Characteristics of carbon based composite desiccant and application for solid dehumidification systems

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Introduction

Dehumidification and cooling are the fastest growing forms of building energy consumption. Using air conditioners and fans to cool accounts for about 20 per cent of the world's total electricity use, and energy demand for building cooling is set to more than triple by 2050 [1].

The water sorption quantity of desiccants coated on the surface of the heat exchange channel of desiccant coated heat exchanger (DCHE) is the main factor affecting its dehumidification performance. These materials are usually porous media such as silica gel [2], SAPO-n (silicoaluminophosphates) [3], silica gel based composite desiccant [4] and metal-organic framework (HKUST-1) [5]. These materials have a large water sorption quantity and can be regenerated at 50-100 °C.

In this paper, carbon based composite desiccant was prepared by the impregnation method. The activated carbon was added hydrophilic by SiO_2 and impregnated with lithium chloride to enhance its sorption quantity. Firstly, the pore parameters and specific surface area of the composite desiccant were studied by nitrogen isothermal adsorption. Then, the thermal conductivity and thermal diffusivity of the composite desiccant were tested. Then the steam sorption kinetics and isothermal adsorption line of the composite desiccant were studied. Finally, the adsorption isotherm fitting equation established was put into the mathematical model to evaluate the dehumidification performance of DCHE.
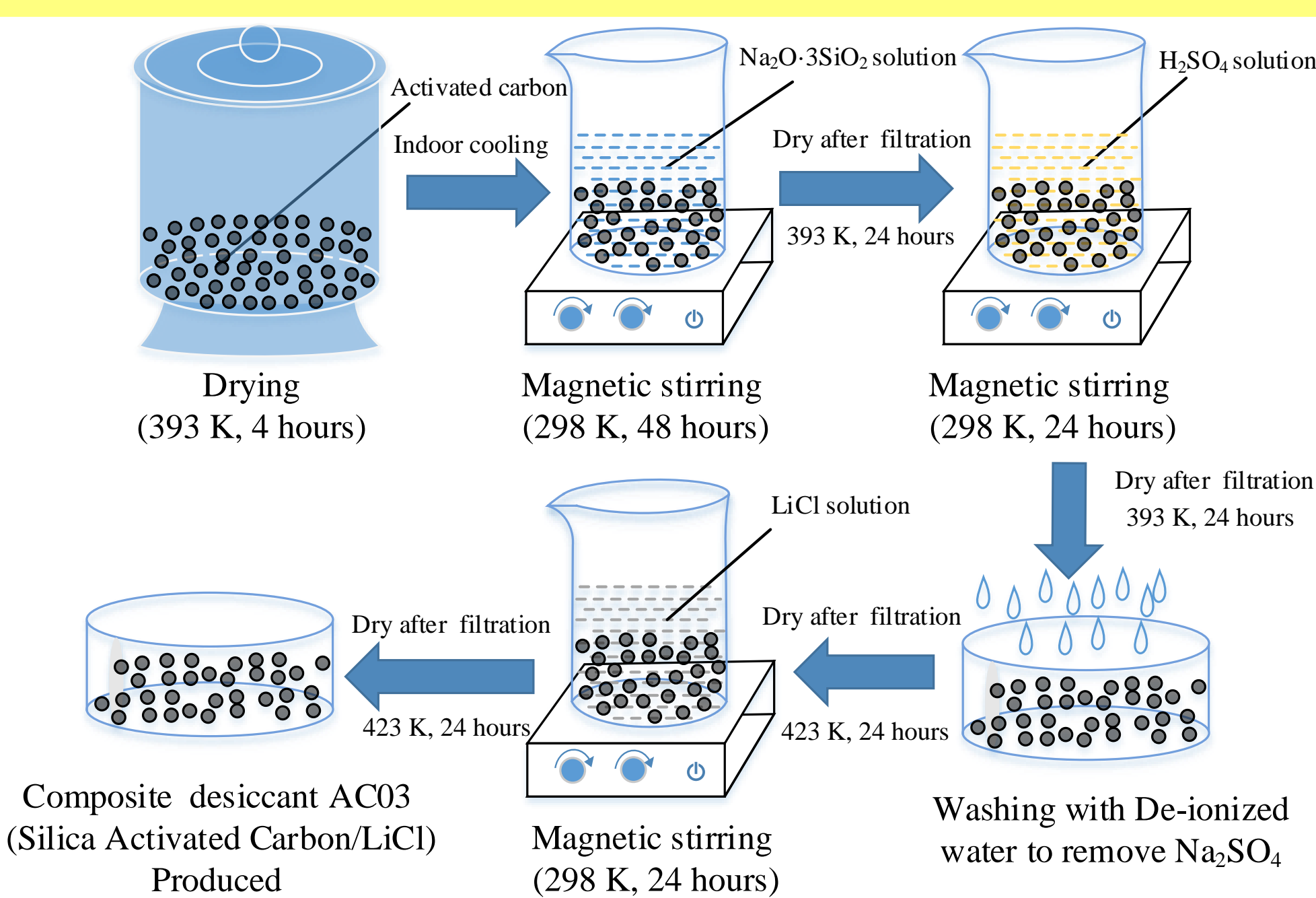

