Development of Absorbents with High Contact Area for Applications in Desiccant Coated Heat Exchanger

Yunxi Li
Hisense Air Conditioner R&D Centre
Hisense (Shandong) Air Conditioner Co. Ltd.
Qingdao, China
liyunxi@hisense.com

Benwei Li
Hisense Air Conditioner R&D Centre
Hisense (Shandong) Air Conditioner Co. Ltd.
Qingdao, China
libenwei@hisense.com

Zhigang Wang
Hisense Air Conditioner R&D Centre
Hisense (Shandong) Air Conditioner Co. Ltd.
Qingdao, China
wangzhiganghh@hisense.com

Abstract—Desiccant coated heat exchanger (DCHE) is developed from the combination of desiccant absorbents and the conventional fin-tube heat exchanger. The performance of the DCHE is mainly due to the adsorption properties of the coated absorbents. Therefore, to improve the DCHE performance, we fabricated porous ion exchange resin (IER) particles which have highly increased contact areas to be used as the DCHE absorbents. The water uptake and adsorption ratio of the porous and non-porous absorbents were both measured and compared against each other. The results showed that the absorbents with porous structure possessed higher water capacity and adsorption rate than that of the non-porous IER.

Keywords: air-conditioner; exchanger; desiccant; porous; ion exchange resin

I. INTRODUCTION

Generally, the dehumidification and humidification are achieved via refrigerating to condense the moist air below the dew point or heating the liquid water above the vapor temperature. Both directions of the humidity control caused plenty of energy waste, which decreased the coefficient of performance (COP) as well [1-7]. Recently, to control the indoor humidity and improve the COP of the conventional air-conditioning system, researches on adsorption refrigeration technology has increased due to many advantages such as utilizing solar and geothermal energies and wastes heat [6-12]. The desiccant coated fin-tube heat exchanger a kind of the DCHEs, developed from the classic fin-tube heat exchanger which is widely used in nowadays air-conditioning system [14-20].

Absorbents such as active carbons, silica gel, zeolites or ion exchange resins are the key component of the desiccant coated fin-tube heat exchanger [2,8,11,13]. Great efforts have been dedicated to investigating the performance of these materials. For example, silica gel has been both analytically and experimentally studied [11-13]. Computer simulation was also applied to optimize the performance of the adsorption refrigeration [14-15].

Compared to those inorganic porous materials, IER can directly attach to the fin surfaces instead of mixing with epoxy resin, which avoids the decreasing of the contact area of the absorbents. However, the IER swells while absorbing water and shrinks after evaporation. The frequent dimensional change of the resin caused the serious decline in durability. Besides, the adsorption properties are

In this work, we propose IER with aromatic chain structures to provide high thermal and mechanical stabilities, which improves the longevity of the absorbents. The aromatic IER was also fabricated with porous structures to increase contact surface areas. The test results showed improved humidity adsorption rate and capacity due to the porous surfaces.

II. EXPERIMENTAL
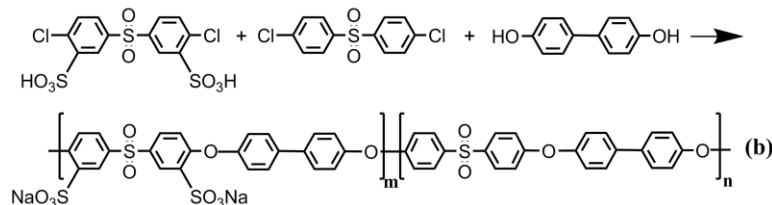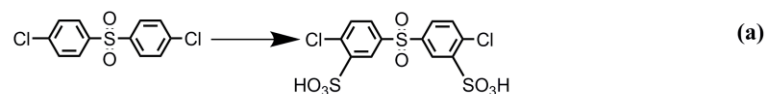
A.   Sythesis of IER

B. *Synthesis of the SPESIER*

The ion exchange resin was synthesized via two major steps as shown in Scheme 1. First, sulphonated bis (4-chlorophenyl) sulphone was obtained via a typical sulphonating procedure utilizing fuming sulfuric acid and bis (4-chlorophenyl) sulphone [21]. Then the sulphonated bis (4-chlorophenyl) sulphone was added into a three-necked, round-bottomed flask with K_2CO_3, biphenol and DMSO (solvent). The SPESIRE was polymerized via aromatic nucleophilic substitution polycondensation. The resulting polymer was washed with DI water and ethanol after polymerization.

