A HUMIDITIY CONTROL SYSTEM WITH AN ADSORPTION MATERIAL AND INDOOR AIR QUALITY IMPROVEMENT

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ABSTRACT
The present study introduces a humidity control apparatus which can hygienically and automatically maintain the appropriate humidity level of indoor air without either a water supply or drainage system. In humidification, the desiccant takes up water vapor from the outdoor air in the adsorption process, and releases it indoors by desorption. Therefore, no water supply is required to humidify. An apparatus having no water supply is more hygienic, because it does not propagate bacteria and does not scatter the calcium and magnesium salts found in the water. In dehumidification, water vapor is removed from the indoor air by the desiccant and is released outdoors by desorption, eliminating the need for drainage system. The absence of a drainage system also eliminates such problems as water leakage and installation. An adsorbent was expected to adsorb extremely little amount of formaldehyde, toluene and xylene in the indoor air. An experiment, therefore, was made to discharge volatile organic compounds (VOCs) outdoors in the desorption process after adsorbing them in the adsorption process. It is possible, therefore, that indoor air pollution due to such VOCs can be prevented on a daily maintenance-free basis.

INTRODUCTION
The effects of relative humidity on various aspects of human health have not yet been fully studied. In general, it is desirable to maintain an indoor humidity level of 40 - 60% for health and comfort reasons. When the humidity level of an indoor space decreases to less than 40%, it should be humidified[1)]. Existing humidifiers used in Japan require a water supply. This causes many problems such as scaling, the increased rate of growth of microorganisms and corrosion[2),3)]. This increased presence of microorganisms and dust in the air from corrosion is especially harmful to the human body. Under certain conditions, humidifiers can also be a source of pollutants.

On the other hand, when the humidity exceeds 60%, it becomes necessary to dehumidify. Portable vapor-compression dehumidifiers commonly used in Japan augment the problems of microorganism growth, corrosion and dirt caused by drainage. Furthermore, existing dehumidifiers cannot perform sufficiently well in temperatures below 10%. Industrial and commercial-type dehumidifiers tend not to exhibit these problems[4)]. However, in the studies on the conventional humidity control technology based on the use of a desiccant material, much emphasis has been focused mainly on the realization of effective dehumidification. Humidification has been achieved mainly by an ultrasonic or heating-type humidifier. Accordingly, to control the indoor humidity, a dehumidifier and a humidifier were always required.

In this study, however, a humidity control system has been proposed in which both dehumidification and humidification can be realized under the same working principle and which has become possible by studying humidification based on desiccant material. In order for humidification and dehumidification to be carried out without a water supply and drainage system, it is desirable that the desiccant have certain adsorption characteristics. The method described in this paper is a breakthrough in solving the problems of indoor air pollution. The criteria for the selection of desiccants, the structure of the system, and its operation will be described in detail.

In addition, actual measurement surveys [5)-6)] were conducted into indoor air pollution due to volatile organic compounds. According to the findings of these surveys, it is necessary to take measures to reduce VOCs indoor concentrations. As one of such measures, an air purifier has been commercially available which adsorbs the VOCs by means of a filter with activated carbon. The activated carbon, however, has a service life of one or two years, which means it has been necessary to replace the filter from time to time. For this reason, a humidity control system employing an adsorbent currently under development was used to study the performance of removing formaldehyde, toluene and xylene. The adsorbent adsorbs VOCs indoors in the adsorption process and discharges them in the desorption process. Here we report on the possibility that the system might enable the prevention of indoor air pollution due to VOCs.

METHODS

The newly-developed apparatus can automatically and appropriately humidify, dehumidify and ventilate indoor air. Fig. 1 shows the cross-sectional view of the apparatus. It is composed of the desiccant unit, the fan, the electric heater, intake/exhaust dampers and the controller. The apparatus is 690 mm long, 190 mm wide and 150 mm high. The desiccant unit, which is 65 mm long, 110 mm wide, 110 mm high, is made of many 13X-type zeolite cells with a diameter of 1.28 mm, which form a lattice structure with inorganic binders.

The desiccant alternately adsorbs and desorbs water vapor in the air. The electric heater, made of Ni-Cr-Al, heats the desiccant unit containing water vapor up to a temperature of approximately 200°C , and the desiccant releases the moisture. The electric capacity is 800 W. The centrifugal fan is designed such that it will send the air at 0.3-1.2 m^3 /min to the desiccant unit. When the fan was operated and air at a temperature of 25°C and relative humidity of 60 percent was adsorbed into the desiccant material at a rate of 1.2 m^3 /min, the difference in static pressure between the inlet into the desiccant material and the outlet from it was 90 Pa .

