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Thermal Energy Storage System Design & Optimization

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Abstract:
The thermal energy storage (TES) system installation provides the optimization of energy source, energy supply security, flexibility of power plant operation and energy production. The aim of given research is feasibility analysis and evaluation of thermal energy storage system installation. Different research methods were used: data statistic processing and analysis, forecasting, financial analysis, correlation and regression methods. Finally, the best mode was chosen with aim to increase of co-generation unit efficiency during the summer and winter period.

1. INTRODUCTION:

Developing efficient and inexpensive energy storage devices is as important as developing new sources of energy. The thermal energy storage (TES) can be defined as the temporary storage of thermal energy at high or low temperatures. The TES is not a new concept, and at has been used for centuries. Energy storage can reduce the time or rate mismatch between energy supply and energy demand, and it plays an important role in energy conservation. Energy storage improves performance of energy systems by smoothing supply and increasing reliability. For example, storage would improve the performance of a power generating plant by load leveling. The higher efficiency would lead to energy conservation and improve cost effectiveness. Some of the renewable energy sources can only provide energy intermittently. The technology of thermal energy storage has been developed to a point where it can have a significant effect on modern life. The major non-technical use of thermal storage was to maintain a constant temperature in dwelling, to keep it warm during cold winter nights. Large stones, blocks of cast iron, and ceramics were used to store heat from an evening fire for the entire night.

1.1 Sensible Thermal Energy Storage

The use of hot water tanks is a well known technology for thermal energy storage. Hot water tanks serve the purpose of energy saving in water heating systems based on solar energy and in co-generation (i.e. heat and power) energy supply systems. State of the art projects have shown that water tank storage is a cost-effective storage option and that its efficiency can be further improved by ensuring an optimal water stratification in the tank and highly effective thermal insulation.

1.2 Underground Thermal Energy Storage (UTES)

UTES is also a widely used storage technology, which makes use of the underground as a storage medium for both heat and cold storage. UTES technologies include borehole storage, aquifer storage, cavern storage and pit storage. Which of these technologies is selected strongly depends on the local geological conditions.

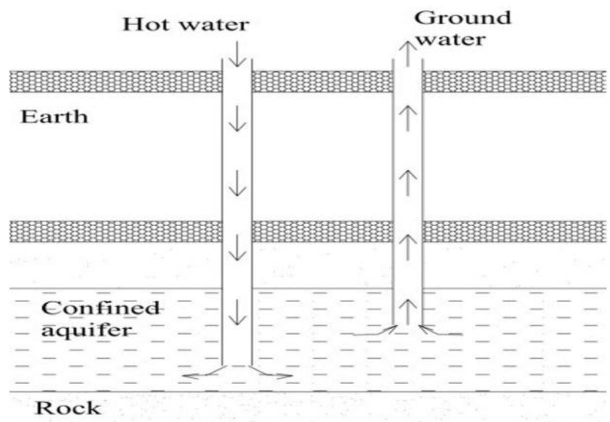


Figure.1. Underground sensible energy storage system

1.3 Solar Energy Storage Systems

Concrete is a relatively good medium for heat storage in passively heated or cooled houses. It is also considered for application in intermediate–temperature solar thermal plants. Consider the thermal energy storage system shown schematically in Figure 2. The system consist of a large liquid bath of mass m and specific heat C placed in an insulated vessel. The system also includes a collector to give the collector fluid a heat gain and a room in which this heat gain is discharge. Operation of the system takes place in three steps; charging, storage and removal processes. At the beginning of the storage process valves A, B, C are opened. Hot fluid from the collector at temperature T_{is} enters the system through valve C.

