An Overview in Energy Conservation of Thermal Storage Techniques for Solar Thermal Applications

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***Abstract*—The traditional electricity operation in solar thermal plants is designed to operate on a single path initiating at power plant and executes at the consumer. Due to lack of energy storage facilities during this operation, a decrease in the efficiency is often observed with the power plant performance. This paper reviews the significance of energy storage in supply design and elaborates various methods that can be adopted in this regard which are equally cost effective and environmental friendly. Moreover various parameters in thermal storage technique are also critically analysed to clarify the pros and cons in this facility. Discussing the different thermal storage system, their technical and economical evaluation has also been reviewed.**

***Index Terms*—thermal energy storage, sensible heat storage, latent heat storage, thermochemical heat storage**

I. Introduction

Solar thermal power plants collect and concentrate the sun's energy to heat through a working fluid that is then used to process heat applications or the generation of electricity. In order for these systems to operate commercially, they must be able to operate during periods of changing levels of insolation and to operate at times that will ensure maximum financial return. This can either be achieved by utilizing existing backup methods, through the use of fossil fuels, or the incorporation of a Thermal Energy Storage (TES) system. The thermal energy storage (TES) can be defined as the temporary storage of thermal energy at high or low temperatures. TES systems also provide an environmentally friendly solution to Solar Power Generating Systems [1].

Energy storage is used in solar thermal energy systems to save the additional energy generated during the times of high solar availability and used in the times of low solar availability (at night or in cloudy weather) which ensures twenty-four hour power generation without using the fossil fuels. However there exists alot of loophole in this facility which results in energy loss and efficiency is decreased. In this paper we have overviewed the applications of TES system and its types. Discussing the thermal storage systems, its technical and economical evaluation has also been reviewed.

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II. Applications of TES Systems

A single TES system cannot be used to fulfil all the applications. The selection of a TES system is highly dependent upon the stability, low cost, reliability, safety, energy capacity and efficiency of the storage media. Furthermore, theTES system could be classified as low temperature or high temperature depending upon the operating temperature of the storage medium [2]. Some of the key applications of a TES system are:

A. Energy Management

At night when energy production cost is low, the energy can be generated cheaply and stored to use in the time of costly production or when needed referred as load leveling.Storing for this purpose enables the power generator to conduct workingin a "peaking" mode of operation.

B. Buffering

Buffering is required in solar thermal power generation to smooth transients and enable a consistent and uninterrupted supply of thermal energy to a heat engine.

C. Period Displacement

It refers to generating excess energy during daylight hours to enable baseload supply to extend into the non-daylight hours. This can enable 24 hour generation during periods of high insolation.

D. Power Quality

The stored energy is only applied when needed depending upon the application. So its power quality must be high even when it is applied for seconds or maybe less to assure the stability and continuity of the system energy.

E. Annually Averaging

During winter, the low radiation of the sun results in low energy generation. So, the large solar plants can use the TES system to store energy to supply it in the time of peak demand or low light.

III. Types of Thermal Storage Systems TES Systems Can be Categorized as:

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A. Active Storage Systems

When the storage medium is a fluid which is able to flow between the storage tanks, then the system is referred as active type systems. If the storage medium which is a fluid, is also used as the heat transfer fluid, then the system is called direct-active system. If the heat transfer fluid and storage fluid are separate then the system is called indirect active type system. In this case an additional heat exchanger fluid is required [1], [3].

B. Passive Storage Systems

When the storage medium is solid, the heat transfer fluid passes through the storage material only for exchanging heat as charging or discharging [3]. Then the system is called a *passive type storage system.*

IV. Methods of Thermal Storage

There are three basic methods for storing thermal energy.

A. Sensible Heat Storage (SHS)

The method of heating a liquid or a solid, without changing its phase is called sensible heat storage. The amount of energy stored depends on the temperature change of the material. The thermal energy is stored as the internal heat of the material. It can be expressed by

$$E = m \int_{T1}^{T2} Cp\, dT \qquad (1)$$

where 'm' is the mass and 'Cp' is the specific heat at constant pressure. 'T1' and 'T2' represent the lower and upper temperature levels between which the storage material operates. Examples of Sensible Heat Storage are water, sand, oil, air, concrete, salts etc.

SHS systems can be further divided into two types [2]

- Solid Storage Media
- Liquid Storage Media

TABLE I: Solid Storage Media vs. Liquid Storage Media(SHS) [2]-[4]

	Material	**Density (kg/m^3)**	**Specific Heat (J/kg.K)**	**Thermal Conductivity (W/m.K)**
Solid Storage Media	Aluminum	2707	896	204 at 20 ℃
	Concrete	2240	1130	0.9 – 1.3
	Cast iron	7900	837	29.3
	Copper	8954	383	385 at 20 ℃
	Stone, granite	2640	820	1.73 to 3.98
Liquid Storage Media	Water	1000	4190	0.63 at 38 ℃
	Dowtherms (Oil)	867	2200	0.112 at 260 ℃
	Hitec (Molten Salt)	1680	1560	0.61
	Sodium (Liq. Salt)	960	1300	67.5

B. Latent Heat Storage (LHS)

The method of heating a material which undergoes a phase change (usually melting) is called latent heat storage. When the heat is applied to the material it changes its phase by storing the heat as latent heat of fusion. The material again goes the phase change when the same energy is recovered by the load. The heat of transformation from one phase to another is small [5]. The amount of energy stored is given by

$$E = m\lambda \qquad (2)$$

where 'm' is mass and (λ) is latent heat of fusion of the material. The examples LHS materials are NaCl, Water, H_2SO_4 etc.

