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Phase change materials for energy conversion

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Abstract: Use of phase change materials (PCMs) currently is a very attractive and feasible technique for thermal energy conservation. Phase change material is a substance which has ability to store and release large amount of energy in the form of latent heat of fusion. These materials undergo solid-liquid phase transformation & vice versa at a particular temperature within the range of a selected thermal application. The amount of energy absorbed or released during the process of phase transformation is entirely dependent on the value of material's latent heat of fusion and the mass of material being used. The process of storing and releasing energy is transient phenomena. PCMs can be used for both energy conservation and thermal management but the major issue is the proper selection of PCM and the amount of PCM to be used for the particular application. The selected material should be stable both chemically and physically over repeated no. of thermal cycles, also it should be compatible with most of the materials, non-flammable, high latent heat of fusion, high thermal conductivity and high specific heat.

Keywords: NEPCM-Nano Enhanced Phase Change material, SSPCM-Shape Stabilized PCMs, BIPV-Building integrated photovoltaic panel, PCMW- PCM filled glass window, HTF-Heat Transfer Fluid.

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1. Introduction: Phase change materials (PCMs) are materials that undergo the solid-liquid phase transformation, which is commonly known as melting-solidification cycle, at a temperature within the operating range for a selected thermal application. As a material changes phase from a solid to a liquid, it absorbs energy from its surroundings remaining at a constant or nearly constant temperature. The energy either absorbed or released during the melting-solidification cycle is known as the latent heat of fusion [1]. The process of storing and releasing heat by PCM is a transient and mass-based process. The amount of energy absorbed or released during the process depends upon the value of material's latent heat of fusion, which is generally expressed as J/g or kJ/kg.

PCMs are used for both thermal management and thermal energy storage purpose. The method of conserving energy with PCM is very much essential and innovative way for thermal management of electronics, garments, medicine packaging etc. The efficient cooling offered by using PCM is also being used for energy storage in buildings, concentrating solar power plants, aircrafts etc. The need for PCM based technology has got a wide importance because it is environment friendly technique of thermal management of heat.

System which operates on high peak load generates a huge amount of heat which has to be dissipated through the heat sink incorporated with fan, which is not so efficient technique of cooling nowadays as it consumes a lot of power and also not efficient in dealing with the overheat problem, but with the use of PCM we can achieve that efficiency as it absorbs the heat during the peak load time until it melts completely. The absorbed heat is released after the completion of duty cycle and again it solidifies and gets ready to be used further. Here we are doing thermal management for preventing overheating of the system the stored energy was not used further, it was released to the atmosphere. While on the other hand when we are utilising PCM in solar power plants, where surplus energy is generated during the peak sunny day hours is stored by using PCM, which is further utilised during the time of decreased supply. Here we are utilising the stored energy inside the PCM. So we can use PCM for both thermal management and energy storage purpose.

2. Literature Review:

Osterman et al. [2] investigated how and where PCMs can be utilised in cooling systems how these systems are related to buildings. The study has shown that the use of PCM in building improves its energy performance but the main problem which they found was the rate of heat transfer and the mass of PCM to be stored. Elarga et al. [3] investigated the thermal performance of a roof space integrated with PCM. He applied three different solutions to a roof which was continuously monitored under hot climatic condition. The three different portions of the roof one without PCM while the other two integrating two PCMs. He founded that the PCM enhanced components are very efficient towards thermal performance for a roof space in the summer season. Kenfack and Bauer [4] developed a new PCM for efficient handling of thermal energy around 100 °C. On comparison with pure salt hydrate they found that the newly developed salt hydrate PYCO-PCM-1 is having high thermal stability and its storage capacity was found to be 83.33 kWh m^{-3} for the temperature range $\Delta T = 20$ K, they founded that expanded graphite was good and promising additive to improve the conductivity of PYCO-PCM-1.

Socaciu et al. [5] showed that how we can make an appropriate selection of PCM by using AHP method for using it in vehicles to maintain its thermal stability. To improve the quality of decision making in terms of selection of PCM they ranked 10 commercials by AHP method keeping in mind the technical specification of the materials. The method of evaluation by AHP method improves the quality of decision making. Efficiency of the system and reduces the chances of failure. Sahoo et al. [6] investigated to study the performance of nano-enhanced phase change material (NEPCM) based heat sink for thermal management of electronic components. This investigation was carried out with and without NEPCM and with and without fins and to find their effect in natural and forced convection. He concluded that for light weight electronic equipment NEPCM based heat sink without fin can be used because unnecessary addition of fins causes the electronic heavy and bulky. Wan-fan Wu et al. [7] studied the effect of Shape stabilized phase change materials on spacecraft Thermal control in extreme thermal environment. The result showed that by the use of Shape stabilized PCM prevents the failure of thermal control system of the spacecraft by absorbing the heat effectively when the spacecraft's outer heat flux changes. They also studied the effects of thermal conductivity on thermal control of spacecraft. Kim et al. [8] measured the thermal performance of a PCM sheet and established the melting- and solidification-temperature ranges at 19 – 26 ˚C. Three identical huts were examined using varying PCM levels under natural and heating conditions. In Hut A, no SSPCM sheets were applied; in Hut B, four layers of SSPCM sheets were applied to the floor; in Hut C, one layer of SSPCM was applied to the floor, walls, and ceilings. The results demonstrated that the application of SSPCM sheets improves thermal performance.

