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The Viability of Thermal Energy Storage and Phase Change Material: A Review

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ABSTRACT

Energy demands vary on daily, weekly and seasonal bases. With rising cost of energy and an increasing demand for renewable energy sources, thermal energy storage (TES) systems are becoming an interesting option. TES is a key component of any successful thermal system and a good TES should allow minimum thermal energy losses. Thermal energy storage is considered advanced energy technology, and there has been an increasing interest in using this essential technique for the thermal applications such as heating, hot water, air conditioning, and so on. The selection of the TES systems mainly depends on the storage period required i.e. ., diurnal or seasonal. Economic viability, operating conditions, and the like. In practice, many research and development activities related to energy have been concentrated on efficient energy use and energy savings, leading to energy conservation. Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require a large surface area. Thermal storage has been characterized as a kind of thermal battery. So this paper emphasized on the capability of thermal energy storage system and its viability.

Keywords: *Thermal energy storage, Phase change material, Latent heat.*

I. INTRODUCTION

Thermal energy storage (TES) is defined as temporary holding of thermal energy in the form of hot and cold substances for latent utilization. TES system deal with the storage of energy by cooling, heating, melting, solidifying or vaporizing of a material and the thermal energy becomes available when the process is reversed. Thermal energy storage (TES) systems correct the mismatch between the supply and demand of energy.

Thermal energy storage (TES) is a technology to stock 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. TES systems are particularly used in buildings and industrial processes. In these applications, approximately half of the energy consumed is in the form of thermal energy, the demand of which may vary during the day, and from one day to next. Therefore, TES systems can help balance energy demand and supply on daily, weekly and even seasonal basis. They can also reduce peak demand, energy consumption, CO2 emissions and costs, while increasing the overall efficiency of energy system. Furthermore, the conversion and storage of variable renewable energy in form of thermal energy can also help increase the share of renewables in the energy mix. TES is becoming particularly important for electricity storage in combination with concentrating solar power (CSP) plants where solar heat can be stored for electricity production when sunlight is not available. There are three kinds of TES systems, namely: (i) sensible heat storage that is based on storing thermal energy by heating or cooling a liquid or solid storage medium such as water, sand, molten salts, rocks, etc., with water being the cheapest option; (ii) latent heat storage using phase change materials (PCM), e.g.

from a solid state into a liquid state; and (iii) thermo-chemical storage (TCS) using chemical reactions to store and release thermal energy.

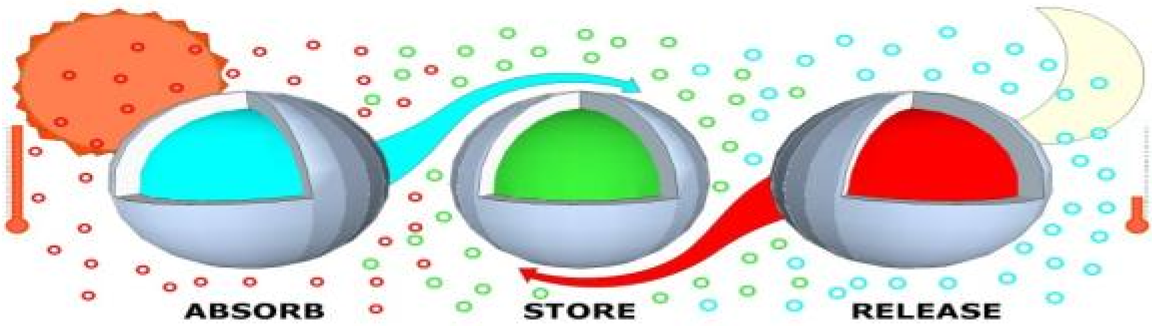

Figure 1. Process of Absorption & Releasing Of Energy

1.1 Phase Change Materials

One of the conventional methods to store latent heat is the use of Phase Change Material (PCM). There are extensive studies on various kinds of PCMs like salts, paraffin waxes, and inorganic acids, eutectics of organic and inorganic compounds was done. Amongst them inorganic compounds come with advantages like high latent heat per unit volume, high thermal conductivity, non-flammability and low cost in comparison to organic compounds .In the current work paraffin wax is used as the PCM and the Comparative Study of Latent Heat Storage System using Nano-Mixed Phase Change Material was done.

