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Influence of drying temperature on NO_2 sorption ability of cedar timber

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Abstract

NO_2 sorption ability of cedar (*Cryptomeria japonica*) timbers was evaluated using a new measuring system that was developed in our previous study. Four drying conditions were applied, namely natural drying and three kinds of kiln-drying at 45, 60, and 105 °C. Aeration experiments were conducted using discoid specimens which had a thickness in the longitudinal direction of 1.5 mm, and a diameter of 10 mm. The moisture content was conditioned to 0 or $9 \pm 1.0\%$ in each drying condition. As a result, the NO_2 sorption ability declined as the drying temperature increased. Based on the analysis of extractives, it was shown that the extractives content had a high correlation with the contribution ratio of extractives in the NO_2 sorption volume of the specimens that were dried below 60 °C. Therefore, it was elucidated that the specimen dried naturally has the greatest NO_2 sorption ability. Furthermore, the result of the gas chromatography–mass spectrometry (GC/MS) indicated that abietadiene influenced the NO_2 sorption ability. Also, the NO_2 sorption volume was high especially at the initial stage, which is higher under the condition with moisture.

Keywords: Japanese cedar wood, Nitrogen dioxide (NO_2) sorption, Drying treatment, Extractives

Introduction

Nitrogen dioxide (NO_2) is identified as an air pollutant that affects human health, particularly the lungs and breathing passages. In Japan, at most monitoring points, the environmental standards regarding NO_2 are satisfied, but at some points where large amounts of car exhaust are emitted, the standards are not satisfied [1]. Also, in the other countries that have air pollutant problems, there is a desire to remove NO_2 [2]. As representative materials used for NO_2 removal, it is known that activated carbon, photocatalysts and volatile compounds from woody plants have high NO_2 sorption ability [3–10]. However, these materials are costly to manufacture, depend on the weather or time, and are difficult to dispose of waste solution, respectively. Recently, it was elucidated that cedar (*Cryptomeria japonica*) wood has high NO_2 sorption ability [11, 12]. Cedar wood is a major plantation species in Japan, and we have abundant available resources of it.

The problem is in using it effectively. When NO_2 sorption ability per unit weight of cedar wood was compared with that of carbonaceous materials, cedar wood was lower in some cases [3, 8, 12]. However, cedar wood itself is available as a NO_2-removing material without any chemical or industrial treatment. Therefore, cedar wood has great potential for use in NO_2 removal. It is considered that the main factors contributing to the NO_2 sorption ability of cedar wood are structural features of tissues, moisture content (MC), and extractives. These factors have been evaluated in previous studies [11, 13]. However, in most of those studies, the NO_2 sorption volume was measured using a system in accordance with JIS R 1701-1 [14] which was developed for photocatalytic materials. Because photocatalytic materials are homogeneous industrial products, it is possible that wood, which is a heterogeneous biological material, its NO_2 sorption ability has not been evaluated appropriately. Furthermore, the specimen size is limited in this system. Therefore, the mechanism that each factor functions has not been evaluated in detail. We constructed a new measuring system with which to evaluate the NO_2 sorption volume of wood with various sizes and forms in our previous study. It was

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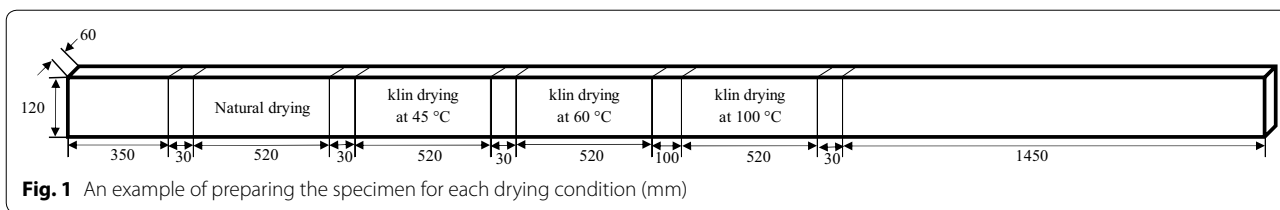Full list of author information is available at the end of the article

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Fig. 1 An example of preparing the specimen for each drying condition (mm)

shown that the interface area of the specimen that comes into contact with NO_2 influenced the NO_2 sorption ability, and the structure of the tracheids in cedar wood contributed to increasing the interface area [15].

