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EXPERIMENTAL PERFORMANCE OF A SOLAR-DRIVEN ADSORPTION ATMOSPHERIC WATER HARVESTING PROTOTYPE

Summary

This work presents the design and preliminary experimental testing of an adsorption-based atmospheric water harvesting prototype using microporous silica gel as adsorbent material. The system consists of two adsorption chambers equipped with finned heat exchangers and operated through high-temperature (HT) and medium-temperature (MT) thermal circuits to perform the adsorption–desorption cycle. Experimental tests conducted at a regeneration temperature of about 70 °C and ambient conditions of 18–20 °C with approximately 60% relative humidity demonstrated the capability of the system to produce about 0.58 kg of water per adsorption chamber per cycle. The measured performance corresponds to an effective uptake of about 16% of the adsorbent mass, approaching the theoretical value of 22% for silica gel. These results confirm the feasibility of the proposed system and highlight its potential for solar-driven atmospheric water harvesting applications.

Keywords: Atmospheric Water Harvesting, Adsorption, Silica Gel, Solar Thermal Energy, Water Production

Field of application for the findings: Renewable-energy-driven water production, atmospheric water harvesting systems, solar thermal applications, decentralized water supply technologies.

Addressed audience: People that work solar thermal systems, adsorption processes, atmospheric water harvesting technologies, and sustainable water-energy solutions.

1. Introduction

Water scarcity is becoming one of the most critical global challenges due to population growth, climate change and increasing water demand. Many regions of the world already experience severe water stress, highlighting the need for sustainable and decentralized technologies for freshwater production. Among the emerging solutions, Atmospheric Water Harvesting (AWH) has gained increasing attention as a promising approach to produce potable water directly from atmospheric humidity (Kim et al., 2017; Tu et al., 2018). Since the atmosphere contains a significant amount of water vapor, AWH technologies can provide freshwater independently from conventional water sources such as groundwater or desalination systems. Several AWH technologies have been investigated, including condensation-based systems and adsorption-driven processes using hygroscopic materials (Fathieh et al., 2018; LaPotin et al., 2020). Adsorption-based systems are particularly attractive because they can operate under relatively low humidity conditions and can be driven by low-grade thermal energy (Wang and Oliveira, 2006; Aristov, 2009), which makes them suitable for integration with renewable energy sources such as solar thermal systems. In adsorption-based AWH systems, water from ambient air is captured by a porous adsorbent material during the adsorption phase. The adsorbent is then regenerated by heating, releasing the stored water vapor which subsequently condenses and can be collected as liquid water. Despite the growing interest in these technologies, experimental studies on prototype systems are still limited and are necessary to evaluate real system performance and identify the main parameters affecting water production. For this reason, this work presents the design and preliminary experimental testing of an adsorption-based atmospheric water harvesting prototype driven by low-temperature thermal energy. The study focuses on the description of the developed prototype and on the analysis of the first experimental results obtained during the testing phase.

2. Prototype Description and Experimental Setup

The developed prototype is an adsorption-based atmospheric water harvesting system designed to investigate the feasibility of water production from ambient air using low-grade thermal energy. The system consists of two adsorption beds and two thermal circuits used respectively for adsorbent regeneration and cooling. Each adsorption bed contains four finned heat exchangers (HExs) filled with a sorbent material. In this study, each heat exchanger was filled with approximately 900 g of microporous silica gel. The heat exchangers are designed to enhance heat transfer during both adsorption and desorption phases while ensuring effective contact between the adsorbent material and the air flow. During the adsorption phase, ambient air is drawn into the system by means of fans and directed toward the adsorption chambers. Water vapor contained in the air is captured by the silica gel through a physical adsorption process. As the adsorption process proceeds, the adsorbent gradually approaches saturation. Once the adsorption phase is completed, the system enters the regeneration phase. Thermal energy is supplied to the heat exchangers through a high-temperature (HT) circuit, which is heated by electrical resistances in the experimental setup and simulates the thermal input that could be provided by solar thermal collectors in a real application. The heating of the adsorbent causes the release of the previously adsorbed water vapor. The released vapor condenses inside the chamber surfaces and the liquid water is conveyed to the bottom of the chamber, where it is collected in a dedicated tank for measurement. Cooling during the adsorption phase is provided by a medium-temperature (MT) circuit connected to external dry coolers, allowing the control of the adsorbent temperature and improving the water uptake capacity of the silica gel. The experimental tests were performed with an HT temperature of approximately 70 °C, while the MT circuit was air-cooled at about 20 °C, close to the ambient temperature. The indoor ambient conditions during the tests ranged between 18–20 °C with an average relative humidity of approximately 60%. The produced water was collected and measured after each operating cycle to evaluate the performance of the prototype.