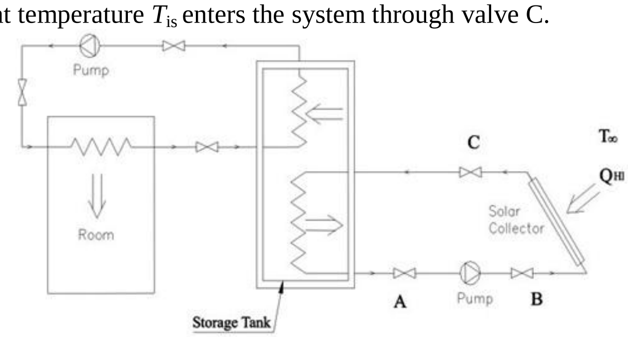


Figure.2. Schematic Diagram of the Solar Energy Storage System

Table.1. Typical parameters of thermal energy storage system

TES System	Capacity (kWh/t)	Power MW)	Efficiency (%)	Storage period (h, d, m)
Sensible (hot water)	10-50	0.001-10	50-90	d/m
PCM	50-150	0.001-1	75-90	h/m
Chemical reactions	120-250	0.01-1	75-100	h/d

2. Phase Change Materials for TES

Sensible heat storage is relatively inexpensive, but its drawbacks are its low energy density and its variable discharging temperature. These issues can be overcome by phase change materials (PCM)-based TES, which enables higher storage capacities and target oriented discharging temperatures. The change of phase could be either a solid/liquid or a solid/solid process. Melting processes involve energy densities on the order of 100 kWh/m^3 (e.g. ice) compared to a typical 25 kWh/m^3 for sensible heat storage options. Table 2 shows some of the most relevant PCMs in different temperature ranges with their melting temperature, enthalpy and density.

TABLE. 2. THERMAL STORAGE PCM PROPERTIES

PCM	Melting Temp., °C	Melting Enthalpy, kJ/kg	Density, g/cm^3
Ice	0	333	0.92
Na-acetate Trihydrate	58	250	1.3
Paraffin	-5 to 120	150-240	0.77
Erytritol	118	340	1.3

2.1 Phase Change Energy Storage

In latent heat storage the principle is that when heat is applied to the material it changes its phase from solid to liquid by storing the heat as latent heat of fusion or from liquid to vapor as latent heat of vaporization. When the stored heat is extracted by the load, the material will again change its phase from liquid to solid or from vapor to liquid. The latent heat of transformation from one solid phase into another is small. Solid-vapor and liquid-vapor transitions have large amounts of heat of transformation, but large changes in volume make the system complex and impractical. The solid-liquid transformations involve relatively small changes in volume. Such materials are available in a range of transition temperatures.

3. ANALYSIS OF TES SYSTEM

In this we are mainly dealing the interrelation of temperatures at hot and cold the experimental analysis of thermal energy storage. We are implementing the new technique of adding the hydrated salts and increasing the solidification of the storage system .The phase change material which helps in the storage of energy. LHS in a phase change material (PCM) is very attractive because of its high storage density. Hydrated salts are attractive materials for use in thermal energy storage due to their high volumetric storage density, relatively high thermal conductivity and moderate costs compared to paraffin waxes, with few exceptions. Phase change material (PCM) is very attractive because of its high storage density with small temperature swing. It has been demonstrated that for the development of a latent heat storage system in a building fabric, the choice of PCM plays an important role in addition to heat transfer mechanism in the PCM.

4. METHODOLOGY

There are three basic methods for storing thermal energy:

1. Heating a liquid or a solid, without changing phase: This method is called sensible heat storage. The amount of energy stored depends on the temperature change of the material and can be expressed in the form-

$$\mathbf{E = m \int_{T1}^{T2} Cp\, dT} \qquad \text{……..(2)}$$

where m is the mass and C_p; the specific heat at constant pressure. T_1 and T_2 represent the lower and upper temperature levels between which the storage operates. The difference (T_2 – T_1) is referred to as the temperature swing.

