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Storage of thermal solar energy

Stockage thermique de l'énergie solaire

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ABSTRACT

Solar thermal energy storage is used in many applications, from building to concentrating solar power plants and industry. The temperature levels encountered range from ambient temperature to more than 1000 °C, and operating times range from a few hours to several months. This paper reviews different types of solar thermal energy storage (sensible heat, latent heat, and thermochemical storage) for low- (40–120 °C) and medium-to-high-temperature (120–1000 °C) applications.

RÉSUMÉ

Le stockage thermique de l'énergie solaire touche de très nombreuses applications, qui vont du bâtiment aux centrales solaires à concentration en passant par l'industrie. Les niveaux de température rencontrés vont de la température ambiante à plus d'un millier de degrés, et les durées d'utilisation de quelques heures à plusieurs mois. Cet article passe en revue les différentes familles de stockage d'énergie solaire thermique (stockage sensible,

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latent et thermochimique), pour des applications à basses (40–120 °C) et moyennes–hautes températures (120–1000 °C).

1. Introduction

Solar energy is available throughout the world and is sufficient to satisfy all human energy demand. However, it is diluted and intermittent. Therefore, energy storage systems must be associated with solar energy capturing to cover energy needs. Among all the different energy storage systems (pumped storage hydropower, compressed air energy storage, flywheel energy storage, electrochemical energy storage, capacitors, hydrogen storage, power to gas, etc.), thermal energy storage is one of the least expensive systems that can be applied to a broad spectrum of applications such as electricity production (using concentrated thermodynamic solar plants), industrial applications (chemical industry, food industry, etc.) and building applications (district heating, domestic hot water, thermal comfort, etc.). Different techniques are used for thermal energy storage. The most widely used is the sensible heat storage method. Other techniques such as latent energy storage and thermochemical energy storage have appeared in the last two decades, offering great heat storage capacity and reduced heat loss during the storage period. New material involving phase change and chemical reactions (peritectic compounds) appear to be promising given their great heat storage capacity.

Sensible heat storage consists in accumulating thermal energy in a solid or a liquid medium whose temperature then rises. For a given temperature elevation, a material's greater heat capacity will result in a larger amount of energy being stored (Eq. (1)).

$$Q = \int_{T_1}^{T_2} \int_{V} \rho c \, \mathrm{d}T \, \mathrm{d}V \tag{1}$$

Water has a particularly high heat capacity (about 4180 $\text{kJ·m}^{-3}\text{·K}^{-1}$), but is limited to applications under 100 °C unless pressure is increased. The heat capacity of most materials used for sensible heat storage varies between 900 and 3000 $\text{kJ·m}^{-3}\text{·K}^{-1}$. The thermal conductivity of such materials is also limited, ranging from 0.5 to 4 $\text{W·m}^{-1}\text{·K}^{-1}$ [1]. Two major applications of sensible heat storage deserve to be discussed further: storage for district heating networks and storage for solar power plants.

Latent heat storage involves the heat absorbed or released when a material changes from one physical state to another (when it is submitted to a phase change) and the sensible heat according to Eq. (2):

$$Q = \int_{T_1}^{T_\mathrm{F}} \int_{V_s} \rho_\mathrm{S} c_\mathrm{s} \, \mathrm{d}T \, \mathrm{d}V + \int_{V_s} \rho_\mathrm{S} L_\mathrm{F} \, \mathrm{d}V + \int_{T_\mathrm{F}}^{T_2} \int_{V_\mathrm{l}} \rho_\mathrm{l} c_\mathrm{l} \, \mathrm{d}T \tag{2}$$

Different phase changes can be encountered: solid ↔ solid, solid ↔ liquid, solid ↔ gas, and liquid ↔ gas. Latent heat storage mainly involves solid–liquid transformations of a material called a phase-change material (PCM). Over the last few years, various review papers [2–7] have presented the available latent thermal energy storage technologies and the current research in this field, focusing mainly on the assessment of the thermal properties of the various PCMs used. Moreover, the design of a cost-effective latent heat-storage system requires the development of thermal performance enhancement techniques. For example, this consists in enhancing heat transfers using mostly high-conductive materials, extended heat transfer surface, intermediate heat transfer medium, or multiple PCMs. Other constraints, such as liquid–solid transition, which sometimes exhibits a supercooling phenomenon, and the development of reliable numerical models, remain a challenge from a scientific point of view. The first one, if it exists, can cause system-wide performance downgrade and must also be considered. The second is necessary to optimize and estimate the thermal energy performance of systems.

Thermochemical thermal heat-storage systems can involve various processes: a sorption process, which consists in the fixation or the capture of a reactive gas by a condensed substance (either a solid – the process is called adsorption – or a liquid – the process is called absorption) or a chemical reaction, as described by Eq. (3).

$$< \mathrm{S} > + m\mathrm{G} \Leftrightarrow < \mathrm{S}m\mathrm{G} > + m\Delta Hr \tag{3}$$

Thermochemical thermal storages are promising given their high-energy densities and the low thermal loss between the storage and recovery steps, because energy is stored as chemical potential. In terms of the whole system, thermochemical storage requires the management of two materials in two different components: the sorbent (solid in a reactor or an adsorber/desorber; liquid in an absorber/desorber) and the active gas (in an evaporator/condenser) rendering the system more complex. The challenge is to take advantage of this complexity: first, it adds degrees of freedom for the management