

A Novel Total Heat Exchanger with a Lower Odor Transfer Using Ion Exchange Resin as a Desiccant

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ABSTRACT

Total heat exchangers are used in many countries as energy-saving devices for air-conditioning in buildings. But they have sometimes caused a problem of odor transfer because of accumulation of offensive odor in the desiccant. We have investigated the cause of this problem and a possible solution. The result is to use a novel total heat exchanger with little odor transfer using ion exchange resin as a desiccant. The odor transfer properties of this novel total heat exchanger were analyzed in comparison with those of a conventional total heat exchanger using silica gel. A comparison was also made with other desiccants such as synthesized zeolite.

INTRODUCTION

A total heat exchanger is an energy-saving device that recovers and reutilizes energy lost in ventilation of buildings and factories. As latent heat (humidity) as well as sensible heat (temperature) can be recovered in exchange, it has a high energy-saving effect, and different types of products have been manufactured in various countries. In order to give it a latent heat (humidity) exchanging function, desiccants are used such as silica gel, alumina, and synthesized zeolite. However, because these materials adsorb odors as well as humidity, they have become the cause of claims against offensive odor generation due to odor transfer. This problem occurs because of preferential adsorption when outdoor air humidity increases supply air cross-contamination. To solve this problem, research was conducted into the properties of various desiccants. Based on the research, we have successfully developed a novel total heat exchanger with little odor adsorption and transfer using ion exchange resin as a desiccant.

In the present study, odor transfer tests for ammonia and others were conducted using this novel total heat exchanger and several total heat exchanger rotors with desiccants such as silica gel A type and others. Odor transfer ratios were compared, and the effect of temperature and humidity in the outdoor air side on odor transfer ratio was examined.

PRINCIPLE OF A TOTAL HEAT EXCHANGER

A honeycomb rotor for total heat exchange is rotated between supply and exhaust air zones at the speed of around 16 rpm. When return air from the inside is passed through the rotor in the upper half of the rotor, most of the total heat (temperature and humidity) in the exhaust air is kept in the rotor and only the dirty air is exhausted. On the other side of the rotor, outdoor air is taken in through the lower half of the cassette where it passes through the rotor. That outdoor air receives the total heat that the rotor has kept. The incoming air is continuously supplied to the building, pre-cooled and dehumidified in summer and pre-heated and humidified in winter. That is to say, a total heat exchanger is an energy-saving device that recycles energy lost in ventilation (see Figure 1).

ADSORPTION DIFFERENCE BETWEEN SILICA GEL AND ION EXCHANGE RESIN

Principle of Adsorption by Silica Gel

Adsorption in silica gel is due to either the silanol radical (Si-OH) or capillary adsorption. The silanol radical has a very strong affinity for water vapor but also adsorbs odor. Also, in capillary adsorption, water-soluble odor elements dissolve in the water, which was adsorbed as water vapor. Finally water-

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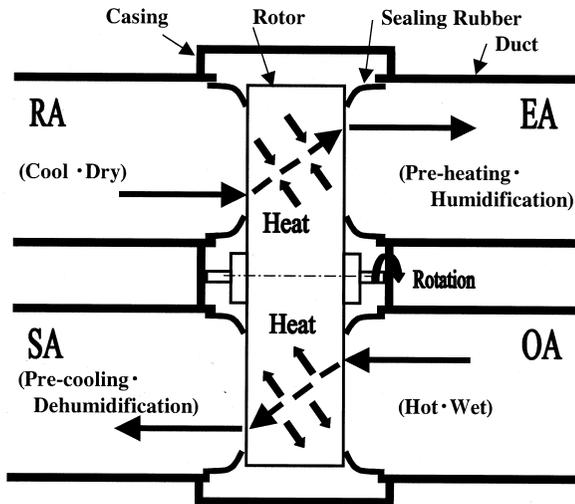


Figure 1 Both heat and moisture transfer through honeycomb.

insoluble odor is adsorbed on the parts of relatively weak hydrophilic micro-pores. As a result of these phenomena, adsorption and transfer of odor cannot be avoided when adsorbents such as silica gel are used because they rely on capillary adsorption.

