacity to maintain suitable internal temperature during power failure.

The effect of ambient temperature can be minimized by fitting vacuum insulated panels into the cabinet walls. They offer twice the level of insulation of polyurethane foam and result in an increased refrigerator storage volume. The main reasons preventing the widespread use of this technology are related to reliability over lifespan and high manufacturing and disposal costs. Refrigerator energy losses resulting from refrigerant charge displacement e.g. due to off-cycle migration and on-cycle redistribution were estimated to be 11%. This energy loss can be prevented by fitting a liquid line solenoid valve to stop refrigerant migration from the condenser to the evaporator during the compressor off-cycle.

The compressor is the single largest energy user in a refrigerator, responsible for more than 80 % of the total energy consumed by the appliance. Compressor manufacturers have developed variable speed compressors that adjust the refrigeration capacity in relation to the load by controlling the motor speed resulting in energy savings of up to 40% [1]. However this technology is still very expensive limiting its use in a market that is particularly sensitive to price.

The use of phase change materials to accumulate thermal energy in domestic refrigerators is a new solution to improve the performance of these appliances. The cooling capacity stored in the PCM can be used to stabilize the temperature in the compartment, by reducing the effects of peak loads and cooling losses during periods when the door is open.

II. THERMAL ENERGY STORAGE

TES systems for both heat and cold are important for good performance of many industrial processes. The most important desirable properties of any TES are high energy storage density and high power capacity. TES could be the most suitable way and method to reduce the gap between the demand and supply of energy and consequently it has become a very attractive technology. It is well known that there are primarily two methods of TES: sensible and latent heat storage. [3]

A. Sensible Heat Storage:

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS utilizes the change in temperature and heat capacity the material during the charging and discharging processes. The amount of stored heat depends on the specific heat of the medium, the temperature change and the quantity of storage material. This temperature change (T=Tf-Ti) depends on the application and it is limited by the heat source and by the storage system. The sensible heat stored in any material can be calculated as follows:

$$Q = \int_{Ti}^{Tf} C_p \, . \, dT \qquad (1)$$

Where Q is the stored sensible heat, dT the temperature change and C_p the specific heat of the material.

B. Latent Heat Storage:

The latent heat storage (LHS) or phase change materials (PCM) absorb and release heat as it undergoes a phase change from solid to liquid or liquid to gas or reverse. The energy stored during the phase change process is called "latent heat" or "heat of fusion". As the materials cool off, they subsequently release the stored heat while solidifying in the same fashion. The phase change takes place at constant temperature of the material. Figure 1-1 explains the mechanisms of heat absorption and release in LHS materials. From the figure 1-1 it is clearly understood that at the melting point, as the temperature of the PCM rises, gradually their chemical bonds break up as the material changes its phase from solid to liquid. The phase change is a heat absorbing (endothermic) process and as a result the PCM absorbs large quantity of heat without getting hotter, i.e. while storing heat, the temperature of the PCM remains almost constant until the melting process completed. It is another means of storing energy is by using phase change materials. The energy density could be increased by using PCM, having a phase change within the temperature range of the storage. Taking into consideration the temperature interval (T=Tf-Ti) the stored heat in a PCM can be calculated as follows

$$Q = \int_{T_i}^{T_{pc}} C_{p,s} \, . \, dT + \Delta H_{pc} + \int_{T_{pc}}^{T_f} C_{p,l} \, . \, d \qquad (2)$$

Where Q is the sensible and latent heat stored and H_pc is the heat of fusion at the phase change temperature (Tpc) or melting temperature (Tm).

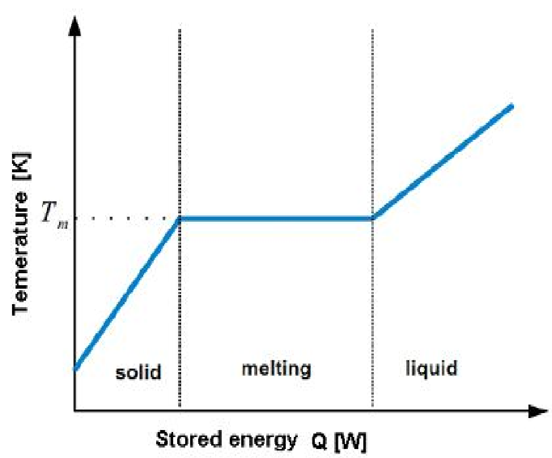

Fig.1 phase change behavior of solid liquid latent heat storage system melting over a temperature range [4]

The phase change could be solid/liquid or liquid/gas; however, liquid/gas transformations are not practical due to the large volume changes or high pressures required to store the materials in the gas phase.

