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Recent Development in Phase Change Material (PCM) in Energy Storage Applications

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Abstract

To overcome increased demand–supply of energies gap because of fast urbanizations, consumerisms and decrease of fossil fuel resource, labor productivities, there is a need for technological developments with renewable energies source. Phase change material most proper material for efficient use of thermal energies from renewable energy resources. This appraisal focuses on applying for different phase change material depending on thermo physical property. Particularly, melting points, thermal energies storage densities and thermal conductivities of inorganic organics, and eutectic phases changing material are most selective basis for different thermal energies storing application with wide temperatures ranges operation. The uses of varying types of storage systems using phase changes material (PCM) is an efficient way of storing of energy and it has advantage of cooling and heating system install to maintain temperature within well-being zones. The detailed different Phase Change Material, their property and characteristic are analyzed. In sensible heat storages (SHS), thermal energies are stored by increasing temperatures of liquid or solids. The SHS system use heat capacities and changes in temperatures of materials during charging/ discharging processes. Latent heat storage (LHS) are dependent on heat absorptions or releases when storage materials undergo phase change from liquid to gas or solid to liquid vice versa. Property like Thermal property, Physical property, and Chemical property are vital for designing of thermal energy storages by use of PCM. PCM are highly used in different storage system for heat pump, solar engineering, and thermal controls during past decades. There are larger numbers of PCM, which melts and solidifies at wider temperature range, to make them attractive in applications. This review Sketch investigations and analyze Phase Change material use in various fields.

Key words: Energy storage, Phase change material (PCM), Sensible heat storages (SHS), Latent heat storage (LHS), Renewable energy resources

1. Introduction

Energies are the key requisites for bringing technical advancements and economic developments for progressions of society worldwide [**1**]. The unrelenting depletions of non-renewable resource and increasing scenarios of global warming compel trends for shifting uses of sustainable energies resource **[2, 3].** It is imperative for exploring sustainable resource for meeting both thermal and energy conversions and storage requirements. The decarburizations of energies sectors can make possible by integrating renewable energies resource with different renewable energy sources are undeniable favor over non-renewable resource exploiting because of its longer-term availability, accessibilities and environment benign [**4**]. There is more emphasis in correct measures taken by overcoming global warming and integrating renewable into energy systems, along with pathways of energy storages are active field of current researchers. The material for latent heat thermal energies storages (LHTE) are termed as Phase Change Material (PCM). PCM are material groups that have intrinsic capabilities of releasing or absorbing heat during phase transitions cycle, which result in charging and discharging. PCM can be inorganic, organic, or eutectics mixtures, different PCM are highly discussed in late section. The exothermic and endothermic phase transitions of PCM can utilize efficiently by incorporation to the TES system and thermal load can be controlled by operating parameters of system. There is different issue like lower thermal conductivities, poor thermal stabilities, high flame abilities, supercooling, corrosiveness, pressure and volume during phase transformations and leaking of molten PCM to surroundings of TES systems, limiting commercial viabilities of PCM research focus extremely on enhancing the physical property of PCM towards commercialization. [**5, 6**].

Different heating/cooling strategy and performance improving technique are done for effectively using wider ranges of PCM in TES systems, based on processes constraint. Different method for overcoming concern includes additives for improving thermal conductivities and eliminates super cooling. Energies are stored in thermochemical heat storages because of dissociation reaction which is recovered in chemical reversible reactions and its thermal cycles have charging, storing and discharging. The heat amount in thermo chemical energies storages have solid-gas phases depend on the gas pressure, where heat transfer coefficients observed by Kuwata et al. is far more in liquid- solid system in comparison to gas-solid system **[7].**Energy storages in sustained manner is capture of energy at one time for use at later ties, a device that store energies are termed as accumulators. Energy come in multiple fume which include chemical, radiation, gravitational potentials, electricity's, elevated temperatures latent heats. The energy storage principle in PCM is shown in Figure 1.

