THERMAL ENERGY STORAGE WITH PHASE CHANGE MATERIAL

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Abstract Thermal energy storage (TES) systems provide several alternatives for efficient energy use and conservation. Phase change materials (PCMs) for TES are materials supplying thermal regulation at particular phase change temperatures by absorbing and emitting the heat of the medium. PCMs absorb energy during the heating process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process.

Keywords Phase,Thermal, Energy, Solar, collectors, latent, storage, tank, pump.

Система накопительная тепловой энергии с материалом с фазовым переходом

Абстракт Системы накопления тепловой энергии (СНТЭ) предоставляют несколько альтернатив для эффективного использования и сохранения энергии. Материалы с фазовым переходом (МФП) для (СНТЭ)-это материалы, обеспечивающие терморегуляцию при определенных температурах фазового перехода путем поглощения и излучения тепла среды. (МФП)поглощают энергию во время процесса нагрева, когда происходит фазовый переход, и выделяют энергию в окружающую среду в диапазоне фазового перехода во время обратного процесса охлаждения.

Ключевые слова Фаза, Тепловая, Энергетическая, Солнечная, коллекторы, скрытые, накопительные, резервуар, насос.

Fazalarda o'zgaruvchan material bilan issiqlik energiyasini boshqarish

Abstrakt Issiqlik energiyasini boshqarish tizimlari (IEBT) energiyadan foydalanish va uni tejash uchun bir qator alternativalarni taqdim etdi. (IEBT) uchun fazani boshqarish materiallari (ABM) - bu atrof-muhitdan issiqlikni yutish va nurlantirish orqali fazaning o'zgarishi aniq haroratda termoregulyatsiyani ta'minlovchi materiallar. (ABM) lar ishlash energiya almashinuvi amalga oshirilgan energiyani o'z ichiga olgan va teskari sharoitlarni yaratishda atrof-muhit sharoitida energiya samaradorligini oshirishda.

Kalit so'zlar Faza, bosqich, issiqlik, energiya, Quyosh, kollektor, yashirin, saqlash, tank, nasos.

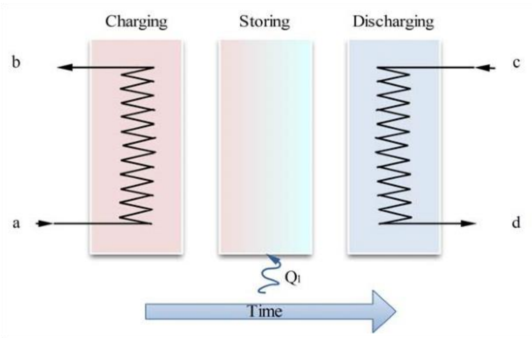
Introduction Thermal energy storage (TES) is defined as the temporary holding of thermal energy in the form of hot or cold substances for later utilization [1]. Energy demands vary on daily, weekly and seasonal bases. These demands can be matched with the help of TES systems that operate synergistically, and deals with the storage of energy by cooling, heating, melting, solidifying or vaporizing a material and the thermal energy becomes available when the process is reversed. TES is a significant technology in systems involving renewable energies as well as other energy resources as it can make their operation more efficient, particularly by bridging the period between periods when energy is harvested and periods when it is needed. That is, TES is helpful for balancing between the supply and demand of energy [1,2].

TES systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale fuel commutating [2]. The selection of a TES system for a particular application depends on many factors, including storage duration, economics, supply and utilization temperature requirements, storage capacity, heat losses and available space [3]. The main types of TES are sensible and latent. Sensible TES systems store energy by changing the temperature of the storage medium, which can be water, brine, rock, soil, etc. Latent TES systems store energy through phase change, e.g., cold storage water/ice and heat storage by melting paraffin waxes. Latent TES units are generally smaller than sensible storage units. More compact TES can be achieved based on storages that utilize chemical reactions [1].

A complete TES process involves at least three steps: charging, storing and discharging. In practical systems some of the steps may occur simultaneously (for example charging and storing) and each step may occur more than once in each storage cycle. In figure 1 is illustrated a simple storage cycle, in which the three steps are shown distinct. Where the heat Q_l is infiltrating and is positive in value for a cold thermal storage. If it is released, it will be toward the surrounding and Q_l will be negative. The heat flow is illustrated for the storing process, but can occur in all three processes [3].