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 heat is mainly stored in the phase-change process (at a quite constant temperature) and it is directly connected to the latent heat of the substance. The use of an LHS system using PCMs is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. The main advantage of using LHS over SHS is their capacity of storing heat at almost similar temperature range. Initially, these materials act like SHS materials in that the temperature rises linearly with the system enthalpy; however, later, heat is absorbed or release at almost constant temperature with a change in physical state.

1.1.1 Characteristics Proprieties of PCMs

PCMs have been used in thermal applications for a few decades. PCMs have:

- Thermo-physical properties (latent heat of transition and thermal conductivity should be high, and density and volume variations during phase-transition should be, respectively, high and low in order to minimize storage volume),
- Kinetic and chemical properties (super-cooling should be limited to a few degrees, and materials should have long-term chemical stability, compatibility with materials of construction, no toxicity, and no fire hazard)
- Economic advantages (low cost and large-scale availability of the PCMs are also very important).

1.1.2 Classification of Phase change Material

LHS materials are broadly classified based on their physical transformation for heat absorbing and desorbing capabilities. As seen from Figure 2, wide classifications of solid–liquid PCMs, which are further classified into organic, inorganic, and eutectic materials, are presented. PCMs are classified as different groups depending on the material nature (paraffin, fatty acids, salt hydrates, etc.).

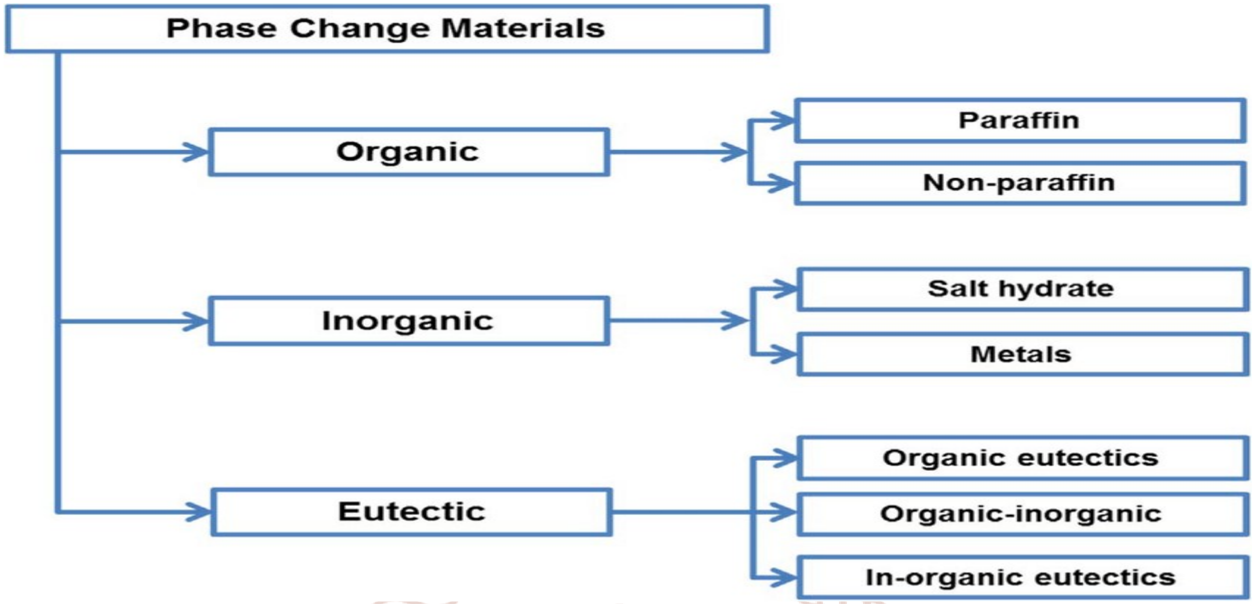

Figure 2: Classification of phase change materials.

II. LITERATURE REVIEW

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. Renewable energy resources appear to be one of the most efficient and effective solutions. The greatest advantage of solar energy as compared with other forms of energy is that it is clean and can be supplied without any environmental pollution. It is also preferred to have thermal energy storage system which can work for an extended period of operation, even after the sun sets. Thermal energy storage, in general and LHS in particular, has gained more popularity in the past two decades, due to its advantages discussed in the previous chapter. In the present work, a detailed survey has been made of the various aspects in this field of research, which includes thermal storage materials, storage system configuration, applications, experimental investigations and modeling of phase change problems.