Principle of Adsorption by Ion Exchange Resin

The ion exchange resin adopted in the present development is a strongly acidic cation exchange resin, and its structure is linear polymers of styrene cross-linked by divinyl benzene. The resin has sulfonic acid radicals (SO_3H) and sodium ions (Na^+) as counter ion (Diaion 1995).

It is said that the desiccant phenomenon in ion exchange resin is caused by hydration power and osmosis of ions, and the authors have tested and confirmed that ion exchange resin has a desiccative characteristic intermediate between silica gel type A and silica gel type B as shown in Figure 2 (Okano et al. 1999). Water vapor is easily adsorbed and desorbed by relative humidity changes by the above-mentioned ion exchange resin (shown in Figure 3). The reason why the ion exchange resin hardly adsorbs odor is as follows. Ion exchange resin has no micropore in the dried condition, and gaps filled with water grow when the resin adsorbs humidity, but there is no space capable of adsorbing compounds other than water vapor. Also, the ion exchange resin is a high polymer electrolyte, and its humidity-adsorbing power is produced by its hydration power and osmotic pressure. It adsorbs humidity by a principle similar to the absorbents such as lithium chloride, but it is different from such absorbents in that the ion exchange resin does not

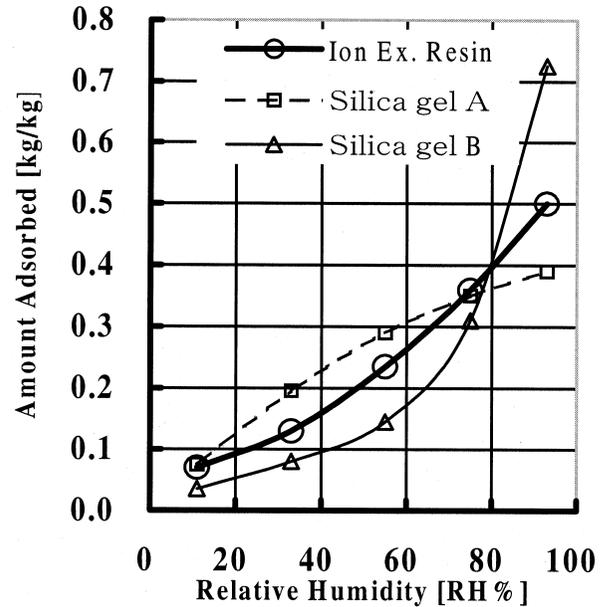


Figure 2 Isotherms of water vapor adsorption.

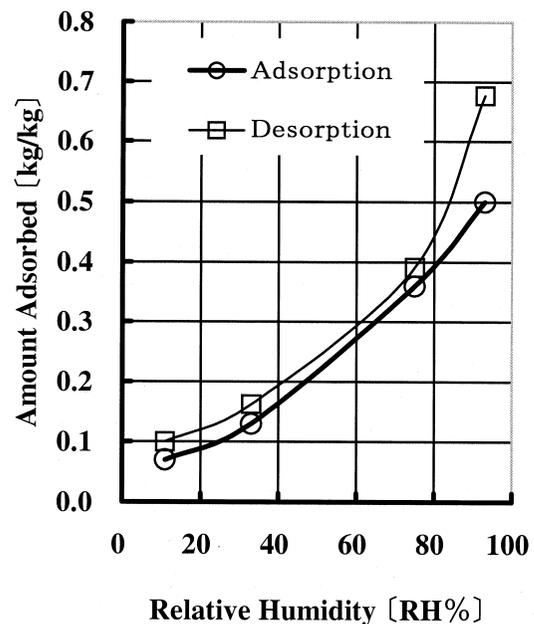


Figure 3 Isotherm for adsorption/desorption.

change to liquid by dissolving in the adsorbed water even if the resin adsorbs humidity to the saturated condition.

