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Examining Experimentally the Combustion Properties of Woody Biomass Grown in Vietnam

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ABSTRACT:

This study examined the effects of particle characteristics and size on the low-oxygen combustion properties of char from coniferous trees (beefwood) and broadleaf trees (beech), which are widely distributed in Vietnam, at two distinct reacting temperatures (800 °C and 1000 °C). The rate of char oxidation was shown to be significantly influenced by the reaction temperature. The rate of char oxidation is substantially faster at higher temperatures than it is at lower ones. Particle size has less of an impact on oxidation than temperature does. Generally speaking, as particle size increases, so do the rate of oxidation and its duration. The properties of biomass have a significant impact on the pace

INTRODUCTION

It is essential to lower CO2 emissions from coal-fired power facilities in order to stop global warming. Since woody biomass is carbon neutral, it is anticipated that it will be used as fuel, resulting in a decrease in net CO2 emissions. An environmentally favorable solution to coal-burning issues is cofiring coal with biomass. Despite the many benefits of woody biomass, including early ignition and burnout and minimal pollution, there are still a number of problems with existing biomass combustion in furnaces, including low thermal efficiency, unstable heat loads, and slagging [1-3]. Furthermore, when cofiring biomass and coal in a fuel combination, the different fuel qualities between the two could result in a challenging procedure for the preparation and burning of the fuel mixture.

MATERIAL AND METHOD

Material Preparation

For this study, beefwood and beech, widely planted in the North of Vietnam, and Indonesian bituminous coal were selected. Bark was separated from inside part of the tree in each biomass fuel, and then, conventional analysis including a determination of proximate analysis, ultimate analysis, and heating value were conducted (as shown in Table 1 and Table 2). Samples were ground and then sieved into size fractions of 0.5 – 1.0 mm and 1.0 – 2.0 mm for biomass samples and 40 – 75 µm and 100 – 300 µm for coal sample.

Table 1. Properties of samples (1/2)

Sample	Bitu. coal	Coniferous (Beefwood)		Broadleaf (Beech)	
		Bark	Inside	Bark	Inside
Moisture (wt%. as received)					
Moisture	19.97	13.18	10.33	10.06	11.12
Proximate analysis (wt%, dry)					

Ash	9.65	4.35	0.51	13.05	1.35
Volatile matter	46.51	70.93	82.65	70.34	80.76
Fixed carbon	43.84	24.72	16.84	16.61	17.89

Table 2. Properties of samples (2/2)

Sample	Bitu. coal	Coniferous (Beefwood)		Broadleaf (Beech)	
		Bark	Inside	Bark	Inside
Ultimate analysis (wt%, daf)					
C	84.47	43.73	54.18	41.45	51.18
H	4.31	8.16	7.14	7.52	5.65
O	8.68	46.15	38.14	49.17	42.23
N	1.28	1.81	0.46	1.67	0.83
S	1.17	0.15	0.09	0.19	0.11
Heating Value (MJ/kg, as received)					
HHV	19.83	15.65	16.61	13.45	16.42

Experimental Conditions

A reaction gas was a mixture of O_2/N_2 with an oxygen concentration of 3 %. The total flow rate of reaction gas was 5 NL/min. Table 3 shows the test conditions in this study.

Table 3. Test conditions

Kind of fuel	Bitu. coal	Coniferous (Beefwood)		Broadleaf (Beechwood)	
		bark	inside	bark	inside
Particle size 1	40-75 µm	0.5 – 1.0 mm			
Particle size 2	100–300 µm	1.0 – 2.0 mm			
O_2 conc.	3 %				
TEMP.1	800 °C				
TEMP.2	1000 °C				

Experimental Device

The general principle of our macro-TG (MTG) reactor consists in holding a sample inside a reactor at atmospheric pressure, swept by the oxidizing agent in N_2 and at a controlled temperature. The weight of the sample is continuously monitored in order to follow the conversion of the sample. The MTG reactor and its principle are shown in Figure 1 and Figure 2.

