Latent Heat Storage for Cooling Application: A Review

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Abstract—This paper presents a review on thermal energy storage using phase change material (PCM). A Thermol Energy Storage system using the cooling concept is an economical energy storage technique, where the energy stored during its free availability in the environment is used during the demand period. Latent heat storage is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. Latent heat storage with Phase Change Materials (PCM) provides a high-energy storage density and has the capability of storing a large amount of energy during the phase change process with a small variation in the PCM volume and temperature. The selection of the substances to be used mostly depends upon the temperature level of the application. Phase change materials (PCMs) are one of the latent heat materials having low temperature range and high energy density of melting-solification. There are a large numbers of PCMs have been found that melt and solidify at a wide range of temperatures. Some of these application include air conditioning of buildings, cooling of electrical and heat engines, cooling food, beverages, milk, greenhouses, medical applications like transportation of blood and hot-cold therapies, waste heat recovery, heating and cooling water, incorporation into textiles for human comfort, space heating and cooling in buildings, solar applications, off-peak energy storage, and heat exchanger improvements spacecraft thermal systems, etc. Initially, the work will go to be undertaken to study the feasibility of storing coldness during the night using PCM (phase change material) and utilizing this cold during the day when a desired temp reach at which PCM start change its phase (its melting point). PCM absorb large amount of heat in the form of latent heat, thus act as free cooling system. When the environmental temperature around the liquid PCM falls, it solidifies again, releasing its stored latent heat. Thus, the managed temperature again remains consistent.

Keywords – Thermal energy storage, Latent heat energy storage, Phase Change Material (PCM).

I. INTRODUCTION

The rapid growth of energy use around the world has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts such as ozone layer depletion, global warming, climate change, continuous increase in the level of greenhouse gas emission. Scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. Thermal energy storage systems provide the potential to attain energy savings, which in turn reduce the environment impact related to energy use. These systems provide a valuable solution for correcting the mismatch that is often found between the supply and demand of energy. As a demand for air conditioning increased greatly during the last decade, large demands of electric power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demand by industrial, commercial and residential activities. In hot and cold climate countries, the major part of the load variation is due to air conditioning and domestic space heating respectively. The integration of various intermittent energy sources into a system for heating and cooling eventually necessitates the incorporation of thermal storage.

Energy storage is an effective approach to increase energy efficiency and energy savings, since many energy sources are intermittent in nature. It is the most appropriate way and method to correct the gap between the demand and supply of energy. Energy storage is not only plays an important role in conservation of the energy but also improves the performance and reliability of wide range of energy systems, and become more important where the energy source intermittent such as solar. Thermal energy storage (TES) is recognized as one of the key technologies for energy storage in the future.

Three major methods are currently considered for thermal storage: sensible heat, latent heat and thermo chemical heat. High energy storage density and high power capacity for charging and discharging are desirable properties of any storage system. Sensible heat storage has been used for centuries by builders to store/release passively thermal energy, but a much larger volume of material is required to store the same amount of energy in comparison to latent heat storage. Latent heat energy storage, using phase change materials (PCM), is the most effective technique because of its advantages of high energy storage density and isothermal characteristics.

II. LATENT HEAT STORAGE MATERIALS

Phase Change Materials (PCM) is latent heat storage materials. As the source temperature rises, the chemical bonds within the PCM break up as the material changes phase from solid to liquid (as is the case for solid-liquid PCMs). The phase change is a heat-seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished. The heat stored during the phase change process (melting process) of the material is called latent heat. Latent heat storage has two main advantages: a) it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density; b) because the change of phase at a constant
temperature takes some time to complete, it becomes possible to smooth temperature variations. The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached. PCM storage volume is two times smaller than that of water. Latent heat storage can be used in a wide temperature range. A large number of PCMs are known to melt with a heat of fusion in any required range. The PCM to be used in the design of thermal storage systems should accomplish desirable thermophysical, kinetics and chemical properties [1].

2.1. Thermo-physical Properties

- Melting temperature in the desired operating temperature range.
- High latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is less.
- High specific heat to provide for additional significant sensible heat storage.
- High thermal conductivity of both solid and liquid phases to assist the charging and discharging of energy of the storage systems.
- Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.
- Congruent melting of the PCM for a constant storage capacity of the material with each freezing/melting cycle.

2.2. Kinetic Properties

- High nucleation rate to avoid super cooling of the liquid phase.
- High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system.

2.3. Chemical Properties

- Chemical stability.
- Complete reversible freeze / melt cycle.
- No degradation after a large number of freeze / melt cycles.
- Non-corrosiveness to the construction materials.
- Non-toxic, non-flammable, and non-explosive materials for safety.

III. CLASSIFICATION OF PCM

There are a large number of PCMs (organic, inorganic and eutectic), which can be identified as PCMs from the point of view melting temperature and latent heat of fusion. However, except for the melting point in the operating range, a majority of PCMs do not satisfy the criteria required for an adequate storage media. As no single material can have all the required properties for an ideal thermal storage media, one has to use the available materials and try to make up for the poor physical properties by an adequate system design.

