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State of The Art : Phase Change Material as Means of Thermal Energy Storage

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ABSTRACT

With the rapid increase in energy demand, focusing on renewable sources of energy have been increased rapidly. As fossil fuels are created in hundreds of years and will be exploited soon, if other sources of energy are not employed then the world may enter in dark age .So there is a paradigm shift in searches for sources of energy from non-renewable to renewable sources. Solar energy, Wind energy, Hydro energy, Tidal energy, Geothermal energy, Biomass energy are getting the attention of the entire scientific community being renewable sources of energy. There are different materials which are used to store thermal energy. Phase Change Material has proved its significant role in thermal energy storage. This article provides a comprehensive view of Phase change material, it's working principle, it's types and application in different fields. As such, this paper summarizes the investigations made on the recent researches in the field of phase change material for thermal energy storage. This paper will benefit the researcher in conducting further research on thermal energy storage.

Keywords : Phase Change Material, Thermal Energy Storage, Latent Heat, Renewable And Sustainable Energy.

I. INTRODUCTION

These days Countries are facing energy demand and supply mismatch due to the rapid growth of population, modernization and increased industrial dependence. Thus a lot of new fields have emerged in the last few decades for meeting the energy demands of the world .Renewable sources are getting more attention and researchers are searching new ,effective and economic ways to generate, store and distribute the electricity, although all these are still in an infancy. According to the International Energy Agency IEA 2019, coal contributed 45%, petroleum and other liquid contributed 26%, traditional biomass and waste contributed about 20% in India's total energy consumption. Primary energy consumption reached 916 million tonnes of oil equivalent by 2018.[1] Renewable sources have contributed little in primary energy consumption of India.[2] India's crude oil imports reached a new hike in the current scenario. India's dry natural gas production remained flat at about 1.1 trillion cubic feet (Tcf) between 2015 and 2019. [3] Such figures force the scientific community to search for new ways for generating and storing thermal energy to fulfil the needs of people.[4] Thus it is found that Energy storage is a

very appealing field to study as excess energy stored properly can be used for future purposes . So countries worldwide increased their focus on alternative sources of energy. Direct sun radiation has been considered as a prospective source of energy .To overcome the mismatch between energy generation and utilisation, thermal energy storage (TES) has emerged as a powerful energy storage concept. For thermal energy storage, Phases Change Materials (PCM) are very useful as it's working is based on the latent heat concept.[5] For example ,when 0^0C of ice changes its phase and converts into water of 0^0C , it stores latent heat which can be released later during solidification process. Thus latent heat stored or released during phase change could be a great source of thermal energy storage. Phase Change Materials like paraffin, salt hydrates and fatty acids and eutectics of organic and non-organic compounds have been widely studied in order to minimize the greenhouse effect and to minimize dependence of the country on foreign oil imports which costs the economy millions of rupees every year.

II. THERMAL ENERGY STORAGE (TES)

Thermal energy storage are used to hold thermal energy for a certain period of time (in the form of heat or cold) in a suitable media and suitable form when it is surplus, and extracting the same at a later time when needed .[6]

Different modes of heat transfer used for storing thermal energy-

Temperature profile of phase change material (PCM) can be divided into different regions like the sensible heat, the latent heat and the thermo chemical energy. [7] These regions of temperature profile represent the mode of heat transfer for storing thermal energy. In The region of latent heat, the temperature remains constant while changing the phase of material. In this region the phase change is influenced by intermolecular forces while in the sensible region translational, rotational and irrational motions of the atoms and molecules plays a vital role. The energy stored in the chemical bonds between atoms is responsible for the thermo chemical component. (Source: Said Al-Hallaj & Riza Kizilel)

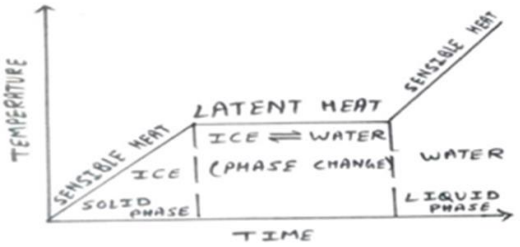

Figure 1-Temperature Profile of a PCM. [8]

Advantages of thermal energy storage (TES) are as follows

- TES helps to achieve a better and efficient use of energy.
- TES reduces greenhouse gas emission and lower pollution. Thus it helps in preserving the environment.
- TES improves system performance and reliability .Thus leads to sustainable energy storage.
- TES reduces the capital and Operational cost so TES are economical in Nature.

