Honeycomb Rotor Adsorption Dehumidifiers for High Efficiency Desiccant Air-Conditioning

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Abstract
Honeycomb rotor adsorption dehumidifiers for desiccant air-conditioning are especially required to exhibit higher efficiency at comparatively low regeneration temperature below 80℃. In the present study, we have manufactured various types of honeycomb rotor adsorption dehumidifiers with different materials and performed efficiency tests to compare and examine their static adsorption characteristics and dehumidifying efficiency. We discuss the most suitable adsorption characteristics of honeycomb rotor adsorption dehumidifiers when they are used for desiccant air-conditioning.

1. Introduction

A desiccant air-conditioning system cools air by a combination of a honeycomb rotor dehumidifier, a sensitive heat exchanger and an evaporative cooler using solar heat and various kinds of exhaust heat as energy sources. It has been tested and studied in many countries for about 20 years and actual commercial application has been increasing recently. Co-generation systems using exhaust heat from private power plants are being examined and adopted in various fields with the recent trend to power liberalization. One of potential candidates is the combination with the desiccant air-conditioning system. In the present study, honeycomb rotor adsorption dehumidifiers suitable for desiccant air-conditioning use have been researched and developed.

2. Desiccant air-conditioning system and honeycomb rotor dehumidifier

A desiccant air-conditioning system attracts attention as an air-conditioning device for low humidity area (below 50% RH) where the conventional refrigeration heat pump is thought to be inefficient, and is gradually coming into wide use commercially. It is used in the following cases typically:

① To aim at the overall energy-saving by combination with other air-conditioners and refrigerators in supermarkets etc.

② To avoid the undesirable over-cooling encountered in the conventional air-conditioning from a health-conscious point of view.

③ To require a high rate of ventilation of buildings

④ To meet HACCP (Hazard Analysis, Critical Control Point) in food industry by an easy humidity control at low humidity range.

Figure 1 is a photograph of an actual desiccant air-conditioning system. A desiccant air-conditioning system generally consists of a honeycomb rotor dehumidifier (desiccant rotor), a sensible heat exchanger, a hot water heater and an evaporative cooler as shown in *figure* 2. The principle of air-cooling is: Ambient air taken into the honeycomb rotor dehumidifier is dehumidified first, and then the adsorption heat generated during dehumidification is removed by the sensible heat exchanger. The evaporative cooler finally cools air by evaporation latent heat of water.

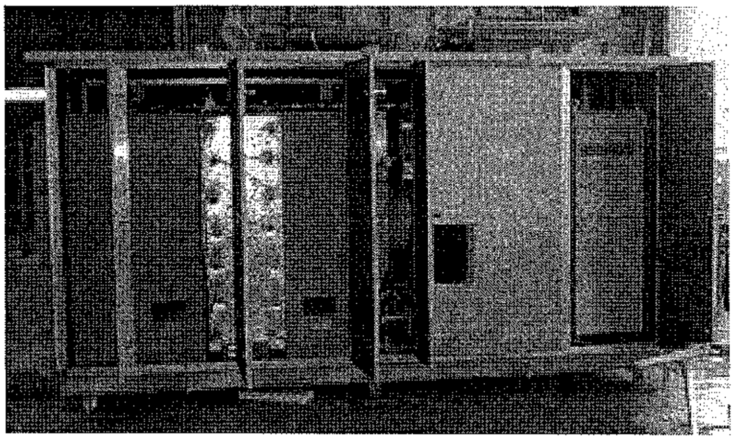

Fig.1 Photograph of the actual desiccant air-conditioning system

Heat source is used for so-called regeneration during which water vapor having been adsorbed is desorbed from the honeycomb rotor dehumidifier to recover the dehumidifying ability.

