Improvement in
Medium with Nanostructured Materials

Abstract: Thermal energy storage (TES), which refers to the storage of low or high temperatures of thermal energy, has various applications from low to high temperature range. In solar energy applications, thermal energy is stored for to obtaining constant continuous power and to derive energy when during non-available solar hoursenergy is not available. This article deals thoroughly analyses the literature to find the methods to increase with the enhancement in the thermal conductivity and the existing rate of charging and discharging of the nano structured TES materials and phase change materials (PCM) in specific. The main disadvantage of PCM is its low thermal conductivity. To overcome this problem, nanostructured particles were have been used by many models to enhance the thermal properties of PCM. The improvement in the thermal storage characteristics of the latent heat storage materials using nano structured materials is being studied for over two decades. PCM's embedded with different nano structured materials haved shown change in their its thermal and physical properties. It has been reported by dDifferent research groups have reported that the thermal conductivity enhancement of the PCM depends to a large extent on the nanoparticle concentration, particle size, shape and temperature. In this chapterarticle, the thermal characteristics of PCM with single nanoparticles, PCM with hybrid nanoparticles and eEutectic PCM with nanoparticles were chosen for comparison. PCM with single nanoparticles were found to execute better performance in thermal conductivity compared to other configurations. PCM with single nanoparticles of aAlumina dispersed in paraffin wax and Al_2O_3-water nanofluid showed better performance in the melting and freezing performance compared to PCM with hybrid nanoparticles and eutectic PCM with nanoparticles.

Keywords: *Nanoparticles, Thermal eEnergy sStorage, TES, charging and discharging, thermal conductivity, phase change material*

1. INTRODUCTION

Thermal Energy Storage (TES) system plays a vital role in meeting the demand of energy for utilization. The availability of solar energy is not a constant source of energy reaching the earth which is affected by dust, clouds with non-availability during nightsand time of the day. For the continuous availability and efficient use of solar energy, the energy could be stored. In such cases, tThe TES system provides energy by recovery of heat and considerably contributes to the performance of the system. TES system uses different mediums to store the energy in the thermal form (charging mode) and releases the stored thermal energy (discharging mode) to compensate the shortage or meet the peak demand from the main thermal source as illustrated in Fig. 1 [1].

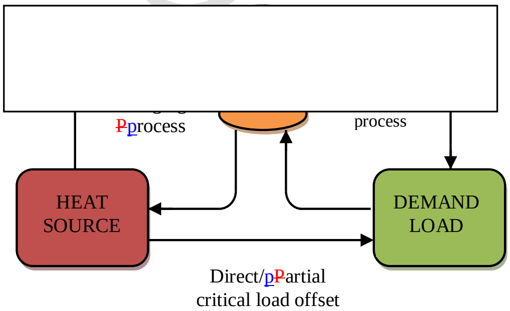

Figure 1- Schematic diagram of Thermal Eenergy sStorage system working [1]

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Abedin and Roser [2] explained TES as a propelled innovation for putting away global warming and reduce that can alleviate natural effects calamities and encourage more productive and clean energy systems. In this context, many countries are encourageing installation of renewable based power projects to meet the ever increasing energy demand. Although Ddevelopment of TES systems began a couple of decades ago, we are and still in the process of creating the most efficient systems are being evolved to meet various the thermal demands in an economic mannereconomically. TES systems can store more energy within a limited space and are designed with using different technologies that are collectively used to accommodate a wide range of needs. TES systems are have been effectively been implemented in collecting solar energy to and storinge excess thermal energy collected for hours, days or even many months. Later, tThe heat load from TES can deliver energy to individual building, multiuser building, for individual building, town, district or even large scale regional energy requirements. As an example, Thus, TES can stabilize the energy demand between the day and the night time. The heat energy from solar collectors obtained during summer can be stored

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inter-seasonally and used in winter;~~,~~ similarly, cold winter air can provide cooling effect during summer [3].

~~The~~ TES systems are classified into three types:

• Sensible heat TES

• Latent heat TES

• Chemical (sorption and thermochemical) TES

Latent heat includes a change of phase of a substance from one state to another at an altered temperature. Usually in TES frameworks~~s~~, energy storage or release ~~happen~~ occur during the phase changes (~~e.g~~i.e., dissolving, dissipating and crystalliz~~ation~~ing). Because of energy content in the medium, high enthalpy change ~~is added~~occurs with the state change, while the latent TES is generally pre~~f~~fer~~r~~ed than the sensible TES for a given energy demand load.

The chemical TES classification involves sorption and thermochemical processes in which reactions of dissociation and chemically reverse reactions of the storage medium occur~~s~~. In thermochemical energy storage, the storage density is higher in compar~~ed~~ison to other types of TES; hence, ~~enormous~~ large amount of energy can be stored using small amount of storage medium. Sorption systems undergo adsorption and absorption chemical processes by the absorptive material (liquid or gas) over the absorbent material (solid or liquid) [2].

