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High temperature latent heat thermal energy storage: Phase change materials, design considerations and performance enhancement techniques

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ABSTRACT

A very common problem in solar power generation plants and various other industrial processes is the existing gap between the period of thermal energy availability and its period of usage. This situation creates the need for an effective method by which excess heat can be stored for later use. Latent heat thermal energy storage is one of the most efficient ways of storing thermal energy through which the disparity between energy production or availability and consumption can be corrected, thus avoiding wastage and increasing the process efficiency.

This paper reviews a series of phase change materials, mainly inorganic salt compositions and metallic alloys, which could potentially be used as storage media in a high temperature (above 300 °C) latent heat storage system, seeking to serve the reader as a comprehensive thermophysical properties database to facilitate the material selection task for high temperature applications.

Widespread utilization of latent heat storage systems has been held back by the poor thermal conductivity and some other inherent drawbacks of the use of PCMs; this paper reviews several heat transfer and performance enhancement techniques proposed in the literature and discusses a number of design considerations that must be taken into account aiming to provide a broad overview for the design of high temperature latent heat based thermal energy storage systems.

Contents

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1. Introduction

Thermal energy storage (TES) is of great importance to many fields of engineering since it offers numerous benefits for various areas of the industry. For instance, one of the most common problems that solar power generation systems face is the gap that exists between the availability of the solar resource and energy demand, causing the need for an effective method by which excess heat collected during periods of high solar irradiation can be stored and retrieved later for use at night or during periods of darkness [1]. In addition to correcting the disparity between energy production or availability and consumption, thermal energy storage increases the effective use of equipment whose operation requires a heat supply [2].

A similar problem occurs in several industrial processes, where a great amount of waste heat could be reused by means of a waste heat recovery system; however in many cases the heat availability period differs from its usage period, and not having a storage system means all that excess energy, unusable at the moment of generation, will be simply wasted.

TES systems can help to reduce backup equipment required to secure power supply in hospitals, computer centers, and all those places where a reliable supply is vital [3] also, thermal energy storage can be used to provide thermal comfort in many types of buildings with heavy heating and air conditioning needs and thereby achieve a reduction in electric rates [1].

2. Thermal energy storage methods

There are three methods for storing thermal energy storage, the first two being the most widely used in TES systems:

- sensible heat storage;
- latent heat storage;
- thermochemical storage.

The present review article focuses mainly on latent heat storage with a transition from solid to liquid phase for reasons explained further on.

2.1. Sensible heat storage

Sensible heat storage (SHS) involves heating a material, without actually causing a phase change in it. Thermal energy is accumulated as a result of increasing the temperature of the storage medium. The amount of energy stored depends on the specific heat, the temperature change and the amount of material [4] and may be represented by the following expression:

$$Q = \int_{T_i}^{T_f} mC_p dT = mC_{ap}(T_f - T_i) \quad (1)$$

SHS systems can be classified on the basis of storage material as liquid media sensible storage (such as water, oil, molten salt, etc.) or solid media sensible storage (such as rocks, and metals).

2.2. Latent heat storage

Latent heat thermal energy storage (LHS) involves heating a material until it experiences a phase change, which can be from solid to liquid or from liquid to gas; when the material reaches its phase change temperature it absorbs a large amount of heat in order to carry out the transformation, known as the latent heat of fusion or vaporization depending on the case, and in this manner the energy is stored.

The following graph further explains the storage mechanism; as a solid material is heated its temperature begins to increase in direct proportion to the received energy until it reaches the melting temperature. Beyond this point, the energy delivered to the material ceases to raise the temperature, and is used instead to perform the transition from solid to liquid (latent heat), that is, the material stores isothermally the thermal energy received; once the transformation is complete and the material is wholly in the liquid state, the temperature begins to increase again as it receives a heat input until it reaches the vaporization point where the occurred in the first phase change is repeated. The heating process works the same way for cooling, which means that it is possible to extract the stored energy as latent heat at a constant temperature (Fig. 1).

As can be seen it is impossible to exclusively store latent heat, as to reach the phase change point the material had to undergo a temperature increase which represents storage of sensible heat. The storage capacity of an LHS system can be represented by the following expression [4]:

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{T_f} mC_p dT \quad (2)$$

$$Q = m[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)] \quad (3)$$

The first term of the equation represents the sensible heat stored by the material temperature increase from its initial temperature to the phase change temperature, the second term represents the energy stored by the latent heat of the material during the phase change, the amount of energy stored depends on the amount of material, the specific latent heat and the fraction of the material

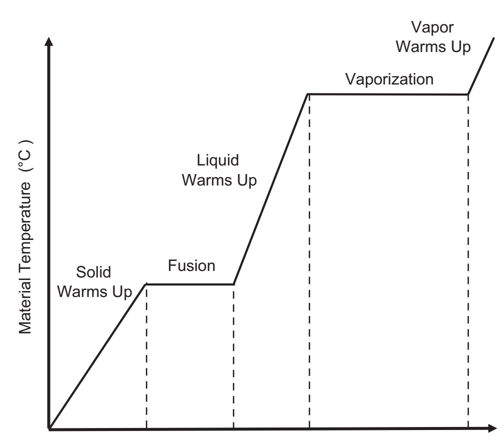

Fig. 1. Temperature increase profile in respect of supplied heat.