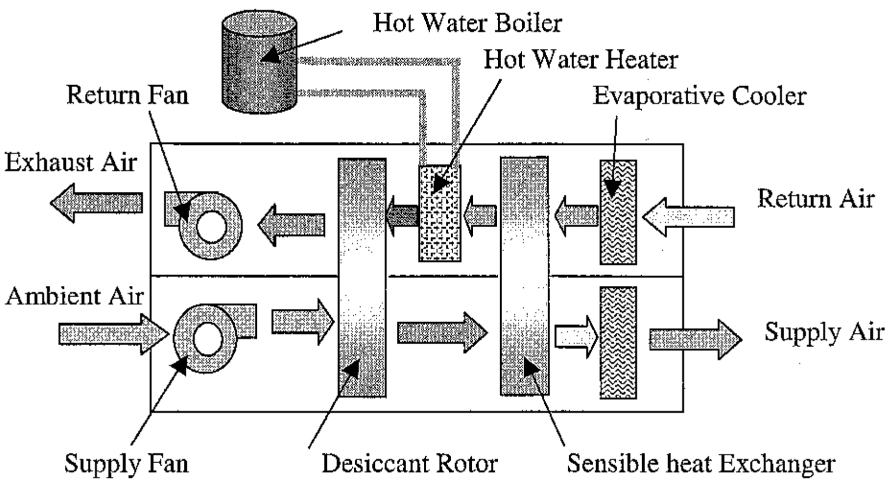

Fig.2 Flow chart of current desiccant air-conditioning

As shown in *figure 3*, a honeycomb rotor dehumidifier consists of a honeycomb adsorbent rotor, which is rotated, in a casing at a low speed of around 16 rph by a geared motor in the outer circumferential drive method. The casing is divided into two sectors of process zone and regeneration zone.

Process air is led in the process zone to contact the rotating honeycomb rotor. While it passes through the honeycomb channels, water vapor is adsorbed and removed by honeycomb adsorbent, and it becomes dry air to be supplied. Sometime later, the honeycomb rotor having got wet due to moisture adsorption enters the regeneration zone by

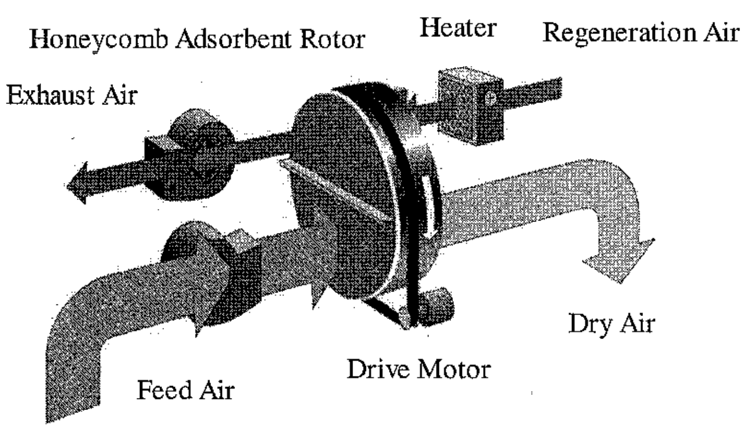

Fig.3 Schematic diagram of a honeycomb rotor adsorption dehumidifier

rotation. The rotor is regenerated by hot air passing through honeycomb channels and turns again to the process zone. Dry air can always be produced in stable conditions by this continuous cycle.

Honeycomb rotor dehumidifiers for industrial use are generally designed and used so as to process at air flow rate ordinarily three times as much as regeneration air rate at regeneration temperature of 100-140℃. On the other hand, in the case of desiccant air-conditioning use, honeycomb rotor dehumidifiers are operated with regeneration air rate increased almost to as much as process air so that regeneration is possible at low temperature of 60-80℃ to utilize exhaust heat from solar heat and co-generation systems. The ratio of process zone /regeneration zone is fixed to 1/1.

3. Experimentals

Honeycomb rotor adsorption dehumidifiers for desiccant air–conditioning are required to have high dehumidifying capacity in low regeneration temperature condition of 60-80℃. Easy regeneration at low temperature is one of important characteristics but it does not necessarily lead to efficiency improvement since temperature rise of dehumidified air by adsorption heat in dehumidification tends to decrease adsorption capacity. In order to investigate what adsorption characteristics of rotors are suitable for desiccant air-conditioning, various test honeycomb rotors were manufactured using adsorbents of different characteristics, and examined in terms of dehumidifying performance.

3.1. Manufacturing method of honeycomb rotor adsorption dehumidifiers

Table 1 is a specification of test dehumidifying rotors manufactured using various adsorbents with different characteristics.