Also, in the interior part of the resin, the shrinking power of the cross-linking (swelling pressure) balances osmotic pressure and hydration power working as expanding power, and it may be considered that adsorption and desorption proceed by the difference between inner pressure and outer water vapor pressure. Therefore, the interior of the resin is

TABLE 1
Comparison with Other Desiccants

Ion exchange resin	Silica gel, zeolite, alumina
Nonporous	Porous
Water is adsorbed by hydration and osmotic pressure	Water is adsorbed by silanol (Si-OH) base and capillary phenomenon
Little odor transfer	Odor is adsorbed and transferred to supply air

kept in considerably higher pressure than that of the aqueous solution of the absorbent at the released condition (Applebaum 1968), and the water soluble odor component is hardly dissolved in the water contained in the resin by this inner pressure. Comparison with various desiccants is shown in Table 1.

Odor Adsorption Property Comparison Test

Static Odor Adsorption Property Comparison Test. Using silica gel, which has been used as a desiccant in conventional total heat exchanger rotors, and ion exchange resin, used in the new type of rotor, the static adsorbed weight percent of isopropyl alcohol (IPA) as an odor element was measured and compared.

Testing Method. Each rotor sample of 950 mm diameter and 200 mm depth is dried in an oven of fixed temperature at 110°C for two hours and is then put in a desiccator (capacity 20 liters). The air and water vapor are removed from the desiccator by a vacuum pump. An odor element is injected into the desiccator when the air is at 27°C with zero relative humidity. The alcohol vapor saturates the desiccator. Then the dry air is left for two hours to get the rotor sample saturated with the alcohol. Each sample is taken out and weighed to calculate the mass of adsorbed alcohol.

Test Results and Considerations. The test results for the above-mentioned isopropyl alcohol (IPA) are shown in Table 2. An apparent difference can be seen between the odor element adsorption volume of silica gels and that of ion exchange resin. From this test result, it can be said that ion exchange resin has less isopropyl alcohol than that adsorbed by silica gels.

EFFICIENCY WHEN USED IN A TOTAL HEAT EXCHANGER

Efficiency Test Equipment

A schematic illustration of the test equipment is shown in Figure 4 and a photograph of the test equipment in Figure 5. The rotor sealing in the test equipment is a contact-type sealing of soft rubber sheet that has little air leakage and is at most 1.0% under conditions of 2.0 m/s velocity of outdoor and return air and 1 kPa of pressure. In order to prevent exhaust air contained in gaps of the honeycomb being transferred to the supply air side by rotor rotation, a purge sector is provided. During the test, the purge sector is adjusted so that static pres-

TABLE 2
Comparison of Adsorbed IPA

Adsorbent	Adsorption IPA
Ion exchange resin	3.44%
Silica gel A type	19.33%
Silica gel B type	16.65%

sure of the air flowing through both sections is kept appropriate for effective operation of the purge. Test conditions are shown in Figure 4.

Total Heat Exchange Efficiency

Test Method and Result. Total heat exchange efficiencies of a conventional silica gel type and ion exchange resin type were tested and compared. The testing method was in accordance with ASHRAE Standard 84 (ASHRAE 1991).

Heat exchange efficiency was calculated by the following formula:

$$\text{Total heat exchange efficiency} = \frac{(I_{sa} - I_{oa}) / (I_{ra} - I_{oa}) \times 100 [\%]}{\quad} \quad (1)$$

where I_{sa} = supply air enthalpy,

I_{oa} = outdoor air enthalpy,

I_{ra} = return air enthalpy.

Test Results and Consideration. Total heat exchange efficiency test results are shown in Figure 6. It was confirmed that the total heat exchanger of an ion exchange resin type has almost the same total heat exchange efficiency as that of a silica gel type.

