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Review of PCM Storage System in Thermal Solar Power Plants

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Abstract:
Energy supply in sufficient quantity and quality is essential for development and improvement in the standard of living. Current renewable energy sources all have their merits and demerits especially in terms of supply periods and stability. Concentrated solar power is one of the most promising energy supply systems available due to its cleanliness and high energy density. However, the intermittent nature of solar energy with respect to season and time of day necessitates the provision of storage system in order to ensure sustainability of power supply which is one of the key factors that will ensure energy security. This prompt the need for continuous and extensive research in the field of materials science and technology in order to come up with more better materials then the ones currently in use. Currently both single organic and inorganic materials as well as a combination of such materials (eutectics) are used as molten salts or [phase change materials (PCMs). This paper attempts to review the various features of importance in this regard vis-à-vis their mer its as well as demerits. The various methods used for improvement of these materials are highlighted.

Keywords: Energy storage, Phase Change material, Thermal energy storage, molten salts, Thermal performance

Introduction:

The supply of energy insufficient and good quality is one of the key objectives of any power system. Different sources of energy are available and they are utilized in various places for both generation and instant consumption as well as stored in other cases for use at a later time. All life applications are affected directly or indirectly by energy. The standard of living generally is largely influenced by the capacity of energy harnessing and utilization in order to make changes and improvements in the existing system. Globally, the quest for energy is on the increase by the day due to various factors surrounding our environment and the sources of energy themselves. Issues of availability, cost, time, volume, ease of use, environmental impact and the technical know-how needed for both installation and maintenance are of paramount importance in choosing the type of energy to harness. In tropical countries with favorable climatic conditions in most times of the year, harnessing solar energy in the form of thermal as well as photovoltaic forms is highly feasible both in terms of technology as well as the cost. In such areas also, developing a storage system that will serve as a back-up to the system is of great importance. Similarly, big countries like India and China with a population of about 1.3 billion people, represents a large market for

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solar energy especially in the Asian continent and if such market is harnessed, it will revitalize the economy by increasing the total solar energy output which will, in turn, reduce the quantity of crude oil importation into such counties. Similarly, the large chunk of conventional energy generation in the world is through coal which produces significant pollution to the environment, as such, utilizing solar energy for both direct generation and utilization as well as storage for future use is an important step towards achieving an environmental-friendly ecosystem as well as ensuring a smart, green and sustainable environment. Energy storage occupies a significant position in any supply system especially as it helps in frequency regulation, peak shaving, standby supply during fault of the grid as well as seasonal storage. This is for both stand-alone and grid-connected systems.

Necessity for Energy Storage:

The nature of solar energy in terms of its merits and limitations, as well as the variability of demand with many factors, called for energy storage. These factors or limitations in the utilization of solar energy makes it a necessity for a storage system to be integrated into the system if at all a sustainable system is needed. These need for storage system can be considered in the following ways:

1. Variable Source: Solar energy is a variable source of energy which is dependent on the movement and positions of the sun. The supply is generally in the day time and zero in the night. However, the demand is all around the day and night, as such it’s obvious that for such a form of energy to be utilized, a storage system is needed. Solar energy is low at early morning hours, high at midday, low at evening hours and absent at night. So, to prevent system or operation from a total power outage, a storage system needs to be designed, implemented and integrated into the system.

2. Variable Demand: Just as the supply is intermittent, the demand also is variable depending on the needs of the consumers for various applications. Various processes require a different amount of supply for use. Also, for many industrial processes, energy is needed maximally during peak hours of the day for production, heating, and cooling. Thus a storage system is essential in order to mitigate the difference that will occur due to large demand within that period.

3. Time-Based Tariff: As stated above, for many industrial processes, the peak of their demand for power is in midday and this causes high demand from the suppliers. However, this competition for supply makes the suppliers increase the tariff within that period so as to gain more profit within a high demand system. This scenario puts many companies in a fixed position with only two options at their disposal, either to pay for an extra charge for using power at that time or to devise a storage system that will supply the extra amount of energy needed at that time. This is also called demand-side management (DSM). Considering, the cost and reliability, many companies prefer the second alternative which is storage.

4. Gap Between Demand and Supply: The case with an increasing population every day and setting up of new settlements and industries pose a great challenge to the power supply system. Constant energy audit always shows a changing trend in energy usage in terms of quantity and therefore more and more energy supply systems need to be set-up. Due to this, suppliers, especially in less developed countries, are always unable to supply the required energy needed by the consumers. Therefore, the consumers need to store energy during supply so as to use during a power outage situation. Also, the suppliers can increase their supply by using a back-up storage system that will keep the system running even during periods of low or zero production.

5. Energy Security: Energy security is the backbone of industrial growth for any nation. In many countries, today's power is supplied for some hours of the day and the remaining hours are spent by the consumers in a power outage situation. This halts many production processes and hinders development. This is the actual difference between developed, developing and under-developed nations. The constant, efficient and reliable power supply is a pre-requisite for development and consequently improvement in living standards.