Table 1 Specifications of honeycomb rotor adsorption dehumidifiers manufactured using various adsorbents with different characteristics

	MSR-U	SZR-A	SZR-B	MSR-L
Honeycomb matrix	Ceramic fiber paper	Ceramic fiber paper	Ceramic fiber paper	Glass fiber paper
Honeycomb size	AS-31	AS-31	AS-31	AS-42
Channel pitch[mm]	3.4	3.4	3.4	4.2
Channel heigh.[mm]	1.8	1.8	1.85	2.3
Cell numbers	211	211	205	134
Adsorbent type	Metal silicate	Zeolite A	Zeolite B	Metal silicate
Adsorbent loading methods	Loading by synthesis reaction	Loading by impregnating	Loading by impregnating	Loading by synthesis reaction
Bulk density of rotor [kg/m^3]	207	238	238	137
Adsorbent content [wt%]	44.5	39.1	37.1	50.0
Adsorbent content on volume[kg/m^3]	92	93	88	68
Rotation speed of rotor [rph](at 2m/s)	20	25	24	30
Pressure loss [Pa] (at 2m/s)	156	151	182	113

Each rotor has a regular honeycomb structure with a number of fine channels of uniform size as shown in *figure 4* by a cross-sectional view. Honeycomb rotor adsorption dehumidifiers were manufactured by two different methods. In one method, adsorbent was synthesized and supported within the matrix of honeycomb wall and in the other method, the honeycomb is impregnated with the dispersion of synthetic adsorbent powder and supported in voids of honeycomb wall matrix.

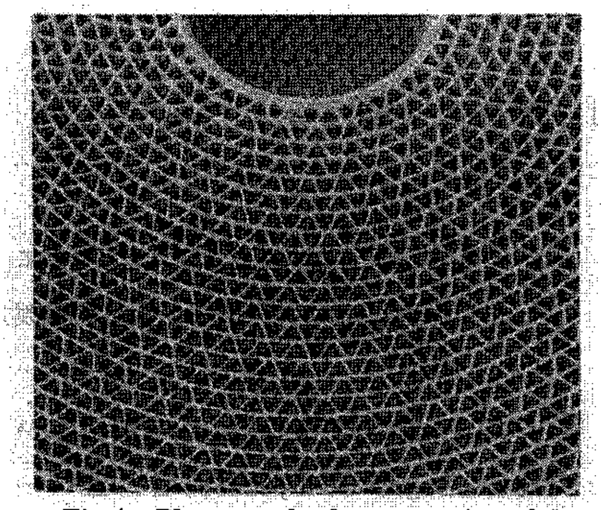

Fig.4 Photograph of cross-section of the honeycomb rotor adsorbent

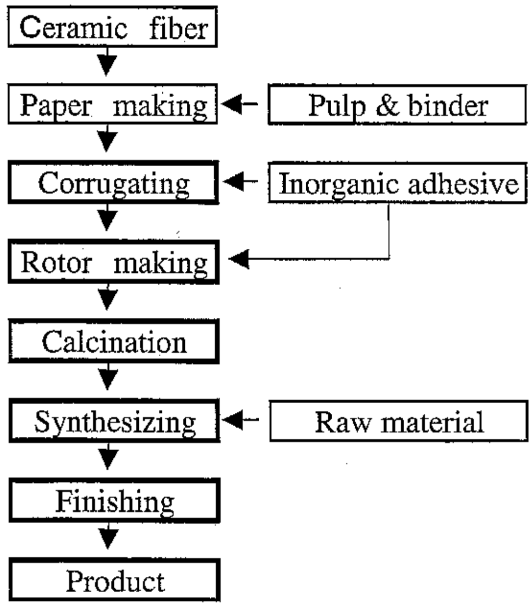

Fig.5 Manufacturing process of honeycomb rotor adsorption dehumidifiers

3.1.1. Manufacturing method of a rotor with metal silicate synthesized (MSR)

Honeycomb rotor adsorption dehumidifiers were manufactured according to the process given in *figure 5*. Inorganic fiber paper with high void age was first corrugated into honeycomb state and was rolled into a cylindrical shape to make honeycomb matrix. Sodium silicate and metal salt were led to react and polymerize inside this matrix to obtain metal silicate honeycomb solidified in honeycomb state by metal silicate. This honeycomb was further finished and fabricated into a dehumidifier. The adsorption capacity of metal silicate thus synthesized was realized at the highest performance because metal silicate itself is chemically combined in synthesis and didn't contain any inert binder that may obstruct the adsorption capacity.