In figure 2 is presented the increase of internal energy, when energy in the form of heat is added to a substance. The well-known consequence is an increase in temperature (sensible TES) or change of phase (latent TES). Starting with an initial solid state at point O, a heat addition to the substance first causes sensible heating of the solid (region O–A), followed by a solid-to-liquid phase change (region A–B), a sensible heating of the liquid (region B–C), a liquid-to-vapour phase change (region C–D), and a sensible heating of the vapour (region D–E). The total amount of heat can be written in the following formula [4]:

$$Q = m \cdot \left[\int_{TO}^{TA} C_{ps}(T)dT + q_{l} + \int_{TB}^{TC} C_{pl}(T)dT + q_{i} + \int_{TD}^{TE} C_{pv}(T)dT \right] \quad (1)$$



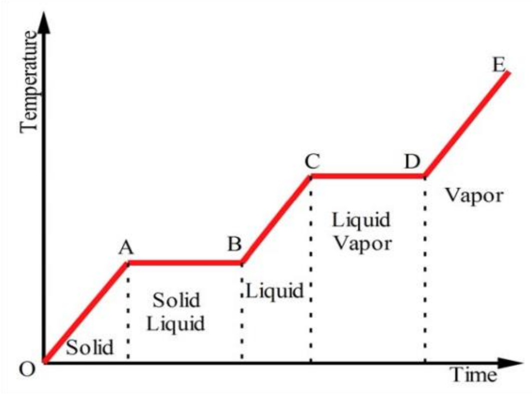
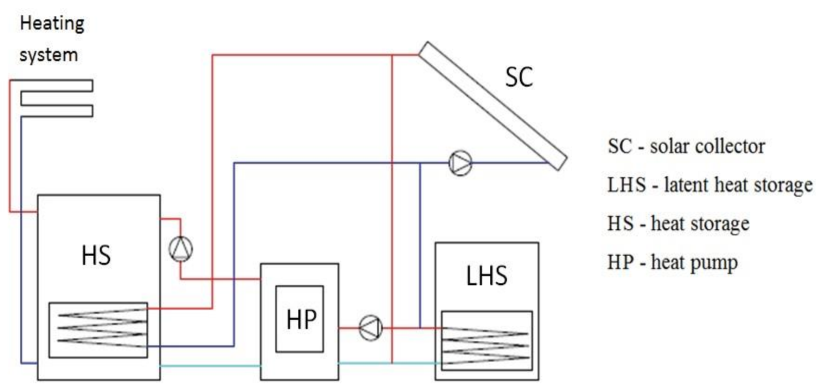


Figure 1. *The three processes*

Figure 2. *Temperature-time diagram in a general TES system*

Latent heat storage is one of the most efficient ways of storing thermal energy [5]. In latent TES systems, energy is stored during the phase change (e.g. melting, evaporating and crystallization). Due to the specific heat of a typical medium and the high enthalpy change during phase change, the latent heat change is usually greater than the sensible heat change for a given system size [1]. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat. Every material absorbs heat during heating process while its temperature is rising constantly. The heat stored in the material is released into the environment through a reverse cooling process. During the cooling process, the material temperature decreases continuously [5]. The stored energy during a latent storage process can be evaluated as: $Q=m\cdot L$ (2) where ***m*** denotes the mass and *L* is the specific latent heat of the PCM (Phase Change Material) [1]. Latent TES systems store energy in PCMs, with the thermal energy stored when the material changes phase, usually from a solid to liquid (for example: energy is required to convert ice to water, to change water to steam and to melt paraffin wax).



Phase change process of PCM from solid to liquid and vice versa is schematically shown in figure 3.

Figure 3. Schematic representation of phase change process

The large heat transfer during the melting process as well as the crystallization process without significant temperature change makes PCM interesting as a source of heat storage material in practical applications. When temperature increases, the PCM microcapsules absorbed heat and storing this energy in the liquefied phase change materials. When the temperature falls, the PCM microcapsules release this stored heat energy and consequently PCM solidify [5].

The energy required to cause these changes is named the *heat of fusion* at the melting point and the *heat of vaporization* at the boiling point. The specific heat of fusion or vaporization and the temperature at which the phase change occurs are very important in design phase. PCMs are either packaged in specialized containers such as: tubes, shallow panels, plastic bags; or contained in conventional building elements such as: wall board and ceiling; or encapsulated as self-contained elements [1,3].

The aim of this research paper was to provide a compilation of practical information on different PCMs and systems developed for thermal management in residential and commercial establishments based on TES technology in building integrated energy system. Types of PCM Figure 4 illustrated a classification of PCMs, but generally speaking PCMs can be broadly classified into two types: Organic PCMs e.g. Paraffin Wax and Inorganic PCMs e.g. Salt Hydrates.

Early efforts in the development of latent TES materials used inorganic PCMs. These materials are salt hydrates, including Glauber's salt (sodium sulphate decahydrate), which was studied extensively in the early stages of research into PCMs [10,11].