2. Heating a material, which undergoes a phase change (usually melting): This is called latent heat storage. The amount of energy stored (E) in this case depends upon the mass (m) and latent heat of fusion ($\boldsymbol{\lambda}$) of the material. Thus,

$$\boldsymbol{E=m\lambda} \qquad \text{…….(3)}$$

The storage operates isothermally at the melting point of the material. If isothermal operation at the phase change temperature is difficult, the system operates over a range of temperatures T_1 to T_2 that includes the melting point. The sensible heat contributions have to be considered and the amount of energy stored is given by

$$\boldsymbol{E = m\left[\left\{\int_{T1}^{T+} Cps\, dT\right\} + \lambda + \left\{\int_{T*}^{T2} Cp1\, dT\right\}\right]} \qquad \text{……..(4)}$$

where C_{ps} and C_{pl} represents the specific heats of the solid and liquid phases and T^* is the melting point. Using heat to produce a certain physicochemical reaction and then storing the products. Absorbing and adsorbing are two examples for the bond reaction. The heat is released when the reverse reaction is made to occur. In this case also, the storage operates essentially isothermally during the reactions. However, the temperature at which heat flows from the heat supply is usually different, because of the required storage material and vice versa.

Some of the considerations, which determine the selection of the method of storage and its design, are as follows:

- The temperature range, over which the storage has to operate.
- The capacity of the storage has a significant effect on the operation of the rest of the system. A smaller storage unit operates at a higher mean temperature. This results in a reduced heat transfer equipment output as compared to a system having a larger storage unit. The general observation which can be made

regarding optimum capacity is that “short-term” storage units, which can meet fluctuations over a period of two or three days, have been generally found to be the most economical for building applications.

• Heat losses from the storage have to be kept to a minimum. Heat losses are particularly important for long-term storage.

• The rate of charging and discharging.

• Cost of the storage unit: This includes the initial cost of the storage medium, the containers and insulation, and the operating cost.

4.1 Sensible Heat Storage

In the case of sensible heat storage systems, energy is stored or extracted by heating or cooling a liquid or a solid, which does not change its phase during this process. A variety of substances have been used in such systems. These include liquids like water, heat transfer oils and certain inorganic molten salts, and solid like rocks, pebbles and refractory. In the case of solids, the material is invariably in porous form and heat is stored or extracted by the flow of a gas or a liquid through the pores or voids. The choice of the substance used depends largely on the temperature level of the application, water being used for temperature below 100°C and refractory bricks being used for temperatures around 1000°C. Sensible heat storage systems are simpler in design than latent heat or bond storage systems. However they suffer from the disadvantage of being bigger in size. For this reason, an important criterion in selecting a material for sensible heat storage is its *(ρC_p)* value. A second disadvantage associated with sensible heat systems is that they cannot store or deliver energy at a constant temperature. We will first take up for consideration the various materials used. Performance of a THS is characterized by storage capacity, heat input and output rates while charging and discharging, and storage efficiency. The storage capacity of an SHS with a solid or liquid storage medium is given by

$$Q_s = mc\,\Delta T = V\rho c\,\Delta T \qquad \text{.....(5)}$$

where *m* is mass, *V* is volume, *c* is specific heat, ρ is density and $\Delta T = T_{max} - T_{min}$ is maximum temperature difference between maximum and minimum temperatures of the medium. This expression can be used to calculate the mass and volume of storage material required to store a given quantity of energy. For a packed bed used for energy storage, the porosity of the bed must be taken into consideration and neglecting the heat capacity of the energy transferring medium in the storage the volume of the packed bed storage is written as

$$V = Q_s / \rho c(1 - \varepsilon)\,\Delta T \qquad \text{......(6)}$$

where ε is the porosity of the packed bed. The storage energy density per unit mass and the storage energy density per unit volume are respectively defined as

