Comparison of Odor Transfer Characteristics of Total Heat Exchangers between Ion Exchange Resin and Porous Adsorbent as Desiccant

Hiroshi Okano[1], Tsutomu Hirose[2], and Wei-Li Jin[1].
(1) Research & Development, Seibu Giken Co., Ltd, 3108, Aoyagi, Koga, Fukuoka, Japan.
(2) Advanced Adsorption Technology, 19-7, 4 Chome, Miwadai, Higashi-ku, Fukuoka, Japan

ABSTRACT

A total heat exchanger can recover both sensible heat as temperature and latent heat as humidity lost by the ventilation in the air conditioning of buildings and has been recognized to be an important device to enhance conservation of energy and reduction of CO_2 emission with keeping a high quality of indoor air. Latent heat (ambient water vapor) is exchanged through honeycomb rotors coated on the surface with desiccant material of porous adsorbent etc. but some complaints are made about accumulation of odor substance on adsorbent and accidental transfer of it back to the room. We have developed and commercialized a new type of total heat exchangers by use of ion exchange resin as desiccant. The heat exchange efficiency of it is equivalent to the conventional ones and the accumulation and transfer of odor is reduced to much less extent. Mechanism of the odor transfer is discussed by comparing odor transfer rate in the total heat exchanger between porous adsorbent such as silica gel and ion exchange resin as desiccant.

INTRODUCTION

Recently, residences and offices have been improved in the air-tightness and insulation for energy saving and the ventilation made up with spontaneous draft has been insufficient. Sick building syndrome attracting a lot of attention is closely related to the lack of ventilation and the importance of artificial ventilation is recognized. A total heat exchanger as shown in Fig. 1 is an energy-saving device that recovers and reutilizes energy lost in the ventilation of buildings since latent heat (humidity) as well as sensible heat (temperature) can be recovered there in exchange between indoor and outdoor air streams by a desiccant rotor. Desiccants used to give a latent heat (humidity) exchanging function have been porous adsorbent such as silica gel, alumina and synthetic zeolite. However, because these materials adsorb various kinds of odors as well as humidity, they have become the cause of complaints against offensive odor generation due to odor transfer. To solve this problem, we have successfully developed a novel total heat exchanger with little odor adsorption and transfer by use of ion exchange resin as a desiccant.

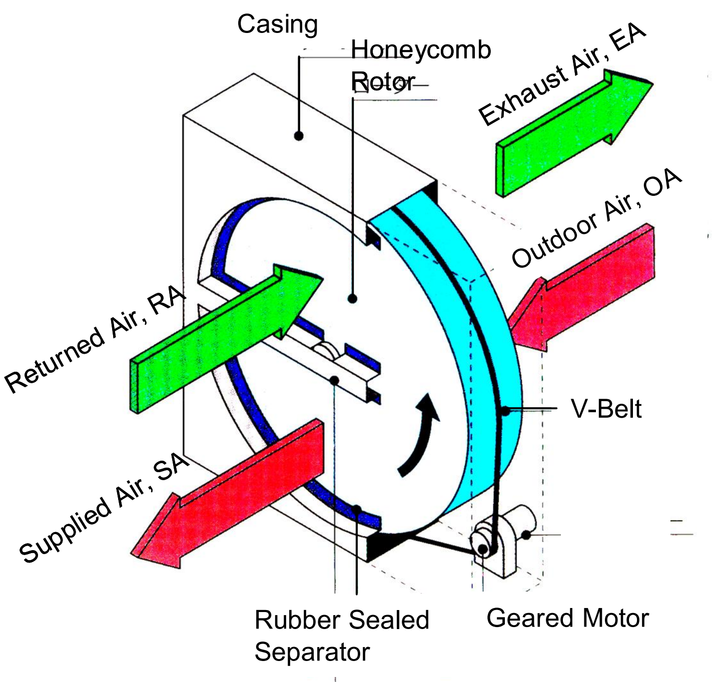

Fig. 1 Schematic diagram of a honeycomb rotor for the total heat exchange

In the present report, odor transfer tests for ammonia and others were conducted using this novel total heat exchanger and odor transfer properties were compared with the conventional types of the total heat exchanger.