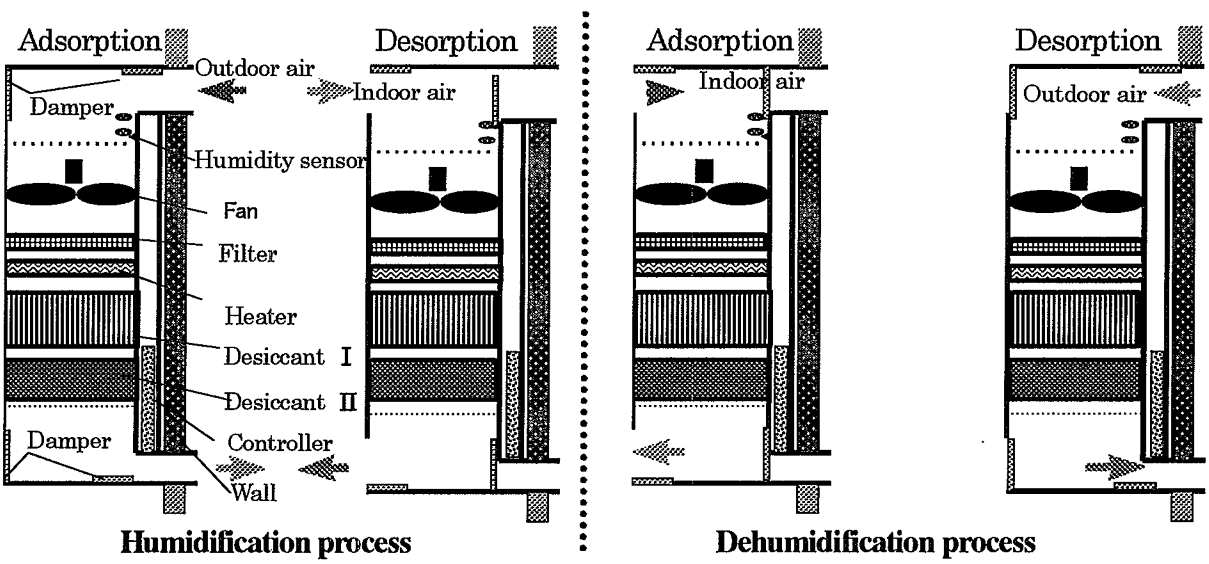

Figure 1. Cross-section view of a newly developed humidity control apparatus

The intake/exhaust dampers open and close the inlet/outlet ports in accordance with a selected operation mode. An electrically charged filter is placed upstream of the fan to clean the air taken in. According to the temperature and humidity detected by the sensors, the controller selects the appropriate operation to maintain an indoor air humidity of 40-60 percent.

The adsorbent to adsorb volatile organic compounds was made of the fiber comprising alumina (Al_2O_3) and silica (SiO_2). After being formed into a honeycomb, this fiber was made to carry the zeolite highly concentrated. This adsorbent was located in the downstream of a humidity control adsorbent as shown in Fig.1.

This is carried out as shown in Fig. 1. In the adsorption process of humidification, in which the outdoor air is brought into the desiccant unit, the controller drives the intake/exhaust dampers and closes the indoor intake and outlet. The moisture taken from the outdoor air is adsorbed onto the desiccant unit. Dust and suspended particles in the air are attracted to the filter through the passages, and the air containing water vapor is purified. The time period for the adsorption process is determined in the controller by the fan flow rate and the humidity level of the outdoor air. In this process, the outdoor air provides the moisture to humidify the indoor air. The desiccant unit heated up to a temperature between 200 and 250°C will desorb and release the water vapor. Since adsorption/desorption alternates at a rate of ten times an hour, humidification of the indoor air can be conducted without an additional water supply.

