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Research Paper

Dehumidification behavior of cross-flow heat exchanger type adsorber coated with aluminophosphate zeolite for desiccant humidity control system

Mitsuhiro Kubota [a],*, Noriko Hanaoka [a], Hitoki Matsuda [a], Akio Kodama [b]

[a] Department of Chemical System Engineering, Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya-shi, Aichi 464-8603, Japan
[b] Faculty of Mechanical Engineering, Institute of Science and Technology, Kanazawa University, Kakuma-machi, Kanazawa-shi, Ishikawa 920-1192, Japan

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ABSTRACT

A cross-flow heat exchanger type adsorber was investigated for a desiccant humidity control system. The aim of the adsorber was to improve dehumidification performance by forcibly cooling an adsorbent with flowing air. Aluminophosphate (AlPO) zeolite was coated on the heat exchanger, because it was expected to regenerate sufficiently even with a low-temperature heat source of around 333 K. Fundamental dehumidification behavior with the adsorber was experimentally investigated at various inlet absolute humidities, regeneration temperatures, and air flow velocities. Dehumidified water in an equilibrium state was kept even at a regeneration temperature of 333 K, indicating that the adsorber coated with AlPO zeolite could be driven using low-temperature heat at 333 K. The dehumidification rate was found to increase as the cooling and the process air velocities increased. However, the increase in the dehumidification rate decreased when the cooling air flowed at a velocity of 2 m/s or more. Heat removed by the cooling air increased as the cooling air velocity increased and the process air velocity decreased. It was also found that dehumidified air could be supplied for a longer period at a sufficiently low absolute humidity suitable for practical use as the cooling air velocity increased.

1. Introduction

Desiccant humidity control systems have been gaining more attention as an environment-friendly air conditioning method because they can be driven by low-grade thermal energy below 373 K, such as waste heat and unused heat. Moreover, they can control latent heat loads easily, independent of sensible heat loads, and can reduce power consumption of air conditioning [1].

A honeycomb rotor has been widely used in desiccant air conditioning systems. The honeycomb rotor rotates at a constant speed, and dehumidification and regeneration are carried out simultaneously. This system has a great advantage of being able to supply dehumidified air continuously using a single rotor. However, a temperature rise accompanied by water adsorption causes a lowering in its adsorption capacity, because dehumidification is performed by the honeycomb rotor under an adiabatic condition.

Recently, some researchers have investigated a new system of using a heat exchanger coated with an adsorbent in order to solve the above-mentioned problem, and to improve the dehumidification performance of the system. Zheng et al. prepared composite desiccants of LiCl and activated carbon (AC), or activated carbon fiber, and characterized the composites in terms of textural properties, water adsorption isotherms, and kinetics. It was found that AC/LiCl had the best dehumidification capacity from a numerical analysis of desiccant coated heat exchanger (DCHE) systems [2]. Zheng et al. also fabricated SAPO-34 and FAPO-34 coated aluminum sheets and reported that the DCHE systems with FAPO-34 achieved 2–3 times more dehumidification capacity than those with SAPO-34 and silica gel at low regeneration temperatures [3]. Kumar and Yadav investigated experimentally silica gel coated heat exchanger (SCHE) based solar-driven desiccant air conditioning. They reported that the SCHE could handle both sensible and latent loads with a good dehumidification capacity [4]. Ge et al. analyzed the performance of DCHE air conditioning system in winter, and reported that the systems could be operated with moderate regeneration temperatures and switch time [5]. Zhao et al. investigated experimentally heat and moisture transfer characteristics of fin-tube heat exchanger with silica gel coating. The correlated formula of Nusselt and Sherwood numbers on the air side of solid desiccant coated heat exchanger (SCHE) and the

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* Corresponding author.
E-mail address: kubota.mitsuhiro@material.nagoya-u.ac.jp (M. Kubota).

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mathematical model for prediction of the performance of SCHE system were established [6]. Zhao et al. also experimentally evaluated the performance of a desiccant dehumidification unit using SCHE and demonstrated that the system had a potential to keep a stable and continuous dehumidification capacity [7]. We have also evaluated the dehumidification performance of direct cooling and heating desiccant system (DCHDS) by fin-tube type heat exchanger coated with aluminophosphate (AlPO) zeolite, and demonstrated the production of relatively stable dehumidifying air in the DCHDS [8]. In the above-mentioned researches, a fin-tube heat exchanger was mostly used for the adsorber.

Based on the above-mentioned findings, we have focused on a novel desiccant humidity control system with a cross-flow heat exchanger type adsorber. Fig. 1 shows a conceptual diagram of the dehumidification system with the focused adsorber. The main component of the system is a multi-layer cross-flow heat exchanger type adsorber, which is fabricated by coating an adsorbent on the primary air flow channel of the heat exchanger. During the dehumidification process, water vapor in the air is adsorbed on the adsorbent from flowing humid air in the primary flow channel, resulting in dehumidified air being available for supply to a room. In this process, cooling air flows simultaneously in the secondary flow channel to actively remove both sensible heat of the adsorber and the heat of adsorption. Meanwhile, during the regeneration process, heating air flows directly in the primary flow channel to desorb adsorbed water. This system can be expected to achieve a large amount of dehumidification and improve the utilization ratio of adsorbent by removing heat forcibly during the dehumidification process. Moreover, this system is simpler than one with water coolant due to no need for a water circulating system, although the cooling effect of the system with air is lower than that with water coolant. However, two adsorbers are required to supply dehumidified air continuously due to its batch operation.