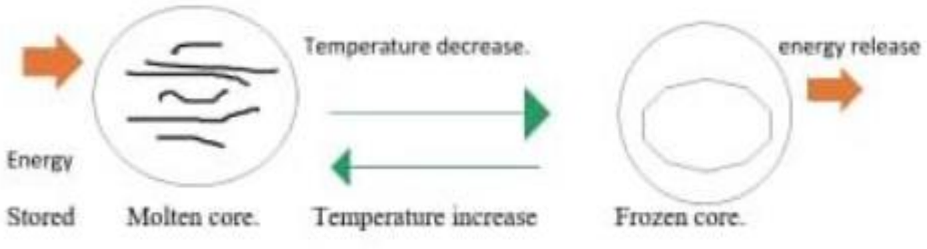

Figure 1: Representation of energy storing principle in PCM.

Energy storages involve conversion of energies from forms that are difficult for storing conventional, economical storage form from small to massives. There are different types of storage systems by phase change material which is an efficient way of storing energies and also for making advantage of heating and cooling system are installed for keeping temperatures in well-being zones. PCM is extremely used in different storage system. For heat pump solar engineering and thermal control application.

Thermal energies are stored by increasing temperatures of solids or liquids. The SHS systems use heat capacities and changes in temperatures of materials during procedures of charging and discharging. The amounts of stored thermal energies depend on special heat of medium, temperatures alter and amounts of storage materials. LHS systems are settled on heat absorptions or releases, when heat provides to systems. When material access some levels of temperature's additional heat energies are stored in systems without any alterations in temperature's, then stored energies in material experiences phase changes from solid to gas or vice versa. It is termed as latent heat storage systems. Energy Storages system, energies are distributed while breakages or reforming molecular bond in fully reversed chemical reactions. In these cases, storages of heat depend on quantities of chemical materials and endothermic heat of reactions **[8].**

2. Heat Transfer Enhancement Methods

Heat transfer improvement techniques are needed for different latent heat thermal energy storage systems; different method is proposed to increase heat passing in latent heat thermal energy storage systems, like Metallic filler, metal matrix constructions, and finned tube use for increasing thermal conductivities of phase change material. Recent improvements techniques are listed below:

1. *Active method of agitator, vibrator, scraper and Clays.*
2. *Microencapsulated PCMs.*
3. *PCMs contain separate higher conductivity particle, Lessing rings.*
4. *PCMs assort with graphite composites materials.*

Energy Storage systems, the energy is occupied and distributed while breakages or reforming molecular bond in fully reversed chemical reactions. In these cases, storages of heat depend on quantities of chemical materials and endothermic heat of reactions. The capital costs for TES is relatively low (70–200 per kilowatt-hour) against electrochemical storage In short, although areas of PCM have nurture in past decades, still different aspect need improvements through researches and developments for optimizations of PCM technologies and advanced this technologies to be in forefront of energy storage. In this work, different PCMs characterization for varying energy storages applications are analyzed depending on current literatures on classifications, selection principles, applications, future trend and advancement in fields of PCMs technologies for TES. Different option of TES for integrating to energy system comprise of renewable energy resources like wind, solar, geothermal, hydro or even with non-renewable resource as in cases of waste heat recoveries exists **[9].**

3. Physical Method of Thermal Energy Storage

In physical TES, heat transfers mechanism leads to storages of heat energies and capabilities for retaining heat depending on thermo physical property of particular materials. Latent heat storages (LHS) and sensible heat storages (SHS) are divided under physical storages. In SHS case, thermal energies are stored as internal energies induce by gain in temperatures of some materials by transfers of heat through conductions, convections or radiations, while LHS involve accumulations of heat at molecular levels in material lead to phase transformations. The amounts of heat in SHS depend on masses, heat capacities of storage materials and temperature's gradient between initial and final State. The SHS can be solid or liquid storage media .Metal like aluminum, copper, cast irons of TES systems consisting of metal are the main obstacles in commercialization .Metal and graphite have higher thermal diffusivity and are thus applicable fast charging and discharging, white rocks, gravels, and stones having lower thermal diffusivities and are better for application in slow charging and discharging cycle. Liquid storages media for SHS includes molten salt, Waters, thermal oil like Calorie HT43 and other available product but lower energies storages densities and thermal conductivities restrict broad spectrum applications of these TES types. The highest specific heat capacities of water make it 1 of promising candidate for SHSs for temperature below 1000Celsious **[10, 11].**

