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Editorial

Adsorption Desalination and Cooling Systems: Advances in Design, Modeling and Performance

Marcin Sosnowski [1,*], Jaroslaw Krzywanski [1] and Norbert Skoczylas [2]

[1] Faculty of Science and Technology, Jan Dlugosz University in Czestochowa, Armii Krajowej 13/15, 42-200 Czestochowa, Poland; j.krzywanski@ujd.edu.pl
[2] Strata Mechanics Research Institute of the Polish Academy of Sciences, Reymonta 27, 30-059 Kraków, Poland; skoczylas@imgpan.pl
* Correspondence: m.sosnowski@ujd.edu.pl

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1. Introduction

The increase in energy efficiency, reducing energy demand, greenhouse gas emissions and the use of waste, renewable and recycled heat from low-temperature sources are significant challenges today and are key parts of the idea of the 4th Generation District Heating (4GDH). On the other hand, currently about one billion people around the world are suffering from water scarcity, and another three billion are approaching this situation. Only 2.5% of the total water globally is freshwater, of which around 70% is not available, and only 0.4% constitutes the most valuable part of freshwater. Adsorption cooling technology is one of the most effective ways of cooling and producing potable water from renewable and waste heat of the near ambient temperature, including sewage water, solar heat and underground resources.

The brief summary of the contributions accepted for the Special Issue of *Energies*, "Adsorption Desalination and Cooling Systems: Advances in Design, Modeling and Performance", is presented in this paper in order of the publication date.

2. A Short Review of the Contributions in the Special Issue

Sztekler et al. [1] tested four newly developed silica-based porous materials and compared them with silica gel, an adsorber commonly paired with water. Extended sorption tests using mercury intrusion porosimetry, gas adsorption and dynamic vapor sorption were performed. The morphology of the samples was determined using a scanning electron microscope. The thermal properties were defined using simultaneous thermal analysis and a laser flash method. Metal organic silica (MOS) nanocomposites analysed in this study had thermal properties similar to those of commonly used silica gel. MOS samples have a thermal diffusivity coefficient in the range of 0.17–0.25 mm^2/s, whereas that of silica gel is about 0.2 mm^2/s. The highest water adsorption capacity was measured for AFSMo-Cu and was equal to 33–35%. For narrow porous silica gel, the mass uptake was equal to about 25%. In the case of water adsorption, it was observed that the pore size of the sorbent is essential, and adsorbents with pore sizes larger than 5 nm are the most recommended for working pairs with water.

Computational fluid dynamic (CFD) analysis of elements of an adsorption chiller with a desalination function were carried out in [2]. The authors presented the results of numerical tests on the elements of an adsorption chiller that comprises a sorption chamber with a bed, a condenser and an evaporator. The simulation is based on the data and geometry of a prototype refrigeration appliance. The simulation of this problem is unique and has not yet been performed and, so far, no simulation of the phenomena occurring in the systems on a real scale has been carried out. The presented results are part of the research covering the entire spectrum of designing an adsorption chiller. The full process of the numerical modeling of the thermal and flow phenomena taking place in the abovementioned components is presented. The computational mesh sensitivity analysis combined in the k-ε turbulence model was performed. To verify and validate the numerical results obtained, they were compared with the results of tests carried out on a laboratory stand at the AGH Center of Energy, Poland. The results of numerical calculations are in good agreement with the results of the experimental tests. The maximum deviation between the pressure obtained experimentally and by simulations is 1.8%, while the temperatures deviation is no more than 0.5%. The results allow the identification of problems and their sources, which allows for future structural modifications to optimize the operation of the device.