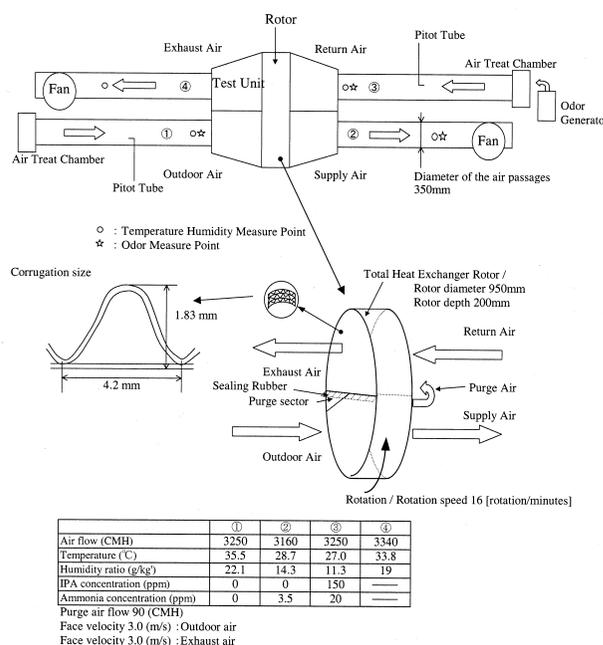


Figure 4 Schematic diagram of test equipment.

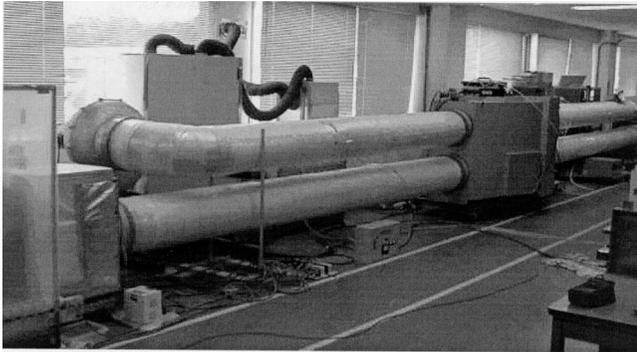


Figure 5 Wind tunnel test equipment (rotor diameter φ 950 mm).

Odor Transfer Test

Odor transfer is a phenomenon in which a desiccant adsorbs odor as well as humidity when the return air from the inside is passed through a total heat exchanger rotor and is exhausted from the exhaust air zone and desorbs odor as well as humidity in the supply air zone when the outer air is taken in to emit them into the supply air side. Even though the probability of a claim is low, once it occurs, odor transfer can become a serious problem. In order to study this odor transfer phenomenon, a rotor using conventional silica gel as a desiccant and a rotor using ion exchange resin were set in a testing machine. Several odor materials, listed in Table 3, were

TABLE 3
Odor Transfer Ratio

Odor	Odor transfer (%)
Ammonia	10.46
Isopropyl alcohol	None
Toluene	None
Acetic Acid	6.50
Formaldehyde	4.65
Styrene	None
Acetone	None
Xylene	None
Ethyl methyl ketone	None
Ethyl acetate	None
Butyle acetate	None
Ethyl alcohol	None
Methanol	None
Total heat exchange rotor (ion ex. resin) Air velocity at the rotor face $v = 4.5$ (m/s)	