Fig.1. Schematic diagram of the preparation of composite desiccant.

Preparation of desiccant

Carbon based composite desiccant is mainly composed of activated carbon, silica gel and lithium chloride. Fig.1 is a schematic diagram of the preparation of composite desiccant. The main production steps of composite desiccant are as follows: 1) 20 g activated carbon is dried at 120 ℃ for 4 h, so the moisture is fully desorbed. 2) The dried activated carbon was placed in 300 mL of 10wt% $Na_2O·3SiO_2$ solution and impregnated at 25 ℃ for 48 h with a magnetic stirrer. 3) The activated carbon impregnated with sodium silicate was washed and dried for 24 h at 120 ℃.4) Put the dried activated carbon into 150 mL H_2SO_4 solution of 3.9 mol/L and stir it at 25℃ for 24 h. 5) After vacuum filtration, wash the activated carbon with deionized water 2-3 times. After drying at 150 ℃ for 24 h, the weighing mass was m_1. 6) Place the dried activated carbon in 300 ml 40wt% lithium chloride solution and stir it with the magnetic force for 24 h. 7) After vacuum filtration, the desiccant is dried at 150 ℃ for 24 h. Finally, the desiccant is screened into 200-300 mesh particles and weighed by m_2.

The pure activated carbon thoroughly dried in the first step was named AC01. The activated carbon impregnated with silica prepared in the fourth step was named AC02, and the carbon based composite desiccant prepared in the sixth step was named AC03. In this paper, type B silica gel (SG) and pure activated carbon (AC01) are control materials. Before testing, each sample was placed in a drying oven to dry at 120℃ for 4h. Fig.2 is SEM images of activated carbon and composite desiccant.
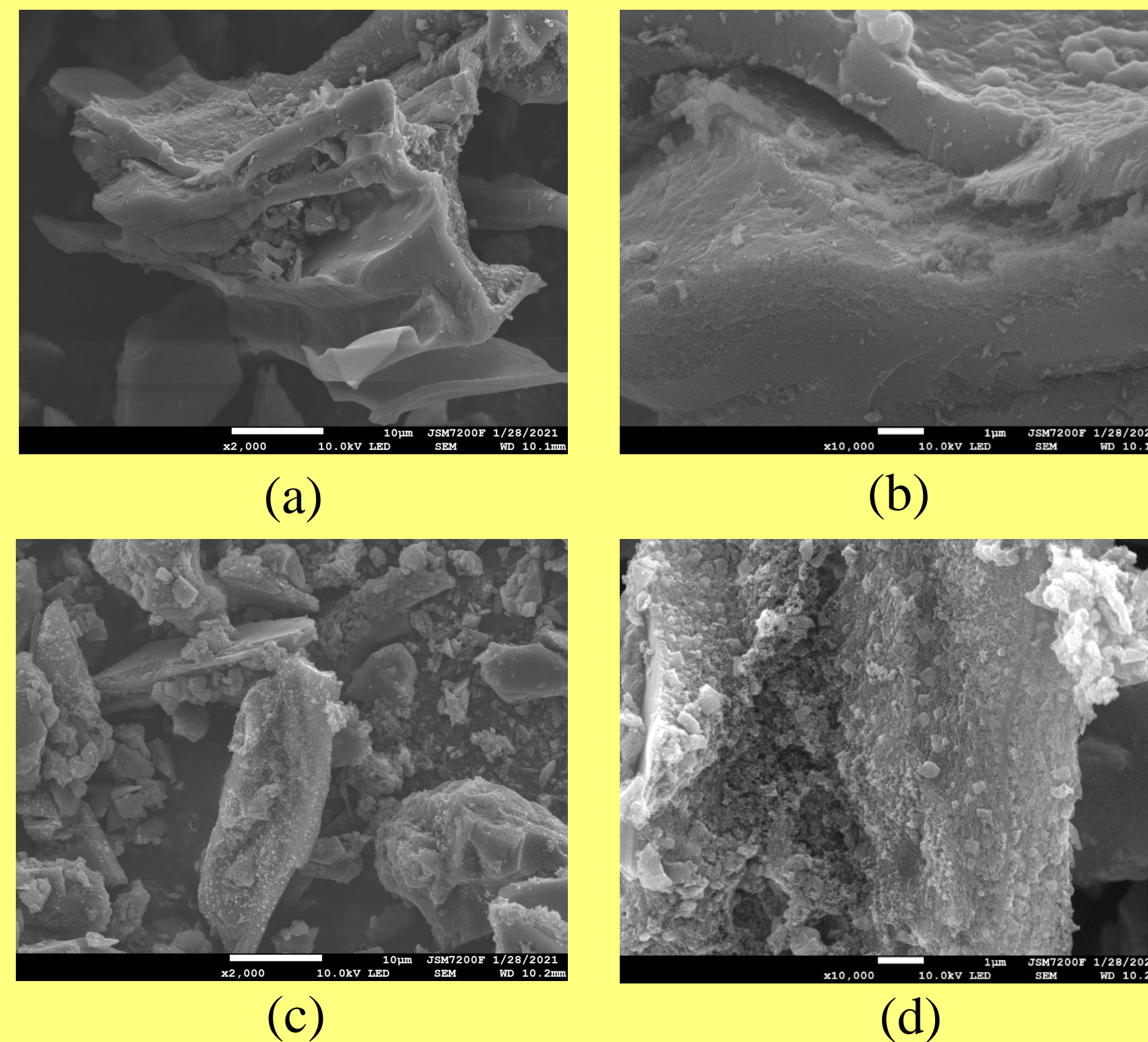