The LHS materials are classified as:

- Organic Storage Materials
- Inorganic Storage Materials
- Eutectic Storage Materials

Some of these materials are given in the table below with some of their properties.

TABLE II: Organic PCMs vs. Inorganic PCMs [4]-[6]

	Material	**Melting Point (℃)**	**Latent Heat (kJ/ kg)**
Organic PCMs	Formic acid	7.8	247
	Caprilone	40.0	260
	Benzylamine	78.0	174
	Camphene	50	239
Inorganic PCMs	H_2O	0	333
	SO3	62.1	331
	H_2SO_4	10.4	100
	K_2CO_3	897	235
	NaCl	802	492

C. Thermochemical Storage

Energy can be stored in chemical compounds as they absorb or release energy during a chemical reaction. It involves a reversible reaction and the products of the reaction can also be stored. The materials with high tendency to absorb solar radiations are preferred [6].

Absorbing and adsorbing are two examples for the bond reaction.

TABLE III: THERMOCHEMICAL STORAGE MATERIALS

Material	Storage Density	Turnover Temperature ℃
Na_2S	2.8	83
Magnesium Sulphate	2.8	122
Silicon Oxide	37.9	4065

V. SELECTION CRITERIA OF TES MEDIA

The selection of material for storage in a TES system needs to fulfil some desirable requirements[7], [8]. These are:

- Energy Density in the storage material should be high
- Operational Flexibility
- Adaptability and compatibility with heat storage medium
- High Storage capacity and power available
- High efficiency between the released and stored energy
- Low thermal losses
- Environmental friendly
- Simple design
- High cycling capacity (Durability) and thermal stability after repeated thermal cycles
- Low cost
- Easy maintenance

VI. TECHNICAL EVALUATION OF STORAGE MEDIA

The performance parameters of a TES system are expressed in accordance to its applications. These parameters give an idea of how applicable that storage technique is to the specified application. The availability of sensible heat storage materials is very high but the problem is the sheer volume such as water. Due to the large size of the storage tanks, stratification takes place. Water is also very corrosive. However the specific heat of water is very high. The large volume of SHS materials also restrict their use in variety of applications such as space heating/cooling, solar refrigeration [7].

The problem of large volume occupation can be overcome by the use of PCM materials. PCMs also has the capability of holding heat or cold in a range of temperatures. These materials are now being used in space to provide the power to satellites. The selection of a right PCM material and suitable heat exchanger fluid can increase the overall efficiency of the system. The LHS materials also provide high thermal stability. The recovered temperature is almost constant which avoids the problems caused by variable temperature materials of SHS. But PCM materials have low lifecycles because of material degradation and other deformation problems [8].

The thermochemical materials possess the capabilities of high specific heat and storage capacity in a very small volume but they are very unstable. They decompose at high temperatures. A lot of research is going on in finding stable chemical compounds as they possess all the desirable properties. But at present, they are hard to handle and maintain [9].

VII. ECONOMICAL EVALUATION OF TES MEDIA

The most important factor in selection of a storage system is its cost because cost is the factor which will ease the commercialization of that technology. The main economic justification for the TES systems is that it requires less investment in operation and maintenance than the primary power generating plant. The power cost is direct measure of the energy converted from a storage system to utilizable power. The total cost of the system is product of this power cost and the power capacity of the storage measured in kW. Cost is actually directly related to the capacity of the storage system. However, the most economical solution for storage is sensible heat storage as these storage materials are easily available. The thermochemical heat storage THS are most expensive which makes their use impossible for small scale applications or low temperature storage [10]-[11].

VIII. CONCLUSION

In this paper, a general overview of some modern storage technologies is explained along with the techno-economic analysis to help reducing the challenges faced by energy production industry. A lot of research is still going on to improve the systems of storage and bring their cost down, still a single technology cannot fulfil all the requirements of an application.

The most economical storage technique is Sensible heat storage without any contend. But its large volume raises a lot of issues and restrict its use in many applications. On the other hand the Thermo-chemical materials have high storage capacity in a very small volume but their cost and instability raises concerns. However, latent heat storage using PCMs is considered a viable solution because of its high storage capacity and a wide range of operating temperatures. The use of complex heat exchanging materials in these systems results in an increased cost but the comparison of its performance parameters concludes them a best solution for large amount of energy storage as they are capable of storing 5 to 14 times more energy in typically less volume than sensible heat storage materials.

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