1. PRINCIPLE AND ENERGY SAVING EFFECT OF A TOTAL HEAT EXCHANGER

A honeycomb rotor consisting of desiccant matrix is rotated for total heat exchange at the speed of 10-20 rpm in a casing cassette that separates between supply and exhaust air zones, as shown in Fig. 1. For example in summer, the indoor air is cool and dry but contaminated with carbon dioxide from respiration while the fresh outdoor air is warm and humid When the return air from the inside is passed through the rotor in the upper half of the rotor, the rotor is cooled and the desiccant is regenerated by the return air while only the contaminated air is exhausted after warmed and humidified by the exchange of the total heat (temperature and humidity). On the other side of the rotor, the outdoor fresh air being warm and humid is taken in through the lower half of the cassette where it passes through the rotor countercurrently. The outdoor air is cooled and dehumidified by the contact with the cool dry desiccant and the incoming cool and dry air is continuously supplied to the building. Thus the refrigerating load of the air conditioner can be saved by the recovery of the total heat from the exhaust air by as much as 70-80% of energy lost in the ventilation, as explained on a humidity chart given in Fig. 2. The principle is the same in winter as well except that the warm and humid inside air is exhausted and pre-heated and humidified air is supplied to the room. That is to say, a total heat exchanger is energy-saving device that recycles energy lost in ventilation. The total heat exchanger can recover and utilize both sensible heat as temperature and latent heat as humidity and has higher advantage of energy saving to recover much more amount of heat than the conventional sensible heat exchanger.

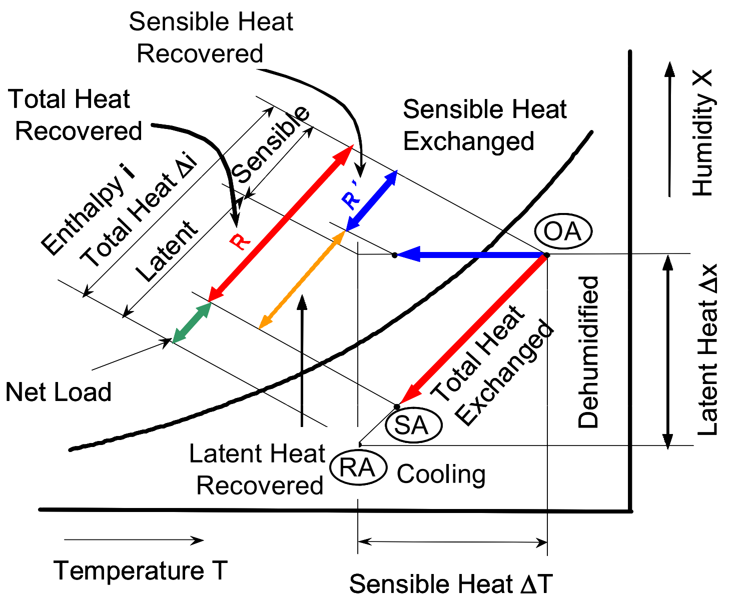

Fig. 2 Presentation of sensible, latent and total heats recovered by a total heat exchanger on a humidity chart

The ability of latent heat exchange in the total heat exchanger is very important in practice. In winter, it prevents troubles of static electricity due to an over-dry atmosphere. Humidity control is important for human health, for example for prevention of flu. In summer, load of latent heat reaches about 50 % of the total load of air conditioning.

The mainstream of total heat exchangers is the rotary type made of aluminum sheet. Metal aluminum itself cannot exchange

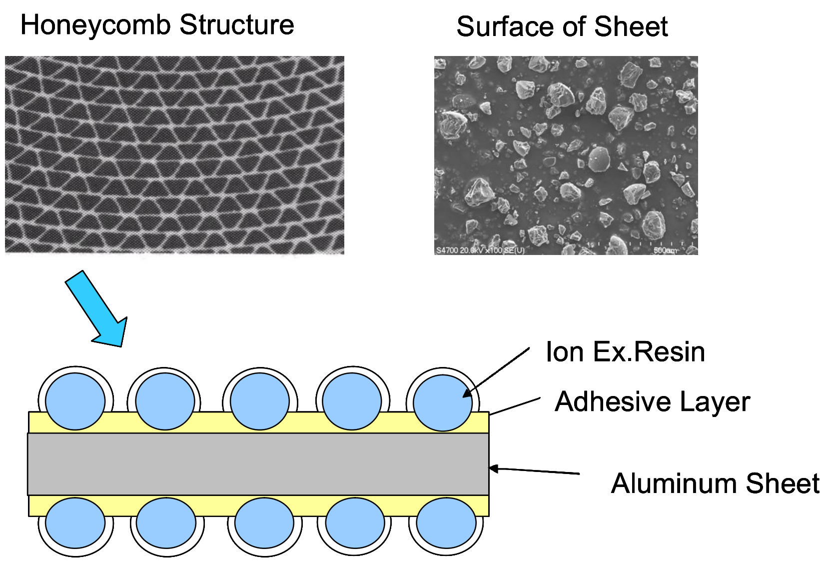

Fig. 3 Detail of honeycomb structure of a total heat exchanger

latent heat (humidity) but is modified to give the desiccating ability in various ways. Thin layer of aluminum oxide is formed by treating the surface of aluminum sheet by some oxidizing agent or aluminum sheet is coated with solid adsorbent such as silica gel, as shown in Fig. 3.