Fig. 2. SEM images of activated carbon (a, b) and composite desiccant (c, d).

Experiment

SURFACE AREA AND PORE PARAMETERS
Fig.3 (a) shows the adsorption isotherms of nitrogen for different desiccants. The diagram line is the type IV isotherm with hysteresis ring under high relative pressure. The nitrogen adsorption capacity of all composite desiccants is less than that of pure activated carbon. It is found that the specific surface area and pore parameters of composite desiccant are smaller than that of pure activated carbon due to impregnation. The specific surface area of pure activated carbon is 1385 m²/g, which is 1.5 times that of composite desiccant AC02 and 3 times that of AC03.

SORPTION ISOTHERMS
Fig.3 (b, c, d) shows the water sorption kinetics, absorption isotherm and sorption potential curves of different desiccant at 20°C. It can be observed from the figure that the isothermal adsorption line of AC03 is on the whole above AC01, which is due to the effect of impregnation salt that the water absorption performance of the composite desiccant has been greatly improved. When the relative humidity is 60%, the water sorption quantity of AC01 and AC03 is 0.18 kg/kg and 1.09 kg/kg, respectively.
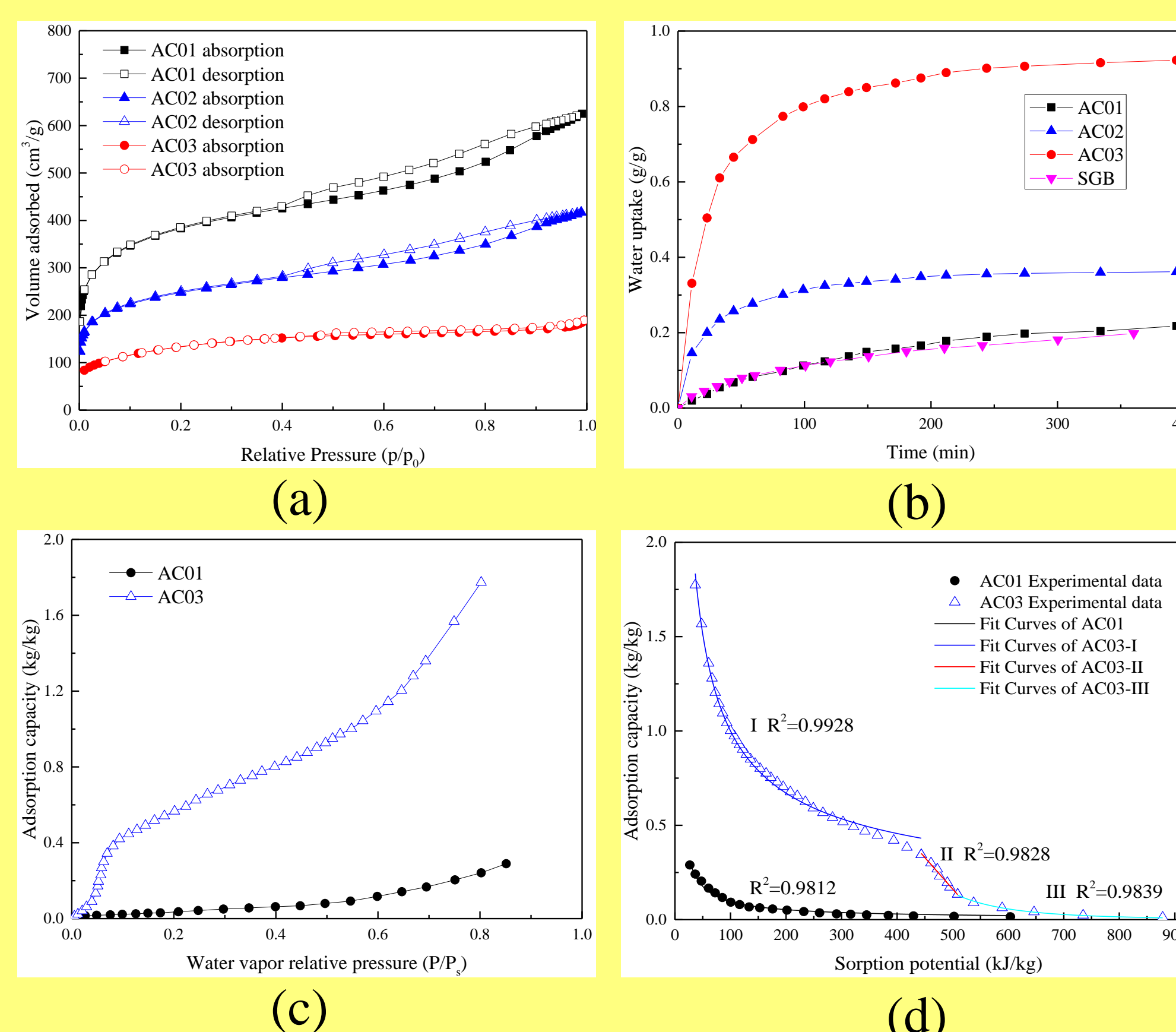

Fig. 3. Adsorption characteristics of desiccant, (a) Nitrogen adsorption isotherm, (b) Sorption kinetics, (c) Water sorption isotherms, (d) Sorption potential curves.