Progress in LHS systems mainly depends on heat storage material investigations and on the development of heat exchangers that assure a high effective heat transfer rate to allow rapid charging and discharging. Latent heat TES systems are broadly classified into the capsule-type and the shell and-tube type, according to the method of containing the thermal energy storage material and to the mode of exchanging heat energy within the container. The various studies carried out by the researchers on different configurations are classified under i) Tubular exchanger ii) packed bed units iii) system with different heat transfer enhancement techniques.

Green and Vliet (1981) developed a numerical model and provided experimental measurements for a PCM storage unit of a shell and tube heat exchanger.

The transient performance of a double pipe heat exchanger as a thermal energy storage container was investigated both experimentally and theoretically by Fath (1991). The results indicated that increasing the HTF inlet temperature and flow rate as well as the heat exchanger length increases the heat transfer rate and stored energy.

Ryu et al (1991) studied the heat transfer characteristics of cool-thermal storage units during the charging period using vertical and horizontal tube systems. The two systems were compared with respect to heat transfer rate, coefficient of performance and super cooling of the PCM and it was found that the vertical tube system exhibits better thermal performance than the horizontal tube system.

Lacroix (1993a) developed a theoretical model to predict the transient behavior of a shell-and-tube storage unit with the PCM filling the shell side and the HTF circulating inside the finned tubes. A series of numerical tests were undertaken to assess the effects of the shell radius, mass flow rates and inlet temperature of the HTF.

B. Zalba et al.[2003]Studied the performance of a latent heat storage system with solid, liquid phase change. This paper also provides a review of studies dealing with thermal energy storage (TES) using phase change materials. This paper contains a complete review of the types of material which have been used as latent heat storage materials, their classification. Characteristics, advantages and disadvantages and the various experimental techniques used to determine the behavior of these materials in melting and solidification. The paper contains listed over 150 materials used in research as PCMs, and about 45 commercially available PCMs.

M.Cheralathan et al.[2006] Investigated the transient behavior of a phase change material based cool thermal energy storage (CTES) system comprised of a cylindrical storage tank filled with encapsulated phase change materials (PCMs) in spherical container integrated with an ethylene glycol chiller plant. A simulation program was developed to evaluate the temperature histories of the heat transfer fluid (HTF) and the phase change material at any axial location during the charging period. The results of the model were validated by comparison with experimental results of temperature profiles of HTF and PCM. The results showed that increase in porosity contributes to a higher rate of energy storage.

Nayak A.O. et al. [2008] He has considered various PCM like paraffin wax, sodium acetate tri-hydrate and phenolphthalein which are used to absorb heat from the coolant water from the engine. Due to conduction and convection of heat transfer heat is stored inside the PCM in the form of latent heat. Convection and heat flux effect due to temperature change has been simulated and studied in detail using GAMBIT and FLUENT. From the temperature profiles obtained from the analysis he concluded that sodium acetate tri-hydrate gives us the most promising results as compared to paraffin wax and naphthalene. Coolant water loses maximum heat to sodium acetate tri-hydrate which is obtained as drop in temperature from 343 K to 324 K (in the coolant water). He observed that the heat absorption in the PCM material decreases gradually as it travels from the inlet of coolant water towards the outlet of coolant water.

Hajare V. S. et al. [2010]In this work paraffin wax is taken as PCM for experimentation work. In paraffin wax Al2O3 nanoparticles were added in 0.5%, 1% and 2% to enhance its thermal performance. For the experimentation solar water heating system is considered as latent heat thermal storage. Experiments were carried out with both base and nano mixed PCM to ensure the enhancement in heat transfer. From experimental investigation carried out it is found that there is enhancement in heat transfer rate of PCM due to the incorporation of nanoparticles. Heat transfer rate in the PCM is totally depends upon the amount of melt fraction. As melt fraction increases, there is increase in movement of nanoparticles which increases the heat transfer rate. From the experiment carried out it is clear that enhancement is depending on the percentage of nanoparticles inside the PCM and position of the spherical ball into the tank. Also maximum enhancement in melting point of 10.65% is observed for dispersion of 0.5% Al2O3 nanoparticles.