One humidification cycle of the newly-developed apparatus is comprised of an adsorption process of 4.5 minutes and a succeeding desorption process of 1.5 minutes. In the adsorption process, air is supplied to the desiccant material at a rate of 1.2 m^3 /min. One cubic meter of the air at 7°C and humidity 60 percent contains 0.052 L of water vapor. The volume of desiccant material in the newly-developed apparatus is designed so that the time required for the humidity at the outlet of the desiccant material to reach breakpoint, which is attained by a slight increase from the absolute humidity of 0 g/kg from the initial absolute humidity of 0 g/kg, becomes 6 minutes. Therefore, about 0.02 L of water vapor is adsorbed onto the desiccant material in the 4.5-minute adsorption process. Based on this, the apparatus is able to humidify about 5 L a day. This apparatus can dehumidify 7 L a day of the indoor air at a temperature of 27°C and a humidity of 60 percent.

RESULTS

Evaluation for dehumidification performance

Both the humidification and dehumidification performances of the present apparatus were tested in a room in a laboratory with a controllable temperature of -10 to 40°Cand a humidity of 10 to 90 percent. The size of the room was 30m^3, and the number of air changes was 0.8 times an hour under no-wind conditions. The newly-developed apparatus which had a setup as shown in Fig.1 was installed on the wall at a height of 1.8meters above the floor. Both the vapor-compression dehumidifier and the ultrasonic humidifier were placed on the floor right under the newly-developed apparatus. During the test period to evaluate the dehumidifying ability of the apparatus, the outdoor temperature and humidity were adjusted to 27°C and 65 percent, respectively. Meanwhile, the indoor temperature and humidity when the experiment was started were adjusted to 25°C and 60 percent, respectively.

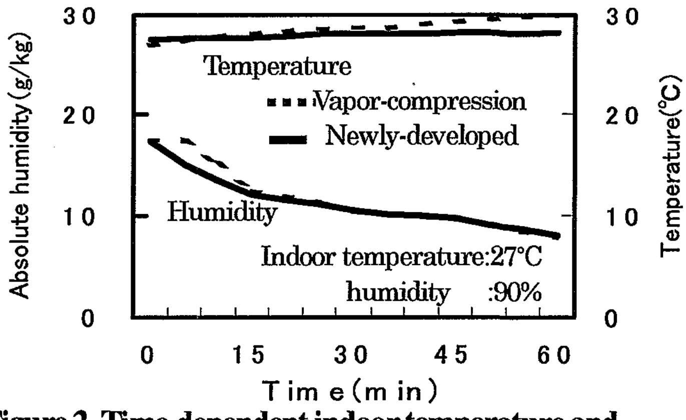

Figure 2. Time-dependent indoor temperature and humidity during dehumidification

In the humidifying-ability evaluation experiment, the outdoor temperature and humidity were adjusted to 5°C and 60 percent, respectively.

In an experiment to determine the amount of moisture adsorbed per day, both the newly-developed apparatus equipment and the vapor-compression dehumidifier were placed on an electronic balance and the entire setup was installed into the previously-mentioned laboratory of which the temperature and humidity were controllable. The amount of moisture adsorbed was calculated from an increased mass which was determined by the electronic balance. In the case, where the amount of moisture adsorbed per day was determined, the individual dehumidifier was operated continuously for three hours while keeping both the indoor humidity and temperature constant during the experiment.

Fig. 2 shows the changes in temperature and absolute humidity for both the vapor-compression type dehumidifier and the newly-developed dehumidifier. Since the performances of both were nearly equal, the humidity level in the room after an hour did not differ much in the two cases. However, the temperature in the room where the existing dehumidifier was employed was about 2°C higher than that in the room with the new apparatus. The reason for this is that all of the electric energy put into the existing dehumidifier dissipated to warm the indoor air because the unit is usually located entirely indoors. On the other hand, in the case of the new apparatus, the energy is mainly consumed in the desorption process and a large amount of the energy is released to the outdoors. Consequently, the adsorption-type unit can dehumidify a room without changing the indoor temperature significantly.

Evaluation of humidification performance

The changes in indoor temperatures and levels of humidity during the operation of the humidifiers are shown in Fig. 3. The capacity of the ultrasonic humidifier is 0.3 L per hour. It can be seen that adsorption/desorption greatly influenced the performances of both humidifiers. When the adsorption of the construction materials of the room reaches saturation, the change in indoor humidity level is proportional to the amount of moisture adsorbed by the humidifiers. The adsorption-type humidification raises the indoor temperature by about 2°C because the desorbing energy has been released indoors. This does not have a negative thermal effect on the indoor environment as humidification is mainly conducted in the winter in Japan.