Results

To further predict the dehumidification performance of the DCHE system, a verified mathematical model was used to predict it [1]. Fig.4 shows the dehumidification capacity of DCHE coated with different desiccant. At the same inlet relative humidity, the dehumidification capacity of SG coating DCHE is the weakest, and the PVA/LiCl and AC03 are the strongest. When the relative humidity of inlet air is 70%, the dehumidification capacity of SG, AC01, AC03, PVA/LiCl and HKUST-1 coating DCHE are 0.65, 0.95, 1.78, 1.87 and 1.63 kg/h, respectively, and the difference between AC03 and PVA/LiCl is only 4.8%. On the other hand, PVA costs twice as much as activated carbon. The dehumidification capacity of AC03 was increased by 173.8% and 87.4%, respectively, compared with SG and AC01. Therefore, AC03 as the coating desiccant of DCHE is the better choice.
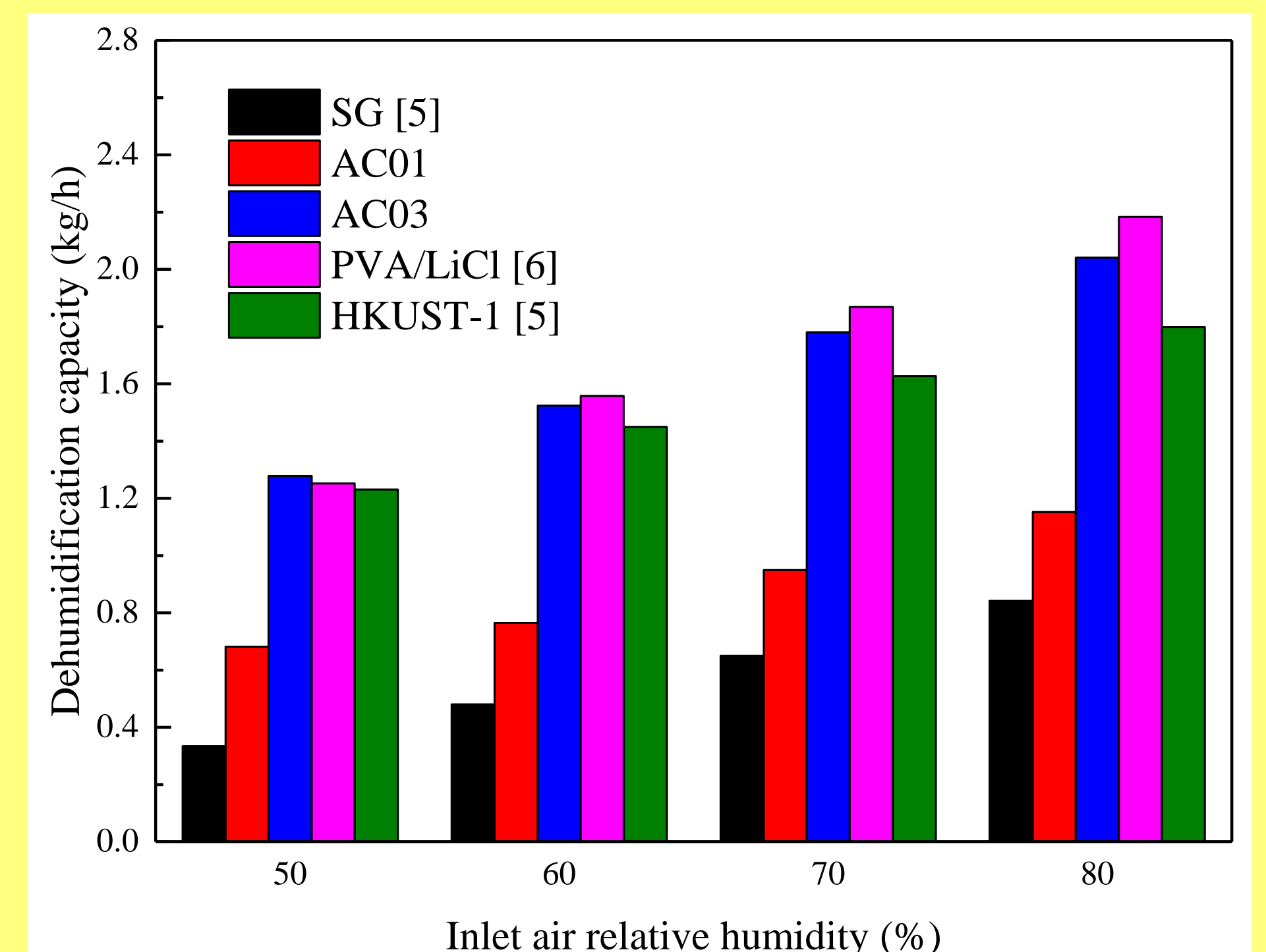

Fig. 4. The dehumidification capacity of DCHE coated with different desiccant.

Conclusions

The main conclusions drawn from all these work are:
- The specific surface area, pore size and density of the composite carbon desiccant AC03 are 457 m²/g, 2.5 nm and 307 kg/m³, respectively.;
- The thermal conductivity of carbon-based composite desiccant AC03 is 0.253 W/mK, almost 1.6 times that of silica gel;
- Sorption kinetics study showed that the equilibrium sorption quantity of carbon-based composite desiccant AC03 was 0.923 kg/kg. When the relative humidity is 60%, the water sorption quantity of the composite desiccant AC03 reaches 1.1 kg/kg, which is 0.9 kg/kg higher than that of the pure activated carbon;
- When the relative humidity is 70%, the dehumidification ability of AC03 coated DCHE is 2.7 and 1.9 times that of SG and AC01, which is only 4.8% lower than that of PVA/LiCl.

References

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