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A Silica Gel-water Adsorption System with an Adsorbent-coated Copper Pipe

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Abstract **–** The aim of this work is to present the results of studies on mass transfer in an adsorber chamber of an adsorption chiller. The experimental setup is described. Results of the experiments are presented. Adsorption of water vapour on silica gel pellets was the subject of the studies. Adsorbent pellets were covered directly on a copper pipe (with cooling water flowing in it) in order to reduce the heat transfer resistance. Binder based on polyvinyl alcohol was used to coat the pipe with a single layer of the pellets. The influence of the velocity of the gas phase and size of adsorbent pellets was considered. The breakthrough curves obtained under different operating conditions are presented. Good mass transfer properties were observed when the volumetric flow rate was relatively low and adsorbent pellets sizes were large. The best results were obtained for the flow rate equal to 0.017 dm^3/s and particles diameters between 1.5 mm and 2.0 mm.

Keywords**:** Adsorption, Cooling, Heat and mass transfer.

1. Introduction

Conventional electricity-driven compression cooling systems are against the concept of sustainable development because of the environmental pollution and considerable energy consumption. Freon employed in these kinds of systems lead to ozone layer depletion. What is more, the International Institute of Refrigeration has estimated that 15% of the world electricity generation is used for air-conditioning and refrigeration (Choudhury et al., 2013). Also, it has been estimated that 45% of energy consumed in households, workplaces and public buildings is used for refrigeration and air conditioning (Fan et. al., 2007). High energy consumption leads to fossil fuels depletion and emission of air pollutants. Therefore, the importance of adsorption chillers has increased significantly in recent years. Environmentally friendly refrigerants, such as water, can be used in adsorption systems. Moreover, such systems can utilize the primarily thermal energy sources, such as solar energy and geothermal energy and the waste heat produced by vehicles or in industrial processes (Askalany et. al, 2013; Dabler et. al., 2012; Ismail et. al., 2014; Sharafian et. al., 2014).

Many other advantages of adsorption systems may be mentioned if one compares them with absorption and compression chillers (Choudhury et al., 2013; Ismail et. al. 2014; Wang et. al., 2006). Low temperature heat sources (temperature may be as low as 52.5–55ºC) may be used to drive them and they are less sensitive to heat source temperature fluctuations. Additionally, there are no problems with corrosion and crystallisation. What is more, they are less sensitive to shocks. Their construction is simple – there are no moving parts so their work is more reliable and maintenance free. There are no vibrations. Their operation is silent.

However, commercial application of adsorption chillers is difficult due to their low Coefficient of Performance (COP) and Specific Cooling Power (SCP). These two parameters allow one to evaluate the performance of a cooling system. COP is a ratio of the cold production [kJ] to the heat supplied to a chiller [kJ]. SCP is the ratio of the cooling power [kW] to the adsorbent mass [kg]. Low values of SCP lead to big sizes of the chillers and high investment costs. COP can be improved if an advanced adsorption refrigeration cycle (e.g. heat or mass recovery cycle) is applied. SCP can be improved by advanced adsorber technology and by utilization of adsorbents with good heat and mass transfer properties (Wang et. al. 2009). Broader application of adsorption chillers still requires a lot of research. Scientists should focus on adsorbent materials, heat and mass transfer properties of the system and advanced cycles to enable adsorption cooling to become a competitive technology.

The aim of this work is to present results of the experimental studies on the enhancement of heat and mass transfer in an adsorber, that is the main part of an adsorption chiller. An experimental set-up will be presented. Adsorption of water vapour on silica gel was studied. The breakthrough curves for different operating conditions will be presented. The influence of adsorbent pellets diameters and gas flow rate will be reported.

2. Adsorption Pair

Operation of an adsorption chiller depends largely on a working pair that is used for adsorption. The pair used in this work i.e. silica gel and water is one of the most frequently used adsorption pair for cooling applications. The experiments were conducted at room temperature. Silica gel can be regenerated after it has been used and therefore one sample can be used many times. Moreover, such a pair is non-toxic and the temperature during experiments is not high so inconveniences and costs connected with safety procedures can be reduced.

Properties of micropore silica gel that was used for the studies are presented in Table 1.

Table 1. Blue silica gel properties.

