Production Test of Torrefied Woody Biomass Solid Fuel in an Original Small Scale Plant:
(2) Effects of Automatic Temperature Control in Torrefaction and the Use of Additives in Pelletization

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A small-scale demonstration plant, which consists of a rotary kiln-type oven and a ring die-type pelletizer, was manufactured to produce upgraded wood fuel by torrefaction. In this study, we improved the temperature control and the pelletization methods. The oven and pelletization operations were optimized by implementing automatic temperature control of the torrefaction oven, and the use of additives in pelletization; which resulted in improvements in pellet productivity. A commercial scale image of the torrefaction plant was designed for operation in a local community. Torrefied fuel could be used for both large-scale power generation and small-scale use, such as for cooking and heating (e.g. in restaurants), in the outdoors, and during emergencies.

Key Words
Woody biomass, Torrefaction, Pellet

1. Introduction
Torrefaction is defined as mild heat treatment in the absence or presence of reduced oxygen to a temperature of 250 °C-320 °C [1]. By combining densification with pelletization, torrefaction can be employed to improve hydrophobicity, durability, grindability, energy density, and ease of transportation. Torrefied fuel is mainly used for thermal power generation through mixing the fuel with coal on a large scale. Currently, our group is focusing the small-scale utilization of forest resources, establishing a new bio-economy within a local community, and designing a demonstration plant [2]. We conducted more than 240 h of operation on a torrefaction oven and produced 2.3 t of torrefied wood chips from Japanese cedar (Sugi, Cryptomeria japonica) [3]. In the combustion test of torrefied pellets, there was no delay in the ignition time. A small decrease in the
heat release rate was observed in comparison to the results from using normal pellets. However, optimized temperature control in the torrefaction oven and improved pelletization were not achieved.

This study reports the optimization of processes at the torrefaction plant and of the production of torrefied fuel.

2. Experimental

Fig. 1 demonstrates the flow production of torrefied wood fuel as well as an overall outline of the demonstration plant. The pelletization of the wood chips was implemented after torrefaction. The demonstration plant consisted of two parts: the torrefaction oven (rotary kiln type) and the pelletization unit (ring die type). Raw wet wood chips are available as the feedstock. The specific details of the demonstration plant are described elsewhere. The feeding rate of wet wood chips was set at 20 to 24 kg/h for the Japanese cedar softwood chips, which had an average moisture content of 55% (on a wet basis). The temperature of the inner cylinder was set between 200°C to 300°C, and the residence time was typically around 60 min.

In the previous study, the preset temperature was changed manually by frequently monitoring the variation in the oven temperature. In this study, the oven temperature was controlled automatically by a feedback mechanism. The torrefied chip from the outlet of the kiln was stored in a 200 L stainless drum. The demonstration plant was open for 24-h day/night continuous operations for 7 days for the months of July, October, and November in 2016.

The pelletizing unit consisted of a crushing mill and a pelletizer. Commercially available potato and corn starch were used to investigate the productivity of the pellets. After mixing the ground torrefied wood powder (obtained from the hammer mill) with starch, pelletization was conducted under the same conditions that were described in a previous study. The mixing ratio of the additive was determined to be 2 wt.%, according to ISO 17225-2. For the torrefied pellet, the calculation for the product is shown in Eq. (1). The mechanical durability and bulk density of the torrefied wood pellets were measured according to ISO 17831-1 and ISO 17828, respectively.

Product yield (wt%) = \( \frac{W_p}{W_p + W_d} \times 100 \) (1)

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

3. Results and discussion

3.1 Operation of the torrefaction oven

Within the temperature range involved in the torrefaction, the reactivity of the wood was relatively high due to the initial stage of thermal degradation. Fig. 2
demonstrates the temperature profile before and after the installation of the automatic control device. By controlling the temperature based on the readings detected from two of the four thermocouples, which are installed in the oven, the operation was almost automatically completed. In addition, there was an approximately 30% reduction in the additional fuel placed in the furnace. In the latter half of the experiment, the remote monitoring unit was added to the system. An attempt was made for manufacturing personnel to remotely instruct the plant operators. The trial was performed on schedule, and there were no significant issues. These results could help decrease labor costs and improve the operation of torrefaction plants for local enterprises.

