Production Test of Torrefied Woody Biomass Solid Fuel in an Original Small-scale Plant

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In this study, an original small-scale demonstration plant was manufactured to produce upgraded wood fuel by torrefaction. The plant consists of a rotary-kiln type oven and a ring-die type pelletizer, and they were optimized for torrefaction based on the commercial models. We succeeded in more than 240 h operation of the torrefaction oven and produced 2.3 t of torrefied chips from raw Japanese cedar chips without drying. The energy yield of the torrefied chips was more than double the energy yield of conventional charcoal chips. The average length of the torrefied pellets was 7.4 mm, which is shorter than the length of the normal wood pellets. In the combustion test using a cone calorimeter, no delay in ignition time and small decease in heat release rate were seen for torrefied pellets in comparison with the results of normal pellets.

Key Words
Wood biomass, Torrefaction, Pellet

1. Introduction
Torrefaction is defined as mild heat treatment in the absence of or drastically reduced oxygen to a temperature of approx. 250-320 °C1. By combining volume reduction with pelletizing, torrefaction has attracted attention to upgrade hydrophobicity, durability, grindability, energy density and transportability. Since the properties of torrefied fuel are similar to that of coal, it is possible to drastically raise the biomass co-firing rate without replacing the existing facilities of coal-fired power plants. Thus, torrefied fuel production plants in pilot or commercial scale, which are large-scale production facilities, have been constructed. Meanwhile, the total growing stock of the forest has reached approximately 4.9 billion m³ in Japan2, but heat resources are strongly dependent on fossil fuels. In accordance with such circumstances, small-scale decentralized use mainly for heat utilization becomes easier to supply raw materials, then replacement from fossil fuel to local biomass can proceed, and this process helps revitalize the regional economy.

Producing torrefied fuel using existing carbonization
equipment helps to reduce the cost of facility. In this work, a torrefaction trial was performed using a commercial carbonization oven for raw wood chips, and the main characteristics of the torrefied wood pellets, such as bulk density, moisture content, and mechanical durability, met the ISO TS 17225-8 guidelines. Then, the demonstration plant was manufactured on a small scale to produce torrefied fuels and conduct some operation tests.

In this study, the plant specification and the first operation result are reported.

2. Experimental

Fig. 1 shows the production flow of the torrefied wood fuel and the outline of the demonstration plant. There are usually two ways to produce torrefied wood fuel, torrefaction of wood chips following pelletization and before pelletization. In this study, the former method was mainly adopted. The demonstration plant consists of mainly two parts, the torrefaction oven and the pelletization unit. In the torrefaction oven, raw wet wood chips can be used as feedstock. They were supplied into an inner part of rotary kiln at feeding rate of 20-24 kg/h. The rotary kiln consists of a double cylinder structure, and the inner cylinder (diameter: 0.55 m, length: 5.6 m) is indirectly heated by hot gas flowing in the outer cylinder. The hot gas was supplied from the furnace, where the pyrolyzed gas of raw material was combusted. To monitor the temperature profile, four thermocouples were set at 1,000 mm intervals in the inner cylinder, other than those set at inlet and outlet of the kiln, as shown in Fig. 2. The temperature of the inner cylinder was between 200 and 300 °C, and the residence time was normally about 60 min. The torrefied chips from the outlet of the kiln were stored in 200 L stainless drums.

The pelletizing unit consists of a crushing mill and a pelletizer. A 37-kW hammer mill type (CPM Challenger 11 × 22) was employed to grind torrefied materials. The pelletizer was a commercial ring-die type pelletizer (CPM 1200) with a hole diameter of 6 mm, which is normally applied for normal wood pellet production. By reducing the volume by pelletization, it is possible to minimize variations in particle density regardless of wood species and parts and
to increase the bulk density to around 700 kg/m³.

In this study, Japanese cedar (Sugi, Cryptomeria japonica) cut chips (moisture content 50-60% on wet basis, under 40 mm square) were employed as raw materials. The operation of the torrefaction oven was performed in two periods. First, the suitable temperature condition was studied to produce torrefied chips by several days of operation in August 2015. Then, about 11 days continuous operation was performed to produce enough torrefied wood chips to convert the torrefied pellets in October 2015.

In the pelletization experiment, to reduce the power consumption and to improve productivity, the effect of adding water prior to pelletization in the demonstration plant was examined. The torrefied wood chips with various water content (20-30%) and various digestion periods were prepared. The torrefied wood chips were employed in the previous study 1). Pelletization was performed by using a ring-die type pelletizer (CPM Master) employed in the previous study 3). The product yield was calculated as shown in Eq. (1).

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\text{Product yield (wt\%)} = \left( \frac{W_p}{W_p + W_d} \right) \times 100
\]

\(W_p\): weight of pellet (g)
\(W_d\): weight of dust (unformed pellet) (g)

The pellets produced in the demonstration plant were employed for the combustion test. The test was done using a cone calorimeter (model C3-type, Toyoseiki, Japan). About 30 g of pellets were placed horizontally in a stainless-steel plate (W × D × H = 75 × 75 × 6.5 mm), and the plate was then set into the sample holder and placed on the holder pedestal, which was connected to the load cell. The igniter rod was set just above the samples, and 50 kW/m² of electrical heat was continuously irradiated above the samples under an air atmosphere. During the test, ignition time, heat release rate (HRR), and sample weight were recorded. A detailed procedure is described elsewhere 4).

