A Review on Nano-Enhanced Phase Change Materials for Energy Storage Applications

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Abstract- **A phase change material (PCM) is a substance with a high heat of fusion which, 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. . This review focuses on the application of various phase change materials based on their thermophysical properties. In particular, the melting point, thermal energy storage density and thermal conductivity of the organic, inorganic and eutectic phase change materials are the major selection criteria for various thermal energy storage applications with a wider operating temperature range. The strategy adopted in improving the thermal energy storage characteristics of the phase change materials through encapsulation as well as nanomaterials additives, are discussed in detail. Specifically, the future research trends in the encapsulation and nanomaterials are also highlighted.**

Index Terms- PCM, Mass Fraction, temperature distribution, pressure distribution, CFD.

I. INTRODUCTION

Phase-change heat storage technologies have received considerable attention in the field of vehicle-mounted waste heat utilization. For the traditional internal combustion engine car, Schatz proposed the concept of a heat battery, which adopts a phase change material (PCM) to store waste heat from engine cooling water. The heat could be used to preheat the cabin and improve engine cold start performance in winter. Korin used latent heat energy to preheat a catalytic converter until it reached the optimum working temperature. Dinker showed that PCM stores much heat more than sensible heat storage materials at constant temperature and many researchers have been studying to use PCMs in battery thermal management. Aldoss built a mathematical model to investigate a lighting thermal management system with a PCM. Adamczyk proposed a vacuum insulation method, and experimental results showed that this method could efficiently realize heat preservation for a long time. Compared with traditional vehicles, extending the operational range and reducing energy consumption are more critical problems for EVs. Because pure electric vehicles (PEVs) do not have engine waste heat, winter heating and battery cold starts have become difficult technical problems and large obstacles for all climate applications. Al-Hallaj considered using heat stored in PCMs to improve the cold start performances of battery packs in cold regions. Park proposed charging the heat and electricity at the same time for EVs using a heat storage device, and discussed coordinated control and application methods. Gao et al. indicated that PCMs can absorb considerable heat from batteries, PCUs, and motors to make their working temperatures stable. In addition, waste heat can be used to defrost and preheat the cabin facilitating heat recovery and energy savings. Therefore, a thermal energy storage setup is important for vehicle-mounted heat energy reutilization and complementation, and it will promote electric vehicle thermal management (VTM) integration involving the battery packs, motors, power control units (PCUs), heat pumps (HPs), etc. At the same time, realizing rapid heat storage and release is a key problem in vehicle applications. Therefore, heat transfer enhancement technologies are necessary and important. At present, technological development mainly focuses on two aspects: the improvement of thermal conductivity and the optimization of the structure for heat exchange.

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.

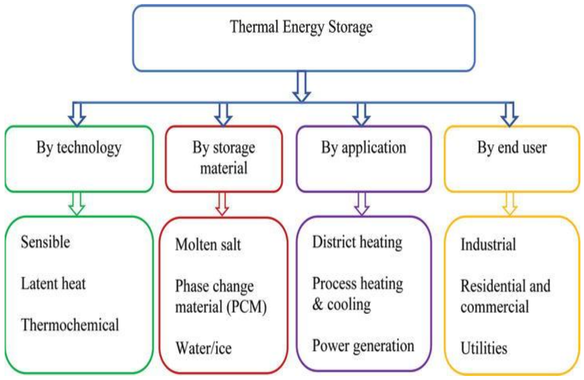

Figure 1: Classification of thermal energy storage materials.

2.LITERATURE REVIEW

A broad review of research in the field of phase change heat storage, especially on salt hydrates, has been done by Lane (1983).

Choi [1995] is the first researcher who worked on nano particles at the Argonne National Laboratory, USA. He demonstrated that nanofluids exhibit an increased thermal conductivity compared to the host fluid.

Saito et al [2001] performed an analytical and experimental investigation on a heat removal process of the thermal energy storage capsule, using gelled Glauber's salt.

Vyshak and Jilani [2007] presented a comparative study of the total melting time of a phase change material (PCM) packed in three containers of different geometric configurations, viz. rectangular, cylindrical and cylindrical shell, having the same volume and surface area of heat transfer by employing a slightly modified enthalpy method, which enables decoupling of the temperature and liquid fraction fields. The governing equation for one dimensional isothermal phase change is discretized using the Crank–Nicholson finite difference scheme and the resulting system of algebraic equations for temperature is solved using the Thomas algorithm, the liquid fraction field is updated explicitly using the currently known temperature field. The results are presented for different masses of PCM filling the containers and inlet temperature of the heat transfer fluid (HTF).