A verification of the possibility of increasing the cooling coefficient of performance (COP) and specific cooling power (SCP) of a laboratory adsorption chiller by optimising the length of cycle times and using a copper additive to silica gel with a mass fraction of 15% to increase heat transport in the bed was presented in [3]. The choice of copper among other considered additives was determined by the conclusions from the research on the sorption kinetics of various mixtures, price and availability and a high thermal conductivity. The device was operated in a two-bed mode aimed at producing cooling. The adsorbate was distilled water. The results were compared with those obtained under similar conditions when the beds were only filled with silica gel. As a result of the testing, it was found that the use of the copper additive with the sorbent increased both the COP and SCP. The tests were performed for different cycle times, of 100, 200, 300 and 600 s. With increasing cycle time, the COP also increased. In contrast, the specific cooling power increased only up to a certain point, whereafter its value decreased.

The effects of using steam to preheat the beds of an adsorption chiller with desalination function were investigated experimentally in [4]. The research was carried out on the adsorption chiller, working on a silica gel–water pair, installed in the AGH Center of Energy, Poland. The chiller was modified to preheat the sorbent with the use of steam. The results show that the use of steam instead of water for preheating the bed leads to higher temperatures in the heat exchanger and the bed. As a result, heat transfer from the heating medium to the bed is more intense, and a significant shortening of the desorption process was observed. In the case of using steam for preheating, the desorption time was about 30 s, while for water, it was 300 s. Thanks to this result, it is possible to reduce the size of the device and increase its efficiency. The proposed solution opens a new course of research on adsorption chillers and broadens the horizon of their applications, as steam is a by-product of many industrial processes.

Ahmad A. Alsarayreh et al. analyzed the performance of a variable mode adsorption chiller at different recooling water temperatures in [5]. Adsorption cooling can recover waste heat at low temperature levels, thereby saving energy and reducing greenhouse gas emissions. An air-cooled adsorption cooling system reduces water consumption and the technical problems associated with wet-cooling systems. However, it is difficult to maintain a constant recooling water temperature using such a system. To overcome this limitation, a variable mode adsorption chiller concept was introduced and investigated. A prototype adsorption chiller was designed and tested experimentally and numerically using the lumped model. Experimental and numerical results showed good agreement and a similar trend. The adsorbent pairs investigated in the chiller consisted of silicoaluminophosphate (SAPO-34)/water. The experimental isotherm data were fitted to the Dubinin–Astakhov (D–A), Freundlich, Hill, and Sun and Chakraborty (S–C) models. The fitted data exhibited satisfactory agreement with the experimental data except with the Freundlich model. In addition, the adsorption kinetics parameters were calculated using a linear driving force model that was fitted to the experimental data with high correlation coefficients. The results show that the kinetics of the adsorption parameters were dependent on the partial pressure ratio. Four cooling cycle modes were investigated: single stage mode and mass recovery modes with duration times of 25%, 50% and 75% of the cooling cycle time (denoted as short, medium and long mass recovery, respectively). The cycle time was optimised based on the maximum cooling capacity. The single stage, short mass recovery and medium mass recovery modes were found to be the optimum modes at lower (<35 °C), medium (35–44 °C) and high (>44 °C) recooling temperatures. Notably, the recooling water temperature profile is very important for assessing and optimising the suitable working mode.

Solovyeva et al. in [6] claims that the rapidly growing population, climate change and environment pollution puts heavy pressure on freshwater resources. However, the atmosphere is an immense worldwide and available water source. The adsorptive water harvesting from the atmosphere (AWHA) method is considered a promising alternative to desalination technologies for remote arid regions. The development of novel adsorbents with advanced water-adsorption properties is a prerequisite for practical realisation of this method. Metal–organic frameworks (MOFs) are a novel class of porous crystalline solids that bring a great potential for AWHA due to their extremely high specific surface area, porosity and tailored adsorption properties. The work addresses MIL-160 as a water adsorbent for AWHA. The water-adsorption equilibrium of MIL-160 was studied by volumetric method, the isosteric heat of adsorption was calculated, and finally, the potential of MIL-160 for AWHA was evaluated for climatic conditions of the deserts of Saudi Arabia, Mongolia, the Sahara, Atacama and Mojave as reference arid regions. MIL-160 was shown to ensure a maximum specific water productivity of 0.31–0.33 g_{H2O}/g_{ads} per cycle. High fractions of water extracted (0.90–0.98) and collected (0.48–0.97) could be achieved at a regeneration temperature of 80 °C with the natural cooling of the condenser by ambient air. The specific energy consumption for water production varied from 3.5 to 6.8 kJ/g, which is acceptable if solar heat is used to drive the desorption. The AWHA method employing MIL-160 is a promising way to achieve a freshwater supply in remote arid areas.