Some researchers have reported dehumidification performance of cross-flow heat exchanger type adsorbers both experimentally and numerically. Weixing et al. proposed a modified cross-cooled compact solid desiccant dehumidifier (CCCD). They numerically predicted the dehumidification performance of the CCCD coated with silica gel particles, and performed a dehumidification experiment with the constructed CCCD at two inlet air humidities both with and without air cooling. It was demonstrated that the CCCD with air cooling achieved a higher cooling effect than that without cooling, especially for high humidity ratio conditions [9]. Fathalah and Aly theoretically analyzed a cross cooled desiccant bed dehumidifier. In the system, silica gel was packed in the passage of the process air flow instead of being coated on the wall surface of the passage. Many advantages were evident for the packed desiccant bed compared to the coated type, for example a high adsorption capacity per unit volume of the matrix. An increase in pressure drop in the flow passages was mentioned as one of the disadvantages of the system [10]. Worek and Lavan investigated the performance of the constructed cross-cooled desiccant dehumidifier. A Teflon web in which 9 μm silica gel was held was used as the desiccant sheet in the process air channel [11].

In our previous study, adsorption experiments with cross-flow heat exchanger type adsorber coated with silica-gel were carried out at various cooling and process air velocities, and with differing amounts of coated silica-gel. It was demonstrated that air cooling of a desiccant unit is greatly effective to enhance adsorption of water on silica gel. The amount of adsorbed water was found to increase with both cooling air and process air velocities at every adsorption time [12].

In this study, AlPO zeolite was employed as a desiccant material coated on the cross-flow heat exchanger in order to promote a further utilization of lower temperature heat sources. AlPO zeolite has the well-known unique S-shaped adsorption isotherm and is expected to maintain a large effective water adsorptivity even in the low-temperature regeneration regions. The main objective of this study is to obtain fundamental findings of the dehumidification performance of cross-flow heat exchanger type adsorber coated with AlPO zeolite at various cooling and process air velocities and initial absolute humidities of the process air.

2. Experimental

2.1. Apparatus

Fig. 2(a) shows a schematic drawing of the experimental dehumidification apparatus. The apparatus consisted of a heat exchanger type adsorber, temperature/humidity controlling chamber, air heater, blower, air flow meter, and two air ducts made of polycarbonate. The whole apparatus was placed in a room in which the temperature was maintained at approximately 303 K. The temperature/humidity controlling chamber was equipped with an ultrasonic humidifier, electric heater, circulator, condenser, and a blower to supply process or heating air controlled at a constant absolute humidity. The air duct for the process and the heating air had an entrance region of 2.4 m upstream of the adsorber in order to supply well-developed air flow. The flowrate, temperature, and relative humidity of the process and the heating air were measured by an ultrasonic air flowmeter (Aichi tokei denki Co., Ltd, TRX80D-C/4P, Accuracy: ±2.0%RS) and hygrometer (Vaisala, HUMICAP HMT-333, Accuracy: ±0.2 K, ±1%RH), respectively. In order to measure the temperature distribution of the process and the heating air in the primary channel, three K-type sheath thermocouples were installed every 50 mm in the flow direction of the cooling air at the inlet and outlet of the adsorber. Three thermocouples were also placed in the same manner in the flow direction of the process air on both sides of the adsorber for measurement of the cooling air. Each thermocouple was set 15 mm away from the adsorber. In this experiment, the process and the heating air temperatures measured at the position of 100 mm in the flow direction of the cooling air were used as the representative ones.

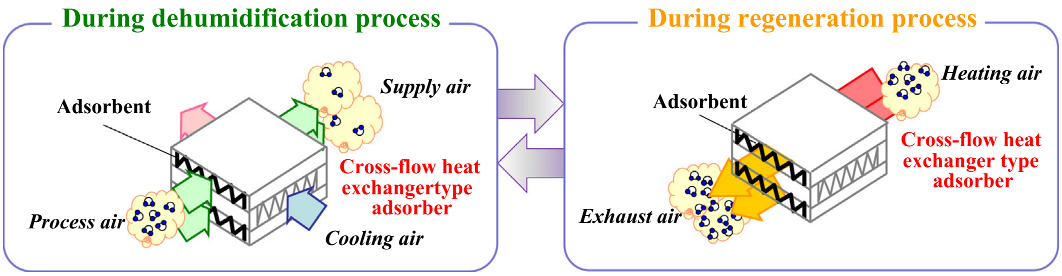

Fig. 1. Conceptual diagram of humidity control system with cross-flow heat exchanger type adsorber.