Table 1 below, itemized the major characteristics of the most common thermal storage technologies available which this paper focuses on and how such can be improved.

Table 1: Key Data for Basic Thermal Storage Technologies

Technical performance	Typical current international values and ranges	
Technology Variants	Sensible Energy Storage (TES)	Phase Change Material (PCM) Storage
Storage Capacity (kWh/t)	10-50	50-150
Thermal Power (MW)	0.1-10	0.001-1
Efficiency %	50-90	75-90
Storage period	d-y	h-w
Cost $/kWh	0.1-10	ott-50
Technical Lifetime (yrs)	10-30	10-30
Load Capacity factor (%)	80	80
Max. Plant Availability %	95	95
Typical Capacity Size (MW)	25	0.5

Installed Capacity (GW)	9-10	<1
Environmental Impact	Negligible with GHG emission reduction	

Concentrated Solar Power:

Concentrated solar power (CSP) systems are known and used for a very long time. The most common are parabolic trough collector, parabolic dish, linear Fresnel reflector, and solar tower. In all these, generation of high temperatures has been achieved and even electricity generation from such systems is not the challenge currently, but the storage of same high thermal energy generated for subsequent use during low solar thermal energy supply [32], hence the need to focus more on the storage

Thermal Storage system :

Thermal energy storage systems are important components of any stand-alone or hybrid system involving concentrated solar power (CSP) if at all sustainability is required. Due to the increasing demand for electricity in the various sectors of the economy, much attention has been focused on developing a reliable and sustainable storage system capable of maintaining the system in operation even during hours of solar energy outage.

Thermal storage systems, depending on the temperature range have some challenges confronting them which if not overcome may become a stumbling block towards the commercialization of such systems. Such challenges include:

i. Storage Material Selection:

The choice of storage material is the most important aspect of the storage system itself. The desired characteristics include high energy density, physical and chemical stability especially at high and extremely low temperatures, super cooling, density and thermal conductivity. Others are the ability to withstand thousands of thermal cycles without degradation, specific heat capacity, cost and availability. All these are important and it is difficult if not impossible to have all these characteristics in one single material or storage system, hence the need for the correct choice of materials in terms of both the storage material as well as the container and transport conduits. For example, most metals have high energy density, high thermal conductivity and are readily available. However, they are relatively costly compared to another organic as well as inorganic systems [41].

ii. Capacity:

The capacity of a thermal storage system is an important factor in choosing a type of storage. As no single system has all the needed characteristics, it seems that sometimes a combination of different materials connected together in a single system can boost the performance. Horst and Robert [42] worked on a cascade latent heat storage for parabolic trough solar power plants. The study focus on thermal storage on temperature ranges from 250^0C to 500^0C. The advantage with the cascaded latent heat storage (CLHS) is that it allows a higher amount of the material (PCM) to go through the phase change during the charging-discharging cycle. Also during discharging, is shows much uniform temperature as compared with other LHS systems which are non-cascaded. Therefore, a cascaded system utilizing synthetic heat transfer oil and a combination of different PCMs in a cascaded form will give a better result for outlet temperatures in terms of stability.

iii. Time (Length):

The length of time for which the storage system is required to supply the needed amount of heat energy at a specific temperature range is important. This is due to the fact that the generation system (turbine) will not operate outside a given range. So, for optimum efficiency, time length with corresponding temperature requirement is of paramount importance. Many storage materials especially PCMs fails to give the needed amount of heat energy at the desired temperature due to some other intrinsic factors associated with them.

iv. Thermal conductivity:

A lot of phase change materials (PCMs) suffer from low conductivity value and that hinders their chances as good candidates for high temperature solar thermal storage. From various researches,itmay beunderstoodthathigh-temperature molten salts and metal alloys are considered two of the most researched PCMs [41]. In many cases, salt materials have a high density for storage but they are drawn back by low conductivity. Various methods are available for improving the thermal conductivity of storage materials. Such methods include microencapsulation, insertion of metal fins, foams and wools into the PCM, use of additives in the form of surfactants, nanoparticles, and adoption of various configurations [33, 43]. However, determining proper configurations as well as the ratio of these fixed, non-moving structures and their interactions with conduction, convection and phase change heat transport mechanisms pose challenging issues [44]. The same goes for the ratio of additives needed to get the maximum output.

v.Stability:

This implies their physical, thermal, chemical stability, as well as reaction stability and they, are one of the key factors in the choice of storage media. However, due to the usually long lifespan of thermal storage systems, not much has been known about it [45]. This is usually more with high-temperature sensible heat storage systems as in the issues such as thermal stress, phase separation,

