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Research paper

Application of silica gel fluidised bed for air-conditioning systems

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HIGHLIGHTS

- We theoretically/experimentally investigates a fluidised bed for dehumidification.
- Fluidised bed, compared with packed bed, increases adsorption/desorption by 20%.
- Fluidised bed, compared with packed bed, reduces pressure drop by 36%.
- Fluidised bed, compared with packed bed, reduces outlet temperature by 30%.
- Adsorption of fluidised bed increases with higher filling height and faster velocity.

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ABSTRACT

This paper theoretically and experimentally investigates a periodic operating silica gel fluidised bed system to adsorb/desorb moisture in air-conditioning systems. First, the theoretical model of a fluidised bed system is utilised to predict the minimum fluidisation velocity, pressure drop, and adsorption/desorption performance of a silica gel fluidised bed. Subsequently, the paper experimentally compares the adsorption/desorption performance of the silica gel fluidised bed with a packed bed at the regeneration temperature of 40 °C, inlet temperature of 30 °C, inlet relative humidity of 60%, and wind velocity of 2 m/s periodically operating for 40 min. Then it applies two kinds of average diameter (3 mm and 5 mm) silica gel particles to the fluidised bed dehumidification system with various filling heights and differing wind velocities. The results show that the fluidised bed system, compared with the packed bed, increases the total amount of adsorption and desorption by 20.8% and 19.8%. It also reduces the pressure drop and outlet temperature by 30% and 36%. Moreover, the adsorption/desorption performance of fluidised bed systems increases with higher filling height and faster wind velocity. The availability of the theoretical modal is verified by 8% relative error between the theoretical and experimental values of the adsorption/desorption performance.

1. Introduction

If a building needs improvement in the quality of its indoor air, fresh air from the outside must be introduced to reduce the concentration of contaminants such as carbon dioxide. However, the climate of subtropical summers is hot and humid, so the direct introduction of outside air causes large energy consumption by the heavy load of air-conditioning systems. Therefore, energy-saving technology that can introduce outside air plays an important role, and the desiccant material applied to air-conditioning systems [1,2] is one of them. A desiccant material captures moisture in the air by the physical or chemical adsorption principle [3] and then is regenerated by high-temperature [4] or low-humidity air [5].

When a desiccant material is applied to air-conditioning systems, desiccants are usually used as a packed-bed type, which is low cost [6,7], to combine with air-conditioning systems. Nevertheless, the pressure drop of a packed bed is too high, and the heat of adsorption caused by the adsorption process [8] lets the temperature of the outlet air increase, bringing about an extra heat load, so the high pressure drop and the increased temperature of the outlet air are energy consumption sources that need to be resolved. For this reason, the gas–solid fluidised beds [9–12] that have high heat and mass transfer rates, uniform properties, and low pressure drops are very suitable for use in air-conditioning systems.

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Ahmed M. Hamed [13] experimentally investigated the adsorption/desorption processes of solid desiccant-inclined fluidised beds in 2005, and the results show that the adsorption/desorption performance is proportional to wind velocity. In 2010, Hamed [14] also investigated the heat and mass transfer rate of an erect fluidised bed and applied those findings to an adsorption system. Compared to the packed bed, the fluidised bed lets the humidity of the outlet air lower by 20%. Akihiko Horibe et al. [15] applied organic sorbent powder to two connected fluidised beds and investigated their adsorption/desorption performance. Two desiccant fluidised beds are connected by stainless steel spiral tubes, and the desiccant powder is transferred from one fluidised bed to the other by spiral tubes to form a circular operation.

In this study, two different average-diameter silica gel desiccant particles are used and applied to air-conditioning systems as a gas–solid fluidised bed system. First, a theoretical model of fluidised beds is established. Next, an experiment regarding a silica gel fluidised bed with periodic operation is executed in a simulated summer climate. Finally, the experimental parameters (average diameter of desiccants, wind velocity, filling height of bed) are changed, and this study investigated the effect on the pressure drop and the adsorption/desorption performance of fluidised bed systems. The paper successfully applied the advantages of a fluidised bed to dehumidification technology and reached its goals, which are a higher adsorption/desorption performance, a lower pressure drop, and a lower temperature increase of outlet air. Then, the effectiveness of the air-conditioning system is improved by replacing the silica gel-packed bed, and the purpose of energy savings is achieved.

