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Research Paper

Feasibility study of simultaneous heating and dehumidification using an adsorbent desiccant wheel with humidity swing

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HIGHLIGHTS

- We proposed a desiccant wheel that used humidity swing adsorption (HSA).
- HSA uses a low temperature and dry air for the regeneration of desiccant.
- Desiccant wheel with HSA can achieve the simultaneous heating and dehumidification.
- The heating and dehumidifying was experimentally achieved by HSA.
- Heat capacity of the desiccant wheel should be improved to enhance the performance.

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ABSTRACT

Adsorptive desiccant dehumidification generates heat from adsorption, which can be used for space heating. Theoretically, a difference in relative humidity between the process air and the regeneration air is sufficient to produce the adsorption and desorption of water vapor onto and from the desiccant wheel. Taking advantage of this phenomenon, we proposed a desiccant wheel that used humidity swing adsorption (HSA), offering simultaneous heating and dehumidification.

We first experimentally investigated the differences in the temperature and humidity of the adsorption air at the inlet and outlet of the desiccant wheel. We confirmed that the dehumidification and a rise in temperature occurred with only a difference in absolute humidity between the dehumidification and regeneration air. The theoretical maximum temperature rise assuming adiabatic dehumidification was estimated to be 15 °C for adsorption and desorption inlet air of 25 °C and 15 g/kg-DA and 25 °C and 3.6 g/kg-DA. The experimentally measured temperature rise was decreased to 9.4 °C mainly due to the heat capacity of the wheel used in the experiments. It was found that a regeneration temperature greater than 13 °C was required to obtain a heating effect under our experimental conditions.

1. Introduction

Since a compressive-type room air conditioner uses fluorocarbons and produces CO_2 emissions in line with electric power consumption, the development of an air conditioner requiring neither refrigerant nor electric power is desirable. As an approach to such a system, desiccant air conditioning has attracted considerable attention. A desiccant system can be powered by low-grade waste heat at temperatures below 80 °C, thereby significantly reducing electricity demand. Such systems separately deal with the latent and sensible heat loads using a desiccant wheel and latent heat exchanger and/or external cooler, obviating the need for a refrigerant. Desiccant cooling systems are therefore considered promising candidates as air-conditioning systems with reduced environmental impacts [1–3], particularly for use in damp climates [4].

Desiccant cooling systems can be divided into two types, using solid or liquid desiccants [3]. Generally, liquid desiccant systems are more complicated their solid counterparts as the handling of solids is easier. Silica gel [4–6], zeolite [7,8], and other chemicals are used as solid desiccants. The adsorbent desiccant wheel, a key component in a solid desiccant air-conditioning system, is fabricated by attaching the adsorbent to the honeycomb wheel base. There are two operational phases: dehumidification (adsorption) and regeneration (desorption). In the first process, humid air is introduced to the desiccant wheel and dehumidified. The adsorption heat causes a rise in temperature; therefore, the dehumidified air is normally cooled by a sensible heat exchanger or an additional

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Nomenclature

Abbreviations

ACB	air control box
DA	dry air
DW	desiccant wheel
EA	exhaust air
H	heater
HA	humid air (adsorption air)
HSA	humidity swing adsorption
Hu	humidifier
RH	relative humidity
rph	rotation per hour
RA	regeneration air
SA	supply air
TSA	thermal swing adsorption

Subscripts

in	adsorption air = HA
reg	regeneration = RA

cooler. After cooling, the air is supplied to the room. In the regeneration process, the water is generally removed from the desiccant by high-temperature air, which is normally exhausted to the outside. However, it has been reported that a desiccant system can also be used as a heating/humidifying system by supplying the post-regeneration air to the room because in winter, it contains a large amount of water [9–11]. These studies have confirmed that heating/humidifying by a desiccant system can achieve highly energy-efficient indoor thermal comfort throughout the year. These results suggest that the range of applications of the desiccant air-conditioning system can usefully be extended.

