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

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Abstract - *As per world's energy scenario energy demands vary on daily, weekly and seasonal bases. The utilization of renewable energy is obvious the attraction point of many researchers now a day due to its availability. Thermal energy storage by using phase change material is one of most demanding and innovative technology for storage of energy. Refrigeration and Air Conditioning are somewhat responsible for present energy crisis. This review article focuses on methods of thermal energy storage system, integration of organic, inorganic and eutectic type of PCM in house hold refrigerator and brief summary of performance of household refrigerator with and without PCM.*

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

1. INTRODUCTION

India is the world's third largest producer and third largest consumer of electricity.[1-2] The national electric grid in India has an installed capacity of 368.79 GW as of 31 December 2019.[3] out of which 24.3 %of energy is consumed by residential utilities. The utilization of refrigeration and air conditioning system increasing day by day which are responsible for present energy crises problem throughout the world. To deal with such type of challenges may researchers and scientists in the field if refrigeration and and air conditioning trying to develop different technical options for improving the energy efficiency of household refrigerator. In order to improve the performance of household refrigerator application of thermalenergystorage system is mostly reliable, green and economic. It is proven that Integration of latent heat storage (LHS)system to the household refrigerator helps to increase the coefficient of performance and running time of compressor is significantly *reduced. Generally*, energy consumption of a refrigerator depends upon its components efficiency, ambient temperature, thermal load, door openings, set- point temperature in its compartment(s), and refriganttype. [31] CM phase change temperature and thickness, and ambient temperature on a PCM slab at the evaporator were investigated by Azzouz et al. [18] Modeling was developed for both compressor ON/OFF modes reflecting PCM charging/discharging.

Present work mainly focused on compressive literature studyonintegrationofphasechangematerial type of organic, inorganic and eutectic mixture in household refrigerator and summarized its performance with and without Phase ChangeMaterial (PCM)

2. METHODS OF THERMAL ENERGY STORAGE SYSTEM

Now-a-days energy storage has become an important part of renewable energy technology systems. Thermal energy storage (TES) is a technology that store thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation.[1] Thermal energy storage (TES) is a technology with a high potential for different thermal applications. Thermal energy storage can be accomplished either by using sensible heat storage or latent heatstorage.[2]

2.1 Sensible Heat Storage System

In Sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.[2] Ioan Sarbu and et.al concluded SHS is applicable to domestic systems, district heating, and industrial need and water is best industrial and residential application. Underground storage of sensible heat in both liquid and solid media is also used for typically large-scale applications. However, TES systems based on SHS offer a storage capacity that is limited by the specific heat of the storage medium. Furthermore, SHS systems require proper design to discharge thermal energy at constant temperatures. PCMs can offer a higher storage capacity that is associated with the latent heat of the phase change.[3]

2.2 Latent Heat Storage System

When the application of heat, changes the phase of the substance, is called latent heat. Latent heat is stored in the substance at constant temperature during phase change. LHS materials are known as PCMs due to their property of releasing or absorbing energy with a change in physical state. The energy storage density increases and hence the volume is reduced, in the case of LHS . The use of an LHS system using PCMs is an efficient way of storing thermal energy and has the advantages of high-energy storage capacity and the isothermal nature of the storage process. In case of latent heat storage system capacity of storing heat at almost similar temperature range. [4]

3. PHASE CHANGE THEORY

The exact definition of the phase of a pure body is "an area in the space of the thermodynamic parameters (T,p,V) of a system composed uniquely of the pure body, in which the free energy is an analytical function".[4] The working mechanism of phase change material is elaborated as follows, where water is used as PCM.

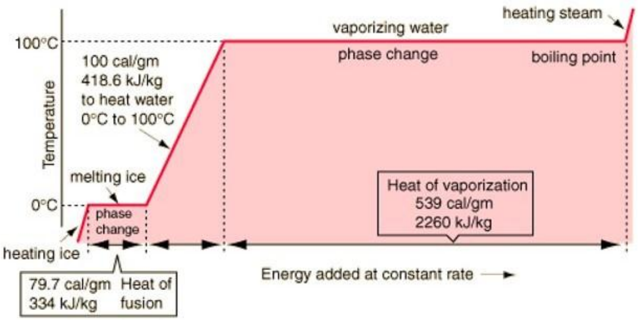

Fig -1: Phase Change Mechanism of Water. [35]

If we supply heat to the ice which is below 0^0C at 1 atmospheric temperature increases its temperature up to 0^0C. further addition of heat convert the ice into water at 0^0C. Here the phase changes from ice to liquid but temperature remains constant. Once all the volume of ice is converted in water further addition of heat increases the temperature of water up to 100^0C. At 100^0C water is converted into steam on addition of heat.