Latent heat Thermal energy storage (TES) is particularly attractive due to its ability to provide high energy storage density per unit mass in quasi-isothermal process. This means that in a particular application where the temperature range is key, for instance in transportation of sensitive temperature products, the utilization of PCM becomes very useful since it can store material at stable temperature corresponding to the phase-transition temperature of the PCM.

III. PHASE CHANGING MATERIAL

Any type of materials to be used for PCM in TES systems should have high latent heat and high thermal conductivity. They should have a melting/freezing temperature lying in the practical range of operation, melt/freeze congruently within minimum subcooling and be chemically stable, non-toxic, less costly and non-corrosive.[5]

A. Working of PCM:

The external heat supplied to a PCM is used up in breaking the internal bonds of lattice and thereby it absorbs a large amount of latent heat at phase changing temperature. Now, when the PCM cools down, temperature goes below phase change temperature (known as sub-cooling or under-cooling) to overcome the energy barrier required for nucleation of second phase. Once phase reversal starts, temperature of PCM rises (due to release of latent heat) and subsequent phase reversal takes place at phase change temperature by releasing back the latent heat to environment. Requirement of sub-cooling or under-cooling for phase reversal is an significant property of PCM governing its applicability in particular application.

Latent heat of PCM is many orders higher than the specific heat of materials. Therefore PCM can store 2-3 times more heat or cold per mass or by volume than heat can be stored as sensible heat in water. As heat exchange takes place in narrow temperature range the phenomenon can also be used for temperature smoothening.[5]

B. PCM Classification

Figure 1-2 shows the varieties of phase change heat storage materials: divided as organic and inorganic materials. Organic materials are further classified as paraffin and nonparaffins. (fatty acids, eutectics, and mixtures). Experiments (melting and freezing cycles) using these materials showed that they crystallize with little or no subcooling and are usually non-corrosive and very stable.

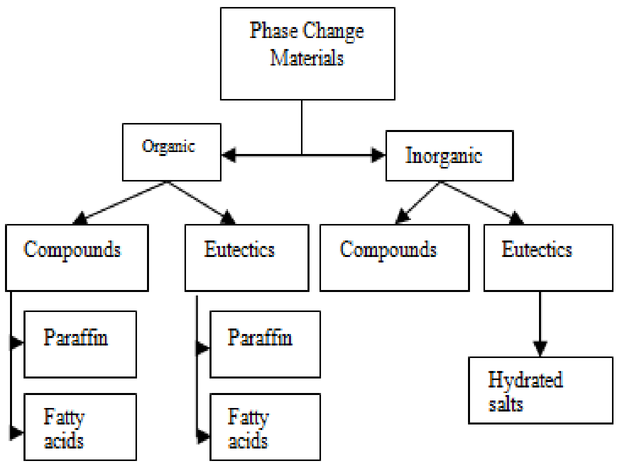

Fig.2 Phase Changing Material classification [5]

Inorganic materials are further classified as compounds and eutectics. Main inorganic materials are salts, salt hydrates, aqueous solutions and water. Salt hydrates may be regarded as alloys of inorganic salts and water forming a typical crystalline solid of general formula Mn.H2O. The solid–liquid transformation of salt hydrates is actually a dehydration of hydration of the salt, although this process resembles melting or freezing thermodynamically. A salt hydrates usually melts to either to a salt hydrate with fewer moles of water or to its anhydrous form. At the melting point the hydrate crystals breakup into anhydrous salt and water, or into a lower hydrate and water. One problem with most salt hydrates is that of incongruent melting caused by the fact that the released water of crystallization is not sufficient to dissolve all the solid phase present. Due to density difference, the lower hydrate (or anhydrous salt) settles down at the bottom of the container. The most attractive properties of salt hydrates are: high latent heat of fusion per unit volume, relatively high thermal conductivity (almost double of the paraffin's), and Small volume changes on melting. They are not very corrosive, compatible with plastics and only slightly toxic. Many salt hydrates are sufficiently inexpensive for the use in storage. The drawbacks of these PCM are incongruent melting, irreversible melting-freezing cycle, poor nucleating properties, supercooling and phase segregation.

Metallic includes the low melting metals and metal eutectics. Because of its larger weight, metallic's are not of prime importance However, when volume is a consideration, they are likely candidates because of the high heat of fusion per unit volume. They have high thermal conductivities. A major difference between the metallic and other PCMs is their high thermal conductivity. Some of the features of these materials are low heat of fusion per unit weight, high heat of fusion per unit volume, high thermal conductivity, low specific heat and relatively low vapor pressure.

A eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently forming a mixture of the component crystals during crystallization. Eutectic always melts and freezes without segregation since they freeze to an intimate mixture of crystals, leaving little opportunity for the components to separate. On melting both components liquefy simultaneously, again with separation unlikely.

Organic materials are categorized as paraffin and non-paraffin materials. These materials include congruent melting; means melt and freeze repeatedly without phase segregation and consequent degradation of their latent heat of fusion.

Paraffin are chemically known as hydrocarbons which are generally found to be as wax at room temperature whereas non-paraffin encompasses fatty acids, glycols, esters and alcohols etc. Paraffin consists of a mixture of mostly straight chain n-alkanes CH3–(CH2)–CH3. The crystallization of the (CH3) - chain release a large amount of latent heat. Both, the melting point and latent heat of fusion, increase with chain length. Paraffin qualifies as heat of fusion storage materials due to their availability in a large temperature range. System-using paraffin usually has very long freeze–melt cycle. Apart from some several favorable characteristic of paraffin, such as congruent melting and good nucleating properties, they show some undesirable properties such as low thermal conductivity, non- compatible with the plastic container and moderately flammable. All these undesirable effects can be partly eliminated by slightly modifying the wax and the storage unit. Non-paraffin materials are flammable and should not be exposed to excessively high temperature, flames or oxidizing agents. Some of the features of these organic materials are high heat of fusion, inflammability, low thermal conductivity, low flash points, varying level of toxicity, and instability at high temperatures.

Fatty acids have high heat of fusion values comparable to that of paraffin's. Fatty acids also show reproducible melting and freezing behavior and freeze with no supercooling. The general formula describing all the fatty acid is given by CH3(CH2)2n COOH Their major drawback, however, is their cost, which are 2–2.5 times greater than that of technical grade paraffin's. They are also mild corrosive. Some fatty acids are of interest to low temperature latent heat thermal energy storage applications.[6]

By far the best-known PCM is water. It has been used for cold storage for more than 2000 years. Today, cold storage with ice is state of the art and even cooling with natural ice and snow is used again. For temperatures below 0 °C, usually water-salt solutions with a eutectic composition are used.

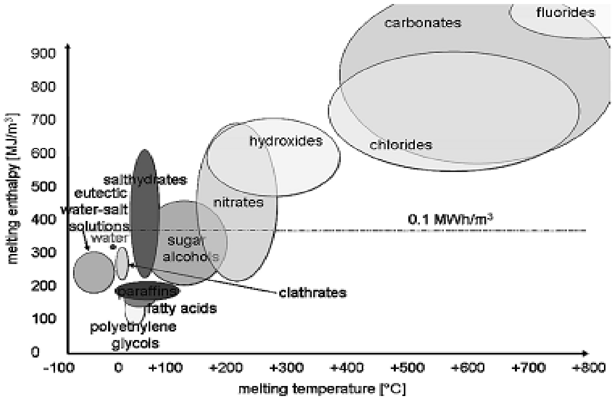

Fig.3 Classes of materials that can be used as PCM and their typical range of melting temperature and melting enthalpy [7]

Several material classes cover the temperature range from -100 °C to about 130 °C. Paraffins, fatty acids, and sugar alcohols are organic materials. Salt hydrates are salts with a large and defined amount of crystal water. Clathrates are crystalline structures in which molecules of one type are enclosed in the crystal lattice of another. Clathrate is also recognized as a gas hydrate when the enclosed molecule is from a gas and the surrounding crystal structure is water. They cover a temperature range from about 0 °C to 30 °C. At temperatures above 150 °C, different salts and their mixtures can be applied. [7]

Eutectic water-salt solutions have melting temperatures below 0 ºC, because the adding up of the salt decreases the melting temperature, and usually good storage density. Eutectic compositions solidify simultaneously out of the liquid at the freezing point. Therefore, none of the phases can be separated and sink down due to density difference. Also the eutectic compositions show a melting temperature and good storage density. The thermal conductivity of eutectic water-salt solutions is similar to that of water and they can subcool like water.

Ethylene glycol and propylene glycol resists freezing. When dissolved in water glycols disrupt hydrogen bonding when dissolved in water. Pure glycols freeze at about −12 °C but when mixed with water molecules they form a solid crystal structure and therefore the freezing point of the mixture is depressed considerably. The minimum freezing point is observed when the ethylene glycol percent in water is about 60%, as shown in the figure 1-4 graph.

C. Desirable Properties of PCM

The desirable properties of PCM for its application in refrigeration systems are as follows [4].