2. RELEASE OF OFFENSIVE ODOR FROM TOTAL HEAT EXCHANGERS

Some odorous matter emitted indoors sometimes is caught in the desiccant rotor and returned back to the room together with the supply air by desorption. Thus, total heat exchangers have not been recommended to be installed in the place encountered with much emission of offensive odor because of this problem of odor transfer. Various kinds of paints, adhesives and construction/interior materials are used even in the ordinary buildings in the case of new construction. A considerable amount of odor substance is emitted from these materials and is expected to be accumulated in total heat exchangers. Transfer of offensive odor was complained in practice in 1-2 years after new construction at the start of the rainy season when the outdoor humidity increased. Situation became serious in some cases although the probability was as low as 0.1-0.4 %.

Mechanism of odor transfer from a total heat exchanger may be explained as follows:

1) Various odor substances and solvent vapors are emitted from construction and interior materials of a new building. Such odor substances are adsorbed and accumulated in adsorbent such as silica gel when the return air from buildings is exhausted through total heat exchangers.

2) In early spring or in the rainy season when the humidity increases rapidly, odor substances are desorbed due to an increased amount adsorbed of water vapor on adsorbent. In other words, accumulated odor substances are desorbed into the room by so called the replacement adsorption of water.

3) When adsorbent of a total heat exchanger is adsorbable to odor substances as well as water vapor, odor released from total heat exchangers is circulated again in the room by transferring from the return air to the supply air. Odor substance cannot be exhausted outdoors endlessly, resulting in customers' complaints.

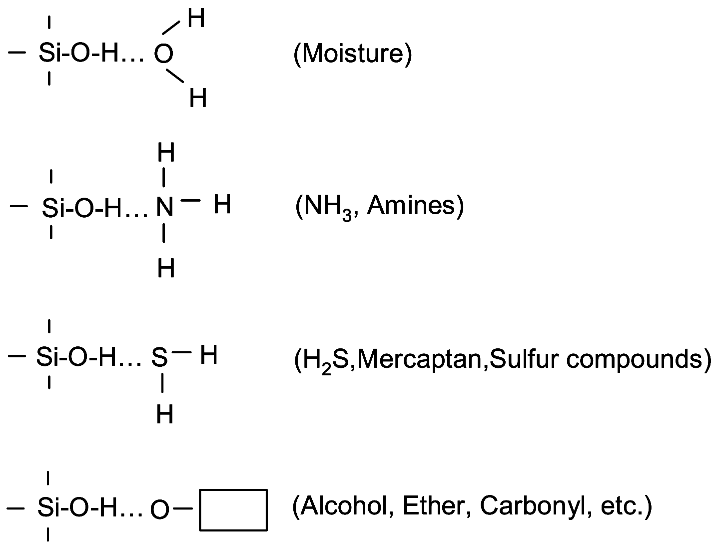

Fig. 4 Mechanism of adsorption of odor substances on a silanol group of porous material

Complaints of the offensive odor transfer are caused by two factors of the replacement desorption of adsorbed odor accumulated and of the endless circulation without exhaust by odor transfer. Total heat exchangers are excellent energy-saving apparatuses and then have been developed by many companies and widespread all over the world. However, this problem of odor transfer has been one of the most difficult problems unsolved.

3. ADSORPTION OF ODOR BY POROUS MATERIAL

Adsorption in porous material such as silica gel is due to either silanol radical (Si-OH) or capillary adsorption. The silanol radical has a very strong affinity to water vapor but also adsorbs odor substances, too, as shown in Fig.4. Also, water-soluble odor substances may be absorbed in the aqueous phase which was adsorbed as water vapor in capillary adsorption. Porous adsorbent such as silica gel adsorbs water vapor in proportional to the relative humidity of air. Many adsorption sites remain vacant and do not contribute to adsorption of water vapor at a low to moderate humidity.

Odor substances are adsorbed on those sites and accumulated there.

When the humidity outdoors is increased in the rainy season, water vapor, too, tends to be adsorbed on sites having been inactive in adsorption/desorption at low to moderate humidity. Odor substances which have occupied such sites are desorbed by the replacement adsorption and released from the total heat exchanger. As a result of these phenomena, adsorption and transfer of offensive odor cannot be avoided when the porous adsorbents such as silica gel are used.