Phase change materials are classified as follows, 1) Organic 2) Inorganic 3) Eutectic

3.1 Organic PCM

3.1.1 Paraffin

With respect to mass paraffins are a resonable option for most of the applications, but they have a small melting enthalpy per unit volume when compared to inorganic alternatives. They almost require no subcooling during solidification. They melt and solidify congruently and have a low thermal conductivity. Paraffin are the mostly common organic PCM, as they are of a soft organic structure, thus during expansion the built-up forces are of considerably small thermal conductivity and their general formula is CnH2n+2

The following Table 3-1 displays examples of paraffins [2]

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting Temp (°C)</th>
<th>Latent Heat of Fusion (kJ/kg)</th>
<th>Thermal Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octadecane</td>
<td>38</td>
<td>200-245</td>
<td>0.148((liquid,40°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.358((solid,25°C)</td>
</tr>
</tbody>
</table>

3.1.2 Fatty acids

A fatty acid is chemically known by the following formula CH3(CH2)n *nCOOH as shown in Table 3-2. In fatty acids the melting temperature is directly proportional to length of the molecules. Since they consist of one component the risk of phase separation is less common, with almost no subcooling, [2] unlike paraffins. Nevertheless fatty acids are not recommended when a metal contact is to be applied, due to their acidic nature.

Table3-2: Fatty acid compounds

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting Temp (°C)</th>
<th>Latent Heat of Fusion (kJ/kg)</th>
<th>Thermal Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caprylic acid</td>
<td>16</td>
<td>149</td>
<td>0.149((liquid,38°C)</td>
</tr>
<tr>
<td>Capric acid</td>
<td>32</td>
<td>153</td>
<td>0.149((liquid,40°C)</td>
</tr>
<tr>
<td>Lauric acid</td>
<td>42-44</td>
<td>178</td>
<td>0.147((liquid,50°C)</td>
</tr>
</tbody>
</table>

3.2 Inorganic PCM

3.2.1 Eutectic water-salt solution
Eutectic water-salt solutions have a phase melting temperature of about 0°C and have a relatively moderate storage density. Water-salt solutions are simply consisting of water and salt, but since salt can be soluble in water a phase separation problem might be experienced during solidification. In order to solve the phase separation problem and maintain a good phase change cyclic stability, eutectic compositions are used. Eutectic compositions are simply two or more constituents solidifying from the same liquid at a minimum freezing point. Eutectic water salt solution has a thermal conductivity similar to that of water and can be sub-cooled.

3.2.2 Salt hydrates
From its name it consists of water and salt in a certain ratio. Their storage density is high, and they share the stable chemical composition, corrosiveness to metals, and the problem of phase separation affecting the cyclic stability exactly as with the eutectic water salt compositions. Salt hydrates as shown in Table 3-5 for example, are used mainly for high temperature applications due to the high phase change temperature [2].

IV. LATENT HEAT STORAGE SYSTEMS
Latent heat storage system use the energy absorbed or released during the isothermal change of materials. Latent heat is defined as the amount of heat stored in the material resulting in change of the material’s phase with a slight increase or decrease in temperature. It takes place when the phase is changing either from solid to liquid, solid-solid and/or liquid to vapor and vice versa, representing the charging energy required and the discharging energy potential when used in any application. However it is important to mention, that there are many studies pointing out the potential of PCMs, but only few PCM are commercialized and suitable for technical processes [2].

4.1 Latent heat storage system for various cooling application

4.1.1 Cooling of building
R. Velraj [5] studies Free cooling/Night ventilation is the process of storing the cool energy available in the night time process of storing the cool energy available in the night time ambient air in a storage device. During the day time the cool energy is retrieved from the storage device in order to cool the building using mechanical ventilation system. The modular heat exchanger developed in this work is a shell and tube type with phase change materials in the shell portion of the module and passage for the flow of air through the tubes.

4.1.2 Ceiling board
Kodo and Ibamoto [6] examined the effects of a peak shaving control of air conditioning systems using PCM (phase change material) for ceiling boards in an office building. Rock wool PCM ceiling board (PCM ceiling board) was enhanced by adding micro-capsulate PCM, with a melting point, of about 25 oC, close to room temperature.

4.1.3 Off-peak electricity storage
Telkes [7], Herrick [8] studied latent heat storage system for air conditioning. Inorganic hydrous salts were used as storage material. However these studies were focused more on the development of new heat storage materials. Lane [9] suggested some PCMs for cooling and dehumidification. The PCM is frozen during off peak hours and coolness is withdrawn as needed during the day. Using off peak electricity, phase change material can be melted/frizzed to store electrical energy in the form of latent heat thermal energy and the heat/coolness then is available when needed. So, if latent heat thermal energy storage (LHTES) systems are coupled with the active systems, it will help in reducing the peak load and thus electricity generation cost can be reduced by keeping the demand nearly constant.

4.1.4 Other application
Cold storage is also developed for other applications like vegetable cooling [10], pre-cooling inlet air in gas turbine [11], or temperature maintenance in room with computers or electrical appliances [12]. The use of PCMs for cold storage were developed for air conditioning applications, where cold is collected and stored from ambient air during night, and its relieved to the indoor ambient during the hottest hours of the day.

V. CONCLUSION
This review paper is focused on the available thermal energy storage technology with PCMs with cooling applications. This paper presents the current research in this particular field, with the main focus being on the consideration of the thermal properties of various PCMs. These thermal storage applications used as a part of space heating and cooling application for buildings, off-peak electricity storage systems, floor and ceiling application. The paper mainly focused on PCMs based latent heat storage system, which is more attractive and useful to the energy conservative system and covered current research papers in particular field.

References