- High latent heat of fusion per unit volume so that a lesser amount of material stores a given amount of energy.
- High specific heat that provides additional sensible heat storage effect and also avoid sub-cooling.
- High thermal conductivity so that the temperature gradient required for charging the storage material is small.
- High density so that a smaller container volume holds the material.
- A melting point is desired operating temperature range.
- The PCM should be non-poisonous, non-flammable and non-explosive
- Reproducible phase change, also called cycling stability to use the storage material as many times for storage and release of heat as required by an application.
- No corrosiveness.
- Also, it should be economically viable to make the system cost effective.

D. Solution to General Problem with PCM

Various drawbacks associated with different classes of PCM necessitate some preventive measures. Phase separation is one of the main problems of cycling stability. When a PCM consists of several components, phases with different compositions can form upon cycling. Phase separation is the effect that phases with different composition are separated from each other macroscopically. The phases with a composition different from the correct initial composition optimized for heat storage then show a significantly lower capacity to store heat. This problem can be tackled by one of the following means: [6]

- By mechanical stirring,
- By encapsulating the PCM to reduce separation,
- By adding of the thickening agents which prevent setting of the solid salts by holding it in suspension,
- By use of excess of water so that melted crystals do not produce supersaturated solution,
- By modifying the chemical composition of the system and making incongruent material congruent.
- By little subcooling to assure that melting and solidification can proceed in a narrow temperature range. Subcooling (also called supercooling) is the effect that a temperature significantly below the melting temperature has to be reached, until a material begins to solidify and release heat. If that temperature is not reached, the PCM will not solidify at all and thus only store sensible heat. For example, liquid water can be cooled to temperatures well below 0 ºC; if highly pure and in small quantities even below -15 °C.

IV. THERMAL ENERGY STORAGE USING PCM FOR LOW TEMPERATURE APPLICATIONS

PCM offer the possibility of thermal protection due to its high thermal inertia. This protection could be used against heat and cold, during transport or storage. Protection of solid food, cooked food, beverages, pharmaceutical products, blood derivatives, electronic circuits and many other is possible. Some of the different applications for cold storage presented are the following ones:

- Cooling: use of off-peak rates and reduction of installed power, ice bank.
- Thermal protection of food: transport, hotel trades, ice-cream, etc.
- Medical applications: transport of blood, operating tables, cold therapies.
- Industrial cooling systems: re-gasification terminal.

Rezaur Rahman et al. [1] investigated the performance of domestic refrigerator improvement with application of PCM with the evaporator in a domestic refrigerator. The researcher analyzed that makes use of phase change material enhances the rate of heat transfer and hence improve the COP of refrigeration. The analysis of the experiment shows the considerable improvement in COP of a conventional refrigeration system. Here the PCM used in a chamber built manually and which surrounds the Evaporator chamber of a conventional refrigerator. Majority of heat transfers by conduction mode from load given to refrigerator cabinet to evaporator and evaporator to PCM. So heat transfer rate of evaporator refrigerant increases considerably which improves the COP of the refrigeration system by approximately 18-26%.

Md Imran Hossen Khan et al. [8] have experimented to investigate the improvement in performance of a household refrigerator with three different phase change materials with different quantities at different thermal loads. He has achieved about 20% to 27% COP improvement with the use of PCM in respect to without PCM. He has also achieved reduction in compressor running time by an average 2% to 36% as compared to without PCM at different thermal loads.

MD. Mansoor Ahamed et al. [4] has investigated the performance improvement of a cold storage with and without PCM panels (Ethylene Glycol). For experimentation the quantity of phase change material (Ethylene glycol) used in the ratio of 4:1 i.e. 4 liters of water with 1 liter of ethylene glycol. Experiments were carried out at different loads to investigate the performance of the cold storage. Experiments showed that by using phase change material (PCM) panels in the walls of a cold store can limit the raise of temperature and can maintain constant temperature up to 8 hrs. Temperature reduction in cold storage plant by using phase change material (ethylene glycol) panels had observed that reduction of 1ºC for every one hour. Depending on the PCM and thermal load around 11% to 20% of COP improvement has been achieved by the phase change material with respect to without phase change material. Depending on the thermal load with phase change material the average compressor running time per cycle is reduced considerably and it is found about 17% to 30% as compared to without phase change material. Experimental results show that the coefficient of performance (COP) of the refrigeration cycle with PCM is considerably higher than that of without PCM panel. The coefficient of performance (COP) is calculated at different loads and it is found that the coefficient of performance (COP) is optimum at 1.5Kg of thermal load while it reduces with the increase in thermal loads. As the PCM melts, it absorbs the heat which enters the cold storage space, thus prevents the rise in the cold store temperature and maintains a constant temperature inside the cold storage during incidence of power failure or done purposely to achieve electrical load shifting.