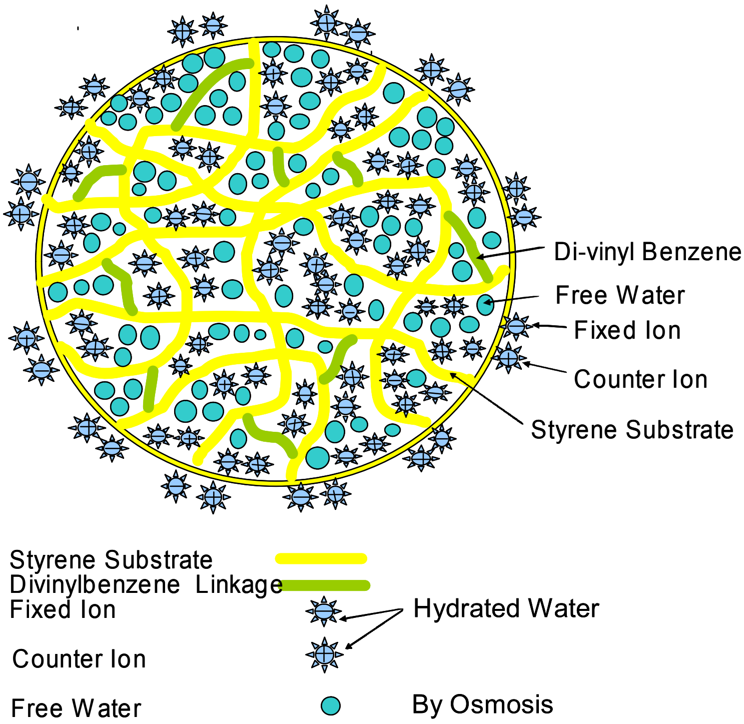

Fig. 5 A structural model of ion exchange resin

4. ION SORPTION TYPE OF TOTAL HEAT EXCHANGERS

We have developed and commercialized a new type of total heat exchangers in which heat exchange efficiency is equivalent to the conventional ones and the accumulation and transfer of odor is reduced to much less extent. The new type is based on the sorption of water vapor into ion exchange resin and the rejection of odor substances and thus it is called an “Ion sorption type” of total heat exchangers in what follows.

Figure 5 shows a structural model of ion exchange resin which is used in the total heat exchanger. Styrene substrates are cross-linked with divinyl benzene in ion exchange resin. A surfonic acid group (-SO_3H) is chemically introduced to this polymer structure as a fixed anion and then neutralized with a counter cation ($Na+$). The desiccant ability of ion exchange resin is caused by hydration power and osmotic pressure as shown in Fig. 6 and is similar in principle rather to that of absorbent such as lithium chloride. Unlike such an absorbent, however, fixed ions inside ion exchange resin are bound with cross-linkage and thus the ion exchange resin is not liquefied even in the case of the saturated absorption. Adsorption isotherms of water vapor are shown in Fig. 7 for various adsorbents together with ion exchange resin. The amount adsorbed on ion exchange resin depends on a degree of cross-linkage and the one used in the total heat exchanger has the moisture content between A-type and B-type silica gels.

