STORAGE OF THERMAL ENERGY

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Contents

Summary

This chapter is concerned with three modes of thermal energy storage (TES), and these are sensible heat storage (SHS), latent heat storage (LHS), and bond energy storage (BES). The SHS refers to the energy systems that store thermal energy without phase change. The SHS occurs by adding heat to the storage medium and increasing its temperature. Heat is added from a heat source to the liquid or solid storage medium. The thermal stratification is important for the SHS. Heating of a material that undergoes a phase change (usually melting) is called the LHS. The amount of energy stored in the LHS depends upon the mass and latent heat of the material. In the LHS, the storage operates isothermally at the phase change of the material. Lastly, comparison of storage system types is given.

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.

Although the sun provides an abundant, clean and safe source of energy, the supply of this energy is periodic following yearly and diurnal cycles; it is intermittent, often unpredictable and diffused. Its density is low compared with the energy flux densities found in conventional fossil energy devices like coal or oil-fired furnaces. The demand for energy, on the other hand, is also unsteady following yearly and diurnal cycles for both industrial and personal needs. Therefore the need for the storage of solar energy cannot be avoided. Otherwise, solar energy has to be used as soon as it is received. In comparison, the present yield in energy gained by fossil fuels and waterpower amounts to about $70x10^{12}$ kWh. But the technical use of solar energy presently poses problems primarily because of inefficient collection and storage.

One of the important characteristics of a storage system is the length of time during which energy can be kept stored with acceptable losses. If solar energy is converted into a fuel such as hydrogen, there will be no such a time limit. Storage in the form of thermal energy may last for very short times because of losses by radiation, convection and conduction. Another important characteristic of a storage system is its volumetric energy capacity, or the amount of energy stored per unit volume. The smaller the volume, the better is the storage system. Therefore, a good system should have a long storage time and a small volume per unit of stored energy.

If mass specific heat capacity is not small, denser materials have smaller volumes and correspondingly an advantage of larger energy capacity per unit volume. The space available is limited both in transport and in habitat applications. The volume occupied by the present available storage systems is considerable and may be an important factor in limiting the size of storage provided. The amount of energy storage provided is dictated by the cost. The cost of floor space or volumetric space should be one of the parameters in optimizing the size of storage.

The technology of thermal energy storage has been developed to a point where it can have a significant effect on modern life. The major nontechnical 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. With the advent of the industrial revolution, thermal energy storage introduced as a by-product of the energy production. A variety of new techniques of thermal energy storage have become possible in the past. A major application for thermal storage today is in family dwellings. Heat storage at power plants typically is in the form of steam or hot water and is usually for a short time. Very recently other materials such as oils having very high boiling point, have been suggested as heat storage substances for the electric utilities. Other materials that have a high heat of fusion at high temperatures have also been suggested for this application. Another application of thermal energy storage on the electric utilities is to provide hot water.

Perhaps the most promising application of thermal energy storage is for solar heated structures, and almost any material can be used for thermal energy storage.
The first-law efficiency of thermal energy storage systems can be defined as the ratio of the energy extracted from the storage to the energy stored into it

$$\eta = \frac{mC(T - T_o)}{mC(T_\infty - T_o)}, \qquad (1)$$

where mC is the total heat capacity of the storage medium and T , T_0 are the maximum and minimum temperatures of the storage during discharging respectively, and T_∞ , is the maximum temperature at the end of the charging period. Heat losses to environment between the end of discharging and the beginning of the charging periods, as well as during these processes are neglected. The first law efficiency can have only values less than one.

Two particular problems of thermal energy storage systems are the heat exchanger design and in the case of phase change materials, the method of encapsulation. The heat exchanger should be designed to operate with as low a temperature difference as possible to avoid inefficiencies.

If one tries to get an overview of heat storage systems one would be overwhelmed by the large number of possible technical solutions and the variety of storage systems. Latent heat thermal energy storage systems, using phase change materials to store heat or coolness, have many applications.

2. Methods of Thermal Energy Storage

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

$$E = m\int_{T_1}^{T_2} C_p dT \quad , \qquad (2)$$

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 (λ) of the material. Thus,

$$E = m\lambda \tag{3}$$

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

$$E = m\left[\left\{\int_{T_1}^{T^+} C_{ps} dT\right\} + \lambda + \left\{\int_{T^*}^{T_2} C_{pl} dT\right\}\right] \tag{4}$$

where C_{ps} and C_{pl} represents the specific heats of the solid and liquid phases and T^* is the melting point.

3. 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.

Of the above methods, sensible and latent heat storage systems are in use, while bond energy storage systems are being proposed for use in the future for medium and high temperature applications. The specific application for which a thermal storage system is to be used determines the method to be adopted. 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.

Other considerations include the suitability of materials used for the container, the means adopted for transferring the heat to and from the storage, and the power requirements for these purposes. A figure of merit that is used occasionally for describing the performance of a storage unit is the storage efficiency, which is defined by Equation (1).. The time period over which this ratio is calculated would depend upon the nature of the storage unit. For a short-term storage unit, the time period would be a few days, while for a long-term storage unit it could be a few months or even one year.

For a well-designed short-term storage unit, the value of the efficiency should generally exceed 80 percent. Table 1 gives an overview of thermal energy storage methods

Type of Thermal Energy Storage	Functional Principle	Phases	Examples
Sensible Heat	Temperature change of the medium with highest possible heat capacity	• Liquid	Hot water, organic liquids, molten salts, liquid metals
		• Solid	Metals, minerals, ceramics
Latent Heat	Essentially heat of phase change	• Liquid-Solid	Nitrids, clorides, hydroxides, carbonates, flourides, entectics
		• Solid-Solid	Hydroxids
Bond Energy	Large amount of chemical energy is absorbed and released due to shifting of equilibrium by changing pressure and temperature	• Solid-Gas	CaO/H_2O, MgO/H_2O, $FeCl_2/NH_3$
		• Gas-Gas	CH_4/H_2O
		• Liquid-Gas	$LiBr/H_2O$, $NaOH/H_2O$, H_2SO_4/H_2O

Table 1: Overview of thermal energy storage methods

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Biographical Sketch

Ö. Ercan Ataer received his B.Sc. degree at Mechanical Engineering Department of Middle East Technical University in Ankara in 1970. He received his M.Sc. (1974) and Ph.D. (1977) degrees at Engineering Department of Lancaster University in Lancaster, UK. He joined the Nuclear Engineering Department of the Hacettepe University in 1978. Subsequently in 1986 he joined the Mechanical Engineering Department of Gazi University in Ankara where he is a professor. He is giving lectures on heat and mass transfer and thermodynamics.at undergraduate and graduate level. His research is on heat transfer, thermodynamics, Stirling-cycle machines.