With regard to the contribution of extractives to the NO_2 sorption ability of cedar wood, Tsujino et al. compared the NO_2 sorption volume of specimens between before and after an extraction treatment using the system of JIS R 1701-1, and reported that extractives of cedar wood make a high contribution to the NO_2 sorption ability [11]. Karino et al. [16] and Shibutani et al. [17] reported that terpenoid and norlignans which are the main extractives in cedar wood vanished or decreased under a heat condition over 100 °C, which is possible to also influence the NO_2 sorption ability. Cedar wood has often been treated by kiln-drying to shorten the production process and prevent dimensional changes. Therefore, the purpose of this study was to clarify the influence of drying temperature. Based on the obtained data, we tried to find the condition to maximize the NO_2 sorption ability of cedar wood. This would give the use of cedar wood as interior materials the additional value. We focused on the change in extractives due to the drying treatment. Then, we tried to elucidate the influence of drying temperature on NO_2 sorption ability using a new measuring system for evaluating the NO_2 sorption volume that was developed in our previous study [15].

Materials and methods
Materials
Cedar heartwoods harvested in Kumamoto Prefecture in Japan were used. This wood was roughly 40 years old. Five pieces of lumber were each cut into 4100 (L) × 120 (T) × 60 (R) mm blocks, where L, T and R correspond to the longitudinal, tangential, and radial axes, respectively. The five blocks were further cut into 520 (L) × 120 (T) × 60 (R) mm specimens. One specimen from each block was randomly selected, and they were separated into four groups to dry at four different temperatures.

The sizes of the specimens used in drying treatment are shown in Fig. 1. Four drying conditions were applied, namely natural drying and three kinds of kiln-drying at 45, 60, and 105 °C. The humidity was not controlled. The details of each drying condition are summarized in Table 1. After the drying treatment, 320 discoid

Table 1 The drying condition

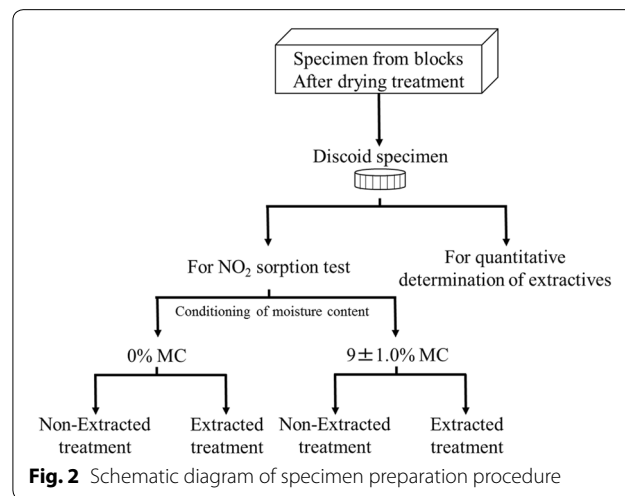| Drying method	Natural drying	Kiln drying		
Drying temperature (°C)	–	45	60	105
Drying time (day)	132	38	15	2
Moisture content after drying (%)	15.4	12.3	13.4	10.8

Fig. 2 Schematic diagram of specimen preparation procedure

specimens with a longitudinal thickness of 1.5 mm and a diameter of 10 mm were prepared [15]. Discoid specimens from each drying condition were conditioned as below described. It was reported that the MC conditions influenced the NO_2 sorption ability [13]. The MC of specimens was conditioned to 0 or $9 \pm 1.0\%$. The specimens at 0% MC were conditioned by drying with a frozen drying device for more than 48 h in consideration of the influence of heat on changing the extractives [18]. The specimens at $9 \pm 1.0\%$ MC were conditioned for at least 3 weeks in a desiccator at 20 °C and $56 \pm 5.0\%$ relative humidity. $9 \pm 1.0\%$ MC condition was used as air-dried condition. In addition, extracted specimens were prepared under each MC condition. The schematic diagram of the specimen preparation procedure is shown in Fig. 2. The proportion of late wood was 18.2% and the mean annual ring width was 4.51 mm, and the density after conditioning was 0.49 g/cm^3.

NO$_2$ sorption test

The NO$_2$ sorption test was conducted based on our previous study [15]. The conditions were as shown below; NO$_2$ gas was aerated under a temperature of 20 ± 1.0 °C and a relative humidity of 0 or $56 \pm 5.0\%$ [13, 19]. The concentration of the NO$_2$ gas was adjusted to 1000 ppb and the flow rate to 560 ml/min. These conditions were determined by a preliminary experiment in which the NO$_2$ sorption ability was evaluated appropriately [12]. Five discoid specimens were inserted vertically at intervals of 10 mm inside the tube [15].

