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Upgraded Pellet Making by Torrefaction—Torrefaction of Japanese Wood Pellets

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Abstract

Upgraded wood pellets were produced and evaluated by torrefaction of wood pellets. In this study, conventional wood pellets were initially prepared and subsequently torrefied on a laboratory and then larger scale. During the laboratory scale production, pellets from wooden parts of Japanese cedar (sugi, *Cryptomeria japonica*) and Japanese oak (konara, *Quercus serrata*) trees were heat-treated in an inert gas oven under nitrogen atmosphere around 170˚C - 320˚C. For the Japanese cedar, the calorific values were improved by heat treatment up to 260˚C. By heat treatment at 240˚C, the upgrade ratio of higher heating value (HHV) was nearly 30% and the energy yield was 97%. For the Japanese oak, the calorific values were improved by heat treatment up to 320˚C. By heat treatment at 280˚C, the upgrade ratio of HHV exceeded 30% and the energy yield was 84%. On a larger scale, a conventional charcoal oven was modified for torrefied wood pellet production, meaning that torrefied wood pellet with 25 MJ/kg of calorific value was produced during heat treatment at 350˚C. A mixture of conventional and torrefied pellets was applied to a commercial pellet stove, and torrefied wood pellets produced in this study might be usable as fuel for conventional pellet stoves.

Keywords

Component, Wood Pellet, Torrefaction, Calorific Value

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1. Introduction

Japan has 25 million hectares of forest, which cover about 67 percent of the land area. The growing stock is 4.9 billion m^3, increasing by 100 million m^3 annually. About 10 million hectares of the forest area are artificial forest, in which the majority of the planted species are Japanese cedar (sugi, *Cryptomeria japonica*) [1]. In the community-based forest, Japanese oak hardwood (konara, *Quercus serrata*) has been used as one of the main species for fuel wood usage and charcoal production.

Torrefaction is a thermochemical treatment process for carbonaceous feedstock such as biomass. It takes place under atmospheric conditions and within a temperature range from approximately 230˚C to 300˚C [2]. It is currently focused as one of the promising technologies to upgrade conventional wood pellets [3] [4], the downsides of which include a lower energy density than kerosene and their weak hydrophobic properties (making them prone to swell in water). Normally torrefaction pellets have been made by wood chips being torrefied and subsequently pelletized [3] [5]-[7]. In this case the grinding energy of torrefied chip before pelletization is significantly decreased [8]-[12]. Techno-economic evaluation of torrefaction, pelletization, logistics and final usage concluded that intercontinental transport of torrefied pellet is economically and energetically feasible [3] [5].

Another method is to torrefy already pelletized pellets. Ren *et al.* studied torrefaction of Douglas fir pellets by microwave irradiation. They reported that higher heating values (HHV) of torrefied pellet were 20.9 - 25.1 MJ/kg, which is a 6% - 31% increase, compared to the HHV of raw biomass [13]. However quite a few reports on the effect of this method on the properties of torrefied pellet have been made.

In this study we produced torrefied Japanese wood pellets via the latter method, and subsequently evaluated their properties. Production was conducted on both a laboratory and larger scale (conventional charcoal oven). To evaluate the combustion properties of torrefied wood pellets, a mixture of torrefied and conventional wood pellets was employed as fuel for a commercial pellet stove.

2. Experimental

2.1. Wood Samples

Japanese cedar softwood (sugi, *Cryptomeria japonica*) and Japanese oak hardwood (konara, *Quercus serrata*) were used as feedstock.

2.2. Pelletizing

Dried cedar and oak wood chips were ground in a commercial mill, whereupon water was then added to adjust the moisture content (about 15% - 20%-wet) in order to pelletize the feedstock smoothly. **Figure 1** shows the pelletizer used in this study (Earth Engineering Corp., Japan). It is of the flat die type with a hole of ϕ 5.9 mm, 40 mm thickness, and production capacity of 30 kg/h. No binders other than water were used during the pelletization.

2.3. Torrefaction

During laboratory scale production, wood pellet samples were torrefied using an inert gas oven (Advantech Toyo Kaisha, Ltd., Japan) under a nitrogen flow of 30 L/min. The weight of the sample was 1kg for cedar pellet and 0.5 kg for oak pellet. The torrefaction temperatures were 170˚C - 320˚C and the heating rate was about 8˚C/min. **Figure 2** shows typical profile of torrefaction for cedar pellet at 260˚C. After maintaining the torrefaction temperature for about 5 min, the oven was slowly cooled to room temperature overnight, whereupon the characteristics of the torrefied pellets, including their mass yield, calorific value, volume density and bulk density were all evaluated according to the literatures [13] [14]. However in case of bulk density measurement, we used a 1L of plastic cylinder and read the scale of the top of the pellet layer, due to the small amount of the torrefied samples. During larger scale production, a conventional bamboo charcoal oven was used for torrefaction. 12 units of stainless vessels with cedar pellets (about 9 kg per unit) were placed in an oven, which was heated using firewood as fuel.