Figure 6 is a photograph of inorganic fiber paper before metal silicate was synthesized, and *figure 7* is a SEM photograph after the synthesis.

An MSR-L rotor was specially designed for desiccant air-conditioning for the purpose of low cost and low pressure-loss by use of glass fiber matrix with a little courser honeycomb structure while honeycomb matrix of an MSR-U rotor was made of ceramic fiber paper. It should be noted that low pressure-loss is an important factor in air-conditioning to reduce power consumption and noise in ventilation.

3.1.2 Manufacturing method of a rotor impregnated with synthetic zeolite (SZR)

Honeycomb rotor adsorption dehumidifiers with synthetic zeolite supported was manufactured by the same process that of MSR (metal silicate rotor) as shown in *figure 5* up to the high temperature incineration. In the chemical treatment process, the rotor was impregnated with adsorbent by being dipped in slurry prepared with adsorbent powder and inorganic binder. Pores of adsorbent were sometimes blocked depending on the chemicals used and concentration of binders, and an increase in heat capacity sometimes influenced the dehumidifying efficiency. So selection of binder and preparation of slurry were important.

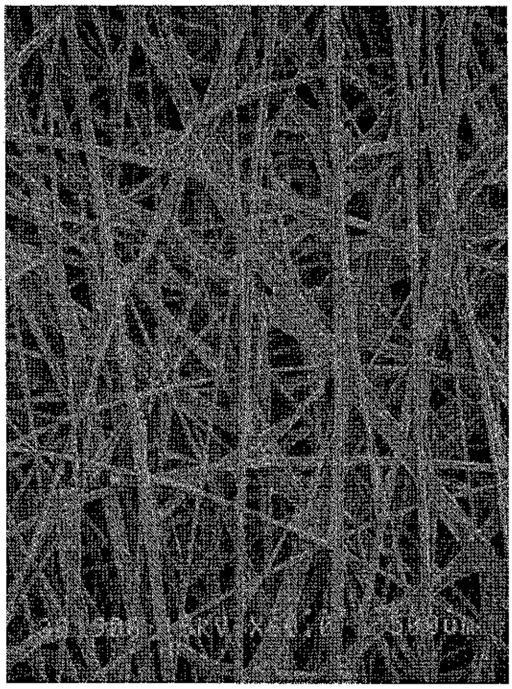

Fig.6 Photograph of inorganic fiber paper before metal silicate was synthesized

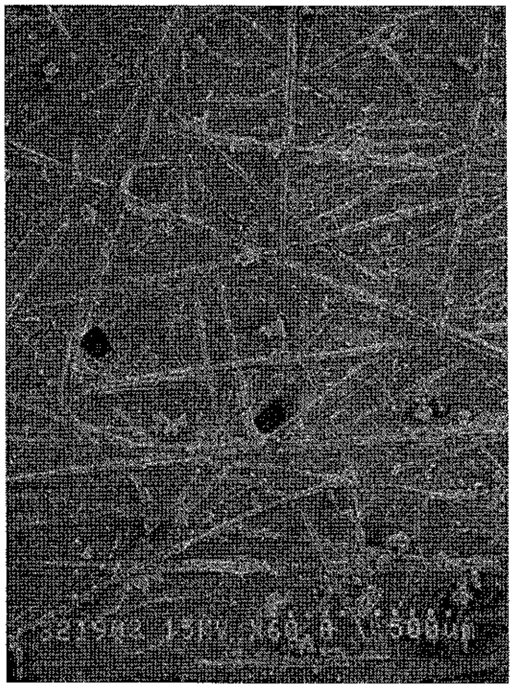

Fig.7 SEM photograph after metal silicagel was synthesized on inorganic fiber paper

Zeolite is known to be the most hygroscopic among various adsorbents but, on the other hand, to be hard to be regenerated. Synthetic zeolites used in this study were of special type of zeolites improved to be regenerated at relatively low temperature of around 100℃. An SZR-A and SZR-B rotors were the same except that characteristics of the starting zeolite powder were different.

3.2. Dehumidifying efficiency test

A series of test for dehumidifying efficiency was carried out for the test dehumidifiers with 320mm in effective diameter and 200mm in width in the test apparatus as shown in *Figure 8* .Volumetric flow rate of air was measured by detecting the static pressure difference through suction nozzles using a precision differential manometer and then converted to superficial linear velocity though honeycomb sectors. A mirror-type dew point meter was used to measure absolute humidity at various points of each dehumidifier. Thermocouples were used to measure temperature at various points.

