Experimental testing of an adsorption thermal energy storage system

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Abstract

The objective of this work is to test and characterize a lab-scale silica gel/water test bench realized at POLIMI labs and operating as Thermal Energy Storage (TES) system for domestic applications. Several charging and discharging cycles were performed setting 20-35, 30-50, and 80-90 °C as heat transfer fluid temperatures for the evaporation, condensation/adsorption and desorption processes. The system performance is evaluated in terms of energy efficiency, charge and discharge rate, and operating cost.

Keywords: Adsorption, Silica Gel/Water, Thermal Energy Storage

Introduction

Despite the fact that 2020 emissions were lower than in 2019 as a result of the COVID-19 crisis and subsequent countermeasures, GHG concentrations in the atmosphere continue to rise, with the immediate reduction in emissions predicted to have a minor long-term influence on climate change. In 2019, global GHG emissions increased for the third year in a row, reaching a new high of 52.4 GtCO2e without land-use change (LUC) emissions and 59.1 GtCO2e when LUC emissions are included. Total GHG emissions are dominated by fossil carbon dioxide (CO2) emissions (from fossil fuels and carbonates). Fossil CO2 emissions in 2019 set a new high of 38.0 GtCO2 [1]. In contrast, global GHG emissions in 2030 need to be approximately 25% and 55% lower than in 2017 to put the world on a least-cost pathway to limiting global warming to 2 °C and 1.5 °C, respectively [2].

Global CO2 emissions are above the targets set by the agreements on Mitigation of Climate Change and the national governments. The major reason is that although energy efficiency considerably improved and renewables have been installed at a large scale, this was overcompensated by economic growth resulting in an increase in emissions. Furthermore, heating/cooling and domestic hot water production represent an important share of the primary energy demand in the residential sector. In such a context, Thermal Energy Storage (TES) systems have the potential to revolutionize the way households meet their energy demands, but the development of efficient and cost-effective units is crucial. In this work, we present the experimental testing of a lab-scale silica gel/water test bench realized at POLIMI labs and operating as a Thermal Energy Storage (TES) system for domestic applications.

Adsorption technology is a promising method for thermal energy storage in residential applications [3, 4]. The technology involves the use of adsorbent materials to store thermal energy in the form of heat. These materials have the ability to adsorb heat by attracting and retaining heat energy at high temperatures. The most commonly used adsorbents are silica-gel and zeolites. Zeolites are porous minerals that have a high surface area, making them ideal for heat storage. They can store heat at high temperatures and release it when needed, making them a promising material for residential thermal energy storage.

Adsorption technology is highly attractive for residential applications due to its high energy storage density, low cost, and ease of integration with existing heating systems. It has the potential to significantly reduce energy costs and improve energy efficiency in residential homes.

Discussion and Results

The studied system is based on a sorption storage technology, which relies on the reversible reaction, associated with a high amount of thermal energy, occurring between a sorbent and a sorbate. Such a process is limited by the slow reaction kinetics, because of the large amount of heat associated as well as the heat and mass transfer diffusion resistance within the material. However, this feature is extremely useful in a residential-type application, since it allows the reaction to be controlled and the discharge power to be regulated precisely. In the proposed concept, the solar (or alternatively, the district) heat is employed to drive a desorption process, which means that solar heat is stored in the form of adsorption potential energy. Moreover, the heat is stored without any loss until the refrigerant fluid (adsorbate) is kept separated from the adsorbent enabling in fact the long-term storage of solar energy. Generally, there are two system configurations for adsorption TES: closed and open cycle. The studied heat storage system belongs to the closed-cycle sorption storage category.

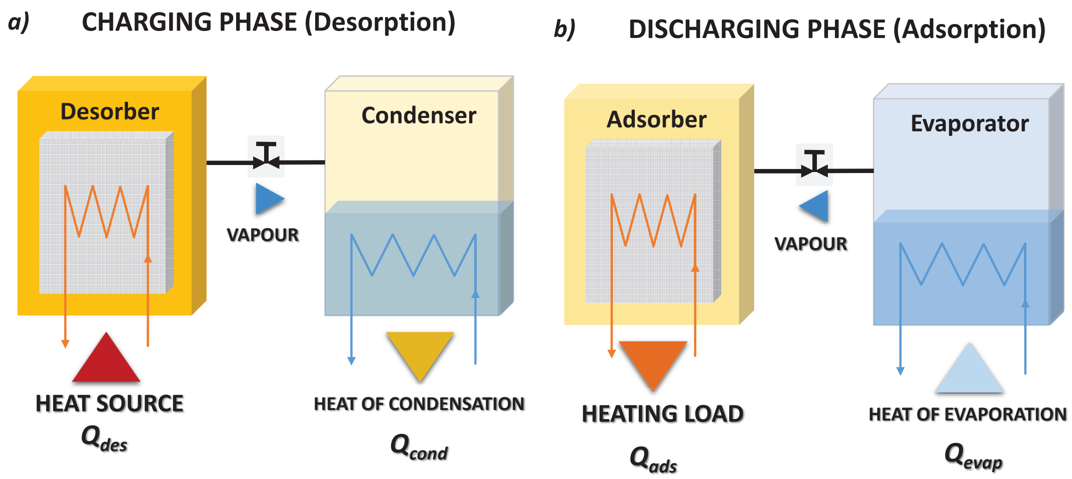

Figure 1: A closed adsorption heat storage cycle: (a) charging phase; (b) discharging phase