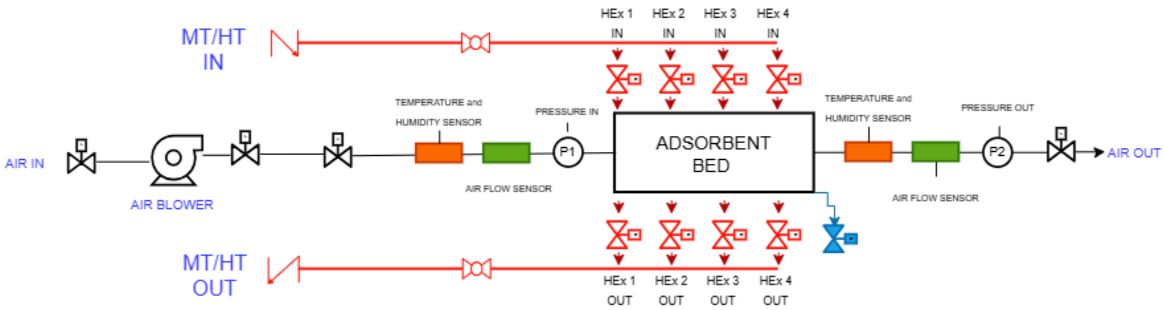

Fig. 1:Simplified schematic of a single adsorption bed of the prototype showing the air flow circuit and the water thermal circuit.

Fig. 2: Experimental prototype of the adsorption-based atmospheric water harvesting system

3. Results and Discussion

Preliminary experimental tests were conducted to evaluate the water production capability of the developed adsorption-based atmospheric water harvesting prototype. The system was operated under the previously described laboratory conditions, with a regeneration temperature of approximately 70 °C and an adsorption temperature close to 20 °C, under ambient conditions of 18–20 °C and about 60% relative humidity.The experimental results confirmed the ability of the prototype to capture atmospheric moisture and produce liquid water through the adsorption–desorption cycle. During the adsorption phase, the silica gel adsorbent captures water from the incoming air flow, while the subsequent regeneration phase enables the release and condensation of the adsorbed moisture. During the experimental tests, approximately 0.58 kg of water was collected per adsorption chamber per cycle. Considering the total adsorbent mass of 3.6 kg of silica gel per chamber, this corresponds to an effective water uptake of about 16% of the adsorbent mass. The theoretical adsorption capacity of the silica gel under the tested conditions is approximately 22%, indicating that the experimental results are reasonably close to the expected value. The difference between the theoretical and measured water production can be attributed to several factors, including experimental uncertainties related to sensor accuracy and the prototype configuration, as well as the possibility that not all the condensed water is effectively collected within the chamber during the experimental cycle. The behavior of the system during the adsorption phase is illustrated in Fig. 3, which shows the variation of temperature (air and water) and relative humidity at the inlet and outlet of the adsorption chamber. The observed decrease in humidity between inlet and outlet air confirms the effective adsorption of water vapor by the silica gel. Overall, the experimental results confirm the feasibility of the proposed adsorption-based system and demonstrate its potential for solar-driven atmospheric water harvesting applications, while highlighting the need for further optimization of the prototype and improvement of the water collection efficiency.

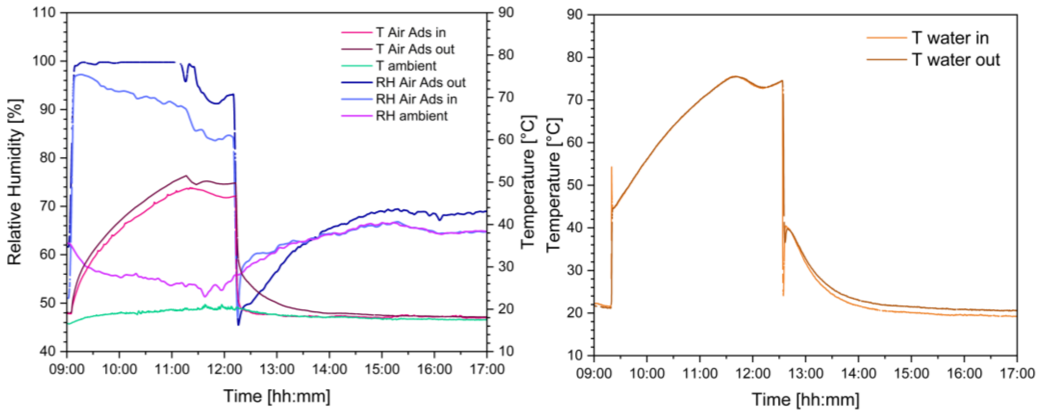

Figure 3 – Plots of temperature (air and water) and relative humidity profiles at the inlet and outlet of the adsorption chamber.

4. References

Aristov, Y.I., 2009. Adsorptive transformation and storage of renewable heat: Review of current trends in adsorption dynamics. Journal of Engineering Thermophysics 18, 201–227.

Fathieh, F., Kalmutzki, M.J., Kapustin, E.A., Waller, P.J., Yang, J., Yaghi, O.M., 2018. Practical water production from desert air. Science Advances 4, eaat3198.

Kim, H., Yang, S., Rao, S.R., Narayanan, S., Kapustin, E.A., Furukawa, H., Umans, A.S., Yaghi, O.M., Wang, E.N., 2017. Water harvesting from air with metal–organic frameworks powered by natural sunlight. Science 356, 430–434.

LaPotin, A., Kim, H., Rao, S.R., Wang, E.N., 2020. Adsorption-based atmospheric water harvesting: Impact of material and component properties on system-level performance. Accounts of Chemical Research 53, 1587–1597.

Tu, Y., Wang, R.Z., Zhang, Y., Wang, J.Y., 2018. Progress and expectation of atmospheric water harvesting. Joule 2, 1452–1475.

Wang, R.Z., Oliveira, R.G., 2006. Adsorption refrigeration—An efficient way to make good use of waste heat and solar energy. Progress in Energy and Combustion Science 32, 424–458.