Equilibrium amount adsorbed on the honeycomb adsorbent of test rotors was measured in a desiccator under various humidities controlled by saturated aqueous solution of salts at room temperature of 15-20℃.

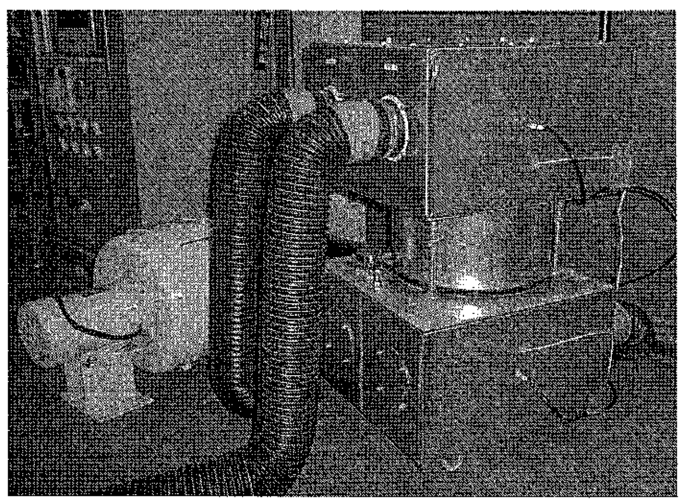

Fig.8 Photograph of the experimental apparatus of a honeycomb rotor adsorption dehumidifier

4. Results and discussion

4.1. Equilibrium amount adsorbed

Adsorption characteristics of various honeycomb rotor adsorption dehumidifiers are compared in *figure9*. Amount adsorbed here is based on mass of the whole element including matrix fiber and binder. Amount adsorbed on MSR-U is the highest in the intermediate region of 20-40% relative humidity (RH) while it is the highest for SZR-B in the low humidity range below 15% RH.

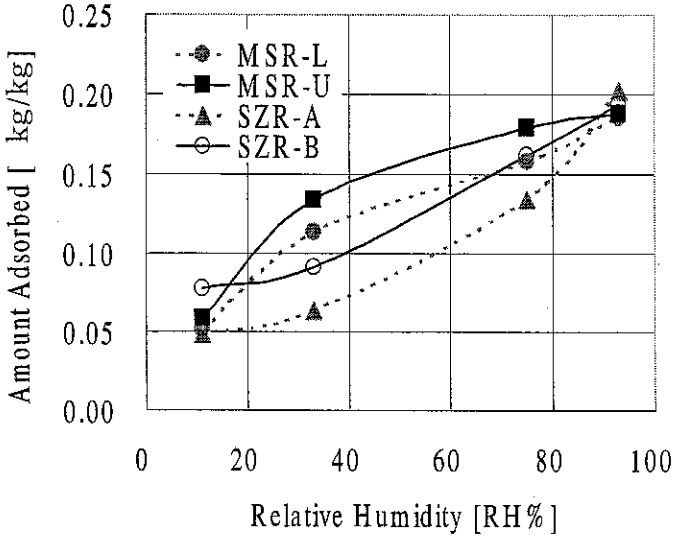

Fig.9 Relation between the relative humidity and amount adsorbed for various honeycomb rotor adsorption dehumidifier

4.2. Dehumidifying efficiency test result

Figure 10 shows comparison of dehumidifying efficiency between various honeycomb rotor adsorption dehumidifiers. Much difference in amount dehumidified ΔX_P are not found between various adsorbents in the low humidity range of inlet air X_{P1} below 7 g/kg'. But difference in dehumidifying efficiency appears due to the adsorbent used above X_{P1} = 10 g/kg'. MSR-U has the highest amount dehumidified and MSR-L, SZR-A and SZR-B follow almost in line.

Figure 11 shows comparison of dry air temperature T_{P2} in exit stream of process zone. Lower temperature is desirable for desiccant air-conditioning use. MSR has the lowest exit temperature T_{P2}. MSR-U and SZR-A follow it and SZR-B gives the highest exit temperature.