Evaluation method of NO$_2$ sorption ability [15]

The variation over time in NO$_2$ concentration after NO$_2$ gas passed through the specimen was monitored. The NO$_2$ sorption volume per minute at each aeration time Q (µmol) was calculated using Eq. (1). According to JIS R 1701-1 [14], the total NO$_2$ sorption volume at aeration time Q_{NO_2} (µmol) was calculated using Eq. (2). The average NO$_2$ concentration monitored with the instrument only, before and after the experiment involving each specimen, was taken to be the reference value for the NO$_2$ concentration:

$$Q = \left([NO_2]_0 - [NO_2]\right) \times 10^{-9} \times \frac{f}{22.4} \times 10^6, \quad (1)$$

$$Q_{NO_2} = \int \left\{ \left([NO_2]_0 - [NO_2]\right) \times 10^{-9} \times \frac{f}{22.4} \times 10^6 \right\} dt, \quad (2)$$

where $[NO_2]_0$ is the reference value for the NO$_2$ concentration (ppb), $[NO_2]$ is the NO$_2$ concentration after NO$_2$ gas passed through the specimen (ppb), f is the NO$_2$ flow rate (560 ml/min), 22.4 is the volume (l) of 1 mol of the gas in the standard state, and t is the aeration time(min).

It is known that some amount of NO is generated by the reaction between NO$_2$ and water [20]. NO turns to NO$_2$ immediately by reacting with O$_2$ in the air. In fact, NO was not generated when the NO$_2$ sorption test was conducted under the condition without moisture. Therefore, The NO$_2$ being consumed by this reaction was not absorbed into the wood. Considering this, under the condition with moisture presence, the NO generation volume G_{NO} (µmol) was calculated using Eq. (3), and the actual volume of NO$_2$ sorption into the specimen Q_{sor} (µmol) was calculated using Eq. (4):

$$G_{NO} = \int \left\{ \left([NO] \times 10^{-9}\right) \times \frac{f}{22.4} \times 10^6 \right\} dt, \quad (3)$$

$$Q_{sor} = Q_{NO_2} - G_{NO}, \quad (4)$$

where $[NO]$ is NO concentration (ppb) after NO$_2$ gas is passed through the specimen. It was shown that the

NO$_2$ sorption volume of wood was evaluated appropriately using the value of the NO$_2$ sorption volume per unit weight in our previous study [15]. Therefore, using Eq. (5), the NO$_2$ sorption volume per unit weight in a unit of aeration time Q_{Wsor} (µmol/g/h) was calculated from the NO$_2$ sorption volume Q_{sor} calculated with Eq. (4):

$$Q_{Wsor} = \frac{Q_{sor}}{W \cdot T}, \quad (5)$$

where W is the specimen weight (g) and T is the total aeration time (h).

Extraction procedure

For the analysis of extractives, extractives were prepared by soaking discoid specimens in ethanol–benzene (1:2, v/v) at 20 °C for 48 h. The amount of ethanol–benzene soluble extractives was calculated by comparing the dried-weight of the flask after the solution was evaporated to dryness to the dried-weight of the flask only. Also, to evaluate each component in the extractives, a gas chromatography–mass spectrometry (GC/MS) analysis was conducted. After the extraction treatment, the MC of each extracted specimen was conditioned to 0 or $9 \pm 1.0\%$ (Fig. 2), and then used in the NO$_2$ sorption test again.

GC/MS analysis

Extractives were dissolved by acetone, and 0.5 mg/ml extractives solution was prepared. As an internal standard, 5 µl/ml naphthalene was added, and 1 µl of the solution was analyzed by GC/MS Agilent 7693A (Agilent Technologies Inc., California, USA). The detailed parameters were as follows. The capillary column was DB-5 ms (30 m × 0.25 mm, inside diameter 0.25 µm film thickness, Agilent Technologies Inc.). Helium was used as the carrier gas at a flow rate of 1 ml/min, and the split ratio was adjusted to 10. The injector and detector temperatures were both 250 °C. The temperature program was 1.0 min at 40 °C, 25 °C/min to 100 °C and 10 °C/min to 250 °C and maintained at 250 °C for 3 min. The mass spectrometer was operated in electron ionization mode at 70 eV. Compounds were then identified using values in the NIST 14 computer library and values from a previous study [21]. In the NIST 14 computer library, the rate of concordance in the mass spectrum was above 90%. The ratio of each peak area to that of naphthalene was compared.

Data analysis

For the NO$_2$ sorption volume, values were obtained for 5 h [14, 15], and then the average of three trials was taken. For the obtained results, an unpaired t test, one-way analysis of variance (ANOVA), or two-way ANOVA was conducted as a test of differences between conditions. In

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one-way ANOVA, if a significant difference was found, then a multiple comparison test was conducted using the Tukey method. In two-way ANOVA, if a significant interaction was found, a simple main effect test was conducted. In all cases, the value of significance probability was 5%.