$$q = Q_s / m = c(T_{max} - T_{min}) \qquad \text{.......(7)}$$

and

$$q_s = Q_s / V = \rho c(T_{max} - T_{min}) \qquad \text{.......(8)}$$

4.2 Liquid Storage Media

With its highest specific heat water is the most commonly used medium in a sensible heat storage system. Most solar water heating and space-heating systems use hot water storage tanks located either inside or outside the buildings or underground. The sizes of the tanks used vary from a few hundred liters to a few thousand cubic meters. An approximate thumb rule followed for fixing the size is to use about 75 to 100 liters of storage per square meter of collector area. Further details about the storage of solar energy are given. Water storage tanks are made from a variety of materials like steel, concrete and fiberglass. The tanks are suitably insulated with glass wool, mineral wool or polyurethane. The thickness of insulation used is large and ranges from 10 to 20 cm. because of this, the cost of the insulation represents a significant part of the total cost and mean to reduce this cost have to be explored. Shelton has shown that in an underground tank, the insulating value of the earth surrounding the tank may be adequate and this could provide the bulk of the insulation thickness required. However, it may take as much as one year for the earth around a large storage tank to reach a steady state by heating and drying, and a considerable amount of energy may be required for this purpose. If the water is at atmospheric pressure, the temperature is limited to 100°C. It is possible to store water at temperature a little above 100°C by using pressurized tanks. This has been done in a few instances.

Heat transfer oils are used in sensible heat storage systems for intermediate temperatures ranging from 100 to 300°C. Some of the heat transfer oils used for this purpose are Dowtherm and Therminol. The problem associated with the use of heat transfer oils is that they tend to degrade with time. The degradation is particularly serious if they are used above their recommended temperature limit. The use of oils also presents safety problems since there is a possibility of ignition above their flash point. For this reason, it is recommended that they be used in systems with an inert gas cover. A further limitation to the use of heat transfer oils is their cost. For this reason, they can be seriously considered for use only in small storage systems. A few molten inorganic salts have been considered for high temperatures (300°C and above). One is an eutectic mixture of 40 percent $NaNO_2$, 7% $NaNO_3$ and 53% KNO_3 (by weight) and is available under the trade name of ‘Hitec’. Hitec has a low melting point of 145°C and can be used up to a temperature of 425°C. Above this temperature; decomposition and oxidation begin to take place. Another molten salt being considered for high temperature storage is sodium hydroxide, which has a melting point of 320°C and could be used for temperatures up to 800°C. However, it is highly corrosive and there is difficulty in containing it at higher temperatures.

5. PROCESS & TECHNICAL APPROACH

Energy storage systems are designed to accumulate energy when production exceeds demand and to make it available at the user’s request. They can help match energy supply and demand, exploit the variable production of renewable energy sources (e.g. solar and wind), increase the overall efficiency of the energy system and reduce CO2 emissions. This brief deals primarily with heat storage systems or thermal energy storage (TES). An energy storage system can be described in terms of the following properties:

● **Capacity:** defines the energy stored in the system and depends on the storage process, the medium and the size of the system;
● **Power:** defines how fast the energy stored in the system can be discharged (and charged)

● **Efficiency:** is the ratio of the energy provided to the user to the energy needed to charge the storage system. It accounts for the energy loss during the storage period and the charging/discharging cycle;

● **Storage period: d**efines how long the energy is stored and lasts hours to months (i.e. hours, days, weeks and months for seasonal storage);

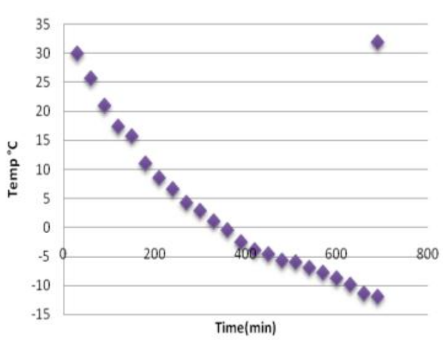
● **Charge and discharge time:** defines how much time is needed to charge/discharge the system

● **Cost:** refers to either capacity (/kWh) or power (/kW) of the storage system and depends on the capital and operation costs of the storage equipment and its lifetime (i.e. the number of cycles).

