© July 2019 | IJIRT | Volume 6 Issue 2 | ISSN: 2349-6002

A Review on Viability of Thermal Energy Storage and Phase Change Material

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***Abstract*- The thermal energy storage is the transitory saving of high-temperature or low-temperature energy to use later. It connects the gap amid the demands and actual energy use. The used thermal storage may include many hours' storage cycles which depend on the systems requirements design. Whereas the output constantly thermal, while the input may be either electrical or thermal. The PCM is a product that saves and releases thermal energy through melting and freezing process. When those material freezing, it will release a large amount of energy in form latent heat of fusion. Conversely, when the material is melted, an equal amount of energy is absorbed from surrounding when it converts from solid to liquid phase. In practice, many research and development activities related to energy have been concentrated on efficient energy use and energy savings, leading to energy conservation. 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.**

Index terms- Thermal energy storage, Phase change material, Latent heat, Applications, Challenges

I. INTRODUCTION

Energy sustainability is a major concern among policy makers, researchers, scientist and engineers. Although renewable energy such as solar, wind, etc., have been considered and developed by researchers to replace the conventional fossil-based energy resources, the optimization of current energy usage should not be overlooked. Before adopting renewable energy, it is important to learn how to conserve and optimize energy usage. One of the method is by using thermal energy storage. The main idea of using thermal energy storage system is to store thermal energy for later usage instead of releasing it to the environment.

There are three (3) types of thermal energy storage, namely sensible heat, latent heat and thermal chemical storage system. Each of the system has their own advantages and disadvantages. It is reported that thermal energy storage density for latent heat storage is higher than sensible heat storage. Latent heat storage system using phase change material (PCM) has been widely investigated and explored by various researchers. PCMs offer promising thermal storage characteristic where they can absorb and release large amount of latent heat during phase transition process. During phase change process, the temperature of these materials remains constant.

1.1 Thermal Energy Storage

Thermal energy storage involves the storage of heat in one of three forms; Sensible heat, Latent heat and thermo-chemical heat storage.

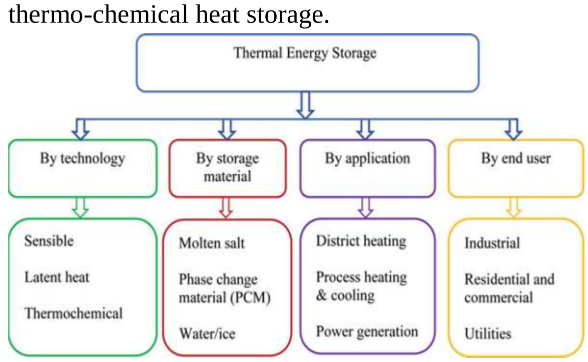

Figure 1: Classification of thermal energy storage materials.

Sensible heat storage is the most common method and has been employed for hundreds of years as hot water tanks. Sensible heat storage simply means changing the temperature of storage medium. The storage medium is most commonly water but rock, sand, clay and earth can also all be used.

Latent heat energy storage involves the storage of energy in Phase-Change Materials (PCM's). Thermal energy is stored and released with changes in the materials phase. The most common phase change to exploit is the solid-liquid transition, as the liquid –gas transition is impractical and solid-solid (crystalline structure) transitions usually have too low an energy density to be useful. When a PCM is heated initially it behaves like sensible heat energy storage and the materials temperature is increased. However, once the transition temperature is reached the material will continue to absorb heat at a constant temperature while it changes state. This heat absorbed at constant temperature is known as the latent heat of the transition. To retrieve the energy the PCM can be changed back from the liquid to the solid phase and the energy stored as latent heat is released.

Thermochemical heat energy storage involves storing heat energy in chemical bonds. A reversible chemical reaction which absorbs heat is used to absorb the heat energy that is to be stored. This reaction can then be reversed to release the stored heat. The most common reactions used for this process is the hydration of salts. The energy storage is based on the release of the heat of hydration. Hence, a salt hydrate storage system is charged by the endothermic thermal dehydration of the respective higher hydrated salt.

1.2 Phase Change Material

It is reported that thermal energy storage density for latent heat storage is higher than sensible heat storage [2–3]. Latent heat storage system using phase change material (PCM) has been widely investigated and explored by various researchers. PCMs offer promising thermal storage characteristic where they can absorb and release large amount of latent heat during phase transition process. During phase change process, the temperature of these materials remains constant as shown in Fig. 2.