Results and discussion

NO$_2$ sorption volume of cedar wood with different drying temperatures

The influence of drying temperature

Figure 3 shows the variation over time in NO$_2$ sorption volume at 0% MC. The NO$_2$ sorption volume was high at the initial stage and then gradually decreased. It reached equilibrium in 5 h. The behavior was confirmed to be almost the same even under different drying temperature conditions. Also, natural drying had the greatest NO$_2$ sorption volume. The average NO$_2$ sorption volume decreased as the drying temperature increased. This was quite noticeable at the initial stage. Figure 4 shows the variation over time in NO$_2$ sorption volume of non-extracted and extracted specimens with natural drying (0% MC). The variation in extracted specimens was almost the same as that in non-extracted specimens. However, the average NO$_2$ sorption volume was decreased by the extraction treatment even if the drying temperature was the same. The NO$_2$ sorption volume of the non-extracted specimens was much greater than that of the extracted specimens, especially at the initial stage, when it was about five times greater. After 2 h aeration, the difference decreased to two times greater, and it reached equilibrium at around 5 h. Figure 5 shows the NO$_2$ sorption volume per unit weight and time of the non-extracted and extracted specimens at different drying temperatures for 5 h (0% MC). In non-extracted specimens, the average NO$_2$ sorption volume of the natural drying specimen was the greatest (0.42 µmol), and it was about twice as much as that of the specimen
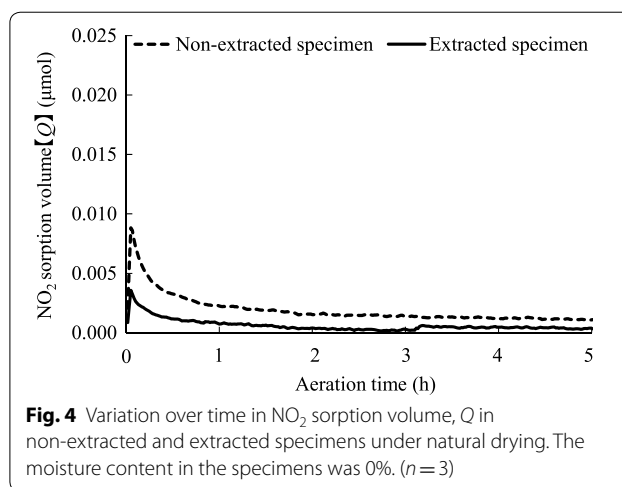
Fig. 4 Variation over time in NO$_2$ sorption volume, Q in non-extracted and extracted specimens under natural drying. The moisture content in the specimens was 0%. ($n = 3$)

dried at 105 °C (0.22 µmol). Furthermore, the average NO$_2$ sorption volume increased as the drying temperature decreased. In the extracted specimens, the average NO$_2$ sorption volume showed almost same values in the range of 0.14–0.19 µmol regardless of the drying temperature. Two-way ANOVA showed significant differences between the extracted and non-extracted specimens and among the different drying temperatures, respectively. It also showed an interaction effect ($p < 0.01$). Testing simple main effects showed that the NO$_2$ sorption volume of non-extracted specimens was greater than that of extracted specimens, and the NO$_2$ sorption volume of the specimen dried naturally and of that dried at 45 °C were significantly greater than that of the specimens dried in the kiln and of that dried at 105 °C, respectively ($p < 0.01$). Because the NO$_2$ sorption volume of the extracted specimens from which the extractives were removed uniformly did not show significant differences among drying temperature, it was suggested that the
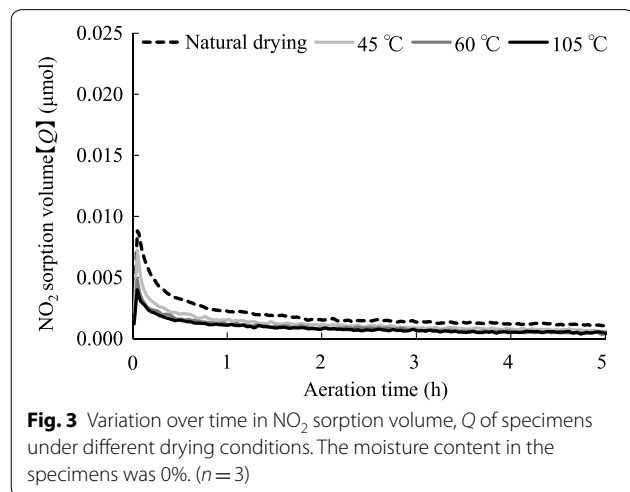
Fig. 3 Variation over time in NO$_2$ sorption volume, Q of specimens under different drying conditions. The moisture content in the specimens was 0%. ($n = 3$)
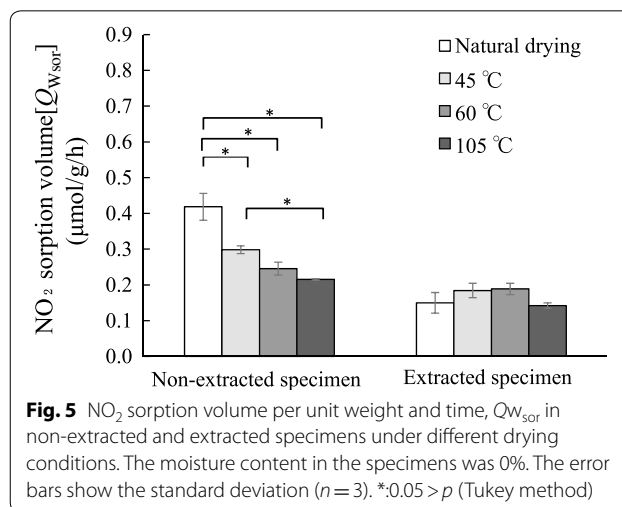
Fig. 5 NO$_2$ sorption volume per unit weight and time, Q_{Wsor} in non-extracted and extracted specimens under different drying conditions. The moisture content in the specimens was 0%. The error bars show the standard deviation ($n = 3$). *:0.05 > p (Tukey method)

