

## Effect of Carbonization Temperature on Adsorption Isotherms of Wood Charcoals

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Carbonization condition of wood affects the adsorption property of chemical compounds. Wood specimen was chipped and meshed into 1 - 9.5 mm size. The carbonization temperature from 400°C to 1,100°C was adopted in nitrogen gas flow which contains oxygen of 0.3%. Adsorption-desorption isotherms by charcoals were measured. Nitrogen, carbon dioxide and water were selected as an adsorbate gas. The isotherms of N<sub>2</sub> showed that as the carbonization temperature increased micropores formed in the charcoal. In the distribution of micropore radius, micropores having the size under ca. 0.7 nm increased in the charcoal carbonized at 600°C and above. In adsorption-desorption isotherms of water, V-typed isotherms were observed in the charcoal prepared at 600°C and above. This result also shows existence of mesopores and macropore in the charcoal. The specific surface area of the charcoals estimated with the BET equation of the charcoal carbonized at 600°C was 400 m<sup>2</sup>/g by N<sub>2</sub> adsorption at 77 K and CO<sub>2</sub> adsorption at 195 K, respectively. As the carbonization temperature increased, the specific surface area by both N<sub>2</sub> and CO<sub>2</sub> adsorption drastically increased and 800 m<sup>2</sup>/g was obtained in the charcoals heat-treated at 1,000°C.

Key words: carbonization, wood, adsorption, isotherms

### 1. INTRODUCTION

Since charcoal carbonized from wood and bamboo has porous microstructure, chemical compounds and water can be adsorbed into the pore surface. Charcoal board as a building interior material has been newly developed by adhering charcoal powder with binder.[1]-[4] The charcoal board is used for adsorbing volatile organic compounds (VOCs) such as formaldehyde, toluene and ammonia in indoor air.

The specific surface area, the pore radius distribution and the chemical structure of the pore surface depend upon the carbonization temperature of wood.[5]-[10] Consequently the adsorption capability of VOCs and water is influenced by the carbonization temperature.[6][7][11]

In this report, we studied the effect of carbonization temperature of wood on the adsorption property of the charcoal. Formation of the micropore is discussed from the results of the pore radius distribution and the specific surface area estimated by using different adsorbates.

### 2. EXPERIMENTAL

#### 2.1 Carbonization

Chips of sap wood of Hinoki (*Chamaecyparis obtusa*) several mm in size were used as a raw material. Apparatus for carbonization of wood is shown in Fig. 1. Wood chips of about 10 g were placed in the center of a quartz tube of 113 mm in inner diameter and 600 mm in length. The quartz tube was heated in a cylindrical electric furnace. Nitrogen gas was introduced into the quartz tube at the rate of 200 cm<sup>3</sup>/min during the

carbonization process. Oxygen concentration was measured at the outlet of the quartz tube, which was 0.3 % during the carbonization. The sample was heated to the carbonization temperature from 400°C to 1,100°C with a heating rate of 20°C/min and held at the carbonization temperature for 120 min. After the carbonization, the sample was cooled to room temperature with furnace cooling for about several hours.

#### 2.1 Adsorption-desorption isotherms

The adsorption-desorption isotherms for the charcoals were measured with an adsorption apparatus (BELSORP 18). In order to eliminate gas component and H<sub>2</sub>O from

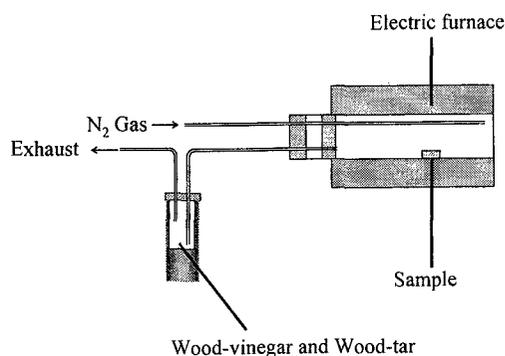


Fig. 1. Apparatus for carbonization.

the surface of the charcoal pore, the charcoal sample of 0.2 g in the sample tube was pre-heated at 305°C for 5 hour in vacuo.

N<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O were used as adsorbate gases which were absorbed into the charcoal and then disorbed from the charcoal at 77 K, 195 K and 298 K, respectively. The specific surface area and the pore radius distribution of the charcoal were estimated with BET equation and HK-plots, respectively, applied for the adsorption isotherms.