While changing the phase of substance latent heat is stored as thermal energy storage.

3.1 Classification of PCM

Fig.2 shows the various types of phase change materials which are further classified as follows:

i. Organic :

High heat of fusion, Self nucleating properties, Safe, non-reactive, recyclable.

ii. Inorganic:

High volumetric latent heat storage capacity, High thermal conductivity, Sharp melting point, Non-flammable.

iii. Eutectic:

Sharp melting point (range of pure substances),

Volumetric heat storage density higher than organic compounds.

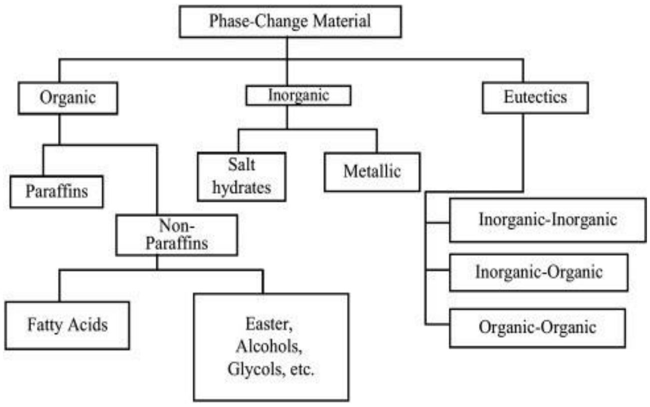

Fig -2: Types of Phase Change Material. [36]

3.1.1 Organic PCM for Cold Storage

Organic—shows the types of phase change heat storage materials; divided as organic and inorganic materials. Organic materials are further classified as paraffin and non-paraffins (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.[5] Atul Sharma and et.al tabulate the data of Organic phase change materials with their chemical composition ,thermal conductivity, melting temperatures which are further described as paraffin and non paraffins. Organic materials include congruent melting means melt and freeze repeatedly without phase segregation and consequent degradation of their latent heat of fusion, self nucleation means they crystallize with little or no supercooling and usually non-corrosiveness.[6] Paraffin is also chemically stable during phase change process. However ,paraffin waxes have disadvantages due to their low thermal conductivities, low latent heat, flammability and high change in volume.[7-8] I M Rasta and et.al experimentally investigated that that only small amount of organic nucleateagent (soya or corn oil ester) was required for the PCM solutions and latent heat of fusion the PCM candidates varied in the range of 171.72—230.68 J/g, while tap water had melting latent heat of 297.44 J/g. found that the PCM candidates had better property than water due to their small of super-cooling especially for medium temperature refrigeration applications.[9]

3.1.2 Inorganic PCM for Cold Storage

Inorganic materials such as salt hydrates have suitable cold storage temperature, larger heat storage capacity, non-flammable and good for cryogenic storage rather than organic material. The temperature requirement of low cold storage is between −20 and −30°C, and the high-temperature cold storage is between 0 and 4°C .but, the ice and water storage systems can only reach 0°C, which cannot meet requirements of low-temperature application. This issue could be over come by adding inorganic salts in the water can ensure that the amount of phase change latent heat almost unchanged and reduce the phase change temperature of cool storage material at the same time. Compound salts can not only further reduce the melting point of solidification but also optimize and modify the overall physical properties of certain materials.[6,10,11,12] Li et al. have studied the preparation, characterization, and modification of a new phase change material $CaCl_2 \cdot 6H_2O—MgCl_2 \cdot 6H_2O$ eutectic hydrate salt. As a result, its phase change temperature and latent heat are 21.4°C and 102.3 J/g, respectively.[13] A ternary hydrated salt mixture is presented by Efimova et al. which is suitable for use in air conditioning systems and thermal analysis is carried out and concluded that the material has a melting temperature of 18—21°C and an enthalpy of fusion of 110 kJ/kg.[14] Pilar et al. selected inorganic salt $SrCO_3$ and $Sr(OH)_2$ as nucleating agents for $MgCl_2 \cdot 6H_2O$; the results show that the addition of 1 wt% $SrCO_3$ and 0.5 wt% $Sr(OH)_2$ almost completely suppress the supercooling and improve the performance of this latent heat storage system.