2.4. Combustion Test in a Commercial Stove

Initially small samples (approx. 1 mg) were employed for differential thermal analysis (DTA, DTG-60, Shimadzu

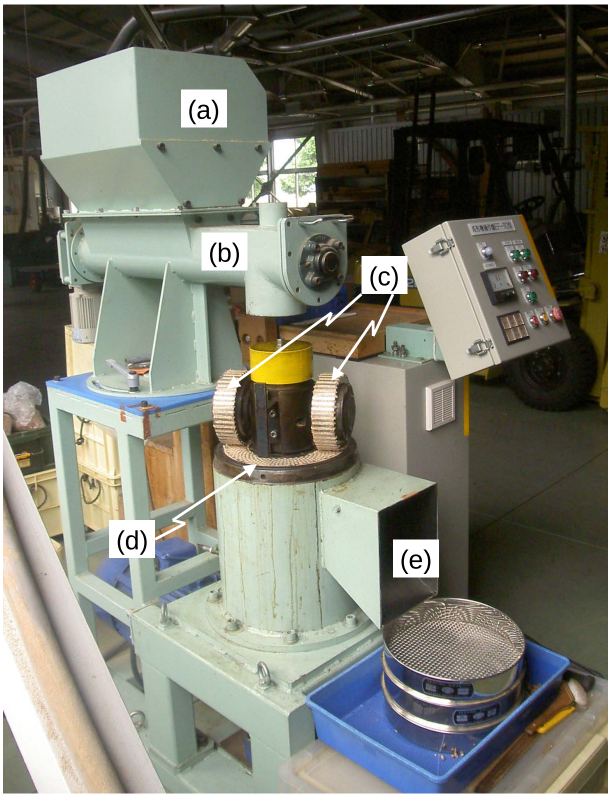

Figure 1. Flat-die type pelletizer used in this study. (a) Hopper; (b) Screw feeder; (c) Press roller; (d) Flat die (diameter: 325 mm, thickness: 40 mm, hole: 5.9 mm); (e) Outlet of pellet.

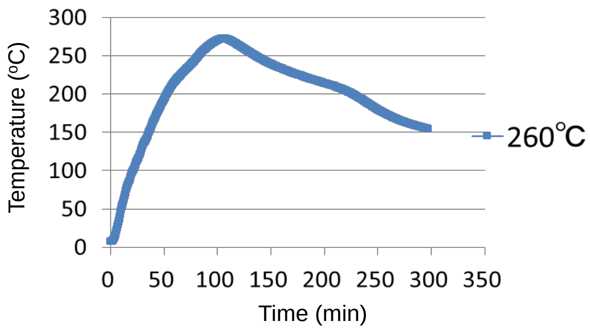

Figure 2. Temperature profile during torrefation of cedar pellets in case of torrefaction temperature at 260˚C.

Corp., Japan) to check the exothermal behavior of torrefied material under the air flow. Subsequently, conventional cedar and torrefied pellets were mixed (80:20 by weight) and the mixture was used as fuel for a commercial pellet stove (FFP-701DF, Sunpot Co., Ltd., Japan) with output of 4.7 kW. To prevent the stove from overheating, we applied the mixing ratio as our first-time trial. The temperature of the combustion zone was monitored. The torrefied pellet used here was prepared by heat treatment of 6 kg cedar pellet at 240˚C for 12 h at 13 kPa (100 torr) in the oven (Yasujima Corp, Japan).

3. Result and Discussion

3.1. Characteristics of the Torrefied Pellets

Table 1 and **Table 2** show the characteristics of the torrefied pellets under various temperatures for Japanese cedar and oak, respectively. Generally, the calorific value per weight increased with increasing torrefaction temperature. For the Japanese cedar, calorific values were improved by heat treatment up to 260˚C. By heat treatment at 240˚C, the upgrade ratio of higher heating value (HHV) by weight was nearly 1.3 and the energy yield was 97% (**Table 1**). For the Japanese oak, calorific values were improved by heat treatment up to 320˚C. By heat treatment at 280˚C, the upgrade ratio of HHV exceeded 1.3 and the energy yield was 84% (**Table 2**). The moisture content was almost zero for torrefied pellets, due to water evaporation of the torrefaction process, which means water content need not be taken into consideration when calculating the lower heating value (LHV).