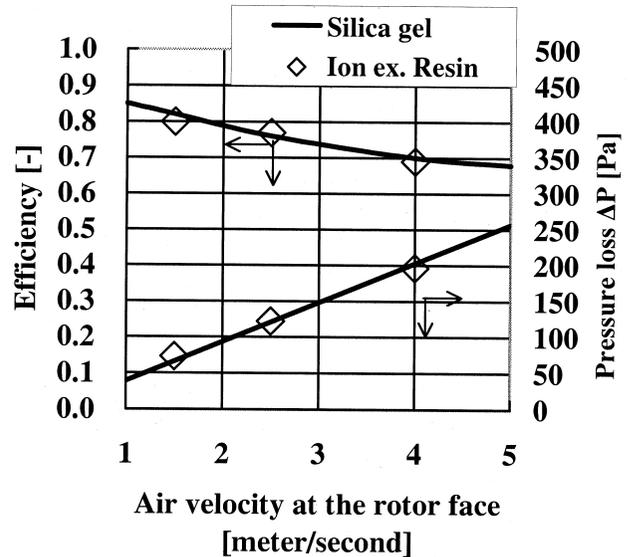


Figure 6 Exchange efficiency and pressure loss.

injected and tests for odor transfer were conducted and compared.

Odor Transfer Test Method. In the test procedure, the testing equipment is set up and air conditions and air velocities in the exhaust air side and the supply air side are settled. When ordinary and stable operation starts, odor is generated in an odor-generating box.

Odor concentration in each part is measured, and an odor transfer ratio is calculated by the formula

$$\text{Odor transfer ratio} = (C_{sa} - C_{oa}) / (C_{ra} - C_{oa}) \times 100 [\%] \quad (2)$$

where C_{sa} = Odor concentration is on the supply air side (ppm), C_{oa} = Odor concentration is on the outdoor air side (ppm), and C_{ra} = Odor concentration is on the return air side [ppm]. As for the testing conditions, temperature was fixed at 27°C and relative humidity at 60% on the room side. Temperature was fixed at 30°C in the outdoor air side, and tests were made changing the relative humidity of the outdoor air from 50% to 60%, 70%, and 80% and also changing air velocity in front of the rotor. Tests and comparisons were also made fixing humidity on the outdoor air side with its changing temperature to know the effect on the odor transfer ratio. Ammonia, isopropyl alcohol, toluene, acetic acid, formaldehyde, styrene, acetone, xylene, ethyl methyl ketone, ethyl acetate, butyl acetate, ethyl alcohol, and methanol were used in this test. Ammonia, acetic acid, and formaldehyde were measured by precision gas detectors. Other odors were measured by gas chromatograph.

Test Results and Considerations. Test results on adsorption of the above-mentioned 13 odorous gases or volatile organic compounds are shown in Table 3. It was found that among odorous materials ammonia is easiest to be adsorbed and transfer. This is because ammonia is a water-soluble odor-

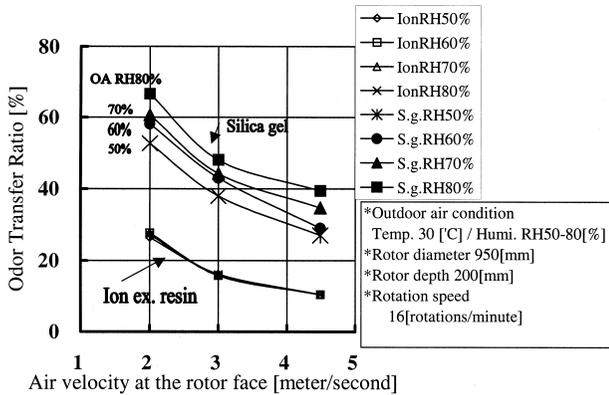


Figure 7 Ammonia odor transfer ratio.

ous material with a molecule diameter that is smaller than that of water vapor, and so ammonia can easily go in and out of micropores. A detailed experiment and estimation have now been done for ammonia, which is easy to transfer.