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differences among the conditions in the non-extracted specimens were caused by the extractives in each specimen. Furthermore, it is known that the drying temperature influenced the amount of extractives in cedar wood in previous studies. Shibutani et al. [17] reported that the amount of extractives, especially terpenoid, in cedar wood dried at an average temperature of 105 °C and a maximum temperature of 120 °C for about 2 weeks was lower than that in cedar wood dried naturally for about 1 month. Karino et al. [16] also reported that the amount of extractives in cedar wood decreased as the drying temperature increased. Considering these reports, it is strongly indicated that the differences in the amount of extractives due to drying treatment influenced the NO_2 sorption volume. In addition, the contribution of extractives to NO_2 sorption seemed to be high, especially at the initial stage, based on the results shown in Figs. 3 and 4.

The influence of moisture

Compared with the specimen at 0% MC, the average NO_2 sorption volume in variation over time at $9 \pm 1.0\%$ MC was always greater and the behavior which the NO_2 sorption volume was high at the initial stage and then gradually decreased was almost the same. To discuss the quantitative relationship of the NO_2 sorption volume, the NO_2 sorption volume per unit weight and time for 5 h was evaluated. The results are shown in Fig. 6. In non-extracted specimens, the average NO_2 sorption volume of the natural drying specimen was the greatest (0.71 μmol), and it was 0.29 μmol greater than that of the specimen at 0% MC. The NO_2 sorption volume decreased as the drying temperature increased. The average NO_2 sorption volume of the specimen dried at 105 °C was 0.34 μmol, which was less than half the sorption volume of the natural drying specimen and 0.19 μmol greater than that of the specimen at 0% MC. The difference in NO_2 sorption volume between the specimen at $9 \pm 1.0\%$ MC and that at 0% MC decreased as the drying temperature increased. In the extracted specimens, the NO_2 sorption volume showed almost the same values with a range of 0.19–0.21 μmol regardless of the drying temperature. Two-way ANOVA showed significant differences between the
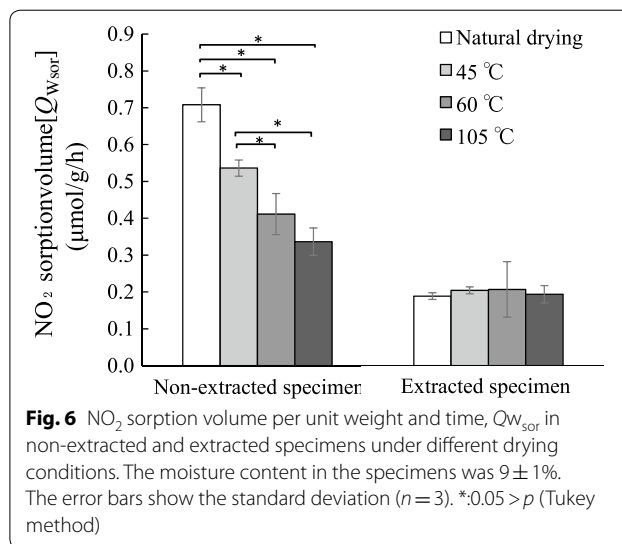