2. Theoretical model

Fig. 1 is a schematic view of a silica gel fluidised bed applied to air-conditioning systems. There are two fluidised bed chambers in this system. Chamber A dehumidifies and supplies low-humidity air to an indoor area. Chamber B regenerates the fluidised bed by heating air, which exhausts to the outside by Valve c. After the fluidised bed in Chamber A is saturated, the three-way valves a, b, and e, are switched, letting heated air regenerate the fluidised bed in Chamber A and turning on Valve d, exhausting the high-humidity air from Chamber A. In addition, outdoor air passes through the fluidised bed in Chamber B and turns off Valve c, letting the low-humidity air pass through the three-way Valve e and supplying fresh air to an indoor area. This silica gel-fluid bed system can provide stable-humidity fresh air by a repeated cycle operation.

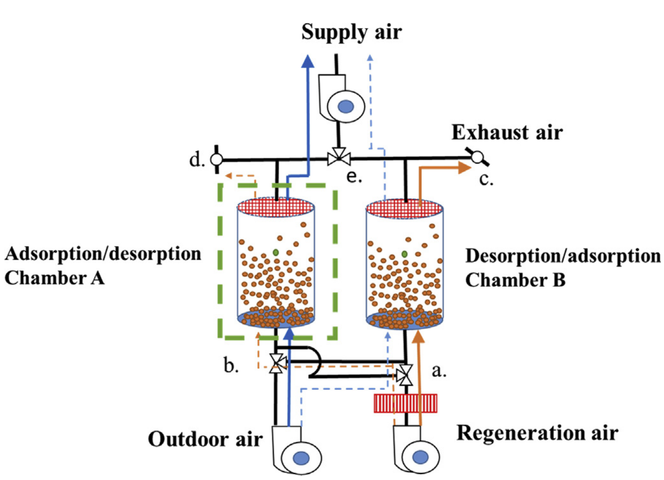

Fig. 1. Schematic view of the silica gel fluidised bed system.

Fig. 2 demonstrates a control volume of the silica gel fluidised bed. This study will consider the following assumptions: The bed is insulation, the temperature and water content of each silica gel particle in the fluidised bed are uniform, the air uniformly contacts the surface of the desiccant, the flow direction of air in the bed is in the z-direction only, and the temperature and humidity ratio gradient direction of air are also in the z-direction only.

On the air side, the mass balance equation takes a short height of the bed (dz) to be a control volume. The mass increase of the air is equal to the amount of water transferring from silica gel particles to air when the air passes though the control volume. It can be expressed as:

$$AU\rho_g dY_g = h_d S_v (Y_p - Y_g) dz \quad (1)$$

where A is the cross-sectional area of the bed, U is a superficial velocity, ρ_g is air density, h_d is the mass transfer coefficient, and S_v is the surface area per-unit length of desiccant. Y_g and Y_p are the humidity ratio of air and the air on the surface of desiccant, respectively. Y_p can be calculated by the science of air temperature and humidity [16]:

$$Y_p = 0.622 \frac{p_s}{p_t - p_s} \quad (2)$$

p_t is atmospheric pressure, p_s is the partial pressure of water vapour in the air, and the value is:

$$p_s = p_{sat} RH \quad (3)$$

p_{sat} is the saturated vapour pressure at specific temperature. RH is relative humidity. According to M. Dupont [17], the RH of the air that is on the desiccant's surface can be predicted by the temperature (T_P) and the water content of the desiccant (W):

$$RH = S_1 T_P W^2 + S_2 T_P W + S_3 W^4 + S_4 W^3 + S_5 W^2 + S_6 W \quad (4)$$

where S_1, S_2, S_3, S_4, S_5, S_6 are constants, and the values of them are:

$S_1 = -0.04031298$
$S_2 = 0.02170245$
$S_3 = 125.470047$
$S_4 = -72.651229$
$S_5 = 15.5223665$
$S_6 = 0.0084266$

W is the water content of the desiccant and is defined by:

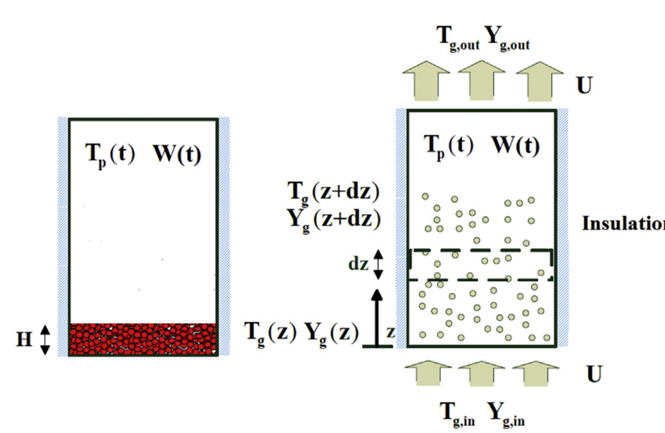

Fig. 2. Control volume of the silica gel fluidised bed.