Drying Methods of Unutilized Cedar Logs for Use as a Source of Heating Fuel

Van H. Hoang, K. Baba, Y. Kawabata, A. T. Saito, T. Wajima, and H. Nakagome

***Abstract*—There are many small, artificial cedar forested areas in Japan, although these areas are often destroyed through neglect. The promotion of forest maintenance is desired, and using unutilized woody biomass as heating fuel is one way to do so. In this study, drying methods of cedar *(Cryptomeria japonica)* logs to be used as heating fuel were examined. Log samples with different patterns of scratches and holes were subjected to a drying test. The experimental results show that logs with scratches or holes dried more rapidly than normal logs. Logs with four scratches dried more rapidly than those with two scratches. Logs with larger holes dried more rapidly than those with small holes, and those with three holes dried more rapidly than those with one hole. The drying time to reach the fiber saturation point was reduced from 5 months to 3 months using this simple method.**

***Index Terms*—Unused woody biomass, cedar log, drying, heat utilization.**

I. Introduction

Unlogged forests have been linked to an increasing number of landslides, which are a serious problem for rural areas. One of the most effective ways to solve this problem is to use woody biomass as a carbon-neutral energy resource [1]. With regard to the use of woody biomass in rural areas, we proposed burning woody biomass as fuel for heaters because the preparation process for logs is simple in comparison with that for other biomass fuels, such as pellets or chips. The target moisture content after drying is lower than 20% for heating fuel [2]. Because drying is essential to prepare the biomass fuel, conserving energy during drying can significantly decrease the overall operating costs [3]. Therefore, in terms of energy savings, a natural drying process, sun drying, is better than forced-drying methods for energy production in rural areas.

According to the results of previous drying experiments, heating and wind are important factors for cedar drying [4]. Short (0.5-m) logs dried more rapidly than long (4-m) logs, and cedar log samples (0.5-m logs) reached the fiber saturation point (FSP) after 4–5 months of drying on the study site, which had good ventilation and plenty of sunlight [4]. When the cedar logs dried, the water in the wood moved to the cut ends and evaporated because of pressure differences on the surfaces of the cut ends. In the cedar logs, most of the water was contained in the outer parts of the log, although water remained in the center of the logs because closed pits in the vessel structures prevented the passage of water [5].

In this study, a new drying method was examined to reduce the drying times of Japanese cedar (*Cryptomeria japonica*) logs to be used as heating fuel. The logs were arranged to have scratches or holes on them to efficiently remove water from their outer and center portions.

II. Materials and Methods

A. Samples

The cedar logs used in this study were collected from a forested area in Sanmu, Chiba Prefecture, Japan. Green cedar was logged, and immediately used as samples in the drying test. The drying test was conducted with logs that were arranged to have scratches or holes on them to efficiently remove water from their outer and center portions.

In the drying test, nine patterns of scratches and holes were used on log samples: a normal log (normal) (Fig. 1(a)), a log with two scratches of 0.02 m in depth (two scratches) (Fig. 1(b)), a log with four scratches of 0.02 m in depth (four scratches) (Fig. 1(c)), a log with one large hole of 0.03 m in diameter (one hole [L]) (Fig. 1(d)), a log with one small hole of 0.012 m in diameter (one hole [S]) (Fig. 1(e)), a log with three large holes of 0.03 m in diameter on the same side (three holes [L–H]) (Fig. 1(f)), a log with three small holes of 0.012 m in diameter on the same side (three holes [S–H]) (Fig. 1(g)), a log with three large holes of 0.03 m in diameter (two of which were on the same side of the log, while the other was on the opposite side (three holes [L–V]) (Fig. 1(h)), and a log with three small holes of 0.012 m in diameter (two of which were on the same side of the log, while the other was on the opposite side (three holes [S–V]) (Fig. 1(i)). The average diameter and weight of the nine log samples were 0.2 m and 11.2 kg, respectively. For each of the aforementioned treatments, four logs were stacked as shown in Fig. 2. The test was conducted on a concrete surface, which had good ventilation and plenty of sunlight, on the campus of Chiba University.

(a) (b)

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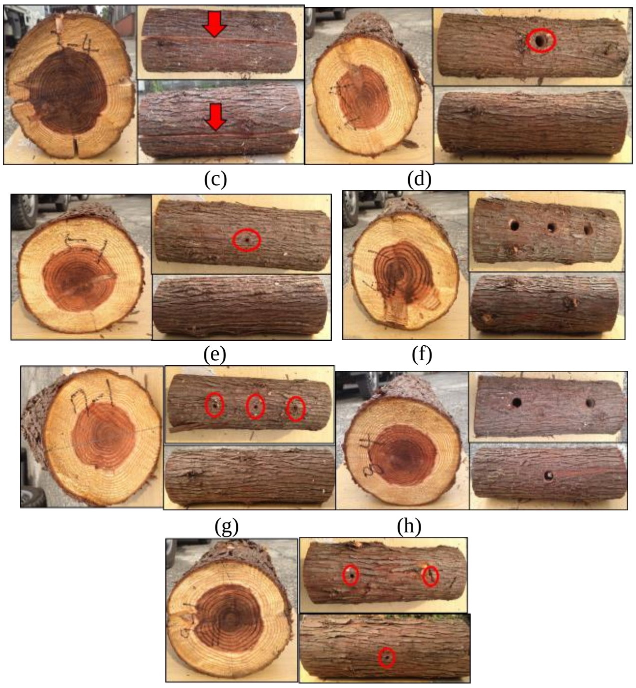