Fig. 6 NO_2 sorption volume per unit weight and time, Qw_{sor} in non-extracted and extracted specimens under different drying conditions. The moisture content in the specimens was $9 \pm 1\%$. The error bars show the standard deviation ($n = 3$). *:$0.05 > p$ (Tukey method)

non-extracted and extracted specimens, and among the drying conditions ($p < 0.01$). It also showed an interaction effect. Testing simple main effects showed that the NO_2 sorption volume of the non-extracted specimen was significantly greater than that of the extracted specimen, and the NO_2 sorption volumes of the specimens dried naturally and dried at 45 °C were greater than those of the specimens dried in kiln and dried at 60 and 105 °C, respectively ($p < 0.05$). These relationships in NO_2 sorption volumes among the conditions at $9 \pm 1.0\%$ MC showed similar tendencies to those at 0% MC. On the other hand, the difference in NO_2 sorption volume between extracted and non-extracted specimens at $9 \pm 1.0\%$ MC was greater than that at 0% MC. This seems that the reactivity between the extractives and NO_2 gas was enhanced by increasing the space for NO_2 gas to contact with the extractives and surface of the specimen and being easy for extractives to move with the presence of moisture. With regard to moisture and extractives, we tried to compare their contributions to NO_2 sorption under each drying temperature based on the NO_2 sorption volume in the non-extracted specimen at $9 \pm 1.0\%$ MC. Each contribution ratio was calculated using the following equation:

$$\text{Contribution ratio of water only (\%)} = \frac{(NO_2 \text{ sorption volume at } 9 \pm 1.0\% \text{ MC}) - (NO_2 \text{ sorption volume at } 0\% \text{ MC})}{(NO_2 \text{ sorption volume at } 9 \pm 1.0\% \text{ MC})} \times 100,$$

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where NO_2 sorption volume is the value in extracted specimen.

$$\text{Contribution ratio of extractives only (\%)} = \frac{(NO_2 \text{ sorption volume of non-extracted specimen}) - (NO_2 \text{ sorption volume of extracted specimen})}{(NO_2 \text{ sorption volume of non-extracted specimen})} \times 100,$$

where NO_2 sorption volume is the value at $9 \pm 1.0\%$ MC.

$$\text{Contribution ratio of others (\%)} = \frac{(A - B)}{(NO_2 \text{ sorption volume of non - extracted specimen at 0\% MC, dried naturally})} \times 100,$$

where A is the difference in the NO_2 sorption volume between 0% MC and $9 \pm 1.0\%$ MC in non-extracted specimens. B is the difference in the NO_2 sorption volume between non-extracted and extracted specimens at 0% MC.

The contribution ratio of both water and extractives was calculated using the following equation:

$$\text{Contribution ratio of both water + extractives (\%)} = 100 - (\text{contribution ratio of water only, extractives only and others}).$$

Figure 7 shows the contribution ratio for the value under each drying condition to the value under the natural drying condition. The contribution ratios of only water and extractives decreased from 38.0 to 8.0% and from 5.5 to 2.5%, respectively, as the drying temperature below 60 °C increased. The contribution ratio of water + extractives decreased from 35.4 to 9.9% as the drying temperature increased.

The sum of extractives only and water + extractives under natural drying was 73.4%. Thus, it seems that the

NO_2 sorption ability was enhanced by the presence of water in non-extracted specimens. The contribution ratio of only water and extractives increased relatively in the specimen dried at 105 °C. This seems to be because the contribution ratio of water + extractives decreased. In the contribution ratio of others, the specimen dried at 105 °C was the lowest (20.1%). However, no clear relationship was shown among the drying temperature conditions. It was reported that the microstructure of dry wood is changed by heating [22]. Thus, the change in the micro-structure could be one of the factors which influenced the NO_2 sorption of the specimen dried over 100 °C. Furthermore, it was also reported that NO_2 reacts with construction components such as cellulose and lignin [13]. These components might have changed due to drying treatment and then might have influenced NO_2 sorption ability. We need to examine these factors separately.