Phase Change Material (PCM)

Phase Change Material (PCM) are those materials which absorb or release large amounts of heat on melting or solidifying as it has the high latent heat of fusion. During the phase change process, heat conduction and heat convection takes place in PCM. Using proper heat transfer techniques in PCM, heat conduction can be increased and heat convection can be decreased. Potential of PCM can be realized in TES because of negligible temperature variations and

remarkable energy storage density.[**9**]PCM works as heat accumulating material. PCM stores heat in the form of latent heat of fusion which is about 100 times more than the sensible heat. For example, latent heat of fusion of water is about 334 kJ/kg whereas sensible heat at 25° Celsius (77°F) is about 4.18 kJ/kg. Two widely used PCMs are water and wax. Water requires a significant amount of energy when it changes from solid phase to liquid phase at 0°C (32°F) or Wax extends the burning time of a candle.

Working principle of PCM-

Phase change process of a PCM can be explained as follows (Source: Said Al-Hallaj & Riza Kizile) in the melting process PCM (Solid State) converted to PCM (Liquid State). Here energy is stored in PCM. It is also known as the charging process. In the freezing process PCM in Liquid State converts into PCM in Solid State. Here energy is released in process. So this process is known as discharging process. This cycle of the melting and solidification of phase change material can be repeated many times.[8]

Criteria for selection of the phase change material (PCM) as TES-

While designing a thermal storage system following criteria should meet:

1. PCM should have a suitable phase transition temperature
2. IT should have high heat conductivity
3. It should have high latent heat of transportation
4. The melting temperature should lie in the range of the operation
5. It should be chemically stable
6. It should be low in cost,
7. It should be non-corrosive
8. It should be nontoxic.[**8**]

Types of PCM

PCM may be classified on the basis of phase transition like solid-liquid, solid-gas, solid-solid, and liquid-gas. (Source: Said Al-Hallaj & Riza Kizilel)

1. Organics PCMs (e.g. Paraffin, Fatty Acids, PEG)

Merits-Available in a large temperature range, No super cooling, compatible with other materials, No separation, Chemically PCMs are stable, safe to use, Non-reactive in nature, recyclable

Limitations-Low thermal conductivity, Relative large volume changes, Flammable, Expensive except technical grade paraffin wax

2. Inorganic PCMs (e.g. salt hydrates, Nitrates, Metalics)

Merits-High volumetric latent heat, less expensive, easily available, Thermal conductivity is higher, Lower volumetric variation, Non- flammable

Limitations-Changed volume is remarkably high, Super cooling, Corrosiveness

3. Eutectics- Eutectics are homogenous mixture of two or more substances (organic / inorganic) in a specific proportion. Melting point of eutectic is generally lower than the melting point of individual components. Also it melts with no phase segregation which is the most important characteristics of eutectics. Example of eutectic are Mg-Zn eutectic metal alloy (P. Blanco-Rodriguez et.al, 2015), Mg-Zn-Al Eutectic alloy (E. Risueñoet.al, 2015), Al-Si Alloy (N. Gokon et.al 2015)

Merits-The melting points of eutectics are sharp. It possesses high volumetric storage density.

Limitations-Data on Thermo physical properties of eutectic are not available properly.

PCMs Composite-

Phase change materials are encapsulated in a polymer matrix to make composite. Composites are mainly employed in case of PCM with low melting temperature such as paraffin waxes. PCMs composite incorporate the structural functionality with Thermal energy storage. Sheo Peng and others studied the solid–liquid latent heat effect of the Polymeric phase change composites for thermal energy storage .Room temperature cured bisphenol-A epoxy and styrene–ethylene–butylene–styrene (SEBS) polymers are chosen as matrix materials because of their excellent chemical and mechanical properties.[10] Moussa Aadmi and others have used the Phase change materials based on epoxy resin paraffin wax with the melting point 27 °C as a new energy storage system.[11]

Heat transfer enhancement techniques for PCM-

Active heat transfer enhancement techniques and Passive heat transfer enhancement techniques.

When external power is supplied then the Heat transfer techniques are known as active heat transfer enhancement techniques while when external power is not supplied then the Heat transfer techniques are known as passive techniques .The passive techniques are more valuable than the active techniques because it can be easily employed in an existing heat exchanger.[12] This combination of techniques is referred to as hybrid heat transfer enhancement which can be used for improving PCM based system performance.