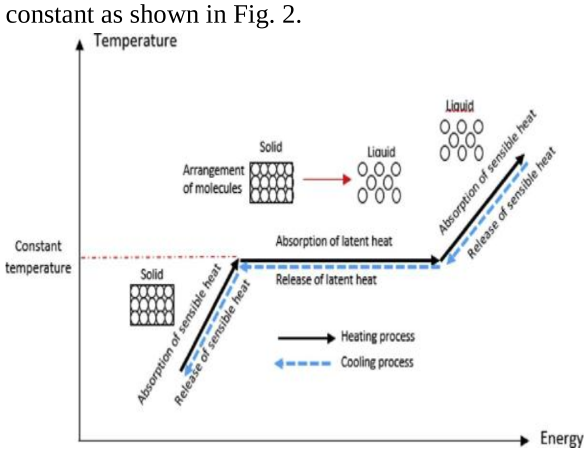

Figure 2: Temperature variation of PCM during heating and cooling processes (ideal case)

PCMs for LHTES can be classified depending upon the phase change mechanism as described in Fig. 3 and phase transition temperature, as discussed below:

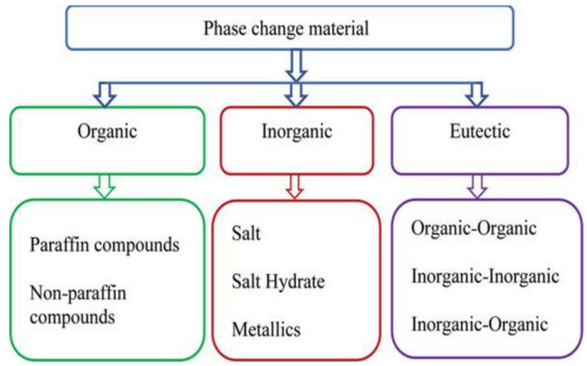

Figure 3: Classification of phase change materials.

In general, PCM is classified based on change of state during phase transition process (solid-liquid; liquid-gas; solid-solid).

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.

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 Al2O3 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 (Al2O3), 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 Al2O3 respect both ZnO that CuO nanoparticles.

III NANO-ENHANCED PCM

PCM doped with nanoparticles is known as nano-enhanced PCM as shown in Fig. 4. Nanoparticles such as carbon nanotubes, graphite, graphene, metal and metal oxide can be dispersed in PCM [15]. It is worth noting that inclusion of nanoparticles will not only alter thermal conductivity characteristic of PCM but also other characteristics as well, including latent heat capacity, sub-cooling, phase change temperature and its duration, density and viscosity.

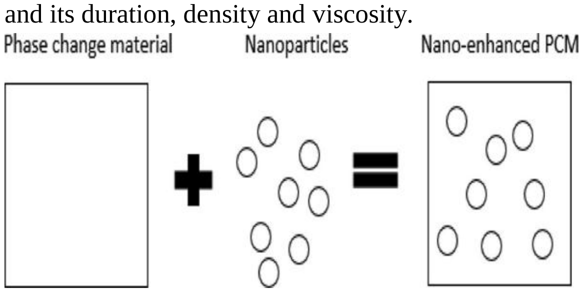

Figure 4: Concept of nano-enhanced PCM

3.1 Characteristics of nano-enhanced PCM

The ideal characteristics of nano-enhanced phase change material are as follows:

a. Suitable phase change temperature – This temperature must match the application temperature. This is to ensure that the heat can be absorbed or released at the right temperature. Paraffin wax has wide range of phase change temperature. The melting temperature of paraffin wax that has been used by researchers are 53 °C - 57 °C and 25 °C. In addition, the melting temperature of paraffin wax depends on the length of hydrocarbon chain.
b. High thermal conductivity – Thermal conductivity represents the ability of a substance to transmit heat. PCM with high thermal conductivity is preferred so that the heat can be stored or released in a short time. This is also echoed by Zhu et al stressing the importance of rapid heat transfer to produce efficient thermal energy storage.
c. Higher latent heat – PCM capable of storing more latent heat is desirable. Latent heat is different from sensible heat in which it is the energy required for phase change process where there will be no variation of temperature observed. During melting process, latent heat is the energy used to overcome the intermolecular forces. Meanwhile, sensible heat increases the temperature of the substance.
d. Small volume change during phase transition process – Small volume change is advantageous to reduce design complexity of PCM storage system.
e. Low sub-cooling temperature - Other name for sub-cooling is super cooling. If the super-cooling is high, the liquid PCM will not starts to solidify even when it reaches freezing (solidification) temperature. It will only start to solidify and crystallize at temperature well below the freezing temperature. Latent heat is released when the crystallization (solidification) starts. Thermal conductivity improvement reduces the effect of super-cooling. Better heat transfer within the material can be achieved when thermal conductivity is augmented.
f. Low cost – The cost of the PCM is preferred to be as low as possible to minimize the investment cost and payback period.
g. Safe – The selected PCM must be non-corrosive, non- toxic and nonflammable.
h. High stability – The PCM must be chemically stable. The properties of PCM must remain unaffected throughout the repeated heating and cooling processes.
i. Low vapor pressure and rapid crystallization.
j. High density especially when applied in limited volume storage.
k. High thermal diffusivity

IV.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.

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