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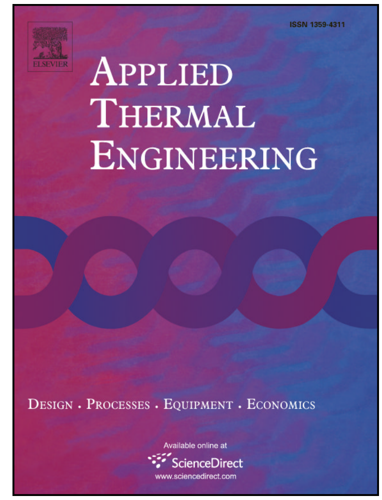

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Predicting performance of adsorption thermal energy storage: from experiments to validated dynamic models

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Abstract

Thermal energy storage can improve the energy efficiency in industrial and residential heating applications by balancing heat supply and demand. High energy storage densities can be achieved by adsorption thermal energy storage (adsorption TES). Adsorption TES can be applied at temperatures up to 300 °C and allows for the integration of waste heat via the heat pump effect. To efficiently apply adsorption TES, a thorough understanding is required of both the performance of the storage unit itself and its dynamic interaction with the energy system.

In this work, we contribute to the understanding and prediction of the performance of adsorption TES by providing a validated dynamic model. To allow for extensive studies within an energy system, the complex geometry of the storage unit is condensed into a 1-dimensional lumped-parameter model. We are able to calibrate the model of an adsorption TES unit using only few experiments of adsorption cycles and heat losses. The developed calibration procedure yields a very accurate description of the performance of the adsorption TES unit. The prediction accuracy of the model is demonstrated for various measurements at different temperatures and storage times ranging from a few hours to days and even seasonal storage. The results show that the dynamic model provides sound predictions, describes heat losses accurately and outperforms models from literature. Thus, the model enables the simulation-based analysis of a wide range of storage applications with excellent prediction of the storage performance.

Keywords: `thermal storage, heat storage, heat pump, water vapor adsorption, zeolite`

1. Introduction

Thermal energy storage (TES) helps to decouple heat supply and demand: surplus energy can be stored for later use, to reduce peak-energy consumption [1]. TES thus helps to improve the resource-use efficiency of an energy system [2]. The design of energy systems with TES requires, amongst other things, high storage capacities and low thermal losses [3]. Adsorption thermal energy storage systems have the potential for high storage capacities and long-term energy storage with limited heat loss [4]. Furthermore, adsorption systems can store thermal energy over a wide range of temperatures [5]. Hence, various applications ranging from residential heating [6] to industrial processes [7] can benefit from adsorption thermal energy storage systems.

The basic principle of adsorption TES is shown in Figure 1 for zeolite and water in a closed system, as investigated in this work. During charging, the heat input Q_{des} leads to an increase of the temperature in the zeolite and to desorption, i.e. to the release of water vapor. The released water vapor can be condensed at a lower temperature. The enthalpy of condensation can be used as low temperature heat Q_{cond} or be dismissed to the environment. During the storage period, zeolite and water are stored separately until the stored thermal energy is needed. During discharging of the storage unit, the charging process is reversed: low-grade heat Q_{vap} is used to vaporize water at low temperatures. The water vapor is adsorbed by the zeolite. Hereby, the enthalpy of adsorption is released and can be used as process heat Q_{ads} at a higher temperature. The low grade heat in the discharging process can be waste heat or come from the environment. Thus, adsorption TES allows to integrate low-grade heat into the process heat supply to enhance energy efficiency [8].

To benefit from the advantages of adsorption TES, a

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