The optimisation of the operation of adsorption chillers with a desalination function was presented in [7]. The results of tests carried out on a three-bed adsorption chiller with desalination function are analysed in order to determine the effect of the cycle time on the COP and SCP. The working pair was silica gel and water. The results confirmed the effect of the duration of adsorption and desorption on the COP and SCP of the adsorption chiller. Increasing the duration of the cycle led to an increase in the COP.

The authors in [8] conducted energy and exergy analyses of an adsorption chiller to investigate the effect of recooling-water temperatures on the cooling capacity and COP with variable cycle modes. They investigated both the effect of the recooling-water temperature and the dead state temperature on the exergy destruction in the chiller components. Their results show that there is an optimum reheat cycle mode for each recooling-water temperature range. For the basic single stage cycle, the exergy destruction is mainly accrued in the desorber (49%), followed by the adsorber (27%), evaporator (13%), condenser (9%) and expansion valve (2%). The exergy destruction for the preheating process is approximately 35% of the total exergy destruction in the desorber. By contrast, the precooling process is almost 58% of the total exergy destruction in the adsorber. The exergy destruction decreases when increasing the recooling-water and the dead state temperatures, while the exergy efficiency increases. Nonetheless, the exergy efficiency decreases with an increase in the recooling-water temperature at fixed dead state temperatures. The effect of the mass recovery time in the reheat cycle on exergy destruction was also investigated, and the results show that the exergy destruction increases when the mass recovery time increases. The exergy destruction in the adsorbent beds was the most sensitive to the increase in mass recovery time.

The paper [9] presents experimental results of the metal-based and carbon nanotube additives influence on sorption kinetics of a silica-gel-based adsorption bed in an adsorption chiller. The purpose of the doping is to improve the efficiency of sorption processes within the bed by use of metallic and non-metallic additives characterised by higher thermal diffusivity than basic adsorption material. The higher the thermal conductivity of the bed, the faster the sorption processes take place, which directly translates into greater efficiency of the refrigerator. Sorption kinetics of pure silica gel sorbent doped with a given amount of aluminum (Al) and copper (Cu) powders and carbon nanotubes (CNT) were analyzed. The tests were performed on a DVS Dynamic Gravimetric Vapor Sorption System apparatus used for dynamic vapor sorption measurements. A decrease in the amount of adsorbed water was observed with an increase in the mass share of the additives in the performed studies. Experimental results show that CNTs seem to be the most promising additives as the sorption process time was reduced with the smallest decrease in water uptake. Any significant reduction of adsorption time was noted in case of the Al addition. Whereas in case of Cu doping, the delamination of the mixture was observed.

Skrobek et al. introduced the artificial intelligence (AI) approach for modeling fluidised adsorption beds in [10]. The idea of fluidised bed application allows a significantly increased heat transfer coefficient between adsorption bed and the surface of a heat exchanger, improving the performance of adsorption cooling and desalination systems [11,12]. The long short-term memory (LSTM) network algorithm was used, classified as a deep learning method, to predict the vapor mass quantity in the adsorption bed. The research used an LSTM network with two hidden layers. The network used in the study was composed of seven inputs and one output. The paper presents numerical research concerning mass prediction with the algorithm mentioned above for three sorbents in fixed ad fluidised beds. The results obtained by the developed algorithm of the LSTM network and the experimental tests are in good agreement of the matching the results above 0.95.