4. Application and Commercial Viabilities

PCM have different application for active and passive heating/cooling as components or integrate parts of Cascades TES system. PCM are applied on system requirement basis as mentioned in selection criteria. Different applications of PCM, that is currently in research and development stages, including smart thermal grids, compact TES system, and CSP plant. The concepts of incorporation of PCM in smart thermal grid systems are firstly instigate by application with larger thermal inertias integrating inconsistent supply of renewable resource needing heat to be stored and supplied as per demands additionally, TES system ideas are attributed basically to ability of PCM for storing higher amounts of heat per cubic meters compared to conventional technology promoting compactness of systems PCM integration to CSP application are also dependent on same concepts with emphasize on performances, costs, and reliabilities. The PCM use in CSP technologies can reduce needed volume of storage tanks to most extents, which leads to reduced costs of material and constructions for systems **[12, 13].** .PCM can be applied in buildings energy storages system waste heat recovering systems, thermo-regulating fiber, smart textile material thermal managements of battery temperature managements of microelectronic photovoltaic thermal (PV/T) application spaces and terrestrial thermal energies storage application and in temperatures managements of greenhouse [**14,15].**

5. Energy Storage in Concentrating Solar Power System

LHS by use of PCM are common storage means of thermal energies in CSP system Different PCMs are investigated for application of TES in CSP system, mainly organic compound (sugar alcohol < 200°C), melted salt (>300°C) and metal alloy(>500°C). Melted-salt dependent PCM are of lower costs and have higher heat-storage densities, anyhow main disadvantage is corrosions of container, pipe, and valve. Vapour pressures, temperature and structure property of molted-salt and metal alloy dependent PCM are analyzed at National Renewable Energy's Laboratories (Golden, CO, USA). Temperature property of $MgCl2$-$NaCl$ –KCl (59.98–19.60 –20.42wt %) ternary melt-salts compounds were analyzed by DSC/TGAs uses from 120 - 450 °C during 3 heating and cooling cycles. The average melting point was 380°C and average heat of fusions was 198.55 Kj/kg. Laing et al. analysed designs of higher-temperatures LHTES system for CSP application and report that graphite or aluminum fin in designs of TES systems prove to be cost-effective. These researcher at DLR-German Aerospace Centers also introduce this sandwiches concepts of fin in LHTES for CSP application and report that no degradations was seen after 172cycle in $NaNO_3$ based PCM having melting points of 306°C. Galione et al. use multi-layered solid PCMs (MLSPCM) .Phase change method within 3 stages PCM units and single PCM units are found for varying thermo-physical property. The 3-stage PCM units show fast charging, and high heat transfers rates and overall work efficiencies than single-PCMs for charging-discharging in similar work conditions. Tank size of multiple-layer configurations is small than single configurations for common energy outputs, which decrease associated costs. Multi layered configurations are common for CSP plants and detailed economic study needing for analyzing the prospect of integrating multiple-layer TES configurations in CSP plant.[**16**].

