Preliminary Production Test of Torrefied Woody Biomass Fuel in a Small Scale Plant

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(Received November 15, 2016)

A small scale demonstration plant was designed to produce upgraded wood fuel by torrefaction. Before starting continuous production, we conducted preliminary torrefaction and pelletization of Japanese cedar. Then combustion test of the torrefied fuel was done using a commercial pellet stove. The main characteristics, such as bulk density, moisture content, and mechanical durability, met the ISO TS 17225-8 guidelines. No time delay and less smoke during ignition were observed when operating the stove using torrefied pellets.

Key Words
Woody biomass, Torrefaction, Pellet

1. Introduction

The torrefaction process, which includes a mild heat treatment of 250-300 °C in the absence of air, has recently emerged as a promising technology for upgrading solid biomass fuel plants similar to coal 1) ~ 4). This process has been studied worldwide for various biomass feedstocks in laboratory-scale 5) 6), pilot-scale 7), and commercial-scale plants 8). Achieving a higher energy density and hydrophobic properties during torrefaction are beneficial for handling and transportation. The specific chemical and physical-mechanical requirements of the pellets made from thermally treated wood have been issued an international technical specification (TS) of ISO TS 17225-8 9) 10).

We previously reported torrefaction of wood chips and pellets on a laboratory scale using batch type ovens at temperatures up to 350 °C, which delivered a 30% higher calorific value and greatly decreased the amount of energy required for grinding 11). Then, we conducted a combustion trial in a commercial pellet stove using a mixture of conventional and torrefied pellets, and the torrefied wood pellets were determined to be acceptable for use with conventional pellet stoves 12).

Based on fundamental studies, the basic flow involved in the production of torrefied fuel was determined, as shown in Fig. 1 13) 14). Wood chips were employed to feedstock for torrefaction to increase the energy density of the torrefied pellet and to decrease grinding energy. To demonstrate production of the torrefied pellet, we designed and constructed a demonstration plant in 2014-2015. In this study we show the results of a preliminary experiment before starting continuous production in the...
2. Experimental

Wood chips from an entire Japanese cedar (Sugi, Cryptomeria japonica) tree were used for torrefaction in this study. The wet wood chips (moisture content: 50 wet wt%) were torrefied by using a commercial rotary kiln type oven [15], which is normally used for making charcoal, from a mixture of sewage-sludge and wood chips. Feeding rate capacity was originally 1.0 t-wet/h (moisture content: 30 wet wt%); however, the rate in this study was 300 kg-wet/h (150 kg-dry/h) because of the lower bulk density of the wood chips. The temperature and residence time in the oven for this study were set to 215°C and 60 min, respectively. Average mass yield was 78 wt% on a dry basis. Fig. 2 shows the grinding and pelletizing unit. The torrefied chips were pelletized by a commercial ring-die type pelletizer (CPM Master) after being ground with a 37 kW hammer mill (CPM Challenger 11 × 22). The hole diameter of the die was 6 mm. Mechanical durability of the pellet and bulk density of the wood chips were measured according to ISO 17831-1. Apparent particle density (volume density, g/cm³) of the pellet was stereometrically determined by the average of 50 measurements [16] in this study. The length and diameter of a single pellet was measured according to ISO 17829. Proximate analysis was done according to JIS M 8812.

The torrefied pellet was used in a combustion test of a commercial pellet stove (Kaneko Agricultural Machinery, VEL 970 (Fig. 3)) with no further mixture with normal pellets. The stove had nominal power of 7.6 kW, and the fuel bed lay in a steel cup with a slit. A stirrer was attached to the bottom side of the fuel bed to prevent clinkers from forming from minerals, and the stirring period was set to 60 sec at 180 sec intervals. Two sets of normal commercially available pellets were used to compare the combustion performance. Normal pellet A was a 6 mm diameter pellet from the Japanese cedar tree and pellet B was a 7 mm diameter pellet from the Japanese pine (Pinus thunbergii or Pinus densiflora).

The same feeding rate (screw rotation from fuel vessel) and air flow rate were used for the stove. Ignition time was calculated as the time from pushing the start button until the first flame was observed. The amount of smoke emitted during ignition was measured using a smoke tester (Bacharach smoke tester, Hodaka HT-1650), which evaluates smoke level on a scale of 0 to 9.

3. Results and Discussion

Table 1 shows the grinding performance of the hammer mill. Although the size of the feedstock for the untreated and torrefied chips differed, power consumption for the torrefied chips during grinding was less than 1/4. The power reduction corresponded to that obtained in a previous study. Bulk density of the torrefied chips was higher than that of the normal chips. The ratio of smaller size torrefied material after grinding was higher than that for the untreated wood chips [10]. The filling in the smaller material between the larger sized chips may have increased

| Table 1 | Grinding performance of torrefied wood chip [10] |
|---------|---------------------------------|
| Feeding rate (kg/h) | 397 | 498 |
| Average power (kW) | 7.57 | 1.56 |
| Power consumption per weight (Wh/kg) | 19.1 | 32 |
| Bulk density (kg/m³) | 147 | 168 |
bulk density of the torrefied chip.