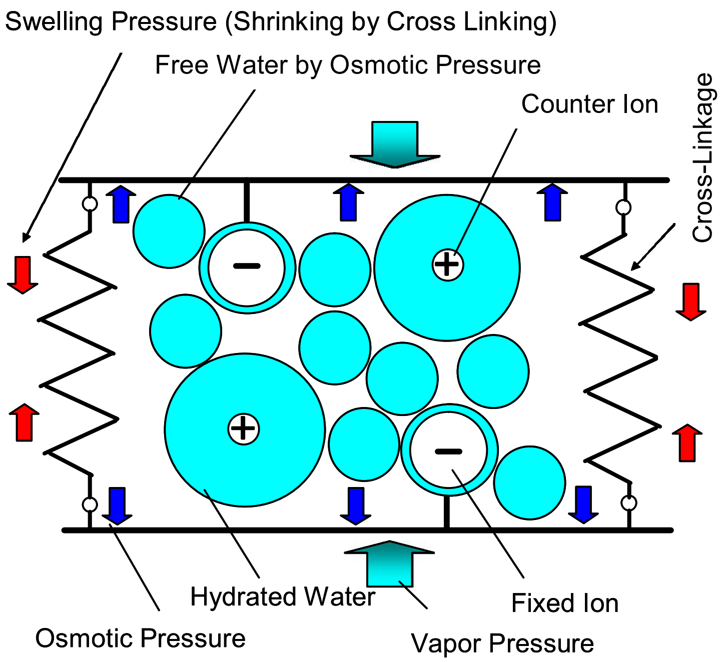

Fig. 6 Pressure balance between swelling and osmosis in ion exchange resin

Ion exchange resin does not adsorb

easily odor substances probably by the following reason. Dry ion exchange resin does not have pores insides unlike porous adsorbents such as silica gel and the void is filled with water sorbed in a hygroscopic state. Thus, odor substances can hardly be caught nor accumulated in vacant sites of adsorption. The shrinking force due to crosslinkage and the swelling force due to hydration and osmotic pressure are balanced inside the resin, and sorption/desorption are caused by the difference between the internal pressure and the external vapor pressure. The interior pressure of the resin is thought to be kept higher than in free liquid solution of adsorbent as shown in Fig. 6. Even a water soluble odor substance is difficult to be solved into water insides resin due to thus high interior pressure and the transfer of odor substance is expected to be depressed correspondingly.

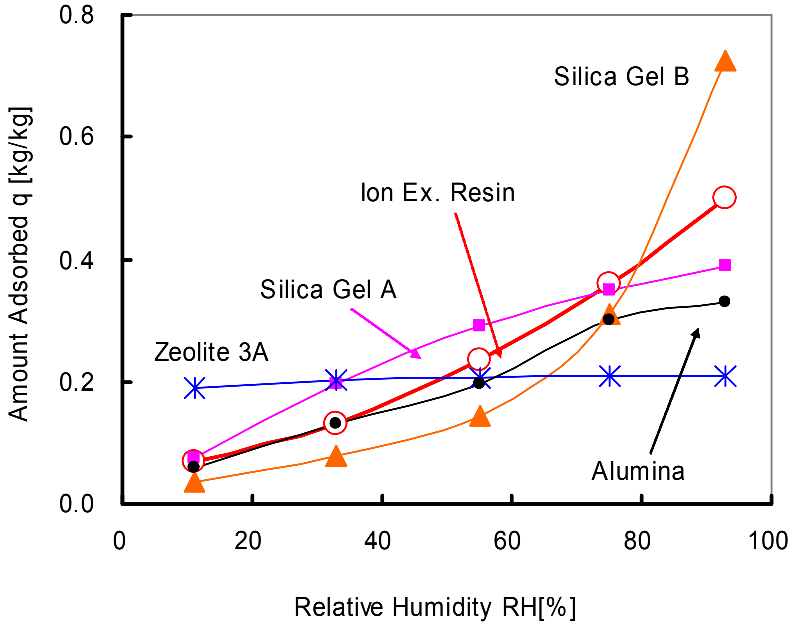

Fig. 7 Adsorption isotherm of water vapor for various desiccant materials

5. HEAT EXCHANGE EFFICIENCY AND ODOR TRANSFER

Humidity, temperature and odor concentration were measured in the return, outdoor and supply air streams in a wind tunnel as shown in Fig. 8, and the result was examined in various ways. The exchange efficiency η of total heat was evaluated in terms of enthalpy I and the water and odor transfer ratios F on the concentration basis C, as follows

Total heat exchange efficiency:

$$\eta = \frac{I_{sa} - I_{oa}}{I_{ra} - I_{oa}}$$

Odor transfer ratio:

$$F = \frac{C_{sa} - C_{oa}}{C_{ra} - C_{oa}}$$

The specific transfer rate R

$$R = (C_{sa} - C_{oa})Vt_c$$

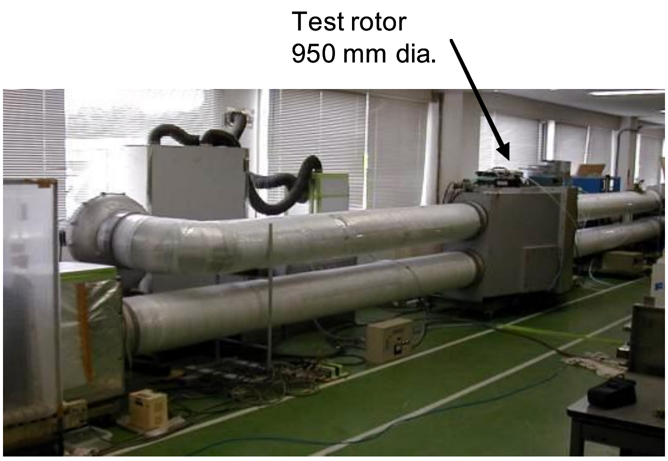

Fig. 8 Schematic diagram of an experimental apparatus for total heat exchange and odor transfer

is defined as amount of water or odor substance per unit cross-sectional area in each revolution of the rotor, in which V is the face velocity or superficial velocity of air and t_c is the time required for one revolution.