Fig. 1. Drying experiment samples. (a) Normal, (b) two scratches, (c) four scratches, (d) one hole (L), (e) one hole (S), (f) three holes (L–H), (g) three holes (S–H), (h) three holes (L–V), and (i) three holes (S–V).

Fig. 2. Set of four treated logs.

B. Specific Gravity

The specific gravity of the log samples was measured to monitor the drying process. The average value of the initial specific gravity of the log samples was 0.89 g/cm^3. The initial specific gravities of the logs before drying and the specific gravities measured at fixed intervals during the drying test were compared, and the reduction rates were calculated using (1).

$$Reduction\,ratio = \frac{Measured\,Specific\,Gravity}{Initial\,Specific\,Gravity} \quad (1)$$

Drying rates were estimated from the changes in specific gravity using first order (2) and second order (3) reaction formulae.

$$v = -\frac{dW}{dt} = k_1 W \quad (2)$$

$$v = -\frac{dW}{dt} = k_2 W^2 \quad (3)$$

These equations were transformed into (4) and (5), respectively.

$$ln\frac{W}{W_0} = -k_1 t \quad (4)$$

$$\frac{1}{W} - \frac{1}{W_0} = -k_2 t \quad (5)$$

v : Rate of decrease of specific gravity[g / (cm^3 .day)]

W : Measured specific gravity [g / cm^3]

W_0 : Initial specific gravity [g / cm^3]

k_1 : Constant of the first order reaction [day $^{-1}$]

k_2 : Constant of the second order reaction[cm^3/(g. day)]

Fig. 3. Sampling points for moisture measurements.

C. Water Content Measurement

The water distribution in green logs and in three log samples (normal, four scratches, and three holes [L–H]) was measured after 3 months to characterize the drying process. Each log was cut in half in a radial direction. After dividing half of the log into three parts (bark, outer portion and core), the water content was measured at five locations in the horizontal direction, for a total of 15 measured locations (Fig. 3). Each part was ground into powder with a power grinder, and then the water content of the samples was measured using a moisture meter (Sartorius MA35 Moisture Analyzer).

III. Results and Discussion

A. Effects of Holes and Scratches on Drying

Fig. 4 shows the changes in the specific gravity of the nine log samples. Compared with normal logs, logs with scratches showed faster decreases in specific gravity, and the specific gravity of logs with four scratches decreased faster than that of logs with two scratches. For logs with holes, the specific gravity of logs with large holes decreased faster than that of logs with small holes, and the specific gravity of logs with three holes decreased faster than that of logs with one hole. The specific gravity of logs with holes on the same side of the log decreased faster than that of logs with two holes on one side of the log and the third hole on the opposite side.

Table I shows the parameters for changes in the specific gravity calculated using the first and second order reaction models. The regression coefficients (R^2) for the second order models were higher that those for the first order models, which means that the drying reaction can be represented by second order reactions. The constants describing the rate of decrease of the specific gravity of the logs with scratches and holes were 1.0–2.3 times higher than those of the normal logs. This indicates that the scratches and holes promote drying.

According to Fig. 4, the specific gravity of two samples (logs with four scratches or three holes [L–H]) decreased to 0.6–0.7 g/cm^3 after 3 months. The water content of the FSP for cedar, which is the point at which all free water is removed during drying and only bound water remains, is about 30% (0.6 g/cm^3 specific gravity) [6]. Two samples of logs (those with four scratches or three holes [L–H]) reached the FSP after 3 months of drying on the campus site, compared with about 1.5 months for normal logs.

