Thermochemical seasonal solar energy storage for heating and cooling of buildings

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ABSTRACT

Actual national and international energy strategies generally encourage the use of renewable energy sources. Thermal energy storage (TES) offers various opportunities in the design of renewable energy systems. Thermochemical heat storage has gained popularity among researches because of higher energy density and lower heat loss compared to sensible and latent heat storage. On the other side solar energy has been recognized as one of the renewable energy sources with the most potential. This paper reviews thermochemical heat storage technologies and systems with emphasis on systems involving solar energy utilization in buildings. The studies are reviewed based on used storage materials, system configuration as well as models to predict and optimize system performance.

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1. Introduction

The key targets of the European Union (EU) 2030 Energy Strategy is to reduce greenhouse gas (GHG) emissions by at least 30% compared to 1990 levels, increase the share of renewable energy sources in final energy use to at least 27% and achieve an energy efficiency increase of at least 27%. Improving the energy performance of buildings is the key to achieve these goals, as buildings are responsible for 40% of energy use and 36% of CO_2 emissions in the EU [1,2]. The easiest and also the most promising measure is to increase the utilization of solar energy. Due to the stochastic nature of solar energy the use of heat storage technologies is necessary to realize its full potential.

Heat storage can be accomplished through physical or chemical processes. With respect to the form of heat involved we distinguish between sensible and latent physical heat storage methods. Sensible heat storage is achieved through the temperature rise of the storage material. In this case the density of the stored thermal energy (i.e. stored energy per unit volume or mass) depends on the temperature lift and thermal capacity of the storage material. Latent heat storage involves heat interactions associated with a phase change of a material (at constant temperature), commonly from liquid to solid, and vice versa. Latent heat storage generally allows higher heat densities than sensible heat storage, since thermal energy change during phase change in usually significantly

higher than the energy change due to temperature rise of a chosen material. Nevertheless sensible heat storage systems are still the prevalent technology for seasonal solar energy storage because of higher thermal stability and significantly lower cost of the involved storage materials compared to phase change materials (PCMs).

On the other side there are thermochemical TES systems which are not yet commercially viable. Thermochemical heat storage involves reversible chemical reactions. During the charging process heat is supplied to the storage material which causes an endothermic reaction. The supplied heat can be stored for an arbitrary time (almost) without heat loss as long as the products of the endothermic reaction are separated. This combined with a several times higher stored thermal energy density compared to sensible and latent storage (Fig. 1) makes thermochemical materials (TCM) a promising alternative for mid- and long-term heat storage.

The main objective of this paper is to review thermochemical heat storage technologies and systems with emphasis on systems involving solar energy utilization in buildings; hence with focus only on TCMs with a charging temperature below 140 °C [3]. The paper is organized as follows: Section 2 sums up the fundamentals of thermochemical heat storage and contains an overview of TCMs suitable for solar energy storage. Sections 3 presents' possible system configurations for thermochemical heat storage and evaluates applications appropriate for reducing the energy needs of buildings. An overview of models for predicting and optimizing the performance of thermochemical storage systems in included in Section 4. Section 5 concludes the paper.

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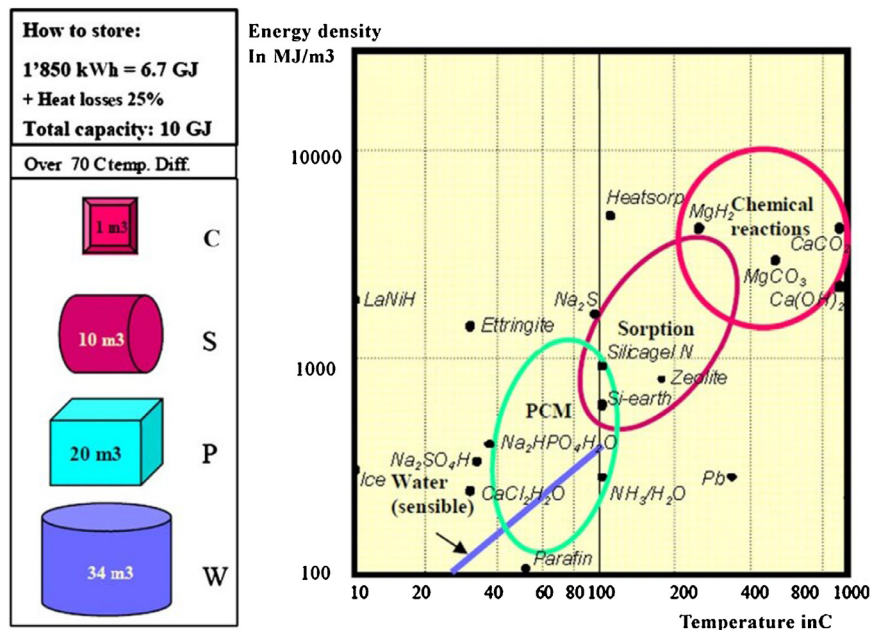*E-mail address:* uros.stritih@fs.uni-lj.si (U. Stritih).