The total heat exchange efficiency of the conventional silica gel type and the present ion sorption type were tested and compared in Fig.9. The total heat exchange efficiency η is as high as

80% at the face velocity of V=2m/s and decreases with increasing face velocity although it keeps 70 % at V=4m/s. It was confirmed that the ion sorption type has almost the same total heat exchange efficiency as a silica gel type.

Figure 10 shows a comparison of the transfer ratio *F* of water vapor and some odor substances between various types of desiccant. The outdoor air was kept at temperature T_{OA}=30 ℃ and relative humidity ϕ_{OA}=50 %

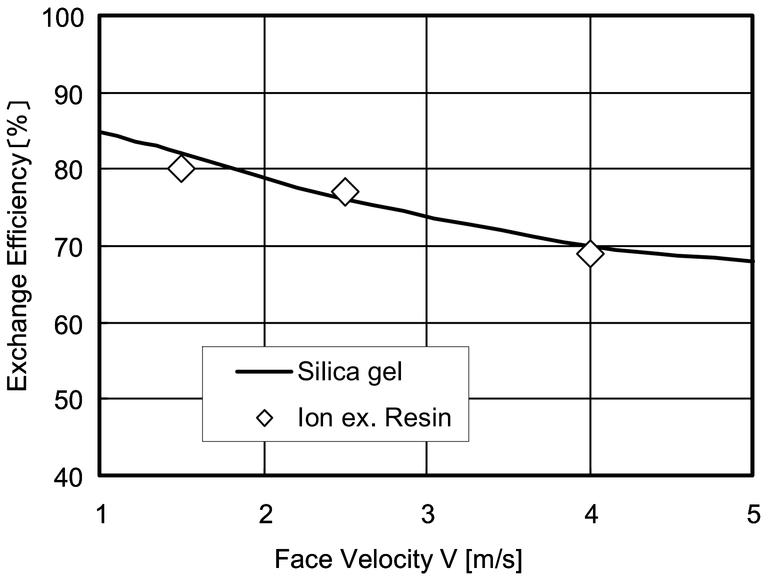

Fig. 9 Comparison of the heat exchange efficiency between silica gel and ion exchange resin