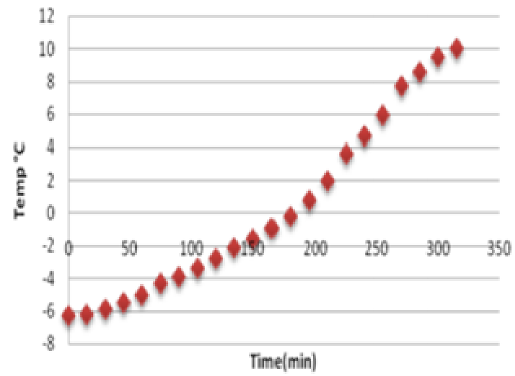
Capacity, power and discharge time are interdependent variables and in some storage systems, capacity and power can also depend on each other. For example, in TES systems, high power means enhanced heat transfer (e.g. additional fins in the heat exchanger), which, for a given volume, reduce the amount of active storage material and thereby the capacity. Thermal energy (i.e. heat and cold) can be stored as sensible heat in heat storage media, as latent heat associated with phase change materials (PCMs) or as thermo-chemical energy associated with chemical reactions (i.e. thermo-chemical storage) at operation temperatures ranging from -40°C to above 400°C. Typical figures for TES systems are shown in Table 1, including capacity, power, efficiency, storage period.

6. RESULTS

The graph shows that, when time increases, correspondingly temperature will start to increase initially. For a certain time period, there will be a constant value in temperature. The constant value will be suddenly tends to increase, due to increase in time and there will be gradual increase in temperature. Increase in temperature. Again, the temperature will start to decrease and attains a constant temperature, even there will be an increase in time. Then, there will be gradual decrease in temperature.

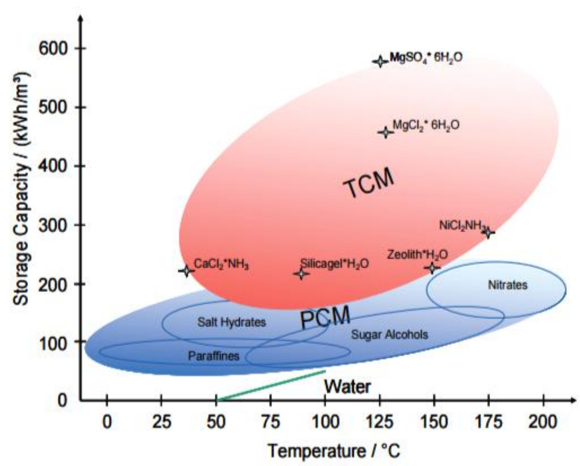


Graph .1. Freezing curve (80%water + salt 20%)



Graph .2. Thawing curve (80%water + 20%salt)

A thermal energy storage system mainly consists of three parts, the storage medium, heat transfer mechanism and containment system. The thermal energy storage medium stores the thermal energy either in the form of sensible heat, latent heat of fusion or vaporization, or in the form of reversible chemical reactions.



Graph.3. Storage Capacity Vs Temperature for Sensible, Latent and Thermo chemical TES.

7. CONCLUSION

Important fields of application for TES systems are in the building sector (e.g. domestic hot water, space heating, air-conditioning) and in the industrial sector (e.g. process heat and cold). TES systems can be installed as either centralised plants or distributed devices. Centralised plants are designed to store waste heat from large industrial processes, conventional power plants, combined heat and power plants and from renewable power plants, such as concentrated solar power (CSP). Their power capacity ranges typically from hundreds of kW to several MW (i.e. thermal power). Distributed devices are usually buffer storage systems to accumulate solar heat to be used for domestic and commercial buildings (e.g. hot water, heating, appliances). Distributed systems are mostly in the range of a few to tens of kW.

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