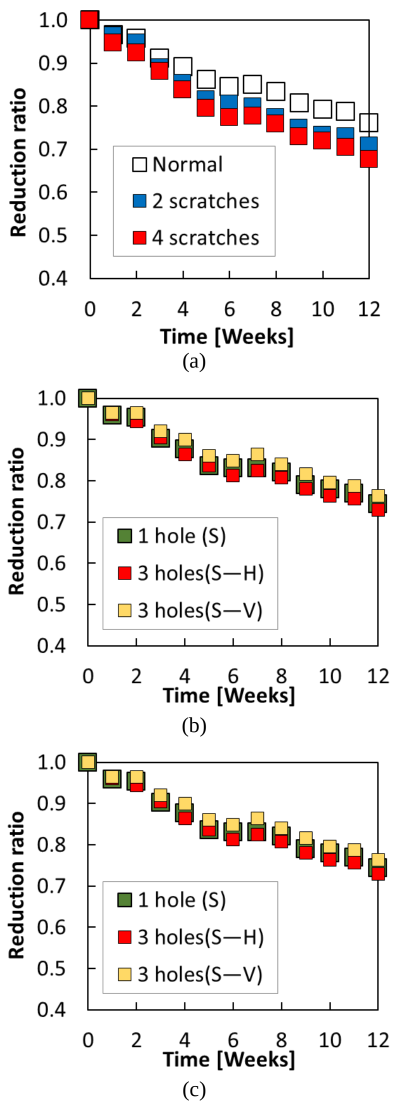

Fig. 4. Changes in the specific gravity of dried logs as a function of drying time. (a) Normal, two scratches and four scratches. (b) one hole (S), three holes (S–H) and three holes (S–V). (c) one hole (L), three holes (L–H) and three holes (L–V).

B. Water Content

Fig. 5 shows the moisture distribution of green and dried logs. For the green log (Fig. 5 (a)), the horizontal water distributions in the bark, outer portion, and core were almost constant, and the water contents of the bark, outer portion, and core were 34, 65, and 26%, respectively (Fig. 5 (b)), which is in good agreement with the results of a study by the Forest Products Research Institute [7].

The moisture distributions of logs with four scratches or three holes (L–H) after 3 months, which demonstrated the greatest reductions in specific gravity, are shown in Fig. 5 (f) and (h), respectively. Normally dried logs had a water distribution in which the water content was high (40% to 50%) in the outer portion of the log. It is likely that the evaporation of water at the cut ends resulted in a low water content (20% to 25%) in the cut-end side and a high water content in the center portion.

TABLE I: PARAMETERS OF FIRST AND SECOND ORDER REACTIONS FOR LOG DRYING

Sample	First Order Reaction		Second Order Reaction	
	$k_1 \times 10^3$ [day^{-1}]	R^2	$k_2 \times 10^3$ [cm^3 / $g.day$]	R^2
Normal	3.3	0.966	3.0	0.979
2 scratches	4.4	0.955	4.0	0.978
4 scratches	4.9	0.945	4.0	0.974
1 hole (L)	4.5	0.949	6.0	0.974
3 holes (L–H)	5.3	0.927	7.0	0.962
3 holes (L–V)	4.6	0.971	5.0	0.987
1 hole (S)	3.7	0.946	4.0	0.967
3 holes (S–H)	3.9	0.955	5.0	0.974
3 holes (S–V)	3.2	0.968	3.0	0.977

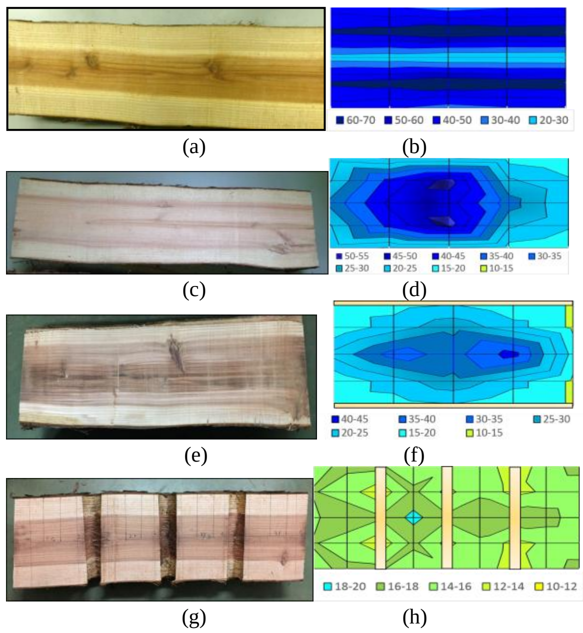

Fig. 5. Moisture distribution in green and dried logs (after 3 months). (a) A green log, (b) moisture distribution of the green log, (c) a normal dried log, (d) moisture distribution of the normal dried log, (e) a dried log with four scratches, (f) moisture distribution of the dried log with four scratches, (g) a dried log with three holes (L–H), (h) moisture distribution of the dried log with three holes (L–H).

In contrast, logs with four scratches exhibited lower water contents (15% to 30%) throughout compared with those of normal dried logs. This could be attributed to the evaporation of water at the cut end and at the four scratches. In the case of logs with three large holes, the water content was less than 20%, indicating that they became suitable for use as fuel within 3 months of drying. This could be attributed to the reduction of water contents in the center of log owing to the evaporation of water at the cut end and at the three holes.

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