3. Types of PCMs:

3.1 Organic PCMs: Organic PCMs are the most well-known kind of PCM, which incorporate and extensive variety of PCM for example alkane family (C_nH_{2n}+2) and fatty acids family ($CH_3(CH_2)_{2n}COOH$). [1] The natural PCM are liberally accessible generally modest and simple to work with. The main advantage of using organic PCM is that it is well suited for thermal management of Electronics and building systems. Organic PCMs possess high latent heat of fusion which helps them to store huge amount of energy in small mass. Organic PCMs are usually stable physically and chemically both. Organics are good with an extensive variety of materials and do not act or corrode with casing materials. Common paraffins usually have latent heat of fusion in the range of 200-300 kJ/kg, while the fatty acids have latent heat of fusion in the range of 100-200 kJ/kg.

The only drawback besides using organic PCM is its low thermal conductivity which reduces its effectiveness in storing large amount of energy. Examples- Octadecane, Tricosane, Tetracosane, Heneicosane paraffins.

3.2 Inorganic PCMs: The group of inorganic PCMs incorporates the salt and salt hydrates. Common salts and salt hydrates used as PCMs include $MgCl_2.6H_2O$, $CaCl_2.6H_2O$, $Na_2SO_4.10H_2O$ (Glauber's Salts), $NaNO_3$, KNO_3, KOH, $MgCl_2$, and NaCl [1]. The salt hydrates have a three-dimensional structure which is sufficient enough to permit water to fit inside the crystal lattice. Salt and salt hydrates can be found with and extensive variety of melting points from 10 ˚C to 900 ˚C. Inorganic PCM is widely used in solar energy plants because salt and salt hydrates possess high specific heat and high melting temperature. The main disadvantage with inorganic PCM is they aggressively attack the casing materials and the salts have a tendency to break down at higher temperature over repeated cycle.

3.3 Eutectic PCMs: It basically comprises c-inorganic, inorganic- inorganic compounds. These are solutions of salt in water with a phase change temperature below 0 ˚C. They have sharp melting point and its density is slightly above the organic compounds. Still a lot of research is going on to develop new eutectic blends.

4. Application of PCMs in different areas:

4.1 Buildings: It's very problematic nowadays to ensure indoor comfort inside a building during summer seasons in residential as well as commercial buildings. Due to the advancement of living standards of peoples living in urban areas the use of air conditioning system has increased a lot to achieve thermal comfort inside the building during hot summer days. There are many ways to use PCM in buildings for example it can be encapsulated in cement, wallboard, ceiling and floor for energy storage purpose. The PCMs having the melting / freezing temperature in the range between 20 ˚C and 32 ˚C are most suitable for building applications. Usually roofs are exposed to most intense heat among all the other parts of the building exposed to Sun. In order to take care of the heat load the photo- voltaic (PV) Technology coupled with PCM are being used nowadays on building roof. The use of building integrated photovoltaic panel (BIPV) causes a significant temperature drop of 4 ˚C. The integration of PCM in photo-voltaic panels increased the power production by 7.2 % at peak and 5.2 % on daily average.

Fateh et al. [9] evaluated, the maximum reduction of heat consumption about 15 %, when PCMs were placed at various location inside a light wall of a building envelope, both experimentally and with a numerical model. Waqas and Kumar [10] performed experimental analysis on energy storage in building ventilation incorporated with phase change material during dry and hot climatic condition to determine its thermal performance he observed that the time required for the solidification of PCM was much more sensitive towards the charging air temperature rather than the air flow rate.Shuhong et al. [11] performed an experiment on PCM filled glass window (PCMW) which showed that thermal insulation and load shifting affects PCMW. Results showed it is (paraffin MG29) applied to PCMW with melting temp 25–31 ˚C. Xiang and Zhou [12] numerically investigated the performance of window-based cooling unit filled with PCMs using transient 3D- model. PCM with thickness of 5mm can solidify within 8 hrs. The same thickness of PCM can solidify in lesser time by increasing the inlet air velocity. Chung and Park

[13] used PCM as a roof finishing material in order to decrease the surface temperature of the ceiling. The result showed that the use of PCM doped tiles cause significant reduction in the surface temperature and chamber temperature in summer weather conditions.