Conversely, volume and bulk density gradually decreased with rising torrefaction temperature. **Figure 3** shows changes in bulk density and calorific value (by weight and volume) for torrefied oak pellets. Calorific value by volume (energy density) decreased gradually although that by weight increased with torrefaction temperature. It means that the benefit of transportation cost per unit of energy for the pellet torrefaction is smaller than that for chip torrefaction followed by pelletization.

3.2. Larger Scale Production

Figure 4 shows scheme of the production. Although there were some problem such as heating control and continuous production, wood pellet with 25 MJ/kg of calorific value could be produced under 350˚C of torrefaction.

3.3. Combustion Test

Figure 5 shows DTA profiles for untreated and torrefied samples for Japanese cedar and oak. The temperature ranges of exothermic peaks were almost the same between untreated and torrefied samples.

Table 1. Characteristics of torrefied pellets under various temperatures for Japanese cedar.

Table Head	Torrefaction temperature (˚C)					
	Untreated	170	200	220	240	260
Calorific value (HHV, MJ/kg)	18.0	20.9	21.0	21.2	23.0	22.9
Upgrading ratio of HHV[a]		1.16	1.17	1.18	1.28	1.28
Volume density (kg/L)	1.18	1.12	1.07	1.01	0.95	0.90
Moisture (wt%-wet)	13.7	0.03	0.03	5.00	0.11	0.10
Mass yield (%)		99.0	97.8	81.5	76.1	63.8
Energy yield (%)[b]				96.0	97.2	81.2

[a]Calculated by ((HHV of torrefied)/(HHV of untreated (25˚C)) × 100; [b]Calculated by ((HHV of torrefied) × ((Mass yield of torrefied)/100))/(HHV of untreated (25˚C)) × 100.

Table 2. Characteristics of torrefied pellets under various temperatures for Japanese oak.

Table Head	Torrefaction temperature (˚C)						
	Untreated	220	240	260	280	300	320
Calorific value (HHV, MJ/kg)	16.8	18.9	19.5	19.7	22.4	25.0	25.3
Upgrading ratio of HHV[a]		1.13	1.16	1.17	1.33	1.49	1.51
Volume density (kg/L)	1.29	1.17	1.14	1.03	0.89	0.72	0.72
Moisture (wt%-wet)	12.4	1.10	2.30	1.60	0.80	0.90	0.90
Mass yield (%)		95.8	88.3	78.6	62.7	47.8	47.8
Energy yield (%)[b]				92.2	83.6	71.1	72.0

[a]Calculated by ((HHV of torrefied)/(HHV of untreated (25˚C)) × 100; [b]Calculated by ((HHV of torrefied) × ((Mass yield of torrefied)/100))/(HHV of untreated (25˚C)) × 100.

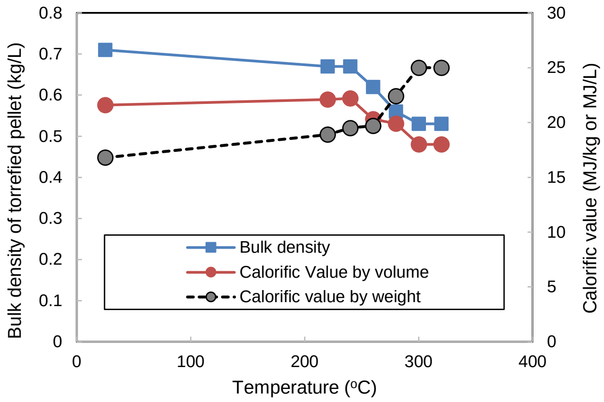

Figure 3. Changes in bulk density and calorific value (by weight and volume) for torrefied oak pellets. Data at 25˚C represent for the untreated pellet.

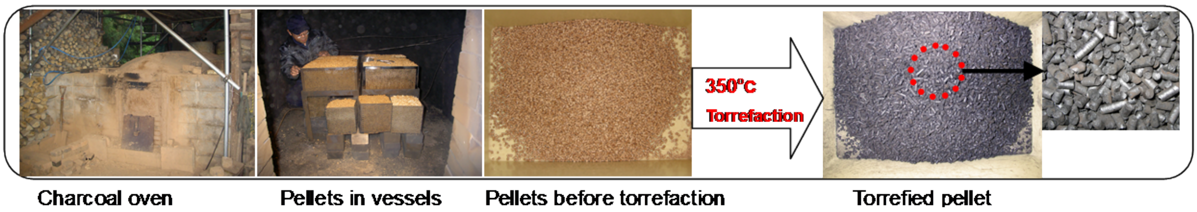

Figure 4. Scheme of the torrefied pellet production using a charcoal oven.