C. *Prepareation of porous absorbents particles.*

The size of the common used absorbents particles are usually in the range of 60~100 μm. Therefore, to develop the absorbents with porous surfaces, the pore size should be much smaller than that of the particle.

In this work, the porous structure was fabricated by the solution casting method. First, the SPESIER was dissolved into NMP with the solid content of 10% and stirring for 12h at room temperature to get a homogeneous solution. Secondly, 1-Ethyl-3-methlimidazolium tetrafluoroborate (EMMBF₄) was separately added into the solution at concentrations of 50wt% of the SPESIER. The mixtures were then stirred for another 12h to ensure uniform dispersion. The casting solution was filtered before pouring onto a flat glass substrate. The glass plates with casting solution on top were first held in the oven at 60°C for 12h and then 80°C in vacuum for another 24h to remove solvents. The dried polymers were then removed from the glass plate and boiled in methanol until constant weight to remove the EMMBF₄ and residuals. The porous polymers were powdered into small particles and the pore structure was observed under SEM.

D. Water uptake

Water uptake was measured after completely drying of the samples at 120°C in vacuum. Then their weights (W_{dry}) were recorded before immersing into DI water. Tests were carried out at different temperatures (20 °C, 40 °C, 60 °C, 80 °C and 100 °C). The W_{wet} were measured after 10mins at each temperature. The water uptake of these membranes was calculated and compared as percentages by the following equation:

$$\text{Water uptake (wt\%)} = (W_{wet} - W_{dry})/W_{dry} \times 100 \qquad (1)$$

E. Adsorption rate

The adsorption rate of the porous IER particles was measured and compared against the non-porous absorbents. The absorbent powder was first dried in the oven at the temperature of 120 °C until constant weight which was recorded as W_{dry}. Then the absorbents were placed in a cube with the salt bath of KCl to create a constant relative humidity (RH) atmosphere. The weight change of these absorbents was continuously measured every 100 seconds.

The adsorption ratio was evaluated by the following equation:

$$\text{Adsorption ratio (wt\%)} = (W_{wet} - W_{dry})/W_{dry} \times 100 \qquad (2)$$

III. RESULTS AND DISCUSSION

A. *Morphology*

EMMBF₄ was used as the pore-forming agent due to its extraordinary compatibilities with polymers. 50wt% of the EMMBF₄ was added into the system and removed by methanol after membrane casting. The choice of solvent for membrane casting plays an important role in the manufacture of uniform pore size distribution. To lower the evaporation speed and avoid the split phase, NMP was used in the work. Figure 2 shows the field emission scanning electron microscopy (FESEM) images of the porous absorbents. The morphological structure exhibited uniform pore size distribution with an average diameter of 0.32 μm.
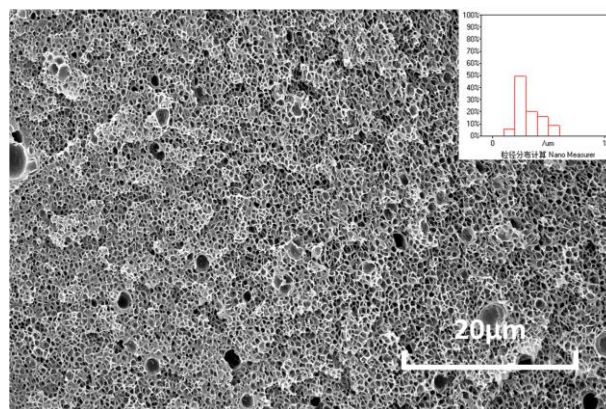

Figure 2. The SEM images of the porous IER.