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chemical decomposition as well as oxidation and reduction that eventually gives birth to corrosion are easily observed. Thermo gravimetric analysis is usually employed to determine the stability of PCMs at different temperatures. Usually, at high to extremely high temperatures, many compounds especially salts with the exception of eutectic materials do undergo phase separation. This is due to the variation of the properties of the individual components of the compound such as conductivity, density, and heat capacity. Consequently, many methods have been proposed and experimented in order to overcome the case of phase separation. Such methods include the development of new materials such as eutectics, the addition of nanoparticles and cascading of different PCMs [46, 47, 32]. Because most high-temperature thermal systems are latent heat dependent, which is essentially an isothermal process, most studies have been focused on more on them [48].

vi. Super cooling:

In contrast to the high thermal conductivity, another problem with many storage materials is the super cooling especially liquid salts at lower temperatures [33]. Super cooling has been one of the serious problems more associated with organic salts than other types of storage materials. However, Mao [46] had posited that expanded graphite in suitable quantities and some forms of nanoparticles can be used as Heat Transfer Enhancers (HTEs) to suppress super cooling and increase the temperature level at the discharge level, hence increasing the efficiency of the system. Safari *et al.* [31] clarified that no much information is available on the factors affecting the level of super cooling. However, some factors such as homogenous and heterogeneous nucleation, rate of cooling and roughness of the metallic structure in metals are all responsible for super cooling. This lack of enough information has made the selection of additives that will mitigate the super cooling effect difficult as no standard for their choice exist [31]. However, on the dimension of the output, it was discovered that the degree of super cooling has a quite little effect on the output at lower temperatures [31].

vii. Degradability:

The level of degradation is determined mainly by the storage materials' properties and also by the way it is used. In many cases, the number of times it is charged and discharged, length of time of charging and level of discharge all aids and increase the level of degradation. The lifetime can be determined by differential scanning calorimetry (DSC), differential thermal analysis (DTA) or thermos-gravimetric analysis. DSC is used more nowadays due to its versatility in terms of the ease and speed with which it can be used to see transitions in materials. It is also capable of

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providing multivariate data of phase change temperature, latent heat and specific heat of the samples. However, for thermal stability analysis, TGA is more applicable.

viii. Energy Loss:

Compared to other storage systems, energy loss is quite low [33]. This is because latent heat storage utilizes isothermal process which has no change in temperature as such less communication with the outside environment. Also, most of the containers used in such storage systems form a nearly complete close system which serves as an adiabatic cover except during charging and discharging.

ix. Material's Compatibility:

The choice of the storage material is important but not the only important material choice. This is because such storage material will automatically be placed in some container and will definitely have direct contact with other system components such as the container itself, pipes, heat transfer fluid and in some cases additives such as nanoparticles used to enhance conductivity or stability. The material for the container must be stable at different temperature ranges and should also be tolerant and resistant to corrosion [45]. Corrosion of the containers and pipes is one of the serious challenges associated with thermal storage systems. This is in two dimensions: The first is the corrosion caused by the storage materials itself while in the second dimension, the thermal enhancers such as surfactants, nanoparticles, and other additives also cause and also aided the storage materials in corroding the containers and pipes. It is interesting to note that whereas so many observations were made in different researches on the case of the former, little attention was given to the latter. This is more noticeable in the case of molten salts which in some cases, the corrosivity multiplies several times than when such nano-particles, surfactants, and additives were not added [3].

x. Environmental Impacts:

The type of material to be used for thermal storage need to have low or no negative environmental impact. Many of the PCMs usually release particulate matter and harmful gases during different stages of the storage process [48]. Various tests are available for the determination of the release or otherwise of such harmful products. One such tool is the National Fire Protection Association (NFPA) of the United States. The aim of this standard is providing visual information on the risk of many common chemicals by means of a colored diamond.

Conclusion:

In conclusion, it can be understood that:

1. Generally, PCM storage is effective and reliable due to its ability for long time stable supply and high energy density.
2. Inorganic PCMs in single and eutectic forms are the best materials for the thermal storage system that will help in achieving more of the objectives at the same time mitigating the problems. This is due to the fact that they have superior quality in terms of high conductivity, non-corrosivity and ability to withstand thermal stress without undergoing phase separation.
3. A cascaded system in TES is more efficient than a single PCM system as it gives better and constant energy supply for electricity generation, has a longer lifespan and wider alternative properties.
4. When a hybrid system is integrated, the life span of the system is longer due to the reduced pressure on the single generation and storage system. This makes the two individual systems to last longer and also give better efficiency since they are not overstretched.
5. In many places especially in rural areas, not all the different forms of energy are available or easily harnessible, so hybrid energy stands a better candidate. Moreover, solar energy in most cases is found in the two components of heat and light, this makes the choice of PV-ST better for a continuous supply.

This study is essentially a short review, the efficiency or other features of systems of the recommended systems may vary from the stated efficiency or there may be some other limitations which may be observed under practical conditions, as such, more experiments are conducted to determine the performance of the selected materials and systems.

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