3.1.3 Eutectic Mixture for Cold Storage

Eutectic mixtures- Melting and cabeza summarized that Eutectic salt-water solutions have near about similar thermal conductivity to that of water also can show considerable volume change during melting and solidification (5–10 vol.%) like water. They are chemically quite stable but can cause corrosion to some materials like metals. [23]

A eutectic system is a mixture of chemical compounds or elements that have a single chemical composition that solidifies at a lower temperature than any other composition made up of the same ingredients. This composition is known as the eutectic composition and the temperature at which it solidifies is known as the eutectic temperature. Eutectics may be a combination of Organic-organic, organic-inorganic, inorganic-inorganic compounds. Utilization of eutectic phase change materials (PCMs) to increase energy efficiencies of refrigerators has supercooling, corrosion and thermal stability problems are challenges that need to be overcome with eutectic salt solutions .[20-21] Yamagishi et al. [16] used two paraffins, n-tetradecane and n-dodecane with a melting point of 5.5 and 13.5 C respectively. Both were microencapsulated and were experimentally investigated as slurry for cold energy applications. Han et al. [17] measured the latent heat during phase change of $NaCl—H_2O$ binary mixture using a differential scanning calorimeter (DSC) at various concentrations observing two different endothermic peaks, one due to a eutectic melting near 22 C, and the other for ice. Fig. 3 shows the DSC results for different concentrations of NaCl in water, concluding that the eutectic mixture is the best mixture, as expected. Furthermore, Liesebach et al.[18] determined experimentally the apparent latent heat of freezing of aqueous solutions of different concentrations of NaCl (3% and 16% NaCl), and Kamasa et al.[19] used the DSC to investigate the fraction of unfrozen water during phase transitions for 9 wt.% $NaCl—H_2O$ solution

4. WORKING OF HOUSEHOLD REFRIGERATOR

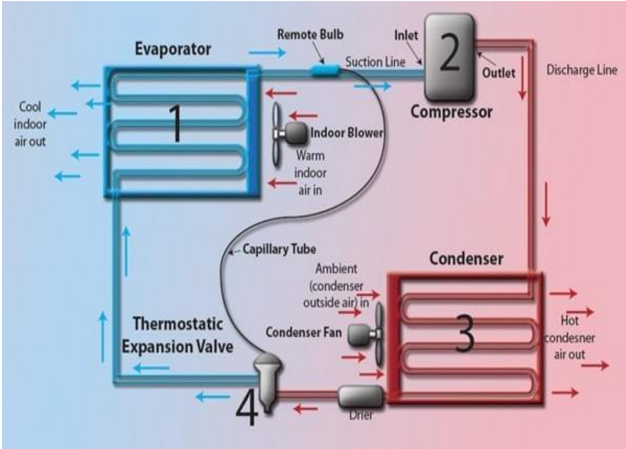

Fig -3: Working Principle of Household Refrigerator. [27]

The compressor compresses the refrigerant gas. This raises the refrigerant's pressure and temperature, so the heat exchanging coils outside the refrigerator allow the refrigerant to dissipate the heat. As it cools, the refrigerant condensed into liquid from and flows through the expansion valve. When it flows through the expansion valve, the liquid refrigerant is allowed to move from high pressure zone to low pressure zone so it expand and evaporates. The coils inside the refrigerator allows the refrigerant to absorb heat, making the inside of the refrigerator cold. The cycle then repeats. [24-25]

5. PERFORMANCE OF REFRIGERATOR WITH AND WITHOUT PCM

Azzuage and et al. proposed the dynamic model of an improved refrigerator introducing phase change material as cold storage. This paper presents a first step in the design of an improved refrigerator using phase change material as a cold storage by replacing free convective heat transfer to air and conducted results for heat transfer from the evaporator with and without PCM which showed 72% increase in COP and 25% reduction in working time of compressor. [28]