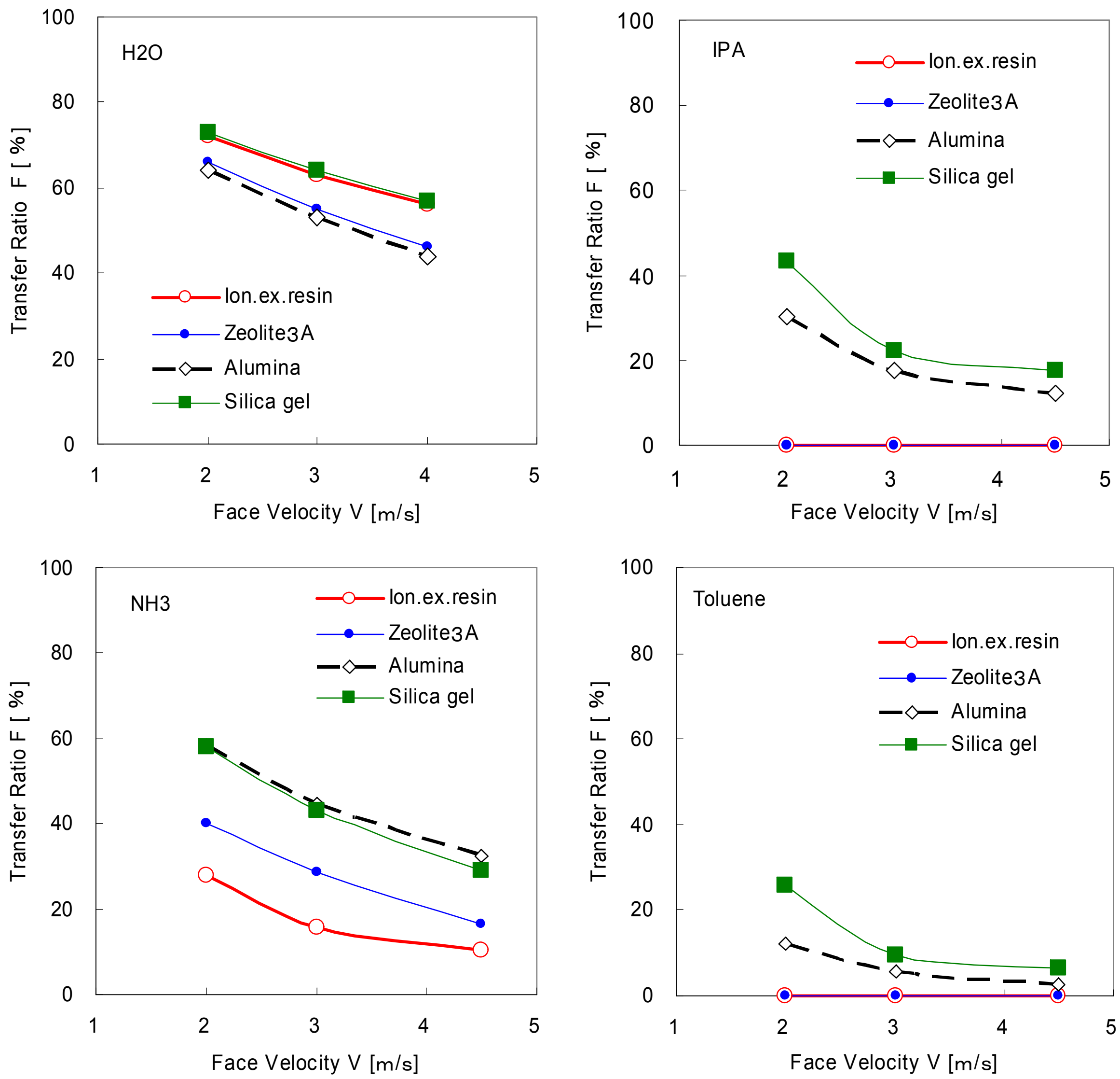

Fig. 10 Comparison of the transfer ratio F of moisture and odor substances between various desiccant materials for a total heat exchanger

while the returned air at T_{RA}= 27℃ and ϕ_{PA}=60 %. The returned air contained the odor substances at concentrations of C_{RA}= 0.016 g/m^3 for NH_3, C_{RA}= 0.13 g/m^3 for IPA and C_{RA}= 0.20 g/m^3 for toluene. The higher value of the transfer ratio F is favorable for water while the lower is favorable for odor substances. The total heat exchanger of ion sorption type has the same transfer ratio F of water to that of the conventional silica gel type and higher ratio than that of zeolite 3A and alumina types. The odor transfer ratio F of ammonium (NH_3) is highest in both silica gel and alumina types, followed by a zeolite 3A type and lowest in the ion sorption type. In the case of IPA (iso-propyl alcohol), no transfer was detected in zeolite 3A and ion sorption types although the odor transfer ratio F is as high as 10-40 % in silica and alumina types. The situation is the same in the toluene case as in IPA although the transfer ratio F for silica gel and alumina types is lower than that in IPA case. The transfer ratio F is influenced by the face velocity V and is decreased with increasing face velocity.

The amount transferred of odor was converted to the specific transfer rate R, Eq.(3), for further discussion from other points of view and the results are shown in Fig. 11. The specific transfer rate R of water vapor per each evolution of the rotor increases with the face velocity V while the transfer ratio F decreases as shown in Fig.10. This is because an increased face velocity, thus increased amount of supplied water vapor, compensates the decrease in humidity in the downstream of the