Namburu et al. [2008] investigated the rheological property of copper oxide nanoparticles in ethylene glycol-water mixture base fluid by varying the nanoparticle concentrations from 0% to 6.12% in the temperature range from 350C to 500C. The nano fluid also exhibited Newtonian behavior in the concentration range tested. For a volume concentration of 6.12%, the viscosity of copper oxide nanofluid fourfold higher than that of the base fluid at 350C.

López et al [2012] investigated that the addition of 10 % of Cel-ZnO to the hexadecane decreases super cooling around a 30 %, providing a promising way of improving the performance of system energy efficiency in building cooling and heating applications.

Guo et al. [2013] found that thermal conductivity of expanded graphite (EG) - erythritol is higher than MWCNT-erythritol due to the rapid transfer of phonon in EG network and higher interfacial thermal resistance of MWCNT

Bauer T. et al. [2014] 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.

Lin and Al-Kayiem[2016]usesParaffin wax and Cu (0.5, 1.0, 1.5, 2.0 wt. %) as nano enhanced material. Thermal conductivity increases non-linearly with the increase of nanoparticles concentration. 46.3% thermal conductivity augmentation is recorded at 2.0 wt. % of nanoparticles. Latent heat for melting and solidification decreases 14.6% and 13.3% respectively, at 2.0 wt. % of nanoparticles compared to that of pure paraffin wax. Melting (184.2 kJ/kg to 157.3 kJ/kg) Solidification (179.3 kJ/kg to 155.5 kJ/kg). Melting phase change temperature decreases 4.3% at 2.0 wt. % of nanoparticles concentration compared to that of pure paraffin wax. Melting temperature decreases from 60.42 °C to 57.81 °C. There are slight changes for the solidification phase change temperatures.

Babapoor et al. [2016] in their experimental study agreed that addition of various types of nanoparticles in the PCM change its thermal properties noticeably. Mixture of liquid paraffin (40 wt. %) and paraffin wax (60 wt. %). The melted mixture is left in room temperature for solidification process. SiO2 (11 and 20 nm), Al2O3, Fe2O3, ZnO and combination of 5 types of nanoparticles (2, 4, 6, 8 wt. %).Solidification phase change temperature changes with addition of nanoparticles. However, there are no specific trend for all types of nanoparticles. At 2 wt. % of all tested nanoparticles, the temperature different (onset and end set temperatures) are lower than base PCM.

3. PROBLEM FORMULATION

From the previous studies by the researchers there are various factors that can affect thermal conductivity of nano-enhanced PCM such as particles concentration, particles dispersion, particle size, shape and type, surfactant and temperature.

Thermal conductivity of PCM added with highly thermal conductive nanoparticles does not guarantee greater than similar PCM added with lower thermal conductive nanoparticles. Factor such as particles homogenous distribution in PCM should also be taken into consideration.

4. CONCLUSION

This review has focused on recent developments on TES using PCMs, in which latent heat is exploited. The PCMs with higher thermal storage density lead to reduction of storage tank size/volume, in addition to a range of flexible operating temperatures. However, large-scale commercial application of latent heat PCMs is still limited and the durability is lower than that of sensible heat materials.

Many of the recent publications are directed at solving problems related to improving performance stability, reducing super cooling and lowering cost towards thermal storage applications in power plants. The selection of organic, inorganic and EPCMs is based on kinetic, thermodynamic properties and availability along with their melting point, latent heat, energy density, and thermal conductivity characteristics as well as cost. Even though inorganic materials show high energy density, high thermal conductivity, and relatively higher melting temperatures, they are more corrosive and exhibit super cooling.

This review also brought out various commercial applications of PCMs and the most promising is towards smart thermal grid system along with intermittent renewable energy sources. Towards enhancing the PCMs properties, specifically encapsulation and nanomaterial additives are the two most prominent approaches in increasing surface area, protecting from the environment, increasing the compatibility with storage materials and reducing corrosion. In particular, nanomaterials are being used for increasing the specific heat and thermal conductivity of the PCMs.

Various properties of the PCMs are also compared from recent literature with very specific applications. The patents on PCMs reviewed towards the end throws light on the developments in the application areas for TES. It is interesting to note that the material costs can be about $15 per kWh with combined sensible/latent heat TES systems.

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