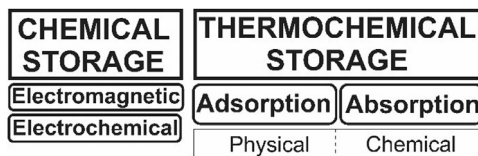**Fig. 1.** Energy density of thermal storage technologies (adopted from [4]).

Fig. 2. Classification of chemical heat storage.

2. Thermochemical heat storage

2.1. Basics

Thermochemical heat storage is generally classified under chemical heat storage processes (Fig. 2). Under the term thermochemical heat storage we usually summarize sorption heat storage processes. Some authors [e.g. [4]] also mention thermochemical storage without sorption but with no exact definition of the latter. Sorption can be defined as a phenomenon of fixation of a gas by a substance in solid or liquid phase [5]. We distinguish between adsorption and absorption. The term absorption is used when the molecules of a substance in gas phase enter a liquid (usually) or solid thereby changing the composition of the liquid or solid [6]. Adsorption is defined as binding of a gas on a surface of a solid or porous material [4]. Adsorption is further divided in physical adsorption or physisorption and chemical adsorption or chemisorption. The attraction between the gas and solid in physisorption is caused by Van der Waals forces. Chemisorption on the other hand is based on valence forces which form stronger bonds than Van der Waals forces. Consequently chemisorption processes enable to achieve higher thermal energy densities than physisorption however may also be irreversible and therefore unsuitable for heat storage applications. In the following sections only reversible sorption processes are considered.

Reversible sorption heat storage processes can be written in the following way:

$$AB + Q \leftrightarrow A + B \tag{1}$$

where AB is a compound of components A and B, Q designates the heat supplied to dissociate AB into components A and B. Hence
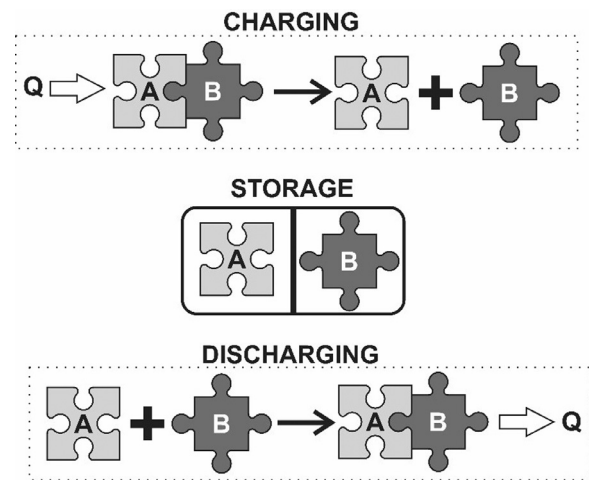

Fig. 3. Thermochemical heat storage cycle.

the dissociation of compound AB represents an endothermic reaction. When components A and B are put in contact heat is released (exothermic reaction) during the forming of compound AB. The supplied heat Q can be stored with negligible heat loss as long the components A and B are separated. As a result of this the dissociation of compound AB is called charging while the forming of compound AB represents the discharging process of the thermochemical heat storage cycle (Fig. 3). The component which is desorbed during charging is named adsorbate. The material capable of adsorbing (absorbing) the other component is called adsorbent (absorbent). The term adsorptive (absorptive) is also used for the adsorbate in the desorbed state, especially when adsorbate and adsorptive differ in chemical structure (not the case in physisorption). In heat storage applications mainly water (vapor) is used as adsorbate because of its availability (i.e. cheap) and nontoxicity.

The heat needed for desorption can be divided into three parts [5]:

$$Q = Q_{sens} + Q_{cond} + Q_{bind} \tag{2}$$