3. Results and discussion

3.1 Operation of the torrefaction oven

Fig. 3 shows the temperature profile of the oven in the first period test. By raising the temperature of the oven and the following pelletization test, the optimum oven temperature of the oven (thermocouple 3 in Fig. 2) was about 260 °C to form the torrefied pellets. The mass yield (dry basis) of the torrefied chips was 73%, and the higher calorific value of the torrefied chips was 22.6 MJ/kg. Assuming the calorific value of the normal wood chips to be 19.2 MJ/kg, the energy yield reached 86%, which is more than double the energy yield of normal charcoal. By controlling the outlet temperature of the hot-air generating furnace, the oven temperature could be maintained between 260 °C and 280 °C.

In the second period test, the continuous operation period reached more than 240 h, and 2.3 t of torrefied wood chips were produced from 6.5 t of wet wood chips. The average mass yield was 71%. Fig. 4 shows the torrefied Japanese cedar wood chips produced from the oven. The correlation between the material yield and the color of torrefied wood chips is shown in Fig. 4.
measurement value of the heat-treatment shows that the degree of torrefaction can be predicted from the color of the chips. The method would be useful in predicting the quality of the products at the manufacturing site.

3.2 Pelletization test

Fig. 5 shows the effect of adding water to the torrefied wood chip feedstock on the productivity of the torrefied pellets. The digestion period of the water was set to 12 h. In addition, the product yield was slightly decreased as the moisture content increased. However, the power consumption was much higher for samples with lower moisture content.

Fig. 6 also shows the effect of water digestion period on the productivity of the torrefied pellets. The moisture content was set to 25% on wet basis. In the case of a 1 h digestion period, the product yield was still lower and power consumption was much higher than 5 or 12 h digestion period. It suggests that certain digestion period is needed before pelletizing.

Table 1 shows an example of ultimate and proximate analyses and mechanical durability of normal (NP) and torrefied pellets (TP). TP obtained from the first operation of the demonstration plant had a high caloric value of

| Pellets | Untreated (NP) | Torrefied (TP) |
|---------|----------------|----------------|
| Average diameter (mm) | 5.93 | 5.92 |
| Average length (mm) | 16.5 | 7.45 |
| Particle density (g/cm³) | 1.26 | 1.22 |
| Moisture content (wt%-% wet) | 7.9 | 5.1 |
| Ultimate analysis (wt%, dry) | | |
| C | 49.9 | 57.2 |
| H | 6.33 | 6.02 |
| N | 01 | 0.11 |
| S | <0.01 | <0.01 |
| Proximate analysis (wt%, dry) | | |
| VM* | 82.1 | 71.1 |
| Ash | 0.3 | 06 |
| FC** | 176 | 28.3 |
| Calorific value (MJ/kg) | 17.4 | 20.5 |

* Volatile matter  ** Fixed Carbon
20.5 to 21.9 MJ/kg, a bulk density of 673 to 697 kg/m³, a mechanical durability \(^a\)\(^b\) of 94.4\%, and an average length of 7.4 mm. In contrast, when the normal wood pellets were made from untreated wood chips, the mechanical durability was 98.1\% and the length was 16.5 mm. Therefore, lower durability and length were observed for the TP in this study.

Furthermore, the production rate of the pelletizer was about 440 kg/h for the normal wood pellets, while the rate for the TP was only about 30 kg/h. It seems that the production rate of TP was lowered, as these wood constituents were decomposed during the torrefaction, resulting in increased extrusion resistance against the compression in the die of the pellets. Thus, the power consumption during pelletization was more than twice that of the wood pellets in the TP. To decrease power consumption and increase productivity, small amounts of additives can be considered with reference to the case of commercially producing torrefied wood pellets.

### 3.3 Combustion performance

Fig. 7 shows the profiles for the HRR and weight loss for both normal and torrefied Japanese cedar pellets used in this study. A comparison of profiles of normal (NP) and torrefied (TP) samples shows that the maximum HRR peak height for TP tends to be smaller than that for NP. The burnout time obtained from weight loss profile was longer for TP, and these results correspond with those obtained using a pellet stove in the previous report \(^c\).

### 4. Conclusion

In this study, an original small-scale demonstration plant was manufactured to produce upgraded wood fuel by torrefaction. We succeeded in 240 h continuous operation of the torrefaction oven and producing 2.2 t of torrefied chips from raw Japanese cedar chips without drying. The average length of the torrefied pellet was shorter than that of the normal wood pellets. Furthermore, in the combustion test using a cone calorimeter, no delay in ignition time and small decease in heat release rate were seen for torrefied pellets in comparison with the results of normal wood pellets.

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