Pellets diameters	Bulk density	Moisture content (drying for 3 h at 150ºC)	Ability to adsorb water (24 h, relative humidity 80%)
1–4 mm	780 g/dm^3	0,1%	28,95%

3. Experimental Set-up and Procedure

Experiments were conducted with the use of an own experimental setup. The main part of the setup is presented in figure 1. The system is similar to a double-pipe heat exchanger. There are two circuits in the system: circuit of air saturated with water vapour and circuit of cooling water. Silica gel was coated on a copper pipe that had an external diameter of 12 mm, a wall thickness of 1 mm and a length of 220 mm. Commercial glue based on polyvinyl alcohol (PVA) was used to cover the pipe and to coat it with a layer of silica gel pellets. Previous studies (Gwadera et. al., 2013) showed that this kind of binder does not significantly reduce the specific area of adsorbent pellets. There was a coaxial teflon rod inside the copper pipe. Its diameter was 8.5 mm. Cooling water flew through a cylindrical cross-section between the copper pipe and the Teflon rod. The copper pipe covered with silica gel was placed coaxially in a cylindrical glass pipe with a double wall. Static air that was between the double walls of the glass pipe played a role of an insulation. The internal diameter of the inner glass pipe was 23 mm and the external diameter of the outer glass pipe was equal to 46 mm.

A preparation of the copper pipe was the first step of the experimental procedure. Copper was used due to its very good heat conduction properties and corrosion resistance. A pipe was covered with PVA binder and then it was coated with a layer of silica gel pellets. The pipe was then dried for 3 h at 150ºC, weighed and installed in the double-wall glass pipe in the experimental setup. From this moment the flow of air saturated with water vapour and flow of cooling water started. Water vapour was adsorbed from air on silica gel pellets covering the copper pipe. The temperature of silica gel layer and the cooling water inlet and outlet temperature values were measured with thermocouples. The values of humidity and temperature of inlet and outlet air were measured with proper sensors. All the values of temperature and humidity were recorded. Recording was stopped when the difference between inlet and outlet air humidity was about 5%. Measurements were conducted for two different ranges of pellets diameters: 0.8–1.0 mm and 1.5–2.0 mm. Diameters lower than 1.0 mm were obtained from the initial material as a result of friction during transport and sieving. The second parameter changed during the experimental studies was the flow rate of air. Measurements were done for 0.017 dm^3/s and 0.083 dm^3/s.

Fig. 1. An experimental setup.

4. Results and Discussion

Figures 2 and 3 present breakthrough curves for different process conditions. The relative humidity of outlet air is on the vertical axis, while adsorption process time is on the horizontal axis. The flow rate of dry air (before saturation with water vapour) is a parameter in figure 2. As can be seen from this figure, when the flow rate is 0.083 dm^3/s, air saturated with water flows too fast around the pellets. Some amount of water vapour is not adsorbed so the air leaving the system contains the adsorbate. If the flow rate of air is reduced to 0.017 dm^3/s, some period of time is required to observe the breakthrough.

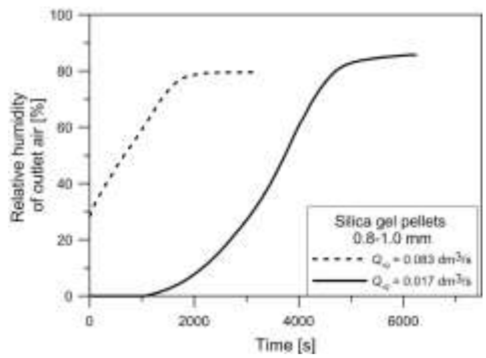

Fig. 2. Breakthrough curves for two values of gas flow rate.

Analysis of figure 3 leads to the conclusion that the larger diameters of the adsorbent pellets, the longer the breakthrough time. Moreover, larger pellets lead to smaller values of the outlet air humidity. One of the reasons for that is the fact that when pellets diameters were between 1.5 mm and 2.0 mm, the mass of the adsorbent coated on the copper pipe was greater (approximately twice greater) than in the case of the pellets 0.8-1 mm. In the case of the large pellets it took longer to saturate the adsorbent layer with water.

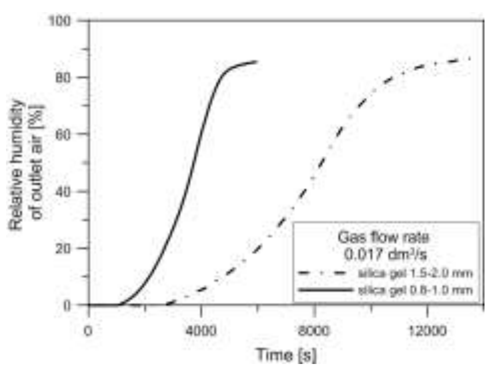

Fig. 3. Breakthrough curves for two sizes of pellets.

5. Conclusion

Adsorption chillers offer an important alternative for cold production. Application of such systems leads to huge energy and carbon saving potential. They can be used for example in hospitals, hotels and factories, in food and chemical industries and for district heating.

The aim of this work is to analyse the operation of a silica gel-water adsorption system with a cooling pipe covered directly with adsorbent pellets. The reported results of measurements lead to the conclusion that to obtain good effects one should use low flow rates of an adsorbate and relatively large sizes of adsorbent pellets. The results presented in this work may be used as guidelines for design and construction of adsorption chillers.

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