Properties of PCMs

a. Thermo physical Properties of PCMs are Latent heat, Suitable heat releasing temperature, Small or no sub cooling, High change of enthalpy at temperature of use, Effective heat releasing time, crystallite size, and Thermal stability during heating and cooling cycles. Phase change temperature useful for application
b. Chemical Properties of PCMs are Stability, Comparability of container Material, Non toxic, Non flammable, Non polluting, No phase separation
c. Economic Properties are Cheap and abundant

PCM Characterization –

The most widely used technique for determining thermo physical properties like - enthalpy, heat capacity, thermal conductivity, thermal diffusivity and density is Differential Scanning Calorimetry (DSC). According to the Japanese Industrial Standard, DSC is of two types-Heat Flux DSC and Power Compensation DSC.Temperature of the sample unit (made up by sample and reference material) is varied with the help of specific program and difference in temperature of sample and reference material is measured as a function of temperature in case of Heat Flux DSCs, while difference in thermal energy applied per unit time to. Sample and reference material is measured as a function of temperature in case of Power Compensation DSC. [13] Other useful techniques are Differential thermal analysis (DTA), Thermo gravimetric analysis (TGA),T-history

Application of PCM

Night Ventilation-Night ventilation (NV) is a productive passive cooling technique which demonstrates a high potential for reducing cooling loads and improving thermal comfort. PCMs can be used as efficient lightweight thermal energy storage for NV. [14]

Cooling System of buildings-PCM can be used in the cooling system of buildings. The cooling strategy of PCM is based on thermal balance concept that it absorbs heat energy at charging period and releases back at discharging period. [15]

Heat storage material-The PCMs used as storage media (for medium-high temperature solar applications as concentrated solar thermal power, CSP) are in general molten salts.

Solar Water Heater-Kulkarni and others found that solar water heater with PCM helps to reduce cooling rate of water, reduces tank size and cost also. Thus it leads to maximum utilization of solar energy.[16]

Helmets-Helmet cooling system using PCM can provide motorcycle riders a comfortable cooling experience. In 2006, Tana and Fok designed a helmet cooling system using PCM. In such a system the heat from the users' bodies is conducted to the PCM pouch which is in contact with users. As PCMs change phase at constant temperature employing latent heat, cooling comfort is provided to the user till PCM completely melts. Heat stored in PCM then discharged by immersing it in water, which again solidifies PCMs. [17]

Heating Pad- Heat packs are made of poly vinyl chloride (PVC), low density polyethylene (LDPE), high density polyethylene (HDPE) etc. packaging materials and contain aqueous solution of sodium acetate trihydrate PCM and metallic triggering device. Akanksha Mishra et.al. found that in these heat packs, PCM remains in a metastable supercooled liquid state, far below its solidification temperature. This property helps in storing the thermal energy as the latent heat of PCM, even at low ambient temperature (~0 °C) for very long time. [18]

Telecom Shelter-Being temperature sensitive Instruments in the telecom sector necessitates to be maintained below 35^0 C. PCMs help in this regard. Ramesh Rathod et. al. found that PCMs absorb heat in case of power shortage or black out thus maintaining the device temperature below 35^0C and get re-charged on availability of power source Thus, PCM store energy using a cheap source of power and release it when that cheap source of power is not available [19]

Memory Application- Cold storage-for improvement of thermal performance of cold storage PCM can be used. Studies shows that application of polyethylene glycol 400 (PEG 400) as a Phase change material (PCM) reduced the rise in the temperature of air inside the cold space in the situations like frequent door openings and electrical power failures.[20]

Hybrid Cooling System-It combines both passive (PCM) and active (fins and fans) cooling solutions. It can be used in telecom base station power amplifiers, where the power is proportional to the traffic load [21]

PCM-based heat sink –It can be used for cooling of mobile electronic devices like notebook, personal digital assistants (PDAs).[22]

Fighter Protective Clothing- Thermal protection of the multi-layered fabrics can be increased using PCM fabrics. The time to reach a second degree burn was largely reduced. [23]

Refrigerated Trucks-PCM can be used in lowering peak heat transfer rates and total heat flows into a refrigerated trailer. Ahmed et. al. worked on paraffin based PCM in the refrigerated truck trailer . They found an average reduction in peak heat transfer rate of 29.1 % for all walls and 11.3 - 43.8 % for individual walls have been observed.[24]

