PERFORMANCE OF HONEYCOMB ROTOR DEHUMIDIFIERS IN IMPROVED METHODS OF ADSORBENT PREPARATION

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Introduction

The authors have developed honeycomb rotor dehumidifiers and discussed the fundamental aspects such as optimum rotation speed, temperature distributions and a semi-quantitative prediction of the performance from an experimental point of view in previous papers (Kodama *et al.*, 1993, Kodama *et al.*, 1994, Kodama *et al.*, 1995). The material of the adsorbent rotor used in the experiment was not varied and limited to silica gel prepared by treating with sulfuric acid. In order to improve the dehumidifying performance, the authors have examined adsorbents prepared by different procedures. The purpose of the present article is to report the fact that the authors

succeeded in manufacturing adsorbent rotors with higher dehumidifying performances than reported previously.

1. Preparation of Honeycomb Adsorbents

Plane strips and corrugated strips of ceramic fiber paper were first stacked alternately with heat resistant adhesive and rolled up into the shape of a honeycomb rotor of 0.3m dia. with a pitch of 3.2mm × 1.8mm and a wall thickness of 0.2mm as reported previously. The ceramic honeycomb rotor was then impregnated with aqueous solution of sodium silicate (Na_2SiO_3). The solution held in the voids of the ceramic fiber sheet was neutralized by three different methods after it was partially dried. The adsorbent rotor was then rinsed, dried, calcined and finished mechanically to complete the honeycomb rotor adsorbent to be

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Fig. 1 Dehumidifying performance of S-rotor in standard type dehumidifier ($T_{P0}=30^{\circ}\text{C}$, $T_{R1}=140^{\circ}\text{C}$, $X_{P0}=X_{R1}$, $L=0.2\text{m}$)

examined for dehumidifying performance. The main constituent of the adsorbent synthesized was silica gel, but the composition and morphology are expected to be different with different procedures of neutralization. Three methods were examined for the same temperature (60°C) and period (3hr) in the neutralizing reaction. Further information of rotor manufacturing is available in the US Patent of Kuma and Okano(1990).

The first one was neutralized with sulfuric acid solution of 25% by weight. Since the byproduct, Na_2SO_4 , was washed out by subsequent rinsing, silica gel was probably only one product adsorbent synthesized in the voids of the matrix sheet. This adsorbent rotor is designated an S-rotor, which was the one used in the experiment reported previously.

A second rotor was treated with a solution of aluminum sulfate of 20 wt%. Some amount of aluminum remained, probably in a form of metal silicate or oxide. The typical mole ratio of Si/Al was between 6 - 10. This type of adsorbent rotor is designated an M-rotor.

The authors tested some other solutions of acids (HCl , H_3PO_4 , HCOOH) and salts (sulfate, chloride, phosphate, nitrate) with varying counter metals (Ti, Al, Mg, Fe, Zr, Mn, Co, Sn, Ca etc.) to find the best performance of dehumidification with titanium or titanyl sulfate. They also found performance improvement with some substances dissolved in the sodium silicate solution prior to impregnation of the rotor matrix. Such an improved adsorbent rotor is designated a U-rotor. In the preparation of the U-rotor, the neutralizing agent was an acidic mixture of titanyl sulfate and aluminum sulfate (20% by weight in total), and up to several percent gluconic acid was added to sodium silicate.

2. Results and Discussion

The three types of adsorbent rotors were tested for dehumidifying performance, which was evaluated in the plot of humidities of the product gas against the feed gas. The humidifiers operated at the optimal rotation speed, which was close to that predicted by the correlation proposed by the authors (Kodama *et al.*, 1993, Kodama *et*

Fig. 2 Dehumidifying performance of M-rotor in standard type dehumidifier

Fig. 3 Dehumidifying performance of M-rotor in symmetric type dehumidifier

al., 1994). The general trend in performance can be seen in **Fig.1** for the S-rotor in the flow system of the standard type where one-quarter of the total cross-sectional area of the rotor was used for the regeneration of the adsorbent rotor by hot air and the rest was used for processing the feed humid air. The dehumidifying ratio $1 - X_{P1}/X_{P0}$ decreases with increasing feed humidity X_{P0} because the rotor temperature gradually rises by adsorption heat and the humidity in equilibrium with the regeneration air becomes higher. The enthalpy exchange efficiency η_H defined as

$$\eta_H = (H_{P1} - H_{P0}) / (H_{R1} - H_{P0}) \quad (1)$$

is favorably small. The lower humidity can be obtained in the product air at lower gas velocity as expected.

Dehumidifying performance is compared between the S-rotor and the M-rotor in **Fig. 2** for the standard type dehumidifier. Improved performance owing to possible coexistence of metal silicate or oxide can be seen for the M-rotor in the figure.

The dehumidifying performance decreases with decreasing temperature of regeneration air. However, this effect can be compensated by increasing the area for regeneration. When the cross-sectional areas are the same for both process and regeneration zones, the dehumidifier is called symmetric. The dehumidifying performance of the symmetric type dehumidifiers is compared between the S-rotor and the M-rotor in **Fig. 3**. The improvement by the

Fig. 4 Dehumidifying performance of U-rotor in standard type dehumidifier

M-rotor can be seen again and low temperature air, as low as 60°C, can be used effectively as the regeneration air in the symmetric dehumidifier. A symmetric and balanced flow dehumidifier is a potential candidate for the adsorptive desiccant cooling system activated at low temperature from waste heat or solar collectors.

The performance of the recently developed U-rotor is compared with the above M-rotor in Fig. 4 for the standard type and Fig. 5 for the symmetric type. These figures show the still higher performance of the U-rotor, compared to the improved M-rotor for both types. The U-rotor of $L = 0.2\text{m}$ width is equivalent or even better than the M-rotor of $L = 0.4\text{m}$ width, i. e., double the width of the U-rotor. This fact contributes to the compactness of adsorption dehumidifiers.

The above discussion concentrated on improvement itself in the performance, but not the actual mechanism of improved adsorption. The surface area, pore size, amount adsorbed, diffusivity and so on are expected to be all dependent on the preparation procedure of the adsorbent rotors. Thermodynamic and kinetic aspects are currently under investigation.

Conclusion

The dehumidifying performance of adsorptive honeycomb rotor dehumidifiers has been improved by changing the neutralizing agents for sodium silicate solution impreg-

Fig. 5 Dehumidifying performance of U-rotor in symmetric type dehumidifier

nating the ceramic fiber sheet of the honeycomb matrix. The M-rotor treated with aluminum sulfate showed better performance for dehumidification than the S-rotor treated with sulfuric acid, and the U-rotor treated with mixed acidic solution was still better than the M-rotor.

Nomenclature

L	= width of rotor	[m]
H	= enthalpy of air	[J/kg]
n	= rotation speed of rotor	[h ⁻¹]
T	= temperature of air	[°C]
U	= superficial gas velocity	[m/s]
X	= humidity	[kg/kg]
η_H	= enthalpy exchange efficiency	[-]
<Subscripts>		
P	= process zone	
R	= regeneration zone	
0	= inlet end of feed air	
1	= inlet end of regeneration air	

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