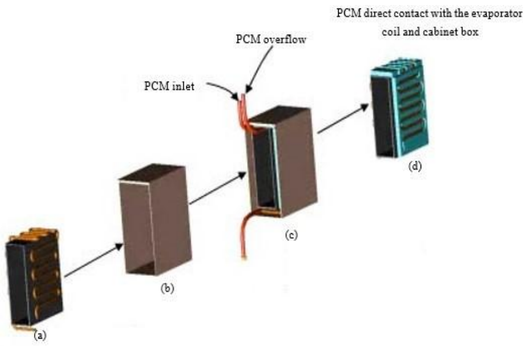

Fig -4: Arrangement of PCM based Evaporator. [28]

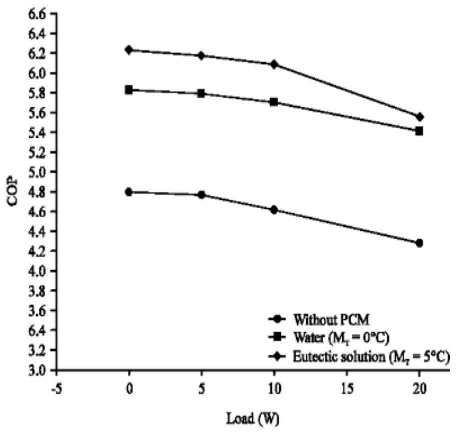

Fig -5: Effect of PCM on COP at Thermal Load (Q=0.00425m³). [28]

Imran Khan et.al improve the performance of household refrigerator by application of PCM as water and eutectic solution and compared its performance without PCM and significantly reduced compressor running time about 2-36% as compared to without PCM.[29]

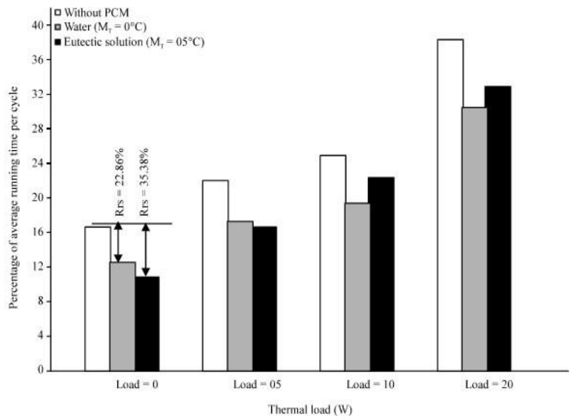

Fig -6: Effect of Compressor running time on Thermal load. [29]

Rezaur Rahman, Md. Examines the improvement of the COP of conventional refrigerator by using water as PCM upto 50-60% also achieved better food quality due to lower hysteresis cycles of ON/OFF for given period of operation.[30]

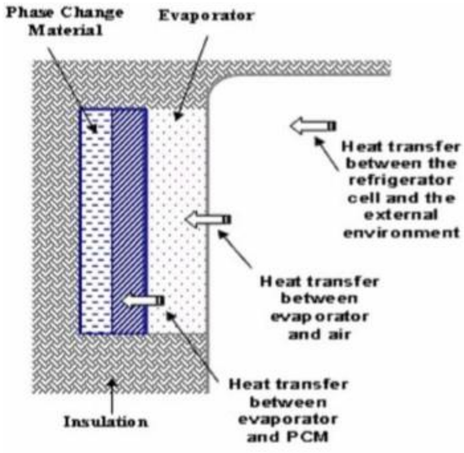

Fig -7: Schematic Model of Refrigerator with PCM.[30]

Number of observation	COP found in Vapor compression Refrigerator Without PCM	COP found in Vapor compression Refrigerator With PCM
1	6.12	9.85
2	5.55	9.42
3	6.12	9.45
4	5.5	9.04
5	5.13	9
6	6.78	9
7	5.1	9
8	5.11	8.91
9	5.02	8.82
10	5.02	8.91

Fig -8: Effect of PCM on COP.[30]

6. CONCLUSION

In this paper review of cold thermal energy storage using phase change material has been carried out. The results of application of organic, inorganic and eutectic type of PCM for cold thermal energy storage has been studied. It implies that mostly eutectic type of PCM are efficient and recommended for TES system. The performance of refrigerator by using PCM and without using PCM also reviewed. It shows that phase change material enhances the efficiency of refrigerator and reduced the compressor on/off timing. That's why utilization of phase change material plays vital role in energy storage methods.

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