C. Marques et al. [9] has analyzed that in conventional refrigerator compressor efficiency improves by increase in compressor displacement for single speed compressor. The method proposed to take advantage of high cooling capacity of large compressor with PCM to increase the refrigerator autonomy i.e. off-cycle period, without power supply, from a few minutes to several hours. Employing thin PCM slabs (≤5 mm) ensures that the net volume of the compartment is not substantially reduced, while moderate length compressor run times (i.e. on-cycle times) is obtained. Both the numerical simulation and the experimental results demonstrated that the integration of a 5 mm PCM slab into the refrigerator allowed between 3 and 5 hours of continuous autonomous operation depending on the thermal load. The research showed that combination of a large displacement compressor and a thin PCM significantly improve temperature stability and refrigerator efficiency.

The Computational fluid dynamics model was developed to predict the airflow and temperature distribution within the thermal storage refrigerator. Several design options were simulated to find out the most effective PCM configuration (horizontal or vertical) and the optimum phase change temperature. This analysis enabled recognition of the best design options to optimize the performance of the thermal storage refrigerator. A horizontal PCM arrangement was found to be more efficient than a vertical PCM. For the horizontal PCM, the model predicted temperatures were compared with experimentally measured values and found to be in close agreement. Both the simulation and the experiments results recommended that a eutectic with a PCM below 0°C would need to be employed to keep the compartment temperature within the required range for domestic refrigerators.

C. Marques et al. [2] has investigated the performance improvement provided by PCM in association 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. The influence of PCM thickness (2, 3 and 4 × 10-3m slabs), ambient temperature (20, 25, 30 and 43 °C) and evaporating temperature (-15 and -10 °C) have been investigated. The results showed that the melting and freezing time increased proportionally with PCM thickness.

The analysis of compressor performance confirmed that larger displacement compressors are more efficient. An effective way to make use of this higher performance is to collect the excess cooling capacity in a PCM. An additional advantage of a larger compressor is that the increased cooling capacity enables more rapid freezing of the PCM. This will allow the compressor off-cycle time to be increased, thereby saving energy. The PCM heat release and storage model showed that the melting and freezing time increases proportionally with PCM thickness. The refrigerator autonomy was strongly affected by the refrigerator heat load and compressor cooling capacity. The effect of an increase in ambient temperature from 20 to 43 °C resulted in a 47 % reduction in autonomy and the freezing time was found to increase by 27 % when the evaporating temperature was reduced from –10 to –15 °C.

Azzouz, K et al. [10] have done experiments to investigate the performance of a household refrigerator using a phase change material (PCM). The PCM is located on the backside of the evaporator in order to improve its efficiency and to provide a storage capacity allowing several hours of refrigeration without power supply. The system has been tested with water and with a eutectic mixture (freezing point-3˚ C) and for a range of operating conditions. The results show that the response of the refrigerator to the addition of PCM and its efficiency are strongly related to thermal load. The addition of latent heat storage allows 5–9 h of continuous operation without electrical supply (to be compared to 1–3 h without PCM) and a 10–30% increase of the coefficient of performance, depending on the thermal load.

The compartment storage capacity of the system is little smaller with an eutectic aqueous solution than with water as a PCM, but the benefit of the eutectic solution is the ability to keep the air in the refrigerated cell at suitable temperature values recommended for the refrigerator.

V. SUMMERY

The performance of refrigerator is improved by a phase change material (PCM) associated with the evaporator in a refrigerator system. As the PCM cool off, they subsequently release the stored heat while solidifying in the same fashion. The phase change takes place without a change in the temperature of the material. PCMs have always been viewed as a suitable candidate for off peak thermal storage, particularly for refrigeration systems, due to the high latent energy densities of these materials. The usage of PCM enhances the heat transfer rate thus improve the COP (Coefficient of performance) of refrigeration. For temperatures below 0 °C, usually water-salt eutectic solutions such as ethylene glycol and water mixture are used. The use of phase change materials to accumulate thermal energy in refrigeration system is a new solution to improve the performance of these appliances.

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NOMENCLATURE

COP	Coefficient of Performance
$C_{p,l}$	Specific Heat of Liquid
$C_{p,s}$	Specific Heat of Solid
H_{pc}	Heat of Phase Change
LHS	Latent Heat Storage
PCM	Phase Changing Material
PEG	Polyethelene Glycol
SHS	Sensible Heat Storage
TES	Thermal Energy Storage
T_f	Final Temperature
T_i	Initial Temperature
T_m	Melting temperature
T_{pc}	Phase Change Temperature

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