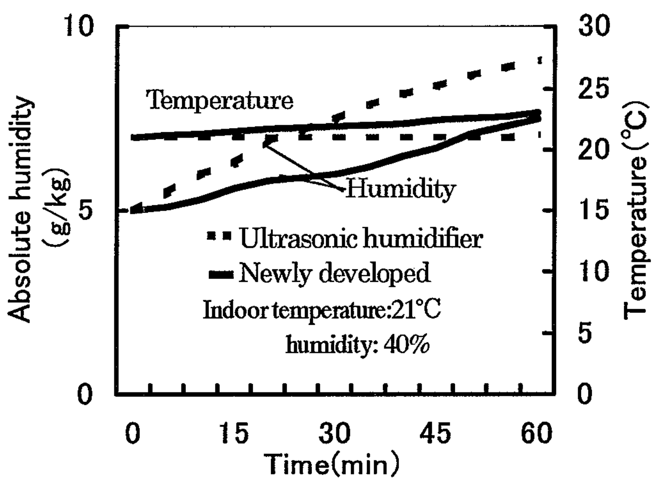

Figure 3. Relationship between dehumidification performance and indoor temperature

The amount of energy required to not only remove the moisture from outdoor air of temperature and humidity of 7°C and 60 percent, respectively, but at the same time also, to humidify the indoor air with this removed moisture at a rate of 0.2 L/h by the newly-developed apparatus is 1070 kJ. On the other hand, the amount of energy required by a heated-pan humidifier is 690 kJ, which is 35% lower than that of the newly-developed apparatus. Accordingly, if the running cost of the newly-developed apparatus is taken into account, the operating efficiency of the apparatus used for humidification needs to be improved.

Capacity to remove formaldehyde, toluene and xylene

Fig. 4 shows the relationship of the equilibrium concentration of the developed adsorbent with its capacity in adsorbing formaldehyde, toluene and xylene. The formaldehyde adsorbed reached 0.1 mg/g at an equilibrium concentration of 0.5ppm. The absorbed amounts of both toluene and xylene, on the other hand, reached 0.8 thru 0.9 mg/g at an equilibrium concentration of 0.5ppm. The developed adsorbent has a capacity to adsorb formaldehyde at one-tenth of that for toluene and xylene. Fig. 4 makes it possible to design an adsorbent according to the disorption of volatile organic compounds.

To study the actual removal performance, the volatile organic compounds' emission rates were determined based on the actual measurement survey [5]. An adsorbent was designed. The system equipped with this adsorbent was installed in a stainless steel chamber with a capacity of 25 cubic meters to study the performance of removing formaldehyde and toluene. The chamber was internally set to an initial formaldehyde concentration of 1.3ppm and toluene concentration of 3.6ppm. To compare the removal performance, an air purifier (Model MS-R740) made by us was also examined for its removal performance under identical conditions. Fig. 5 shows the formaldehyde removal performance, with toluene coexisting. The air purifier could reduce formaldehyde to a residual ratio of zero in 60 minutes. The system developed, on the other hand, compared unfavorably with the air purifier in the sense that formaldehyde could be reduced to a residual ratio of 22% in 60 minutes. This told us that the adsorption of formaldehyde in the developed system was already saturated 60 minutes after starting. After desorbing formaldehyde, therefore, it was adsorbed all over again. 30 minutes after the start of the 2nd adsorption process, it was confirmed that formaldehyde had reached a residual ratio of 0%. Fig. 6 shows the toluene removal performance, with formaldehyde coexisting. As with formaldehyde, the developed system compared unfavorably with the air purifier in removal ratio. Nevertheless, it was verified that the developed system was definitely capable of removing toluene and that toluene could be reduced to a residual rate of 0% in the 3rd adsorption process.