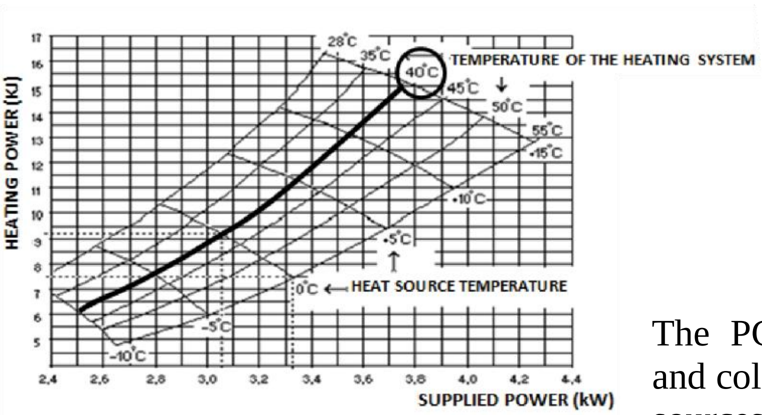


Figure 4. Diagram for determining COP.

The phase change properties of inorganic PCMs are shown in table 1 [9-12] and the most promising selection of organic PCMs is shown in table 2 [10,11].

Results and Discussion

The PCM can be used as natural heat and cold sources or manmade heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time. There are three different ways to use PCMs for heating and cooling of buildings exist: PCMs in building walls; PCMs in building components other than walls i.e. in ceilings and floors; and PCMs in separate heat or cold stores. The first two are passive systems, where the heat or cold stored is automatically released when indoor or outdoor temperatures rise or fall beyond the melting point. The third one is active system, where the stored heat or cold is contained thermally separated from the building by insulation. Therefore, the heat or cold is used only on demand and not automatically. In building applications, only PCMs that have a phase transition close to human comfort temperature (20–28ºC) can be used. Some Commercial PCMs have been also developed for building application [7,8,19]. Commercial PCMs suitable for building applications are presented .

Material and Method Thermal energy storage in the walls, ceiling and floor of the buildings may be enhanced by encapsulating or embedding suitable PCMs within these surfaces. They can either capture solar energy directly or thermal energy through natural convection. Increasing the thermal storage capacity of building can increase human comfort by decreasing the frequency of internal air temperature swings so that indoor air temperature is closer to the desired temperature for a longer period of time [8]. Some application areas for PCM in buildings are illustrated in Figure 6: No. 1: Latent heat store for space heating. No. 2: Plaster and compound systems with high heat storage capacity. No. 3: Transparent insulation and day lighting schemes. No. 4: Shading PCM compounding system. No. 5: PCM in gypsum products and paints. No. 6: PCM to buffer temperature variations in solar-air systems [21].

Among all the PCM applications for high performance buildings, the PCM integrated wall is most commonly studied and concerned due to its relatively more effective heat exchange area and more convenient implementation. Generally speaking, there are two ways to integrate phase change materials with building walls: “immersion” and “attachment”. The solution of “immersion” is to integrate the phase change materials with the construction material of the building envelope, such as concrete, bricks and plaster. There are normally three ways to immerse PCM with the building construction material: direct immersion, macro-encapsulated PCM and micro-encapsulated PCM [22].

Floor is also the important part of a building and heating and cooling of buildings were tried using it. Electrical under-floor heating system is one of the most commonly used methods to provide heat. In many countries, the electricity tariffs are different between peak hours (usually during daytime with high-tariff) and off peak hours (usually during night time with low-tariff).

A major development in this area is to develop a PCM which will maintain good heat storage during the day and heat loss to the environment during night time [7]. The use of a complete solid-liquid-vapor phase change cycle will further increase the storage density. Such systems are technically feasible, but quite a bit more complicated than the simple (and passive) solid-liquid-solid cycle [21].

PCM Integrated in Wood – Light Weight – Concrete

Wood –lightweight- concrete is a mixture of cement, wood chips or saw dust, which should not exceed 15 % by weight, water and additives. This mixture can be applied for building interior and outer wall construction. The incorporation of PCM has two additional reasons: to increase the thermal storage capacity and to get lighter and thinner wall elements with improved thermal performance [19]. It was shown that PCMs can be combined with wood-lightweight-concrete and that the mechanical properties do not seem to change significantly. The authors reported the following advantages:

- Thermal conductivity: λ between 0.15 and 0.75 W/m K;

- Noise insulation;
- Mechanical properties: density between 600 and 1700 kg/m^3;
- Heat capacity c_p within 0.39 to 0.48 kJ/kg K at ρ =1300 kg/m^3;
- Density about 60-70% of the value of pure concrete (0.67 kJ/kg K at ρ = 2400 kg $/m^3$).

  During the night time with relatively low temperatures (compared to the thermal comfort value), the face of the inner blind integrated with PCM is rotated to be exposed to the room air so that the stored energy is released back to the room, avoiding over-reduction of the room temperature below the thermal comfort value.

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