Bauer T. et al. [2012] This paper focuses on latent heat storage using a phase change material (PCM). The paper lists of literature and gives the current status of medium working range temperature of 200 to 350oC. In this paper the system with KNO3-NaNO3 is discussed in detail with their thermo-physical properties in the liquid and solid phase. A comparison of literature data and own measurements for the density, heat capacity, thermal diffusivity and thermal conductivity is presented in detail. The melting temperature and enthalpy of the KNO3- NaNO3 is 222oC and 108j/g was identified respectively. Different properties such as thermal conductivity, density are also collected from the different literatures.

Thogiti Arunkumar[2016] Analyzed the thermal characteristics of evaporator in refrigerator and compared for with pcm chamber and without pcm chamber at different refrigerants HFC – 134A, Ethylene glycol and propylene glycol and water. CFD analysis is done on the evaporator to determine the heat transfer coefficients without pcm and with pcm. Thermal analysis is also done by varying two materials for the evaporator Copper and Aluminum.

Müslüm Arıcı , Ensar Tütüncü, Miraç Kan, Hasan Karabay [2017] In this study, melting of paraffin wax with Al_2O_3 nanoparticles in a partially heated and cooled square cavity is investigated numerically. The thermally active parts of the enclosure which are facing each other are kept at different constant temperatures while the other parts of the enclosure are insulated. The effect of nanoparticle concentrations (/ = 0 vol%, 1 vol%, 2 vol% and 3 vol%) and orientation of the activated walls together with the temperature of the hot wall on the melting process and stored energy is investigated. Thermophysical properties of NEPCM are considered to be temperature and phase dependent. The computed results showed that considered parameters have a significant effect on the melting rate and stored energy. The results reveal that the highest enhancement is attained for the enclosure filled with / = 1 vol% of nanoparticle concentration and heated from bottom, and nanoparticle concentration beyond / = 1 vol% defeats the purpose thus enhancement decreases.

M.Auriemma and A. Iazzetta [2016] A numerical study on variations of thermo-physical properties of Phase Change Material (PCM) due to dispersion of nanoparticles is presented in this article. Dispersed metal oxide nanoparticles in paraffin wax might be a solution to improve latent heat thermal storage performance. Thermo-physical properties such as thermal conductivity and latent heat could be changed for different concentration of dispersed nanoparticle. The paper will focus on numerical investigation of the melting of paraffin wax dispersed with three different metal oxide Alumina (Al_2O_3), Copper Oxide (CuO) and Zinc Oxide (ZnO) that is heated from one side of rectangular enclosure of dimensions of 25 mm × 75 mm. The integrated simulation system ANSYS Workbench 15.0 for the numerical study was used including mesh generation tool ICEM and FLUENT software. In FLUENT, the melting model with Volume Of Fluid (VOF) that includes the physical model to disperse nanoparticles in the PCM and their interactions is applied. During melting process, the enhancement of heat transfer is considered. For each nanoparticle analyzed, three different volume fractions are considered and compared. Dispersed nanoparticles in smaller volumetric fractions show a rise the heat transfer rate. The thermal performances are slightly greater using Al_2O_3 respect both ZnO that CuO nanoparticles.

The literature review reveals that no researcher was used the Beryllium oxide as nanofluid for optimizing the thermal energy storage system parameters in which PCM is stored.

III. CONCLUSIONS

In this review of revampment of phase change material final conclusion can be drawn in such a way that, there is definite need of revampment of phase change material for energy storing application. For the revampment of the phase change material nanoparticles are playing an important role. From the above review study it can be concluded that, by dispersion of the nanoparticles into the phase change material the poor properties of PCM such as melting point, specific heat and thermal conductivity can be revamped. There are number of parameters has to be considered while selecting the nanoparticle for the selected operation.Selection of nanoparticles is based on several parameters such as thermal conductivity, particle size, cost, volume fraction and type of base fluid etc. Particle size is an important parameter because shrinking particles down to By revampment of properties of PCM with the help of nanoparticles energy storing capacity can be increased to 20-30%. Also charging time can be decreased due to increase in thermal conductivity. no researcher was used the Beryllium oxide as nanofluid for optimizing the thermal energy storage system parameters in which PCM is stored.

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