TES are designed to store energy when the production exceeds demand and to generate excess energy available on demand. They help to match the energy supply and demand, ~~the variable production of~~ act as a source of renewable energy ~~sources~~ (~~e.g~~i.e., the wind and solar), improv~~inge~~e the overall efficiency of the system and reduc~~inge~~e CO_2 emissions. TES system ~~can be~~ are characterized by the following properties [4]:

● Capacity: ~~it defines~~ the amount of energy stored in a system and depends ~~up~~on storage process, size and medium.~~;~~

● Power: ~~defines~~ the rate or speed at which the energy is charged (or discharged).~~;~~

In sensible heat TES, heat (or energy) is stored/discharged by heating/cooling the fluid without phase change in association with a heat exchanger. The measure of energy input to a TES in a sensible heating framework is identified with the mass and specific heat capacity of storage material, its discharge limit and the difference in temperature of the storage medium between its initial and final states.

● Efficiency: ~~defined as~~ the ratio of the energy provided to the user according to the amount of energy needed to charge the storage system. It accounts for the energy loss during the storage period and the charging/discharging cycle.

● Storage period: ~~it is~~ the time duration in which~~of~~ the energy is stored, ~~and~~ last~~ings~~ from hours to months.

● Charging and discharging time: ~~it is~~ the amount of time ~~which is~~ needed to charge or discharge a system.~~;~~

● Cost: refers to cost involved in maintaining either the capacity (₹/kWh) or the power (₹/kW) of the storage system. It depends on the operational and capital costs of the storage equipment and its lifetime (the number of cycles).

Nanotechnology is an emerging ~~trend of~~ science ~~where~~ that investigat~~ion~~es ~~are made on~~ matter or materials at the nanoscale level for various applications [5]. The applications of the phase change materials (PCM) in latent TES system are~~is~~ shown in ~~the~~ Fig. 2 [5].

Khodadadi and Hosseinizadeh [6] studied the functionality of PCM by the dispersion of nanoparticles. They concluded that the addition of nano enhanced phase change materials (NEPCM) improves the thermal conductivity of the PCM. The suspension of the nanoparticles in~~to~~ the conventional PCM such as water~~,~~ shows that the NEPCM has real potential in TES applications. The heat release rate and higher thermal conductivity of the NEPCM w~~ere~~as found to be better than the conventional PCM. NEPCM promises ~~for~~ a better utilization in various energy sectors.

~~In t~~The present article~~,~~ presents a detailed summary ~~on use~~ of nanotechnology use in TES medium and their applications ~~is~~are reported.

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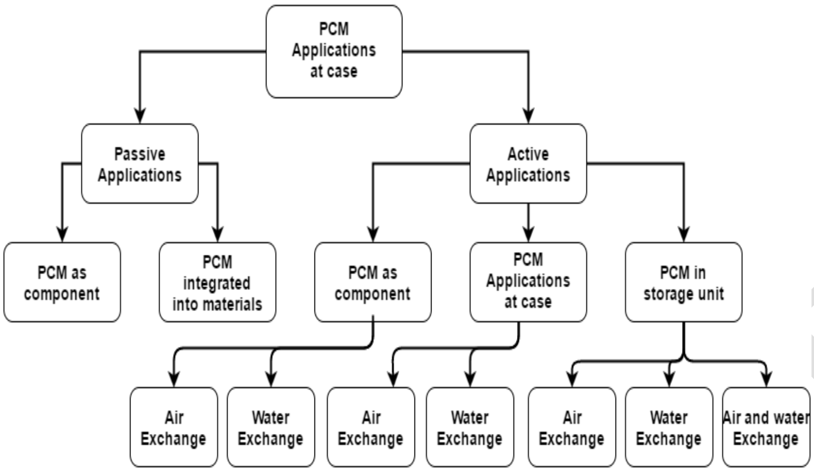

Figure 2- PCM applications in latent thermal energy storage [4].

2. THERMAL CONDUCTIVITY STUDIES ON PCM WITH NANOSTRUCTURED MATERIALS

2.1 PCM with ~~S~~single ~~N~~nanostructured particle

The influence of various thermal parameters on thermal conductivity of the PCM by the dispersion of nanostructured materials present in the PCM ~~wasere~~ has been studied ~~undertaken~~ by various researchers ~~for enhancement of thermal conductivity of the phase change materials by the dispersion of nanostructured materials in the PCM material was observed~~. The enhancement in the thermal conductivities of the various nanostructured materials dispersed into various PCMs is presented in Table 1.

Studies conducted on NEPCM show that certain nanoparticles execute higher thermal conductivity when dispersed in a specific PCM ~~material~~. From Table 1, it was observed that an improvement in thermal conductivity with 1.0% by weight multi-walled carbon nanotube (MWNT) dispersed in Palmitic acid shows 51.6% improvement in comparison to c~~C~~arbon nanotubes (CNT) [16].

Graphite nanoparticles when dispersed in paraffin wax showed relatively higher thermal conductivity compared to CNT [15-18]. ~~-~~The studies undertaken with other mixtures of nanoparticles and PCM are shown in Table 1 [6-20].