### 3. RESULTS AND DISCUSSION

I-typed adsorption-desorption isotherms of N<sub>2</sub> at 77 K for the charcoal carbonized at temperature from 400°C to 1,100°C are shown in Fig. 2. In the vicinity of  $P/P^0=0$  the absorption amount increases drastically, and gradual increase is observed above  $P/P^0=0.1$ . With increasing the carbonization temperature the adsorption amount increases. In the charcoal prepared at 1,100°C, the absorption amount decreases. These results suggest that as the carbonization temperature increases micropores forms in the charcoal, but at 1,100°C micropores are reduced.

Distribution of micropore diameter of the charcoals carbonized at temperatures from 400°C to 1,100°C, which are estimated in the N<sub>2</sub> adsorption isotherms, is shown in Fig. 3. In the charcoal carbonized at 400°C, no pores of diameter under 1.5 nm were observed. Micropores having the size under ca. 0.7 nm increase in the charcoals prepared at 600°C and above. In the charcoals carbonized at 800°C and above, the peaks at 0.8 nm and 1.1 nm appear. In the charcoal prepared at 1,100°C size of micropores of the size under 0.7 nm is reduced.

In Fig. 4, effect of carbonization temperature on pore volume of the charcoal estimated by N<sub>2</sub> adsorption isotherms. The pore volume of micropore and mesopore was estimated by MP-plots and DH-plots, respectively. The both pore volumes increase with increase of the carbonization temperature and those decrease in the charcoal prepared at 1,100°C.

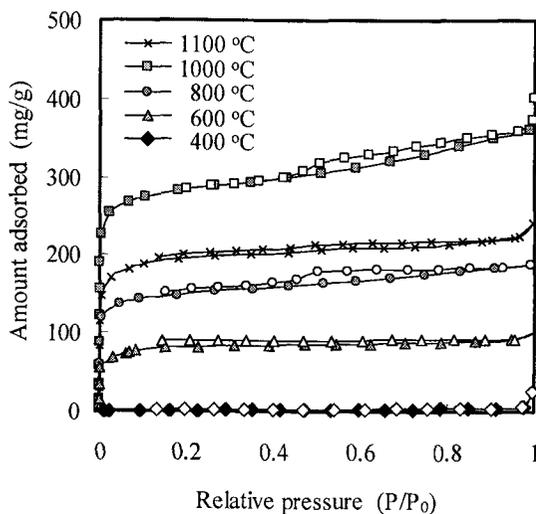


Fig. 2. Adsorption-desorption isotherms of N<sub>2</sub> for the charcoal carbonized at 400, 600, 800, 1000, 1100 °C.

In Fig. 5, adsorption-desorption isotherms of water at 298 K (25°C) are shown on the four charcoal samples carbonized at 400°C to 1,000°C. V-typed isotherms are appeared in the charcoal carbonized at 600°C showing existence of mesopores and macropores in the charcoal. In the carbon prepared 800°C and 1,000°C, definite hysteresis in isotherms is observed, which means that capillary condensation of water vapor takes place in mesopores. It is evident from the isotherms shown in Figs. 2 and 5 that the hysteresis loop of the water isotherms is notably different from those of the nitrogen isotherms. The area of the hysteresis loop in the water isotherms is large compared with those in the nitrogen isotherms. The experimental findings for charcoal at 800°C and 1,000°C, suggests that the capillary condensation of water vapor takes place in the mesopores.[12]

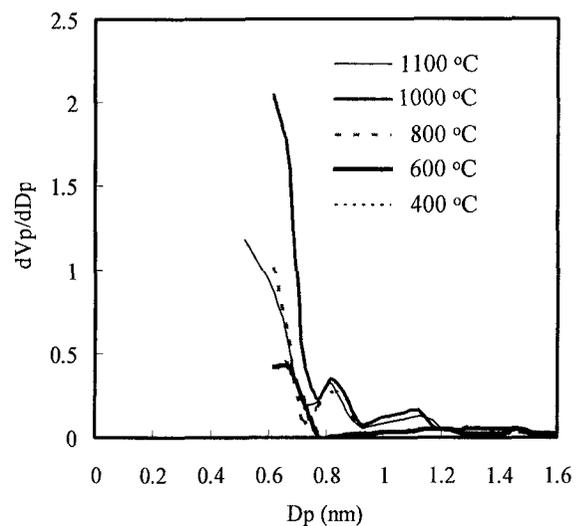


Fig. 3. Distribution of micropore diameter of the charcoal estimated by N<sub>2</sub> adsorption isotherms at 77 K.