The relationship between the amount of extractives and NO_2 sorption volume

The extractives content, namely the ratio of the extractives weight in the oven-dried specimens to the weight
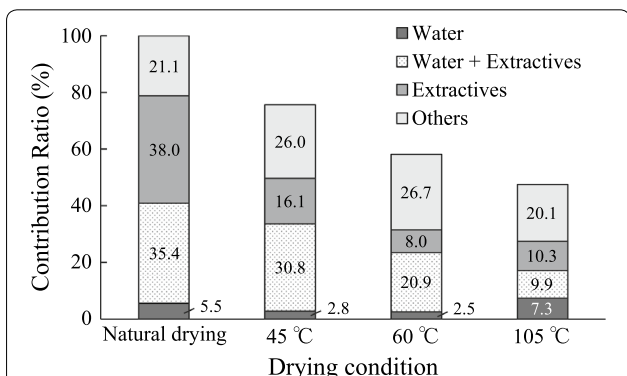

Fig. 7 Contribution ratio of water only, extractives only, water + extractives, and others in NO_2 sorption under different drying conditions. The ratio for each kiln-drying condition shows the ratio of its value to the value under the natural drying condition
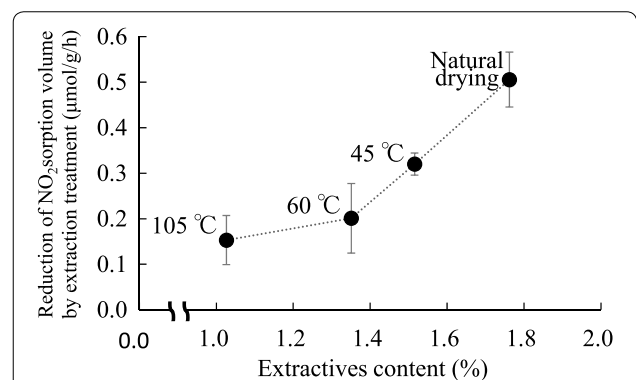

Fig. 8 The relationship between the reduction of NO_2 sorption volume by extraction treatment and the extractives content. The error bars show the standard deviation ($n = 3$)

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Table 2 Composition of main components among four drying conditions

RT (min)	Component	Natural drying		Kiln drying					
		Mean	SD	45 °C		60 °C		105 °C	
				Mean	SD	Mean	SD	Mean	SD
Monoterpenes									
4.23	α-Pinene	1.7×10^{-5}	0.0000	1.3×10^{-5}	0.0000	1.1×10^{-5}	0.0000	1.0×10^{-5}	0.0000
Sesquiterpenes									
9.07	α-Cubebene	0.0081	0.0001	0.0193	0.0001	0.0122	0.0005	0.0140	0.0004
9.31	α-Copaene	0.0025	0.0001	0.0071	0.0002	0.0045	0.0003	0.0044	0.0002
10.04	β-Caryophyllene	0.0002	0.0001	0.0006	0.0003	0.0005	0.0002	0.0004	0.0002
10.18	cis-Thujopsene	0.0165	0.0003	0.0532	0.0003	0.0365	0.0016	0.0356	0.0004
10.32	Humulene	0.0052	0.0001	0.0128	0.0001	0.0073	0.0006	0.0057	0.0002
11.00	α-Muurolene	ND	–	0.2142	0.0009	0.1141	0.0055	0.1081	0.0024
11.04	β-Bisabolene	0.0038	0.0004	0.0058	0.0002	0.0032	0.0003	0.0030	0.0003
11.14	δ-Cadinene	0.2124	0.0058	0.4266	0.0022	0.2470	0.0105	0.2286	0.0052
12.27	Cedrol	0.0908	0.0039	0.1622	0.0014	0.0916	0.0043	0.1153	0.0060
12.45	Epicubenol	0.1903	0.0065	0.2435	0.0566	0.1284	0.0246	0.1619	0.0073
13.12	α-Bisabolol	0.0081	0.0007	0.0119	0.0004	0.0052	0.0016	0.0080	0.0010
12.56	12.56	0.1082	0.0057	0.1203	0.0851	0.0747	0.0531	0.0876	0.0876
Diterpenes									
17.27	Abietadiene	0.0333	0.0036	0.0395	0.0005	0.0218	0.0014	0.0174	0.0014
19.13	Sandaracopimarinol	0.8055	0.1175	0.9938	0.0265	0.5489	0.0458	1.2232	0.2256
19.41	Ferruginol	1.9534	0.3518	1.8339	0.0187	0.9971	0.0792	2.1468	0.4194

Data are expressed as the ratio of the peak area of each component to that of naphthalene. $n = 3$

ND not detected

of the oven-dried specimens, was compared to examine the influence of drying temperature on the extractives in the specimen. Natural drying showed the greatest extractives content (1.76%). The ratio of the extractives content decreased as the drying temperature increased. Figure 8 shows the relationship between the extractives content and the reduction of NO_2 sorption volume by extractive treatment. The ratio of the NO_2 sorption volume in non-extracted specimens to the difference of the NO_2 sorption volume between non-extracted and extracted specimens was calculated as the ratio of the contribution of extractives to the NO_2 sorption volume. It was confirmed that the extractives content had a high correlation with the ratio of the contribution of extractives to the NO_2 sorption volume of the specimens that were dried below 60 °C. In the specimen dried at 105 °C, the reduction of the NO_2 sorption volume in the extracted specimen was less than the others while the ratio of the extractives content decreased. This indicates that the extractives that volatilize below 60 °C influenced the NO_2 sorption ability. The components of the extractives were analyzed by GC/MS. Table 2 shows the ratio of the peak area of the main component which was commonly detected under most drying conditions to the ratio of the naphthalene peak area. One-way

