Thermal Energy Storage and its Significance (Review)

Chandrakala.S.Doddamani[1] Sharanabasappa.B.Patil[2]
[1]P.G. Student [2]Assistant Professor
[1,2]Department of Ceramic and Cement Technology
[1,2]P D A College Of Engineering, Kalaburagi - 585102, Karnataka, India

Abstract— Energy plays a vital role in every aspect of life. The changeover from non-renewable to renewable sources of energy will not happen overnight, hence it is necessary to conserve and store energy. The possible ways of energy storage are in the form of electrical, chemical, mechanical, biological and thermal. Energy storage is accomplished by physical media or devices that store energy to accomplish useful processes at a later times. Thermal energy storage (TES) is an emerging technology which can alleviate environmental issues and deliver efficient energy to the society. Hence an effort has been made based on literature review, regarding the classification of TES. A brief classification of thermal energy types (TES) i.e. latent heat storage, sensible heat storage and thermochemical heat storage is given. The principle behind all the three types of thermal energy storage is presented with suitable examples. The advantages and limitations of each kind of thermal energy storage methods is also highlighted.

Key words: Thermal Energy Storage (TES), Latent Heat Storage (LHS), Sensible Heat Storage (SHS), Thermochemical Heat Storage

I. INTRODUCTION

Energy is the capacity of a physical system to perform work. Energy is the key input in economic growth of a nation. The growth of the industries as well as the society is directly related with the energy aspects. The demand for energy is growing continually and on the other hand the resources to meet these energy demands are getting scarcer. Most of the energy we consume originates from fossil fuels, which are non-renewable sources. Once these reservoirs of renewable sources get over them cannot be replenished, hence conservation and storage of energy is very important as it lessens our dependency on imported fossil fuels and translates into financial savings. The renewable energy resources such as wind, solar, tidal are intermittent in nature. This necessitates the storage of energy in order to bridge the gap between the demand and supply. Energy stored in stars such as sun, is explored for utilization by human beings directly through solar heating or indirectly by agricultural harvests or conversion into electricity in solar cells. The ability to store energy when the supply surpasses the demand is the key factor for effective utilization of renewable energy, as many renewable resources such as solar, tidal and wind are discontinuous in nature. Storage is helpful at the times when it is available and not needed, and also at the times when it is required but not available. Storing energy allows balancing between the supply and demand. Thermal energy storage can link the gap between the demand and supply of energy.

Thermal energy storage (TES) is the temporary storing of thermal energy in the form of hot or cold substances for later utilization. TES systems have wide spread applications such as solar power plants, air-conditioning, water heating, heat sinks and regenerators. Installation of TES system in solar plant can result in increase in the solar energy storing capacity of the plant and increase in the solar share of the power plant, thereby decreasing the supplementary fuel (fossil fuels) requirements. TES systems can recover the industrial waste heat. The excessive energy generated during low-demand periods can be used to charge a TES in order to increase the generation capacity, and can be used during high-demand periods. Thermal energy storage can be used for air conditioning; it is used for cooling buildings.

There are three forms of thermal energy storage (TES) systems:

– Latent
– Sensible
– Thermochemical

The choice of TES system for a specific application is governed by several factors such as storage capacity, temperature requirement, space availability, storage time, heat losses, and economics.

II. THERMAL ENERGY STORAGE TYPES

A. Latent Heat Storage (LHS)

Latent heat storage is accomplished by using phase change materials (PCM's).In latent TES systems, energy is stored during phase change (melting, crystallization, evaporation) due to the enthalpy change accompanying the phase change. Phase change materials are useful over a small temperature range, at which the phase changes take place. The energy stored in a phase change material during the process of phase change can be calculated as:

$$Q = m.L$$

Where, m is the mass and
L is the specific latent heat of phase change material.

Water, eutectic salts, paraffin's, $MgCl_2/KCl/NaCl$, KNO_3/KCl is few common phase change materials. Amongst the various phase change materials available, salts are frequently used for the reasons of their abundance in nature and also low-cost .But the thermal conductivity of the salts is low, hence it decreases the efficiency of the heat storage system. [1, 2].Metallic phase change materials are promising materials for TES systems since they have good thermal, physical and chemical properties [3]. Zhengyun Wang et al. studied six different compositions of Al-Si alloys and found that the latent heat of Al-Si composition increases with increase in Si concentration because of the large latent heat of Si than that of Al [4].

In general phase change materials are good thermal storage materials with medium energy density and can be used at moderate temperatures. Corrosively and low heat conductivity properties of the materials are the drawbacks associated with them.

B. Sensible Heat Storage (SHS)

In sensible heat storage (SHS), thermal energy is stored by raising temperature of a solid or liquid media which doesn't undergo phase change. SHS utilizes the heat capacity and the temperature change of the material during the process of charging (heating) and discharging (cooling) to store the heat. The amount of heat stored depends upon the specific heat of the material used, the temperature change during the process and the amount of storage material used. The heat stored for SHS can be calculated using the equation mentioned below:

$$Q = m.C_p.dT$$

Where, Q = heat stored
m = mass of the storage media
C_p = specific heat of the storage media
dT = Temperature change

There exists a criteria for selection of material for SHS applications. The material should possess following thermo-physical, chemical and mechanical properties.

Factors affecting the choice of SHS media:

- Melting point
- Density
- Specific heat
- Thermal expansion
- Good chemical properties
- Mechanical properties

The melting point of the storage material should be higher than the operating temperatures in order to prevent the melting of the material during operation. The material should have high density in order to attain high thermal storage. The material should have high specific heat (specific heat is defined as the amount of energy required to raise the temperature of unit mass of substance by 1^0C) as it facilitates large amount of heat storage. The material shouldn't undergo decomposition during operating temperatures. It should be non-toxic, non-explosive and low corrosion potential or reactivity towards heat transfer fluid (HTF).The material should be strong and should not crack due to thermal cycling. Apart from these properties the material should be cheap and abundantly available and should have low carbon footprint.