In both dehumidifying/cooling and humidifying/heating, the dehumidifying performance is controlled by the adsorption isotherms of the desiccant. Fig. 1 shows typical adsorption isotherms of the desiccant wheel. As can be seen, the amount of adsorption in the desiccant is dependent on the relative humidity, so that the desiccant system is driven by the difference in relative humidity between the adsorption (dehumidification) air and the regeneration air. As noted above, air heated by exhaust heat or solar heat is generally used in the regeneration process to reduce the relative humidity. This operation is called thermal swing adsorption (TSA). In TSA, the dehumidified air passing through the desiccant wheel should be heated by both heat from adsorption and by the high-temperature air used for regeneration in the desiccant wheel. The adsorption/desorption process can be theoretically realized when the temperature of the regeneration air is the same as or lower than that of the adsorption air, since the relative humidity is affected not only by the temperature but also by the absolute humidity. This operation is called humidity swing adsorption

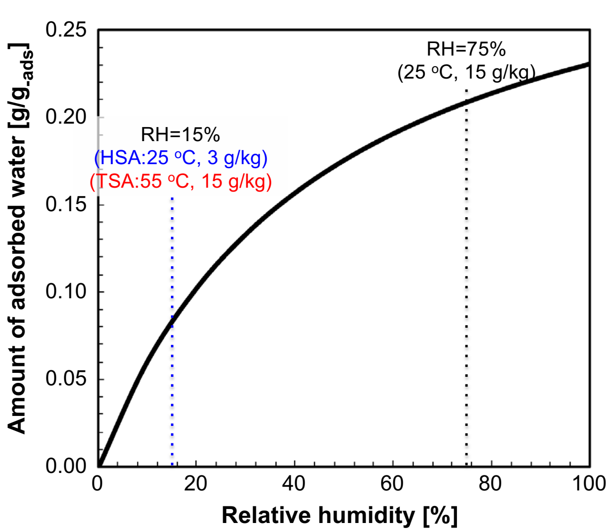

Fig. 1. Typical adsorption isotherms of desiccant wheel.

(HSA). HSA can achieve simultaneous heating and dehumidification, since dehumidification generates adsorption heat. Heating and dehumidification by HSA is a novel approach to desiccant air conditioning although it was reported in absorption cycle [12,13], and is particularly appropriate in applications with limited heat sources and low-humidity air.

An example of such an environment is a greenhouse in the winter season when, to maintain a suitable temperature for plant growth, a heater such as a fuel oil boiler or a heat pump is used. However, the large difference in temperature between the inside and outside of the greenhouse causes condensation, while plant transpiration increases the humidity. Since this may cause disease or damage to the plants, dehumidification is required [14–16]. If this is achieved through increased ventilation [17], the heating load is increased since the outside air must be heated to maintain the greenhouse temperature [16]. A heat exchanger [18,19] or heat pump [16] may be introduced to the ventilation system to limit the increase in the heat load. However, the heat exchanger cannot supply air at a higher temperature than that in the greenhouse, and a heat pump has high energy consumption since the air must be cooled for dehumidification then reheated. In contrast with these conventional dehumidification methods, which require large energy inputs, a desiccant air-conditioning system using HSA can supply high-temperature and low-humidity air without requiring an additional heater and the associated increase in heat load. Since it is able to use dry air, it can work as an auxiliary heater, offering a significant reduction in energy consumption in the winter season. Although the HSA desiccant system is a promising heating/dehumidifying system, it should be noted that the use of rotary regenerator such as a desiccant wheel and/or enthalpy wheel is restricted where pollutants such as unpleasant smells or smoking exist in the room because part of the exhaust gas moves back to the room, unlike fixed-type recuperators [20–22]. Since there are almost nil or few restrictions for air quality in a greenhouse, it is a suitable environment for the HSA desiccant system as mentioned above. Moreover, if HSA desiccant system is installed to the greenhouse in winter, attention need to be paid to the following two phenomena due to the low temperature in winter. First, moisture in the exhausted air can condense, which requires condensate discharge. Condensation is associated with the recovery of latent heat, increases the heat flux and heat recovery efficiency. The other is icing phenomenon occurring at negative value of inlet air temperature. This negative phenomenon causes an increase in flow resistance [23], can also cause mechanical damage to permanent structures regenerator. The experiments have been conducted [23] for typical value of indoor temperature 20 °C and a large range of humidity values from 20 to 75% and more of an exhausted air. The heat exchanger worked in the real conditions of the winter climate in Bialystok (Poland).

The HSA desiccant system can therefore help reduce energy consumption in applications requiring simultaneous heating and