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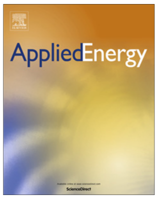

Sorption heat storage for long-term low-temperature applications: A review on the advancements at material and prototype scale

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HIGHLIGHTS

- A review on recent advancements on sorption heat storage is provided.
- Emphasis is on adsorbents, salt hydrates and composites with water as sorbate.
- Solid sorption systems based on the reviewed materials are analyzed.
- Prototype performance and experimental conditions are specified and compared.

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ABSTRACT

Sorption heat storage has the potential to store large amounts of thermal energy from renewables and other distributed energy sources. This article provides an overview on the recent advancements on long-term sorption heat storage at material- and prototype- scales. The focus is on applications requiring heat within a temperature range of 30–150 °C such as space heating, domestic hot water production, and some industrial processes.

At material level, emphasis is put on solid/gas reactions with water as sorbate. In particular, salt hydrates, adsorbents, and recent advancements on composite materials are reviewed. Most of the investigated salt hydrates comply with requirements such as safety and availability at low cost. However, hydrothermal stability issues such as deliquescence and decomposition at certain operating conditions make their utilization in a pure form challenging. Adsorbents are more hydrothermally stable but have lower energy densities and higher prices. Composite materials are investigated to reduce hydrothermal instabilities while achieving acceptable energy densities and material costs.

At prototype-scale, the article provides an updated review on system prototypes based on the reviewed materials. Both open and closed system layouts are addressed, together with the main design issues such as heat and mass transfer in the reactors and materials corrosion resistance. Especially for open systems, the focus is on pure adsorbents rather than salt hydrates as active materials due to their better stability. However, high material costs and desorption temperatures, coupled with lower energy densities at typical system operating conditions, decrease their commercial attractiveness. Among the main conclusions, the implementation within the scientific community of common key performance indicators is suggested together with the inclusion of economic aspects already at material-scale investigations.

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Nomenclature

C	cost (€)
E	volumetric energy density (GJ/m^3)
p	pressure (mbar)
P	power (kW)
RH	relative humidity (%)
T	temperature (°C)
t	time (h)

Abbreviations

CHP	combined heat and power
COP	coefficient of performance
DHW	domestic hot water
DRH	deliquescence relative humidity
DSC	differential scanning calorimetry
DTA	differential thermal analysis
ENG	expanded natural graphite
NMR	nuclear magnetic resonance
PSD	particle size distribution
SEM	scanning electron microscopy
TGA	thermogravimetric analysis
WSS	wakkanai siliceous shale
XRD	X-ray powder diffraction

Subscripts and superscripts

ads	adsorption
des	desorption
el	electrical
sorp	sorption
th	thermal

1. Introduction

The awareness of humankind's role into climate change [1] and the increasing energy intensity in developing and underdeveloped countries [2] are among the main drivers for a more sustainable production and use of energy. The energy grid consists of a system in which multiple carriers are produced, transported, consumed, and stored. The level of complexity of this system is constantly increasing due to technological advancements such as energy production systems with new requirements, transportation and storage methods that are more efficient, new policies, and new types of consumers and other stakeholders. The advance of renewable energy sources, cogeneration, and intermittent power sources in general, is drastically changing the requirements on the energy grid. Some of the new energy production units are characterized by relatively low and decentralized installed capacities, intermittent and often unpredictable production patterns frequently driven by the owner's needs or by the source availability, and production of multiple energy carriers. Therefore, the energy network is constantly evolving [3,4] to cope with new types of stakeholders and an increasing penetration of intermittent distributed production sources. Storage of multiple energy carriers, demand side management, exchange and relocation through conversion of energy carriers are among the main practices that the future system will have to incorporate to gain the needed flexibility [5]. Energy storage is useful to handle fluctuations in energy demand to spread the production of energy needed during demand peaks over a different time period and to make efficient use of fluctuating production sources such as renewables, increase energy grid safety, and improve the overall system efficiency [6]. In Table 1-1, an overview of the main storage technologies, their costs, efficiencies, and typical response times is displayed.

Thermal energy storage is an attractive storage category because in principle it can be more economical than other technologies, it has a wide range of storage possibilities with storage periods ranging from minutes to months, and finally because thermal energy dominates the final energy use in sectors such as industry or household (Fig. 1-1 left). Thermal energy storage can be divided into three main categories according to how energy is stored: sensible heat (e.g. water tanks, underground storage) [11–13], latent heat (e.g. ice, phase change materials) [14–16], and sorption heat storage.

1.1. Sorption heat storage

Sorption heat storage implies the use of physical or chemical bonds to store energy. The principle of sorption occurs during a