A variety of materials have been used as SHS media like water, rocks, pebbles, refractory bricks etc. The choice of a substance used depends largely on the temperature range of the application. Ceramic materials such as alumina, concrete, silicon carbide, cast iron and stainless steel can be used at higher temperatures [5].

Sensible heat storage systems are simpler in design than latent heat and thermo-chemical heat storage systems, however they bear the drawback of occupying large volume. In order to overcome this drawback, during selection criterion a material with large (C_p) and high density value should be selected. Another disadvantage of SHS system is that they cannot store or deliver energy at a constant temperature.

Performance of a SHS system is judged by storage capacity, heat input and output rates while charging and discharging and storage efficiency.

1) Solid Storage Media

Solids are suitable media for SHS than liquid SHS media as they can be used at high working temperatures due to the fact that melting temperature of most of the solids are generally higher than that of the liquids. Handling of solids is easy and also corrosion problems can be avoided. Few common SHS materials are listed below in the table1.

Medium	Specific heat (J/kg)	Density (kg/m^3)
Aluminum	896	2707
Alumina	840	3900
Calcium chloride	670	2510
Cast iron	837	7900
Copper	383	8954
Earth(dry)	795	1260
Earth(wet)	2093	1700
Potassium chloride	670	1980
Sodium carbonate	1090	2510
Granite stone	820	2640
Limestone	900	2500
Marble stone	800	2600
Sandstone	710	2200

Table 1: Common solids materials for SHS [6]

2) Liquid Storage Media

Liquids can also be used as SHS media, water is an example of liquid SHS medium with high specific heat (4190J/(kg.K)).Heat transfer oils are also used in SHS at intermediary temperatures ranging from 100-300^{0}C.Mineral oil, silicone oil, and liquid sodium are commonly used SHS liquids. The drawbacks associated with the use of oils are that they tend to degrade with time and also there are the likelihoods of ignition beyond flash point, hence they should always be used in system with inert gas cover. Apart from this the high cost of oils restricts its use at large scale. Commonly used liquid storage media for sensible heat storage is given in the table 2.

Medium	Heat capacity ($J/m^3 K$)	Density (kg/m^3)
Water	4190	1000
Water-ethylene glycol(50/50)	3470	1050
Ethylene glycol	2382	1116
Engine oil	1880	888
Ethanol	2400	790
Synthetic oil	2300	900

Table 2: Common liquids for SHS [6]

C. Thermochemical Energy Storage

In thermochemical energy storage, energy is stored during dissociation reaction and then recovered by reversing the chemical reaction. Thermochemical energy stored has a high storage density than the other thermal energy storage systems types (SHS and LHS).The main principle of thermochemical TES is reversible chemical reaction.

$$X + Heat \rightarrow Y + Z$$

In the reaction mentioned above is a thermochemical solid. X absorbs energy and is transformed chemically into two components Y and Z. The reverse reaction follows when materials Y and Z combines together to form X. During formation of X, energy is liberated and enables the recovery of thermal energy from the TES system. The storage capacity of thermochemical energy storage system is the heat of reaction when material X is formed. The energy density of this storage system is high and it is compact in nature. The heat losses are very low here, hence insulating expenses can be saved. These characteristics of thermochemical energy storage make it a promising field for energy storage. Before selection of thermochemical energy storage materials, certain factors has to be considered like

- Reaction temperature
- Reaction rate
- Energy storage density
- Availability
- Life of the material

C. Agrafiotis et al. coated Co_3O_4 on cordierite foams and honeycombs and successfully proved the occurrence of redox reaction of Co_3O_4 in the temperature range 800-1000^{0}C and showed that Co_3O_4 is a useful material in thermochemical heat storage [7]. The feasibility of the concept of thermochemical heat storage through cobalt oxide powder was demonstrated by Neises.M et al. [8]. Kevyn Johannes investigated on Zeolite 13X for heat storage and found that a constant power supply of 2.25kW could be obtained for more than two hours that is 27.5W/kg of material [9].

	Types of thermal energy storage (TES)		
Parameter	**Latent TES**	**Sensible TES**	**Thermochemical TES**
Storage density	Moderate	Low	High
Temperature range	Low	Very high	Moderate
Life time	Limited	Long	Depends on the reactants degradation time
Advantage/advantages	Occupies less volume	Low cost, simple process	High energy density,
Disadvantage/ disadvantages	PCM's are corrosive	Large volume requirement	High capital cost, technically complex
Status	Commercially available but at some temperatures and materials	Commercially available	Commercially not available, still under research studies

Table 3: Comparison between different types of TES

III. Summary and Conclusions

A review on various types of thermal energy storage has been presented. The basic principles behind each kind of TES and criteria for selection of materials have been reported. Some of the commonly used thermal storage materials has been highlighted. Among the three types of thermal energy storage methods viz: latent heat storage (LHS), sensible heat (SHS) and thermochemical heat storage, SHS is simpler and economically viable. But it has the drawback of large space requirement for storage media. Latent heat storage (LHS) on the other hand overcomes this drawback of SHS as it requires less space, but the cost of LHS is comparatively higher than the SHS and necessitates selection of appropriate phase change material for a particular temperature range. Thermochemical energy storage has the highest energy density among the three thermal storage methods, but it is too expensive and not yet commercialized. All the types of TES have got its own advantages and drawbacks. Selection of TES system for a particular application can be decided based upon the conditions of requirements like amount of heat required to be stored, temperature range, cost and other such factors. Research is required in the field of thermochemical energy storage in order to scale it up and exploit it commercially.

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