Room Cooling Application-Energy consumption of air conditioning systems can be reduced by using the phase change material (PCM) as thermal energy storage. Temperature difference between day and night is utilised in PCMs to store and release thermal energy. [25]

Boiler -PCM embedded heat exchanger (PCM-HEX) is used for recovering the waste heat from the exhaust

of a gas-fired combi-boiler to heat the domestic water is placed at the top of the combi-boiler and connected with the exhaust of flue gas. In the charging mode, PCM turns into liquid phase by storing thermal energy, while in discharging mode PCM turns into solid phase releasing energy when demand arises. . [26]

PCM textile-To improve athletes' performance, the textile industry is employing advanced manufacturing technology in sports wear by using PCM in fabrics. In this technology PCM microcapsules are incorporated in fabrics, and the property of PCM to change phase within a temperature range that is just above and just below human body temperature to store body heat and then release it when needed. [27][28]

Therapeutic Applications-Rohitash Kumar et .al experimentally demonstrate that addition of ethylene glycol (EG) in aqueous sodium acetate trihydrate (SAT) enhanced the softness of SAT crystallite, enhance the degree of supercooling and increase the heat releasing time by ~10%.EG-SAT composite phase change materials can be used in low ambient temperature to get rid of cold and for the therapeutic application as it has high thermal energy storage density and suitable heat releasing temperature.[29]

Commercial Status of PCMs as thermal energy storage

According to EPRI, thermal energy storage systems like Steam accumulator are in commercial stage, two tank direct and indirect thermal energy storage are in pre commercial proto type stage, while PCMs are still in developmental stage. (Source: EPRI, 2009) [30] Wide Spectrum of PCMs applications includes solar pumps, solar heater, solar cooker, thermal comfort in building, refrigerated trucks (freight at specific temperatures),hybrid vehicles using Li-ion batteries with PCM ,telecom sector, PCM based heat sinks for cooling electronics etc. But all these are not suitable for field applications.

Research Gaps in Literature Review & Future Research Directions

Despite profound contributions by research scholars and academicians in the use of PCM as solar thermal energy storage, still there are wide range of research gap, which has to be addressed in the future research Author proposed following research topics after rigorous literature Review: Anusuiah Vasu and others (2017) in their work studied the corrosion behaviour of PCMs, especially salt hydrates with container materials. Stainless steel has been found to be a more compatible material for making containers in TES than Aluminium. Condition is more serious in case of large scale solar power production. Research is required in the field of Anti corrosive compatible container Material that can be used with PCMs so that the potential of solar energy to harnessed completely .[31] For high temperature thermal energy storage, Attention of the scientific community must be drawn to draw out the utilities of PCMs Composite. Different composite PCMs must be analysed. With respect to their performance curve to know best Composite PCMs for thermal energy storage. Multifunctional storage units which work on both sensible and latent heat need to be developed. Other properties besides thermal properties like chemical, mechanical need to be addressed properly.

III.CONCLUSION

According to California Public Utilities Commission (CPUC, 2010) PCM can be used as storage media for storing the excess wind and off peak energy so that it can be used later when needed. Thus it can be concluded that Phase change materials need of hour .These materials have proved its efficiency in thermal energy storage. With proper utilisation of PCM ,industries can enjoy the advantage of day-night temperature difference .It has covered a vast area in the recent years due to its latent heat properties , large heat storage capacity and isothermal behaviour during the charging and discharging

processes. PCMs help in developing alternative renewable, reusable and cost effective heating sources .PCMs help in storing available thermal energy (solar energy, waste energy etc.) at high temperature, retain it at lower ambient temperature and release the latent heat later when needed. But it has low thermal conductivity which reduces its practicability. To enhance the commercial acceptability of TES applications employed with PCM, such systems should be made economical. So some additives are used with base fluid to increase the thermal conductivity of PCM. Such PCMs are now known as nano enhanced phase change material (NEPCM). Hence to harness the efficacy of PCMs , for any latent heat thermal storage (LHTS) applications, extensive research must be carried out in the field of Nanoparticles (NPs) inclusion in PCMs so that the world can be freed from energy mismatch and can moved towards a better and sustainable tomorrow. Thus it can be concluded that phase change material has started a new era in thermal energy storage.

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