Figure 1 reports the working phases of closed adsorption. During the charging phase, the adsorber, in which the adsorbent material is saturated with adsorbate, is regenerated by exploiting heat coming from the solar field. The desorbed vapour is then condensed in the condenser, and the heat of condensation, Qcond, is either dissipated in the ambient or delivered to a proper load if the temperature level is adequate. Once the charging process is completed, and the adsorbent material is dry, the connection between the condenser and adsorber is closed. In this condition, the system can keep the stored energy for an indefinite time since the thermal energy is stored as adsorption potential between adsorbate and adsorbent material. To recover the stored thermal energy the connection between the liquid adsorbate reservoir, which in this phase acts as an evaporator, and the adsorber is again opened. During this discharging phase, the adsorbate is evaporated adsorbing heat from the ambient, Qevap, or providing a cooling effect to the domestic user. Then, the vapour fluxes to the adsorber and, since the adsorption process is exothermic, the heat stored is released to the load. It is self-evident that in this heat storage system, the adsorbate is continuously condensed/evaporated in a closed device without any mass exchange with the ambient, thus ensuring proper operation in dry climates.

Next Fig 2a, b reports the schematic layout and a photo of the experimental set-up that has been built at POLIMI labs to test adsorption units and their components. The core of the system consists of a single adsorbent bed, a falling-film evaporator equipped with a recirculation pump to improve the heat transfer efficiency and a condenser. The adsorbent bed was made of granular RD silica gel embedded in a finned heat exchanger. The three components are connected by two electric-actuated valves to allow the passage of water vapour enabling the ad/desorption phase. The external sinks/sources consist of three hydraulic circuits with a nominal capacity of 2 kW for the evaporator and condenser and 5 kW for the adsorber, with flow rates between 200 and 1000 L/h. The test bench is provided with several Pt100 temperature sensors, pressure transducers and flow meters to measure the relevant quantities required to monitor the system's evolution and performance. A real-time control and data acquisition software was realised employing the LabView™ language. More details on the test bench realized at POLIMI are reported elsewhere [5].

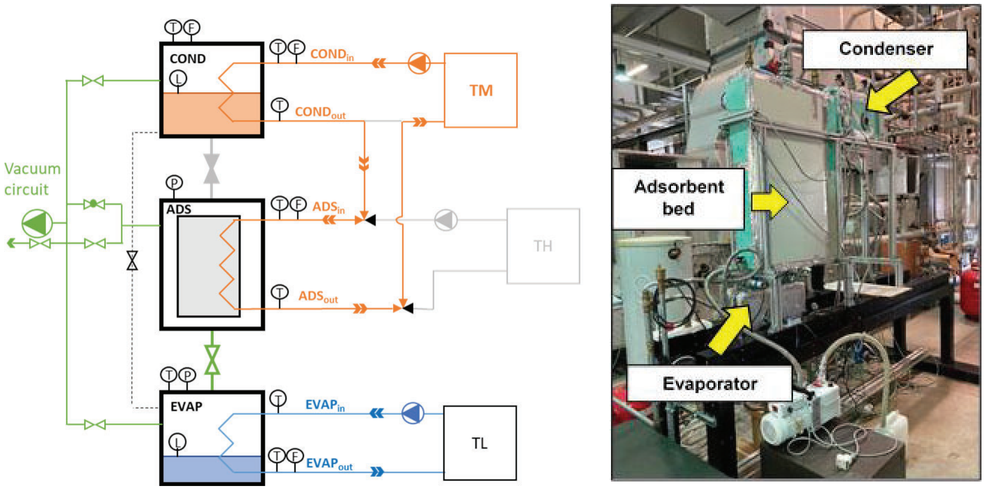

Figure 2a, b – Adsorption test rig schematic and photo

Testing activity is currently in progress according to the typical operating conditions of an adsorption TES system driven by a low-grade heating source (80-90°C) at different temperatures of evaporation and adsorption/condensation. The system performance is evaluated in terms of energy efficiency, charge and discharge rate, and operating cost. Preliminary testing results confirm the high potential for adsorption thermal energy storage systems in the residential sector and highlight the importance of continued research and development in this field.

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