Experimental study of three-bed adsorption chiller with desalination function was carried out in [13]. The laboratory test stand included one evaporator, one condenser and three separate tanks for water, desalinated water and brine, respectively. The test stand's scheme and description were presented. All results were obtained during several test hours with stable temperature conditions in the range of 57–85 °C for the heating water. It was found that the COP increased from 0.20 to 0.58 when the heating water temperature increased from 57 to 85 °C. A similar finding is reported for SCP, which increased from 27 to 160 W/kg as the heating water temperature increased from 57 to 85 °C. It can be concluded that the heating water temperature strongly impacts the performance of the adsorption chiller.

The review concerning adsorbents, working pairs and coated beds for natural refrigerants in adsorption chillers is presented in [14]. The selected working pairs were thermodynamically characterised and ranked in terms of refrigerant evaporation temperature values. This was found to be a key parameter affecting the applicability of a given adsorbent/adsorbate pair and the value of SCP and COP, which are now commonly used comparison criteria of adsorption chillers. In the analysis of the coating studies, the focus was on the effect of individual parameters on the performance of the cooling system and the effect of using coated beds compared to packed beds. It was found that a fundamental problem in comparing the performance of different cooling systems is the use of different operating conditions during the tests. Therefore, the analysis compares the performance of the systems along with the most important thermodynamic cycle parameters for the latest studies.

3. Conclusions

The Special Issue of the journal *Energies* brings together research on the advances in design, modeling and performance of adsorption desalination and cooling systems and comprises eleven creative research articles and one review article. The authors of the papers are representatives of six countries, as depicted in Figure 1.

The papers published within the Special Issue are proof of the importance of design, modeling and performance of adsorption desalination and cooling systems. Further investigations concerning the application of adsorption technology for cooling and desalination can be found in [15–20]. Considering the large number of citations of the contributions to the Special Issue, the initiative of proposing topics or Special Issues dedicated to adsorption technology seems to be reasonable.

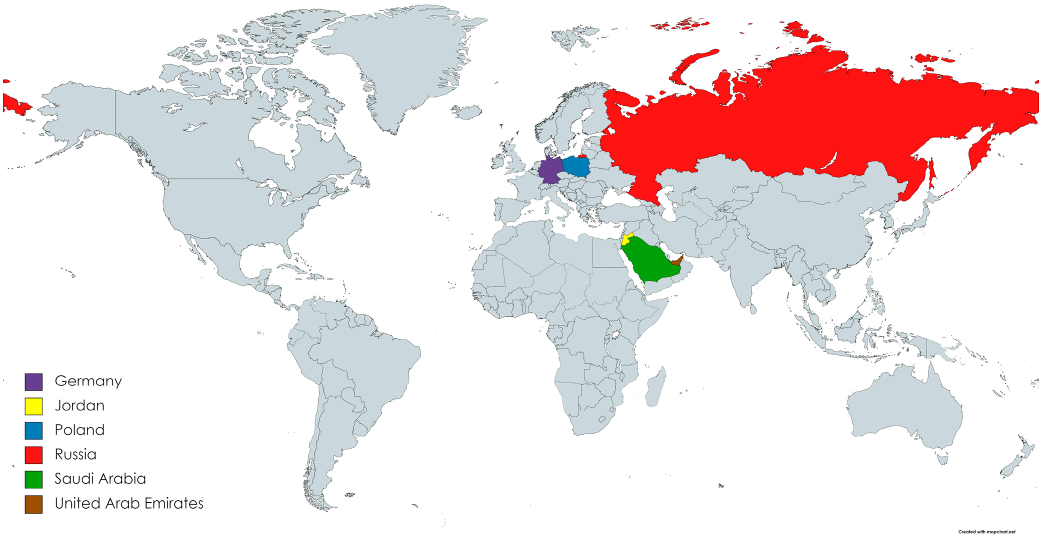

Figure 1. Authors' countries of origin.

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