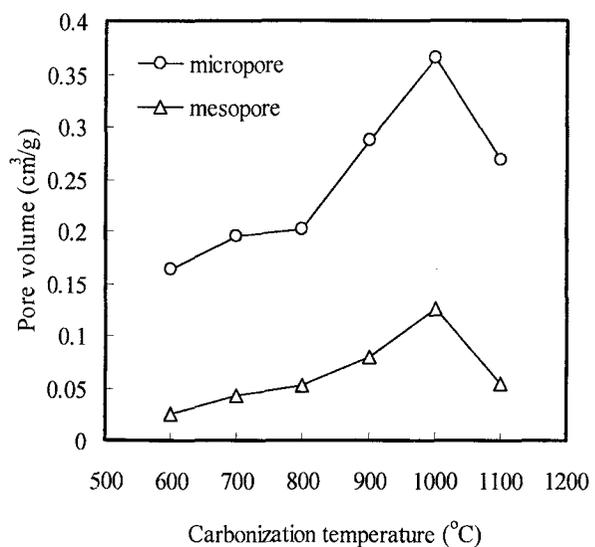


Fig. 4. Effect of carbonization temperature on pore volume of the charcoal estimated by N<sub>2</sub> adsorption isotherms.

The adsorption isotherms of N<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O for the charcoal carbonized at 1000°C are shown in Fig. 6. In the N<sub>2</sub> adsorption at 77 K and in the CO<sub>2</sub> adsorption at 195 K, the I-typed adsorption isotherm is observed where abrupt increase in the low pressure region, which suggests the existence of micro pores in the charcoal. In the H<sub>2</sub>O adsorption at 298 K (25°C), the V-typed adsorption isotherm is observed showing the existence of mesopores and macropores in the charcoal.

Distribution of maicropores diameter of the charcoal estimated CO<sub>2</sub> adsorptin isotherms is shown in Fig. 7. In the charcoal carbonized at 400°C, formation of micropores is observed, though no pores of diameter under 1.5 nm in the distribution estimated N<sub>2</sub> adsorption isotherms were observed as shown in Fig. 3. Micropores

increases with increase of carbonization temperature. In the charcoal prepared at 1,100°C micropores is reduced, which is the same as the results of N<sub>2</sub> adsorption.

Figure 8 shows change of the specific surface area of the charcoals vs. the carbonization temperature from 400°C to 1,100°C. In N<sub>2</sub> adsorption experiment the specific surface area increases with increasing the carbonization temperature, which corresponds to the results of the pore radius distribution in Figure 3. In the charcoal carbonized at 400°C, the specific surface area is small value, 10 m<sup>2</sup>/g. However, the specific surface volume estimated by CO<sub>2</sub> adsorption for the charcoal carbonized ad 400°C is 380 m<sup>2</sup>/g, and the volume increases gradually with the increase of the temperature. These results suggest that in the lower carbonization

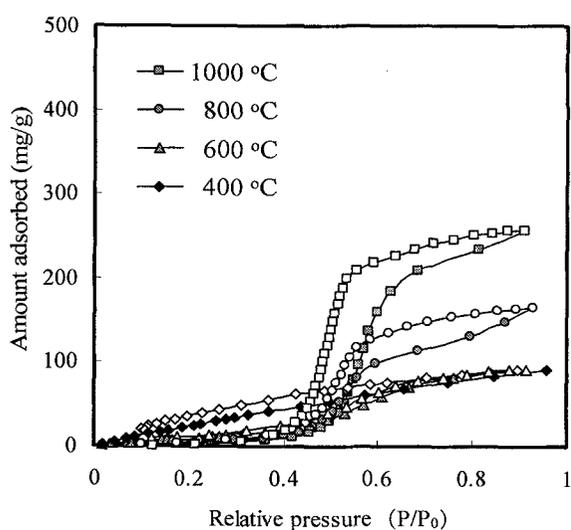


Fig. 5. Adsorption-desorption isotherms of H<sub>2</sub>O for the charcoal carbonized at 400, 600, 800, 1000 °C.

