Control of Adsorption by Microwave Irradiation

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(Received May 8, 1996)

The process of gas adsorption is controlled only by temperature and pressure. When these parameters are fixed, the adsorption capability and selectivity cannot be changed. The microwave has characteristics to excite particular components such as water without destroying it. Thus, using microwaves, we have studied the adsorption of CFCs on zeolite from gas mixtures containing water which interferes with the adsorption. It was found that CFCs adsorption improved outstandingly when adsorption was conducted under microwave irradiation.

Since thermodynamically adsorption is determined solely by the temperature and pressure, the adsorption process is controlled by these apparent two factors alone after fixing sorbent. Alternatively, if they can be controlled by electromagnetic or ultrasonic waves etc., the adsorption capability and selectivity can be controlled, and the process can be simplified. Although the adsorption control by microwave is similar to temperature control, it has a special feature in that it excites only a particular component such as water. There have been examples in the application of microwaves for the desorption of the adsorbate from activated carbon in the regeneration process,[1,2] but there was no example of microwave application to adsorption equilibrium.

Recently, we have reported the use of zeolites for the recovery of chlorofluorocarbons, CFCs, which are considered to cause global environmental pollution.[3,4,5] In this study, using microwave, we tried to adsorb CFCs on zeolite selectively from exhaust gas containing moisture.

The experiment was conducted with the adsorbing equipment capable of flowing multi-component gases. It was equipped with a microwave irradiation system as schematically shown in Figure 1. Adsorption of CFC-113 (1,1,2-trichloro-1,2,2-trifluoroethane) and H_2O (moisture = water) was carried out under the following conditions : (1) The adsorbent used was about 0.6g of NaY zeolite, with a very strong hygroscopicity. (2) The adsorption gas was 1,000 ppm of CFC-113 and 8,000 ppm of H_2O in helium, with the flow rate of 400 ml/min. (3) When microwaves were not applied, the adsorption temperature was controlled by the cooling medium (CFC-112). (4) The concentration of H_2O and CFC-113 at the outlet was analyzed online with a mass spectrometer. (5) The microwave irradiation device used was of 2.45 GHz, 1.2 kW. Incidentally, we verified that no CFC-113 adsorption occurred when H_2O adsorption was completed under these conditions without microwave irradiation.

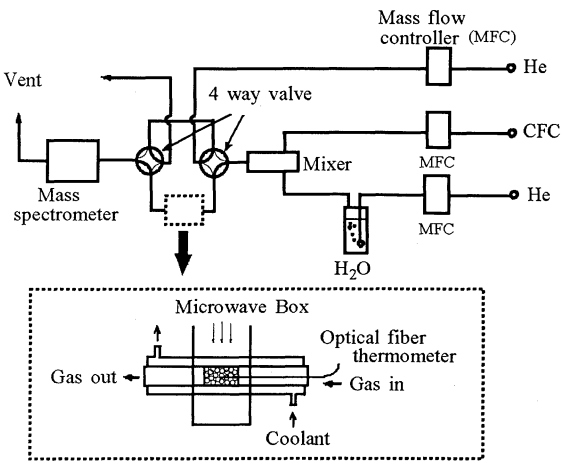

Figure 1. Adsorption apparatus.

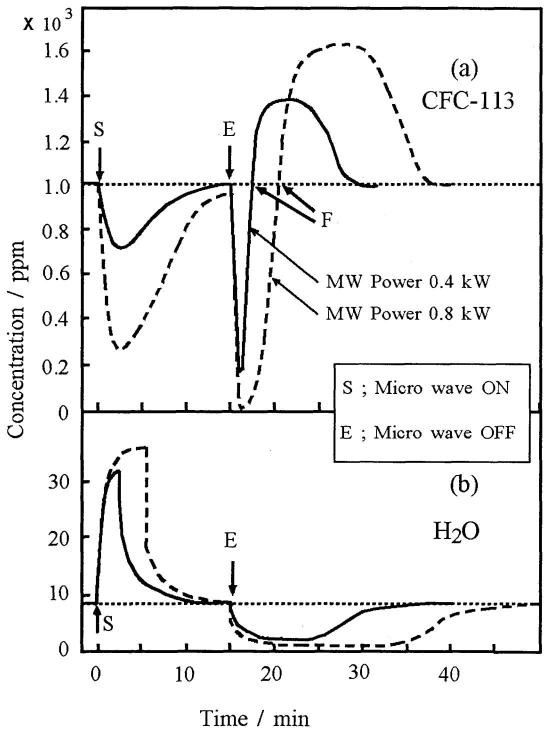

Figure 2. Adsorption - desorption curve.