- Figure 7 shows the relation between face velocity in front of the rotor and odor transfer ratio, along with the effect of relative humidity on the outdoor air (OA) side. In the drawing, “Ion” shows ion exchange resin rotor and “S.g.” shows silica gel rotor.
- The ammonia odor transfer ratio of a rotor using silica gel is affected by the relative humidity of the outdoor air. For silica gel, the higher the relative humidity is, the higher the transfer ratio becomes. This is because the substitutional adsorption phenomenon (water vapor is adsorbed preferentially and odor is driven out instead of it) occurs more when humidity coming in from the outdoor air side is higher. However, substitutional adsorption appears to be smaller in the ion exchange resin. The ammonia odor transfer ratio of a rotor using ion exchange resin is little affected by relative humidity of the outdoor air.
- Ammonia odor transfer ratio for silica gel tends to decrease as face velocity at the rotor front increases. The reduction is greater in a rotor using ion exchange resin. For example, in the case of a rotor using silica gel, the ammonia odor transfer ratio tends to decrease in proportion to $V^{-1/2}$ ($-1/2$ power of air velocity). In the case of a rotor using ion exchange resin, it tends to decrease in proportion to V^{-1} (minus first power of air velocity).
- The ammonia odor transfer ratio of a rotor using ion exchange resin is much lower than that of a rotor using silica gel: In the typical face velocity range of a total heat exchanger of 3m/s or above, the ammonia odor transfer ratio of the rotor is only one-third to one-fourth of the odor transfer ratio of a rotor using silica gel.
- Figure 8 shows the relation between temperature of the

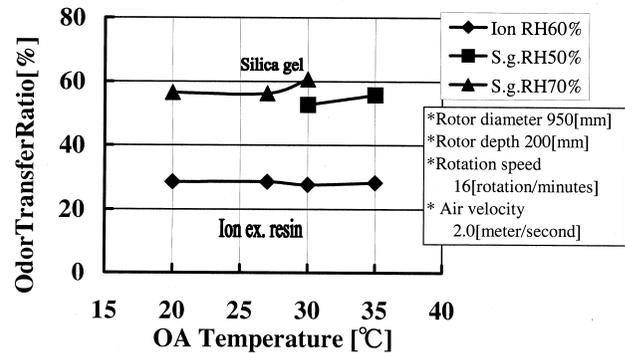


Figure 8 Ammonia odor transfer ratio.

outdoor air and the ammonia odor transfer ratio. Odor transfer ratio of neither silica gel type nor ion exchange resin type is affected by temperature of the outdoor air.

Table 4 shows comparison results of ammonia odor transfer ratio with trial rotors using ion exchange resin and other desiccants such as silica gel type A, silica gel type B, lithium chloride, and synthesized zeolite. The ammonia odor transfer ratios of trial rotors were, in decreasing order, silica gel B, lithium chloride, silica gel A, synthesized zeolite (3A), and ion exchange resin. These results suggest that the larger the diameter of micropores and the weaker the desiccating power, the higher the odor transfer rate. The molecular sieve effect of synthesized zeolite (3A) is expected, but ammonia has less molecular diameter than water and such an effect cannot be obtained. Therefore, it is considered that its odor transfer rate becomes relatively high. In the case of using lithium chloride, the porous base material itself carrying lithium chloride has absorbing capacity, and lithium chloride dissolves in water from the water vapor absorbed in ordinary air conditions. The odor transfer occurs by dissolving the hydrophilic odorous material in the solution.

CONCLUSION

Under the test conditions of this research, a new type of total heat exchanger using ion exchange resin as a desiccant has a lower ammonia odor transfer ratio than total heat

TABLE 4
Comparison Odor Transfer with Other Rotors

Type of desiccant	Ammonia odor transfer ratio
Ion exchange resin	Around 17%
Silica gel A type	Around 43%
Silica gel B type	Around 80%
Air Velocity 3.0 (m/s), OA 35°C RH 50%	

TABLE 4
Comparison Odor Transfer with Other Rotors

Type of desiccant	Ammonia odor transfer ratio
Zeolite 3A type	Around 36%
Paper + LiCl	Around 60%
Air Velocity 3.0 (m/s), OA 35°C RH 50%	

exchangers using silica gel, lithium chloride, and synthesized zeolite. We are investigating the odor transfer ratios of other organic gases or vapors of volatile organic compounds as well. We are obtaining very promising and desirable results, and the work will be reported in future papers.

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