The pellet produced in this study is shown in Fig. 4. No further water was added during pelletization. Tables 2 and 3 show the ultimate and proximate analyses of the feedstock (untreated) and the torrefied pellets. A small increase in carbon content and a decrease in hydrogen and oxygen contents were observed. The change in the H/C and O/C atomic ratios almost fit the dehydration scheme on the coal band diagram. The weight loss during torrefaction resulted in a decrease in volatile matter and an increase in ash content.

The characteristics of the torrefied pellet are shown in Table 4 compared to the ISO TS 17225-8 specification.

The moisture content obtained here was very low, because the temperature of the ring die on the pelletizer, as measured by a radiation thermometer, reached 150 °C, and almost all of the water in the torrefied chip evaporated during pelletization. Bulk density was ≥ 700 kg/m³ which met the standard value for the TW1a property class. The lower heating value, mechanical durability, and ash content met the TW2a class. However, power consumption during pelletization was 388 Wh/kg-pellet, which was much larger than a previous report. This issue requires further study.

Table 5 shows the ignition properties for combustion in a commercial pellet stove. The average ignition time was shorter for the torrefied pellets. The fuel ratio (Table 3), which is characterized by the ratio of fixed carbon to volatile matter, is typically used to estimate ignition properties. As the torrefied pellet had a higher fuel ratio, it might not be necessarily related to ignition. Low moisture content of the torrefied pellet (Table 4) may have affected shorter ignition time. Particle density can also affect ignition time. Further study on the mechanism for the shorter ignition is needed. The average smoke level during ignition indicated that less smoke was observed for the torrefied pellet. This was due to lower volatile matter content.

4. Conclusion

To produce upgraded wood fuel by torrefaction, we carried out a preliminary experiment before continuous operation of the demonstration plant. The main characteristics, such as bulk density, moisture content, and mechanical durability, met ISO TS 17225-8. Using the torrefied pellet led to no time delay and less smoke during ignition.

Acknowledgment

This study was supported by the Research and Development Projects for Application in Promoting the New Policy of Agriculture, Forestry and Fisheries program (21056), under the Ministry of Agriculture, Forestry, and Fisheries of Japan, and by the Development of Processing and Utilizing Woody Biomass project of the Forest Agency of Japan. The authors sincerely thank Dr. Osamu Ohkuma for the helpful suggestion during the torrefaction.

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**Table 2 Ultimate analysis**

|          | C   | H   | N   | S   | O   |
|----------|-----|-----|-----|-----|-----|
| Untreated| 49.1| 5.72| 0.18| 0.03| 45.0|
| Torrefied**| 54.5| 5.24| 0.24| 0.03| 40.0|

* By difference (O content was determined by 100 − (C + H + N + S)).
** Analyzed for pellet

**Table 3 Proximate analysis**

|          | VM* | Ash | FC** | Fuel ratio*** |
|----------|-----|-----|------|---------------|
| Untreated| 79.8| 1.6 | 18.6 | 0.23          |
| Torrefed***| 68.8| 1.9 | 29.3 | 0.43          |

*Volatile Matter, ** Fixed Carbon, *** FC/VM, **** Analyzed for pellet

**Table 4 Characteristics of the torrefied pellets**

| ISO TS 17225-8 | Torrefied pellet |
|----------------|-----------------|
| Bulk density (kg/m²) | ≥700 | ≥650 | 734 |
| Moisture (wt%, wb) | ≤8 | ≤8 | 1.3 |
| LHV* (MJ/kg) | ≥21.0 | ≥20.2 | 207 |
| DU ** (%) | ≥97.5 | ≥96.0 | 96.0 |
| Ash (wt%, db) | ≤1.2 | ≤30 | 1.9 |

* Lower heating value
** Mechanical durability

**Table 5 Ignition properties for the combustion test using the commercial pellet stove**

|          | Normal pellet | Torrefied pellet |
|----------|--------------|-----------------|
| A | B | A | B |
| Particle density of pellet (g/cm³) | 1.20 | 1.28 | 1.38 |
| Ignition time (s) | 325 | 332 | 264 |
| Smoke level (-) | 6.2 | 2.8 | 2.0 |
experiment. The authors are also grateful to Mr. Kunihiko Karasawa of Ceres Co. Ltd., for the analytical work using the pellet stove.

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