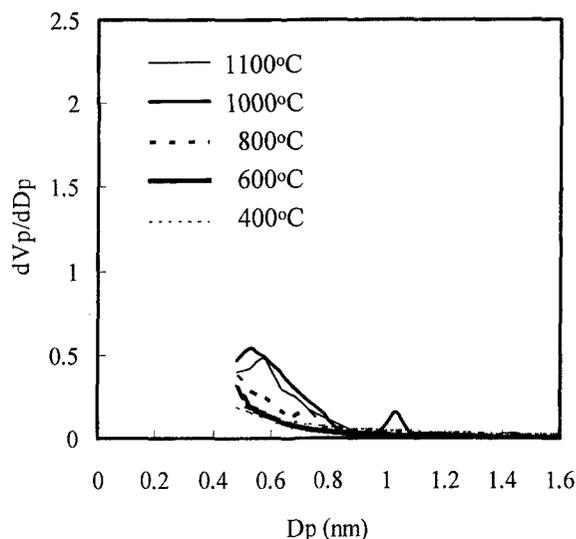


Fig. 7. Distribution of maicropores diameter of the charcoal estimated by CO<sub>2</sub> adsorption isotherms at 195 K.

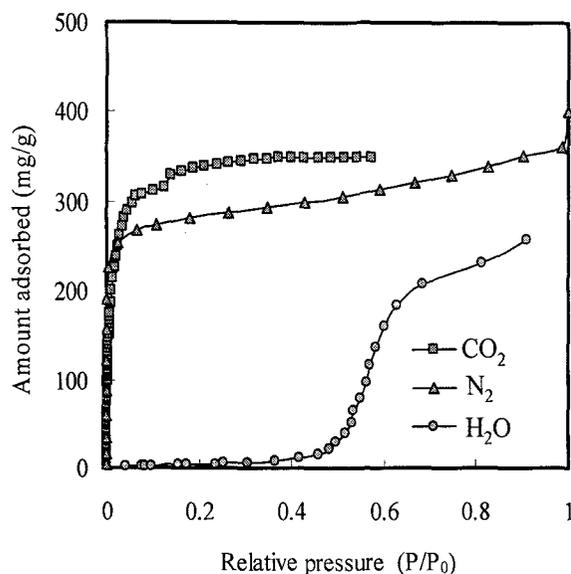


Fig. 6. Adsorption-desorption isotherms of N<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O for the charcoal carbonized at 1000 °C.

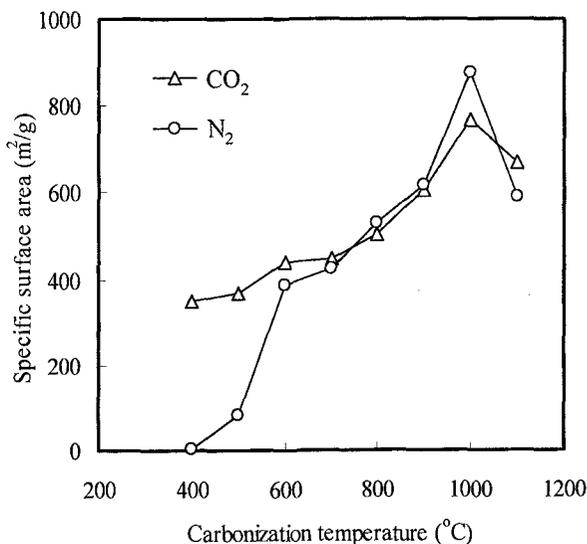


Fig. 8. Effect of carbonization temperature on specific surface area of the charcoal estimated by N<sub>2</sub> and CO<sub>2</sub> adsorption isotherms.

temperature the number of sub-nm pores increases. As the size of CO<sub>2</sub> molecule is 0.4 nm, which is a little larger than that of N<sub>2</sub> (0.32 nm). CO<sub>2</sub> can disperse easily into micropores because adsorption taken place at 195 K. [13]

#### 4. CONCLUSIONS

It was found that carbonization temperature affects the adsorption of adsorbate gases; N<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O. The isotherms of N<sub>2</sub> showed that as the carbonization temperature increased micropores formed in the charcoal. In the distribution of micropore radius, micropores having the size under ca. 0.7 nm increased in the charcoal carbonized at 600°C and above. In adsorption-desorption isotherms of water, V-typed isotherms were observed in the charcoal prepared at 600°C and above. Those results shows existence of mesopores and macropored besides micropores in the charcoal. The specific surface area of the charcoals estimated with the BET equation of the charcoal carbonized at 600°C was 400 m<sup>2</sup>/g by N<sub>2</sub> and CO<sub>2</sub> adsorption, respectively. As the carbonization temperature increased, the specific surface area by both N<sub>2</sub> and CO<sub>2</sub> adsorption drastically increased and 800 m<sup>2</sup>/g was obtained in the charcoals heat-treated at 1,000°C.

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