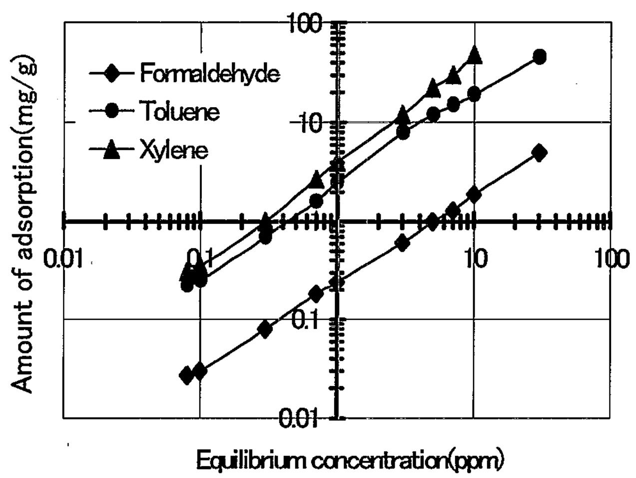

Figure 4. Adsorption isothermal of formaldehyde, toluene, and xylene

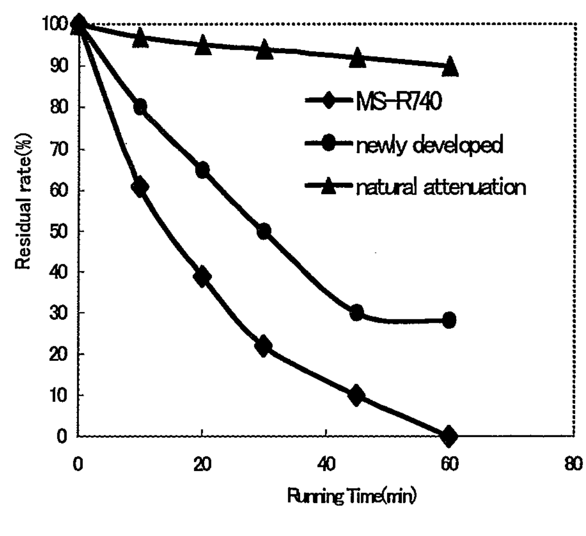

Figure 5. Removal performance of formaldehyde with toluene coexisting

DISCUSSION

For health reasons, it is extremely important to control the humidity of indoor living spaces. Humid air promotes the rapid growth of mould, propagation of ticks and allergies. If the humidity is too low, the propagation of viruses will lower the ability of the human body to resist disease. Therefore, a suitable humidity level is important for maintaining comfort and health. Improvements have been such that nowadays, dwellings are increasingly air-tight, and the adsorption/desorption capacity of interior materials has been decreasing. Therefore, humidity control technology will definitely play an increasingly important role in the future.

This study examined a humidity control apparatus based on adsorption technology, which can significantly improve indoor air quality. The present apparatus has several advantages:

(1) The apparatus represents a hygienic system, because humidification requires no water supply and therefore neither propagates bacteria nor scatters calcium and magnesium salts into the indoor air;

(2) As there is no drainage, the system does not require installation of a drainage system, and does not result in such problems as water leakage, etc;

(3) Since both humidification and dehumidification are carried out using the same operational principle, the system can easily control the indoor humidity level and be put into operation inexpensively.

(4) The adsorbent developed to adsorb VOCs was capable of adsorbing formaldehyde and toluene at a level of 0.5ppm and of desorbing these adsorbed gases again. This indicates that the developed system might possibly be useful in preventing indoor air pollution due to volatile organic compounds by running adsorption and desorption processes alternately.

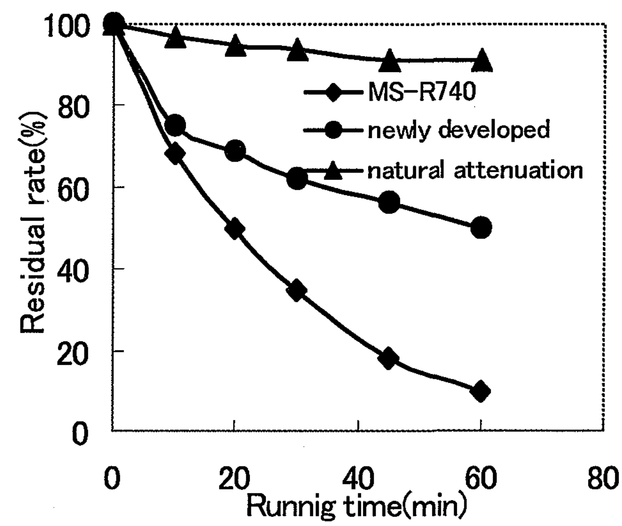

Figure 6. Removal performance of toluene with coexisting formaldehyde

ACKNOWLEDGEMENTS

This research is a part of the research results of the year of 1997 of R & D for healthy consideration technology of *House Japan Project* which is a supplementary by the Ministry of International Trade and Industry.

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