Table 1-Thermal properties of PCM with n~~N~~anostructured materials

Author	Type of nanoparticle and dimension	PCM	Method of characterization	Enhancement properties
Motahar et al.~~,~~ ~~2014~~ [6]	Mesoporous silica (MPSiO$_2$), 300nm	n-octadecane	Transient plane source (TPS) technique	6% for 5wt% in liquid phase and 5% for 3wt% in solid phase
Yu et al.~~, 2014~~ [7]	Carbon nanoparticles (xGnP and CNT)~~-~~, size < 10nm	organic fatty acid ester PCM	Differential scanning calorimeter (DSC)	1.0, 3.0, and 5.0 wt% increased by 78%, 297%, and 336%
Zeng et al.~~, 2009~~ [8]	Multi-~~-~~walled carbon nanotubes~~-~~, 5-30nm	Palmitic acid (PA)	DSC	26% improvement by increasing 5% MWCNT in solid and liquid phase~~.~~
Yavari et al.~~, 2011~~ [9]	Graphene	1-octadecanol (stearyl alcohol)	NA	4wt% increased 140% in solid and liquid phase~~.~~

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Wang et al.~~, 2010~~ [10]	Carbon nanotubes (CNT), dia- 30nm	Palmitic acid	Transient ~~S~~short ~~-~~ hot~~-~~wire method	46% at solid state and 38% in liquid state~~.~~
Wang.,~~ 2010~~ [11]	Al_2O_3, 20nm	Paraffin wax	DSC	5wt% increases 12%% in solid state
Fan and Kodadadi~~.,~~ ~~2012~~ [12]	CuO	Cyclo hexane based NE~~e~~PCM	TPS~~ransient plane source~~ technique	5.2% increase for 2wt% in solid phase
Elgafy ~~et al.,~~ and Lafdi ~~2005~~ [13]	Carbon nanofibres, 100nm	Paraffin wax	DSC	36% increase for 4wt% at room temperature
Liu et al.~~, 2009~~ [14]	TiO_2, 20nm	$BaCl_2$ solution	Transient hot~~-~~wire method	15.65% increase with 1.13% volume fraction
Kim and Drzal ~~et al., 2009~~ [15]	Graphite nanoplatelets, <10nm	Paraffin	DSC	207% increase with 7wt% of nanoparticle
Wang et al.~~, 2010~~ [16]	MWCNT, 30nm	Palmitic acid	Transient short hot -wire method	51.6% for the addition of 1% MWCNT
Xiang ~~et al.,~~ and Drzal ~~2011~~ [17]	Graphite nanoplatelets, 10nm	Paraffin wax	Unitherm™ model 2022	2.5W/mk for 0.05% volume fraction
Cui et al.~~, 2011~~ [18]	CNT and CNF, 200nm for CNF and 30nm CNT	Paraffin wax and soy wax	KD2 PRO, Decagon devices	10wt% of CNT/soy wax and CNF/soy wax is 0.403 and 0.469 W/mk. 10wt%. CNT/paraffin and CNF/ paraffin is and 0.450W/mk
Zeng et al.~~, 2010~~ [19]	Ag nanowires	1-Tetradecanol	Hot d~~D~~isc thermal constant analyzer	63.7wt% increased the thermal conductivity to 1.46W/mk
Zeng et al.~~, 2008~~ [20]	MWNT, 10-30nm	Polyaniline (PANI)/ tetradecanol	Hot ~~D~~disc thermal constant analyzer	30% enhancement for 0.1g MWNT~~.~~

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2.2 PCM with h~~H~~ybrid ~~N~~nanostructured particle

~~Studies for improving~~ TES capacity was improved by enhancing thermal conductivity ~~were taken~~ and by dispersing hybrid nanoparticles in PCM. The hybrid nanoparticle is a combination of two different types of nanoparticles, or a mixture of two different nanoparticles (composite), i.e., ~~– that is~~ dispersed in a PCM. PCM with~~t~~ the addition of hybrid or composite nanoparticles has attracted the ~~imterest~~interest of several researchers. The studies conducted upon the thermal conductivities of hybrid nanoparticles show that PMMA and SiO_2 when dispersed in paraffin show greater thermal conductivity than the other hybrid mixtures such as SiO_2-Al_2O_3, CuO~~–~~-TiO_2 and Halloysite clay nanotubes (HNT). This led to ~~An improvement of about~~ 57.4% improvement in the thermal conductivity of the PCM with hybrid nanoparticles ~~was observed compared~~ in comparison to that of PCM with PMMA [25].

Harikrishnan et al. [26] ~~performed experiment with~~ investigated CuO~~–~~-TiO_2 composite nanomaterials for TES. The thermal conductivity and thermal storage properties ~~are~~ were found to be better with ~~copper oxide~~ CuO than ~~whereas~~ TiO_2 ~~showed the least improvement~~. However, to conclude on the efficacy of the PCM ~~To evolve at a concrete conclusion~~ further studies ~~has to be undertaken as~~ are needed to find out if ~~know which PCM could show better enhancement i.e.,~~ PCM ~~either~~ added with single nanoparticle would be better than ~~or~~ PCM with hybrid nanoparticles.

The studies conducted by various research groups to determine thermal conductivity of PCM with hybrid nanoparticles is listed in Table 2.

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