ANOVA showed significant differences in the ratio of the peak area in abietadiene among drying temperatures ($p < 0.05$). Multiple comparisons showed that the ratio of the peak area of abietadiene at 60 °C and 105 °C

Fig. 9 The peak area ratio of abietadiene under different drying conditions to the peak area of naphthalene. The error bars show the standard deviation ($n = 3$). *:$0.05 > p$ (Tukey method)

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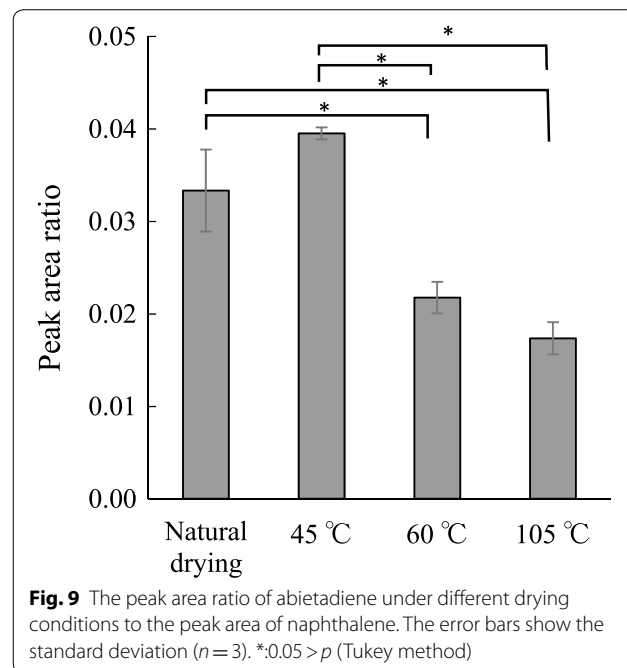
was significantly lower than that of at 45 °C (Fig. 9). Ohira et al. reported that the NO_2 removal ratio of abietadiene was very high among diterpenes [23]. The reason that the natural drying did not show a significant difference from 45 °C seemed to be that monoterpenes and sesquiterpenes were impacted at the range of this temperature because they volatilize more easily than diterpenes [24–26]. Furthermore, Okuda et al. reported that even a moderate-temperature drying treatment, which was below 70 °C, can cause a quantitative change in terpenes in sugi [21]. With regard to the discussion in Fig. 8, there seems to be some factors that makes a high contribution to NO_2 sorption in sesquiterpenes. However, in this study, the sesquiterpenes that were related to the NO_2 sorption ability could not be confirmed. In Table 2, the ratio of the peak area of sesquiterpenes at 45 °C was almost same or larger than that at natural drying. Okuda et al. also showed that the content of some sesquiterpenes at 1–2 mm from surface of cedar wood dried at 40 °C were larger than that at natural drying [21]. The discoid specimen in this study was prepared inside 1–2 mm from surface. It is possible that the content of some sesquiterpenes at 45 °C were not influenced only by the drying temperature but also the other factors. It is difficult to compare both results of the previous and this study because the humidity condition, specimen shape, and extracting solvent in the experiment of Okuda et al. were different from those in this study. In addition, it does not necessarily imply that the component that contributes to the NO_2 sorption ability under the NO_2 aeration test is the same as the component that is ethanol–benzene soluble. Therefore, the method of evaluation for the contributions of extractives needs to be further examined.

Conclusion

NO_2 aeration test was conducted using specimens of cedar timber under different drying temperatures, then each NO_2 sorption volume was evaluated focusing on the extractives and moisture in the specimen. As a result, it was elucidated that the cedar timber dried naturally has the greatest NO_2 sorption ability, and the moisture content in the cedar timber contributes largely to the NO_2 sorption. Also, it was suggested that the extractives which volatilize below 60 °C influenced the NO_2 sorption ability. Abietadiene was one of the extractives which influenced the NO_2 sorption ability.

Abbreviations
MC: Moisture content; GC/MS: Gas chromatography–mass spectrometry; ANOVA: Analysis of variance.

Authors' contributions
MN carried out all the experiments, analysis and manuscript writting. KU, KK and SK gave the suggestion to the interpretation of the data and provided important revisions of the manuscript. All authors read and approved the final manuscript.

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