Figure 12 shows comparison of increase in enthalpy ΔI_P of process air due to dehumidification.

$$\Delta I_P = I_{P2} - I_{P1} \qquad (1)$$

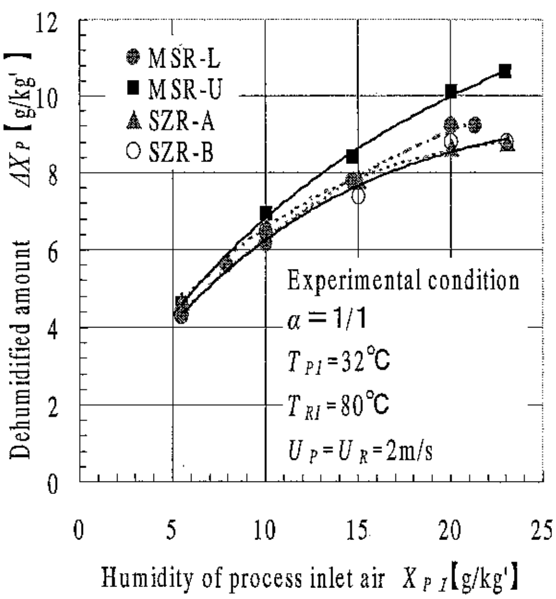

Fig.10 Variation of dehumidifier amount with humidity of process inlet air

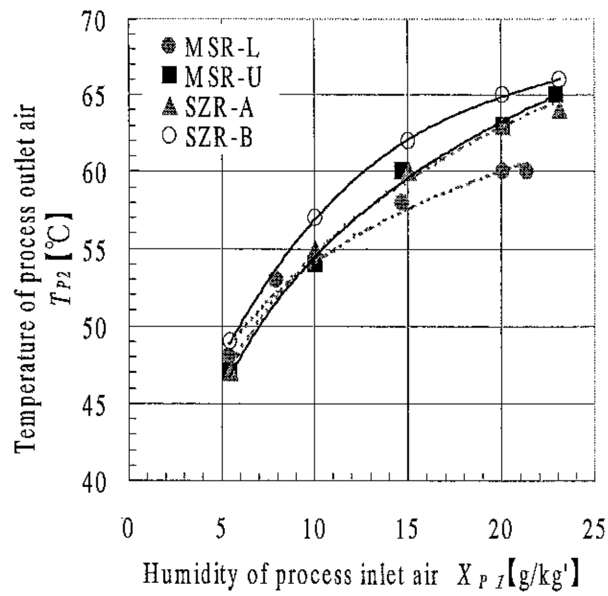

Fig.11 Variation of Temperature of process outlet air with humidity of process inlet air

Enthalpy increase consists of two contributions of regenerative heat transfer from the regeneration zone by rotation of the rotor, and difference between adsorption heat and condensation heat. (If adsorption heat is the same that condensation heat, latent heat just changes into sensitive heat and the enthalpy increase of process air becomes zero.) Enthalpy increase in process air dehumidification cannot be eliminated but its reduction as low as possible leads to improvement in the overall efficiency of the system as a whole. MSR-L has the least enthalpy increase ΔI_P. MSR-U, SZR-A and SZR-B follow it in increasing order.

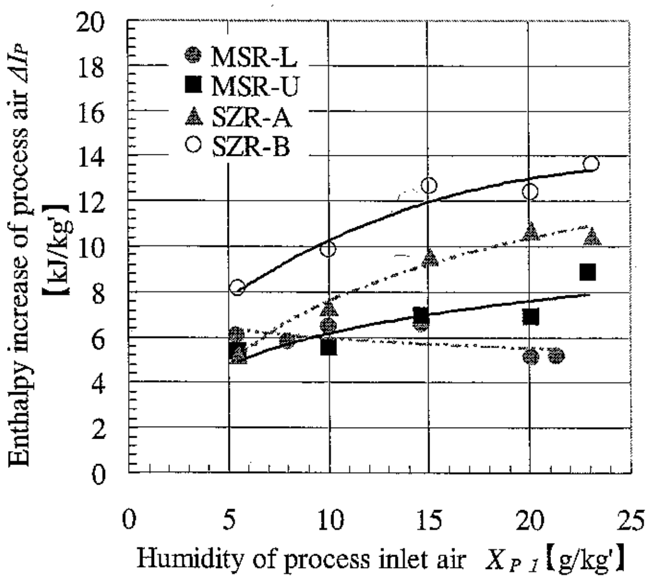

Fig.12 Variation of enthalpy rise of process air with humidity of process inlet air

In both cases of SZR-A and SZR-B, enthalpy increase ΔI_P tends to increase as process inlet air humidity X_{P1} increases. MSR-U has a similar tendency but the increase is little. Enthalpy increase ΔI_P of process air in the case of MSR-L is almost independent of inlet humidity of process air.