B. *Water uptake*

Water uptake at various temperatures could reveal the highest water capacity of the absorbents. As expected, both the porous and non-porous absorbents exhibited improved water uptake along with the increasing of temperature. Besides, as we can see in Fig. 3, the porous absorbents outperformed that of non-porous absorbents over the entire range of temperatures. The porous absorbent have a higher water uptake ratio of 5.9 wt% than the non-porous particles (5.6 wt%) after 10mins immersed into water at 20°C, indicating the enhancement of the porous surfaces on water uptake.
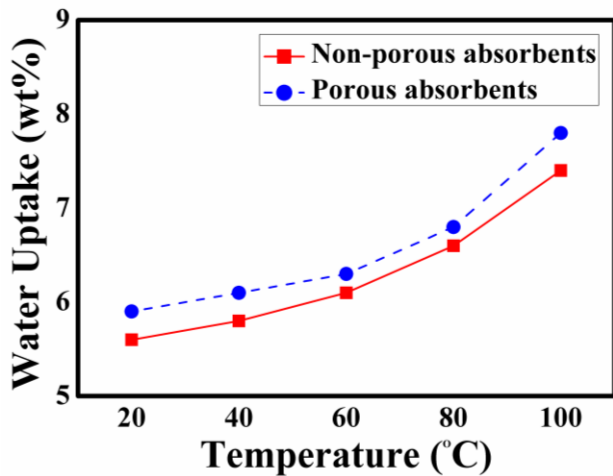
Figure 3. Water uptake of both porous and non-porous absorbents.

C.   *Adsorption*

KCl salt bath was placed in a cube to create constant RH atmosphere. The RH was continuously measured until constant for 5mins (68.7% RH). Then the dried porous and non-porous absorbents were both placed in the oven and the weight change was recorded for comparison. Both samples exhibited high adsorption rate at first and slowed down after 300s. The porous absorbents showed higher adsorption rate than that of non-porous samples. As shown in figure 4, the porous absorbents also had higher adsorption ratio (6.3 wt%) after fully absorbed.
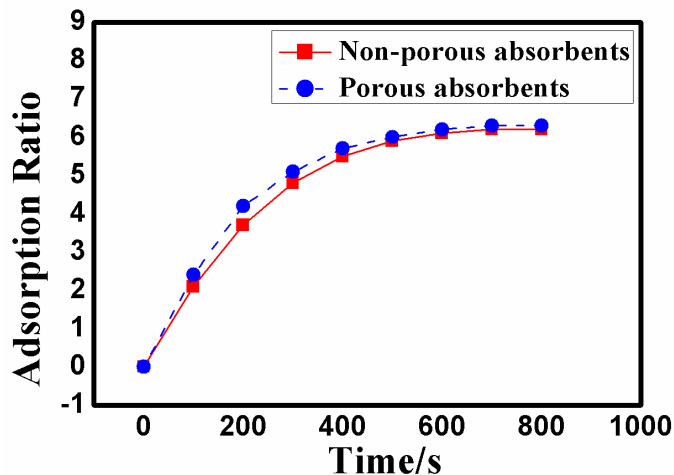

Figure 4. The adsorption ratio of both porous and non-porous absorbents.

IV.   CONCLUSION

The sulphonated poly ether sulfone ion exchange resin was successfully synthesized. To improve the adsorption capacity, the IER was fabricated with porous structure to increase the contact area with the moist air. Water uptake and adsorption ratio are investigated and compared with the non-porous absorbents. It turns out the porous absorbents exhibit both higher humidity adsorption rate and capacity due to the morphological changes. This works may provide a new method for developing high-performance desiccant coated heat exchangers.

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