3.2 Pelletization test

In a previous study, the production rate of the pelletizer significantly decreased when using torrefied pellets because of an increase in extrusion resistance against the compression in the pellet die. For potato starch as an additive, almost no improvement in productivity was observed. This may be due to the agglomeration of starch and water due to insufficient mixing. Table 1 presents the product yield, bulk density, and mechanical durability of the torrefied pellet using the corn starch additive. The product yield was 1.7 times higher than that with no additives. We also found that the bulk density and mechanical durability were higher for the pellet with the additive. The corn starch additive was found to be effective in improving the productivity and quality of torrefied pellets.

Table 1 Effect of the additive of corn starch on product yield, bulk density and mechanical durability of torrefied pellets

| Additive | No additive | With additive |
|----------|-------------|---------------|
| Product yield (wt%) | 63.9 | 93.5 |
| Bulk density (kg/m³) | 720 | 737 |
| Mechanical durability (%) | 93.1 | 96.2 |

3.3 Image for commercial plant

A proposed image of a commercial plant in a local community was designed based on our demonstration torrefaction plant. The capacity of feedstock for the torrefaction oven was estimated to be 1 t/h (moisture content: 50 wt% on wet basis) under day/night operation. Thus, the annual demand of wet feedstock would be about 7000 t. The capacity of the pelletizer would be 500 kg/h for normal pellets during day operation; the annual production is 2,500 t. In the operations, the operator manages both the torrefaction oven and the pelletizer because the temperature control of the torrefaction oven is automatic.

Fig. 3 demonstrates the overall structure of simulated costs for torrefied pellets in the commercial plant. Case
1 is based on the test conditions of the previous study, assuming that the raw materials were purchased for JPY 8/kg-wet. It is also assumed that the total number of laborers required is ten (six personnel for the operation of the torrefaction oven and the remaining four for the operation of the pelletizer). Case 2 indicates that raw materials are purchased by JPY 8/kg-wet. In Case 3, it is assumed that the torrefaction plant is built in sawmill, and that the residue left in this sawmill is employed for the feedstock on site. In Cases 2 and 3, the number of laborers is six where the same operators can operate the torrefaction oven and the pelletizer together. This is possible due to the installation of the automatic temperature control and the remote operation of torrefaction oven.

Fig. 4 demonstrates the results from the cost simulation. The production cost per weight in Cases 2 and 3 decreased compared with that estimated in a previous study (Case 1). For example, the labor cost decreased by about 40% due to the decrease in labor required. The cost of electricity decreased due to the improved productivity of the torrefied pellets. However, the price of torrefied pellets corresponded with charcoal briquette, which was nearly 2.5 times higher than that of normal wood pellets.

It has been reported that the cost of torrefied pellets was higher than that of normal pellets. Thus, in large-scale thermal power generation, torrefied pellets are used where there is a relatively low cost of transportation and grinding. In local communities, the distance of transportation is shorter and grinding is unnecessary. We then investigated the other uses for torrefied fuel.

In Japan, sales of yakiniku barbeque increases annually. Charcoal is the main fuel used in the barbeque. Much of the charcoal used for the barbeque is imported (around 90% of total consumption). Torrefied fuel may be considered as an alternative to the imported charcoal used in cooking. Torrefied fuel can also be utilized outdoors and in cases of emergency relief, such as natural disasters, because of its advantages in hydrophobicity, handling, and durability. If torrefied fuel is stored in public schools, it would normally be used as teaching material for education on energy as well as fuel for cooking and heating in an emergency. Given the hydrophobicity and durability of torrefied wood chips, they can be used as covering materials for indoor and outdoor planting as well as material for pavement. For example, the local community enterprise produces torrefied chips and pellets from wood resources, and they are then utilized for fuel and materials internally or externally of the local community. Conventional charcoal chips can be produced via the appropriate control of the manufacturing plant, because torrefaction is a mild carbonization process. Torrefaction can be considered a next-generation carbonization process in the local community, and is one of the newest bio-economy models for local wood utilization.

4. Conclusion

A small-scale demonstration plant for the torrefaction of wet wood chips was manufactured to produce an upgraded wood fuel. An optimized work flow for the oven and pelletization processes were implemented in the demonstration plant. A proposed commercial scale image of demonstration torrefaction plant, operated at the local community, was designed. Torrefied fuel could be used for both large-scale power generation as well as small-scale use such as for cooking and heating (e.g. in restaurants), in the outdoors, and during emergencies.

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