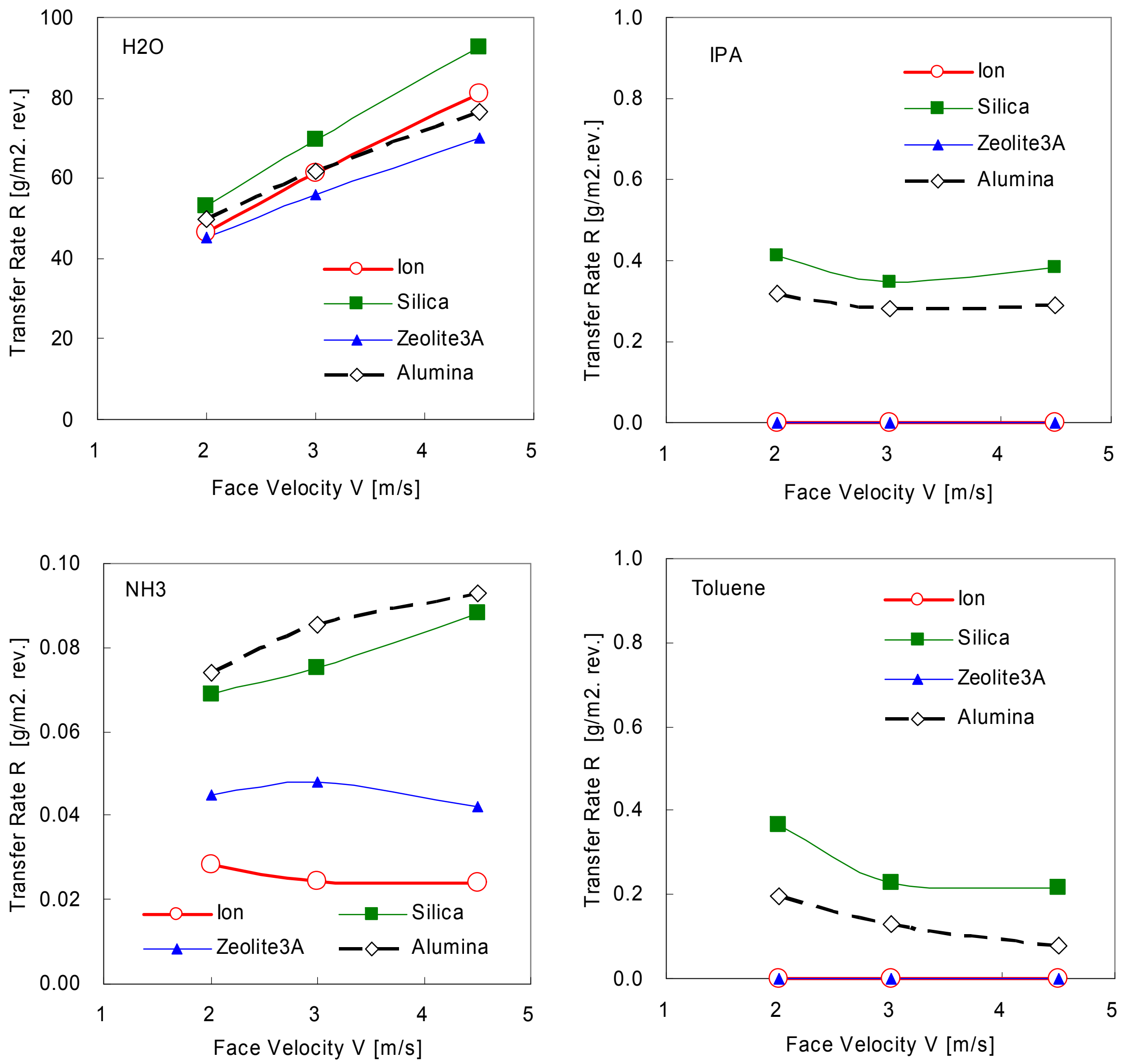

Fig. 11 Comparison of the specific transfer rate R per unit cross-sectional area in each revolution of the rotor between various desiccant materials for a total heat exchanger

outdoor air, resulting in an increase in adsorption.

In the case of ammonium, the specific transfer rate *R* increases with increasing face velocity *V* in silica gel and alumina types as in case of water. This is due to the adsorption together with water by a strong affinity to water. On the other hand, it is independent of the face velocity and a constant amount of NH_3 is transferred in zeolite 3A and ion exchange resin types. Ammonium molecules hardly enter ion exchange resin as described previously and the specific transfer *R* rate is kept at a low value.

The specific transfer rate *R* of IPA is found to be independent of the face velocity both in silica gel and alumina types. IPA is adsorbed on silica gel and alumina but the rotor reaches the adsorption breakthrough very early because of a low level of equilibrium amount adsorbed. Thus the specific transfer rate of IPA does not change with increase or decrease in the face velocity.

In the case of toluene, the specific rate decreases with increasing face velocity unlike other cases. This unexpected result may not be explained well although toluene once adsorbed may be desorbed by the replacement adsorption with water vapor of which adsorption was enhanced by increased face velocity.

CONCLUSIONS

The mechanical ventilation is important in a recent trend of an air-tight residences and offices and total heat exchanges have been recognized to be very efficient from an energy saving point of view. The most serous problem to be solved has been the odor transfer in which odor substances emitted inside the room is returned back with the supplied air by transferring from the returned-exhaust stream to the outdoor-supplied stream. The authors developed a new “Ion sorption type” of total heat exchangers by use of ion exchange resin as desiccant. The heat exchange efficiency of it is equivalent to the conventional ones and the accumulation and transfer of odor is reduced to much less extent. Mechanism of the odor transfer is discussed by comparing odor transfer rate in the total heat exchanger between porous adsorbent such as silica gel and ion exchange resin as desiccant.

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