6. Passive thermal managements in battery

Demands for rechargeable batteries, especially for lithium-ion battery (LIBs) grow fastly because of their higher energy density for portable electronic, battery power tools, and electric vehicles. The main barrier in use of these battery for larger fleets of vehicle on public road are safety, cost based on cycles and calendar lives, and performances [17]. These challenges are coupled with thermal effect in battery. For good battery packs, the rates of heat dissipations must be rapid so battery packs never reach thermal runaway temperature [**18**]. Anyhow, large power demand and incrementing energetic densities of lithium-ion batteries pack results in high operating temperature **[19].** Most commercial LIB chemistry degrades or ages at or more of 60°C, which lead for fast losses of capacities over charges/discharges cycle and reduce total power outputs. To address these concerns, some study in active and passive thermal managements system for batteries undertake different application that uses LIB. Thermal management systems rely on transfers of heat away from cell surfaces, thus inhibiting core temperatures rises and limit materials degradations. PCMs are mostly used for efficiently mitigating larger temperatures escalations during discharging and charging, thus relieving performances degradations over life of batteries and incrementing safeties of battery systems. Passive thermal managements by use of PCM for LIB in all-electric vehicle (EV) and hybrid electric vehicle (HEV) are analyzed by Said et al. and Samimi et al. They Investigated carbon fibers-PCMs composite for thermal managements of Li-ion cell. The improved thermal conductivity of material result in effective temperature management of Li-ion batteries packs. Passive thermal managements of battery for application are currently working, for carrying friendly battery sizes, safety, and dependent device weights are most vital constraint and need furthermore research **[20, 21].**

7. Thermal Storages in Building

TES using PCM for spaces heating and cooling of buildings has become popular because of the costs of fossil fuel and environmental concern. In extreme cold or hot areas, electrical energies consumptions change partly because of varying demands for domestics cooling/heating. PCM in active storage systems are capable of decreasing the variation and are studied widely. Mahkamov analyzes research and development for passive thermal controls in building by use of PCM and provide thermal characteristic of available commercial PCMs dependent products for building application **[22].** Zhenjun et al. analyzed nano-improved PCM for temperature management in building, a PCMs ceiling ventilations systems linked with solar PVTs were found and 25 % more heat was discharged in buildings. Yin et al. Proposed solar roofing systems of PV module linked with TES assemblies depending on PCMs, PCMS to have applications in thermal managements of building thus reduce energy demands in building [**23, 24**].

The major development about PCM undoubtedly directed to lower-temperature application like district heating/cooling and drying process. Higher-temperatures application like TES in solar thermal powers or industrial process heat sectors are not much developed. So, most recent development focused on CSP thermal storage and other higher temperatures storages system **[25].** Anyhow, detailed investigations are needed for other application for higher-temperatures TES that can improve thermal property and suppress supercooling characteristic of PCM. PCM have higher latent heats during phase transformations, but lower conductivities can affect chargings-dischargings/charging energies rate. Consequently, it is important to have higher thermal conductivities for getting faster thermal charging and discharging during phase transformation. Once PCM reach its freezing temperatures it remains liquid and on reaching temperatures below melting points, the solidification processes are initiated. This condition is termed as supercooling and can limits usage of PCM on applications. In consequences, decreases in temperatures below phase changing temperatures that trigger crystallizations are sought for releasing latent heats, which release only after crystallizations. These conditions are not desired in energy storing applications. Researches are going on to overcome these limitations which could enhance the usage of PCMs in near future with greater potential. Encapsulations of PCMs are one of the methods for overcoming some problems of PCMs.

This includes lower conductivities, thermal instabilities and supercoolings, which lead to decreases in rates. Encapsulations are process where particles are enclosed by coating materials or embedded in matrix (either homogeneous or heterogeneous) in order for capsule formation **[26].**

8. Conclusion

This review focuses on recent developments on TES by PCM, in which latent heat is made used. The PCM with high thermal storage densities leads to reductions of storage tanks sizes/Volumes, additionally to flexible operating temperature ranges. Anyhow, do many large-scale applications of latent heat PCM are still limited and durabilities are less than sensible heat material. Many recent publications are pointing out new solutions related to improved performances stabilities, reduced super cooling and reducing costs towards thermal storing application in power plant. This study analyzes different commercial application of PCM and most promising are towards smart thermal grids systems along with renewable energy source for improving PCM property specially encapsulations and additive of nano-material are 2 most prominent approach in increased surface areas, protecting from environments, increasing compatibilities with storage material and decreasing corrosions. Particularly nano-material is used for increment in specific heats and thermal conductivities of PCMs. The improved PCMs discussed towards end throw light on development in application area for TES.

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