Figure 2 shows the concentration curves at the exit of the adsorption tube, and Figure 3 shows the variation of temperature in the tube. Figures 2(a) and 2(b) are for CFC-113 and H_2O, respectively. The curves above the dotted line represent desorption, while those below represent adsorption. The solid lines show the result of experiment with 0.4 kW microwave power at 25 °C adsorption temperature. Initially, the adsorption gas was fed until saturation (water; 24wt%, CFC-113;0%), and then the irradiation was started at the point S. At that time, the temperature of the sorbent rose from 25 to 45 °C with a simultaneous increase in the H_2O exit concentration, indicating that H_2O began to desorb. Conversely, the CFC-113 exit concentration decreased, showing that CFC-113 was adsorbed. When microwave irradiation was stopped (point E), the temperature of the sorbent fell from 44 to 25 °C, and H_2O concentration began to decrease, showing clearly that H_2O adsorption in fact occurs. In contrast, the concentration of CFC-113 further decreased, which shows that CFC-113 adsorption resumes. This adsorption continues to point F. The desorption of CFC-113 from point F was caused by displacement adsorption of H_2O.

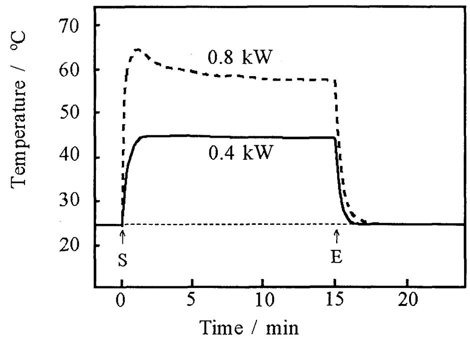

Figure 3. Temperature in the adsorption tube.

The adsorption of CFC-113 from point S to E suggests that CFC-113 molecules adsorbed at the vacant sites created by the desorption of H_2O molecules. The peculiar adsorption of CFC-113 between E and F can be explained as follows: (1) The vacancies created by the H_2O desorption remain. (2) Microwave excites not only H_2O but also CFC- 113, slightly. Therefore, if the microwave irradiation is stopped, CFC-113 is adsorbed in the vacancies like the adsorption of H_2O.

The broken line in Figure 2 shows the result when microwave irradiation power was increased to 0.8kW. With this irradiation power, the temperature of the adsorbent rose to 64 °C. This result shows that the adsorption amount of CFC-113 remarkably increased with power. Figure 4 shows the relationships between micro wave power and relative adsorption amount (R) for CFC-113 defined by the following equation.

$$R = \frac{\text{Amount of CFC-113 adsorbed between S and E.}}{\text{Desorption amount of } H_2O.} \qquad (1)$$

The relation between the power and adsorption temperature is also shown in Figure 4. It is found that the relative adsorption amount increases with an increase of temperature. These phenomena are strange because normally the relative adsorption amount should decrease with an increase of temperature. This can be explained as follows. Since the desorption of H_2O becomes very large with intensified microwave irradiation, the increase in the vacancies available for adsorbing CFC-113 surpasses the decrease of adsorption amount with an increase of temperature.

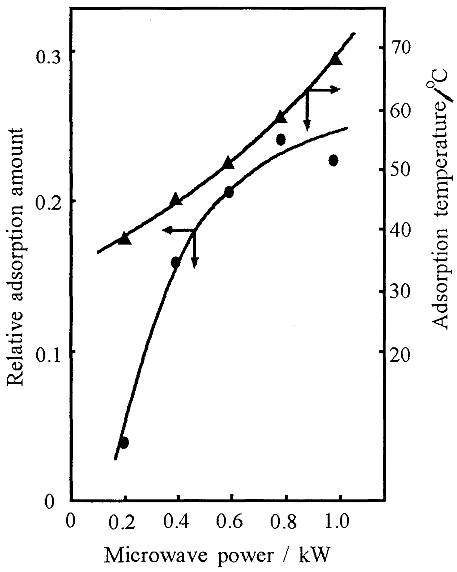

Figure 4. Relative adsorption amount of CFC-113 and adsorption temperature.

The principle of these phenomena is regarded as follows : Zeolites hygroscopicity is very strong, so the adsorption amount of H_2O is much larger than the one of CFCs. However, since the dielectric loss ($\varepsilon \cdot \tan\delta$) of H_2O is quite large (dielectric loss is the order of magnitude of 10), and that for CFCs is very small (presumably below 0.01), microwaves excite H_2O molecules rather than CFCs according to the following equation;

$$P = 0.556 \times 10^{-10} \cdot f \cdot E^2 \cdot \varepsilon \cdot \tan\delta \qquad (2)$$

where P is the power dissipated, f is the frequency, E is the electric field strength, ε is relative dielectric constant, and $\tan\delta$ is dielectric loss angle. Therefore, H_2O desorbs, and CFCs adsorb in return.

This phenomenon is not limited to only the system for H_2O and CFCs. For example, it can be applied to the methanol-benzene mixture. And by pulsing the microwave irradiation, adsorption and desorption may be accomplished using a single adsorbing tower, that is, CFCs adsorption via microwave irradiation, while CFCs desorption results from the adsorption of H_2O without microwave irradiation.

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