From this study it was found that the use of phase change material in the building reduces energy consumption of building as well as improves the thermal comfort by enhancing the thermal energy storage capacity of the building. Experimentally it was observed that the time required for the solidification of PCM was much more sensitive towards the charging air temperature rather than the air flow rate. The same thickness of PCM can solidify in lesser time by increasing the inlet air velocity. Proper selection of PCM as per required melting temperature is the main decision-making part. The major problem which was found was the rate of heat transfer and the volume of PCM needed to be stored.

4.2 Solar Energy Plants: The concept of concentrating solar power is used to design commercial solar power plants. In this power plant a carrying fluid is heated by concentrating the sunlight. Mirrors are used to reflect the incident sunlight to the receiver. Vacuum tube is used to reduce the convective losses in receiver pipe. The carrier fluid circulates through the receiver pipe. The high temperature, high pressure, heat transfer fluid (HTF) is used as carrier fluid in commercial solar power plants. Depending on the design direct steam generation can be obtained. HTF is directly passed through the solar field resulting in direct vaporization. The vapour is then directly passed through the turbine without the use of intermediate heat exchanger. Its benefit can also be replaced by small scale solar system. The lack of concentrators in this system restricts the temperature of the HTF from reaching high temperature. In this system the HTF will not turn to vapour to drive a power system but can be used as heat source for domestic hot water tanks marginally reducing the dependence on electrical heating and natural gas during the overnight hours.

4.3 Electronic Components: A large segment of the consumer is using portable electronic items such as: tablets, mobile phones and many other gadgets which requires an efficient thermal management system to drive the heat generated in the system. The challenges posed by high chip heat fluxes and ever more stringent performance and reliability constraints make thermal packaging a key enabling technology in the development of electronic systems for next generation**.** Passive cooling (Thermo-syphon and PCM based cooling) along with design for manufacturability and sustainability can be expected to play pivotal roles in future electronic systems**.**

The cooling requirements of next generation electronic components when addressed within the cost targets, attention must be devoted to three primary issues [14].

- Highly effective cooling - removing dissipated power from one or several advanced chips within minimal volumes.
- Heat spreading - from a relatively small area contiguous with the chip to a relatively large heat sink or cold-plate base.
- Interfacial heat transfer - from the chip to the next level of thermal packaging.

Designing a PCM based Heat Sinks Challenges

- Very low thermal conductivity of PCM creates gradients during melt process
- Voids created in order to accommodate the volume change during phase change.

Design Considerations

- Reduce thermal gradients with proper thermal conductivity enhancer
  - Fin pitch and thickness
  - Nano particle weight/volume fraction

- Foam porosity, pore density and pore diameter

- 8 – 15 % change in volume between solid and liquid phase
- Requires void volume when PCM is solid
- Trade-off between thermal gradients and PCM volume

4.4 Spacecraft: A satellite orbiting around earth encounters drastically different thermal environment cyclically as it passes in and out of earth's shadow. Ideally, a PCM package can store and release solar energy to damp the otherwise large temperature changes experienced by the spacecraft. That a spacecraft would experience during the orbit cycle. The compartment could be enveloped by a layer of PCM that would absorb and release solar energy during the orbit to provide isothermal conditions at the melting-point of the PCM. Another example of variable spacecraft thermal environment is encountered by landing vehicles on planets or moons that do not have an atmosphere. The day/night cycle on those bodies presents a thermal environment that changes radically. If the landing craft is enveloped with PCM, a large amount of solar energy can be conserved which can be used during the night, to ensure a stable inner thermal environment for crew and components.

4.5 Other Areas of application: PCMs are also being used for packaging of medicines, blood and tissue. It is also used for thermal protection of automobile parts and batteries. It is also used in textile industries to enhance the comfort level in extreme hot and cold conditions. PCM based heat exchanger and packed bed design are also being designed to meet the requirements and many other areas are there where PCMs can prove a promising approach to achieve the goals.

5. Conclusions: The potential of PCM applications for both thermal management as well as energy storage are vast as discussed in this paper, the next generation PCMs with wide acceptance are yet to be synthesized. These next generation PCM materials with high latent heats and high thermal conductivities are yet to be isolated. The safety concerns of PCMs especially of organic origin with high probability of inflammation are also to be taken care of. Pure paraffins are much expensive preventing its wide sustainable applications.

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