4.3. Recommendations for the best dehumidifier

Enthalpy increase ΔI_P tends to increase with increasing amount dehumidified and vice versa. Thus, performance evaluation based on the single parameter of enthalpy increase is not practical. Instead of enthalpy increase, a specific increase in enthalpy $\Delta I/\Delta X$ was defined as enthalpy increase per unit amount dehumidified as given by Eq.(2).

$$\Delta I/\Delta X = (I_{P2}-I_{P1})/(X_{P1}-X_{P2}) \qquad (2)$$

The specific increase in enthalpy was calculated and results are compared in *figure13*.

In both cases of MSR-U and MSR-L, specific increase $\Delta I/\Delta X$ tends to decrease as inlet humidity X_{P1} increases. The reason for this is considered as follows. Different adsorption sites having higher and lower adsorption capacities are distributed in case of silica-base adsorbent such as MSR-U and MSR-L. Higher adsorption energy is required generally and adsorption takes place on sites with the highest adsorption capacity in a low humidity range (for example, at process air temperature 32℃, inlet humidity 33% RH and exit humidity 3-4% RH), resulting in adsorption heat higher than condensation heat. Sites with low adsorption capacity, too, participate in adsorption in a medium humidity range (for example, at process air temperature 32℃, inlet humidity 66% RH and exit humidity 7-8% RH). Thus the adsorption heat is low and approaches condensation heat, making enthalpy increase $\Delta I/\Delta X$ low as a whole.

Specific increase in enthalpy $\Delta I/\Delta X$ is almost constant over the wide humidity range in cases of SZR-A and SZR-B unlike MSR-U and MSR-L. This is considered because adsorption capacity inside the adsorbent is almost uniformly distributed in the case of synthetic zeolite A and B and adsorption heat in the medium humidity range is as high as in the low humidity range.

Finally MSR-L is recommended for the air conditioning use in the light of the lowest value of specific increase in enthalpy as well as lower pressure-loss by about 30%.

5.Conclusions

MSR-U has the highest dehumidification capacity among the test honeycomb rotor adsorption dehumidifiers manufactured for the present work. But MSR-L is the most suitable for desiccant air-conditioning use because of less specific increase in enthalpy $\Delta I/\Delta X$ and of less pressure-loss by almost 30%. It was made clear that, for higher efficiency of honeycomb rotor adsorption dehumidifiers for desiccant air-conditioning, the balance between adsorption capacity and regeneration easiness is important and the most suitable adsorbent should have characteristics such that mixture of sites, some of which have high capacity and some of which can be easily regenerated are contained.

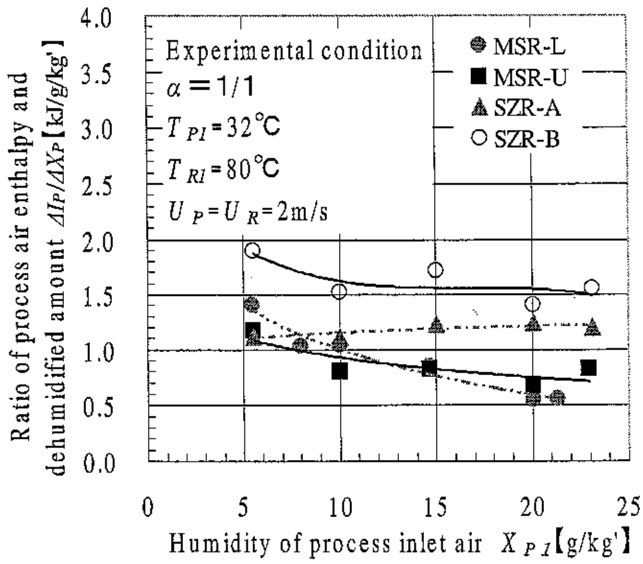

Fig.13 Variation of enthalpy rise of process air with humidity of process inlet air

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