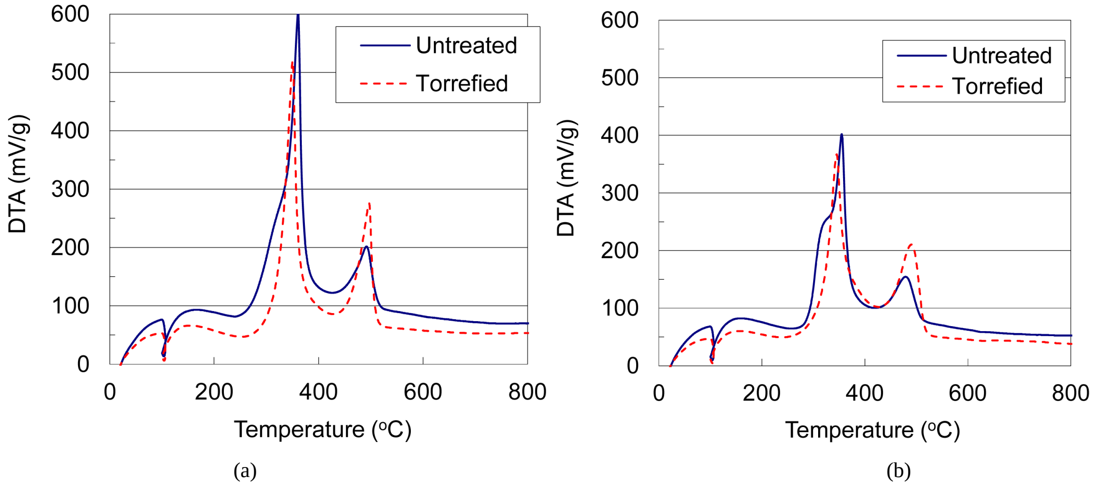

Figure 5. DTA profiles for untreated and torrefied (300˚C) samples for Japanese cedar (a) and oak (b).

Figure 6 shows a commercial pellet stove and mixed fuel (conventional pellets:torrefied pellets = 80:20). **Figure 7** shows the temperature profile of the combustion zone for conventional pellets and a mixture of conventional and torrefied pellets. A small increase in combustion temperature for the mixed pellet was observed. On the contrary there was no significant difference in ignition time, extinction time, and exhaust gas composition, meaning the torrefied wood pellets produced in this study might be usable as fuel for conventional pellet stoves. Further studies are necessary in order to apply 100% of torrefied pellet to the stoves.

4. Conclusion

Upgraded wood pellets (torrefied wood pellets) were produced and evaluated by torrefaction of wood pellets. In

(a) (b)

Figure 6. A commercial pellet stove and mixed fuel.

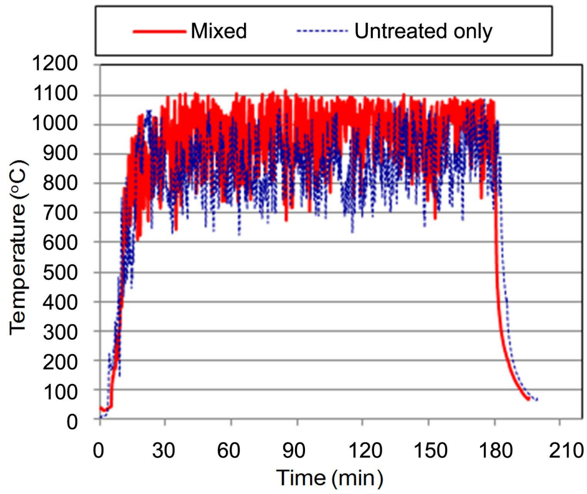

Figure 7. Temperature profile of the combustion zone for conventional pellets (dotted blue line) and a mixture of conventional and torrefied pellets (solid red line).

this study, conventional wood pellets were initially prepared and subsequently torrefied on a laboratory and then commercial scale. Calorific values were improved by heat treatment, with an HHV upgrade ratio of nearly 30%. On a commercial scale, a conventional charcoal oven was modified for torrefied wood pellet production. Consequently, torrefied wood pellets with 25 MJ/kg of calorific value were produced at heat treatment at 350˚C. A mixture of conventional and torrefied pellets was applied to a commercial pellet stove, and torrefied wood pellets produced in this study might be usable as fuel for conventional pellet stoves.

Acknowledgements

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