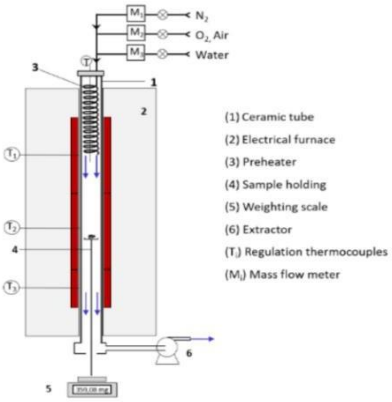

Figure 1. MTG reactor

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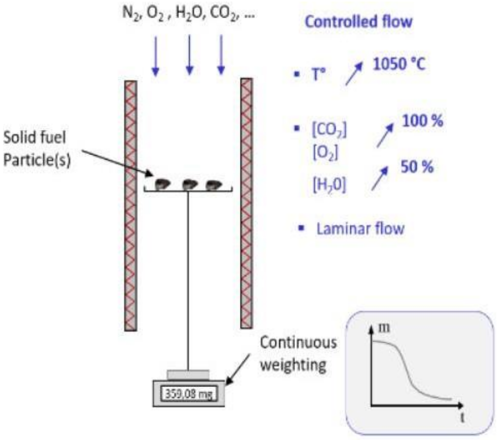

Figure 2. Principle of MTG

The reactor consisted of a ceramic tube, 111 cm in length, with an internal diameter of 7.5 cm (1), placed in an electrical furnace (2). Heating was ensured by three independently controlled heating zones (T_1, T_2, and T_3), ensuring the temperature was uniform throughout the reactor. The furnace can provide a maximum temperature of 1200 °C for the reactor. The reaction atmosphere was generated by a mixture of N_2 and a reacting gas (H_2O, CO_2, or O_2) in selected proportions. Each gas was controlled by mass flowmeters (M_1, M_2, and M_3). The gas mixture was preheated in a 2 m long coiled tube (3) located in the upper heated part of the reactor. At the outlet of the reactor, the gas flow was sucked by an extractor (6) and flown outside.

A weighting system comprised an electronic scale (5) having an accuracy of ± 0.1 mg at the bottom of the equipment, a ceramic stick (4) placed over the scale to hold the platinum container in which the biomass particles are placed. The stick was strong enough not to be affected by the flow of gases along the reactor and avoid disturbance on weight recording. All of the samples and the holder were weighted and monitored continuously in the computer with the help of monitoring software. The reliability of this system has been proven by a series of previous tests [8-9].

Experimental Procedure

Raw masses of around 400 mg for wood samples and around 200 mg for coal samples, that makes the char mass of around 100 mg after devolatilization, were spread out on the whole surface of the 46 mm diameter platinum basket placed on the weighting system (Figure 3).

Figure 3. Initial samples arrange on the basket

For each experiment, the reactor was first heated to the desired operating temperature (800 °C or 1000 °C). Then, the sample holder was lifted from the bottom of the reactor to the desired position (which is at the oxidation temperature) with less than 20 seconds and maintained under a flow of N_2 to carry all moisture and volatile matter out the sample. This can be achieved within around 8 – 10 minutes for biomass and 10 – 12 minutes for coal. We refer to the mass of the sample after devolatilization as the initial mass of char. When the mass of sample kept stable, the gas flow of the mixture of oxygen and nitrogen was introduced, the mass of char progressively decreased until a constant mass - that of ash - was achieved to conclude a test as depicted in Figure 4.The MTG system allowed recording char mass at frequencies from 1 – 10 seconds. In this present work, the char mass was

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recorded at 5 seconds intervals. The data were afterward smoothed so that we can reduce the noise in the curves of oxidation rate and reactivity.

Selected particles were devolatilized at reacting temperature in an atmosphere of nitrogen. The obtained chars were observed by Scanning electron microscopy (SEM) to clarify differences in a structure of char samples.

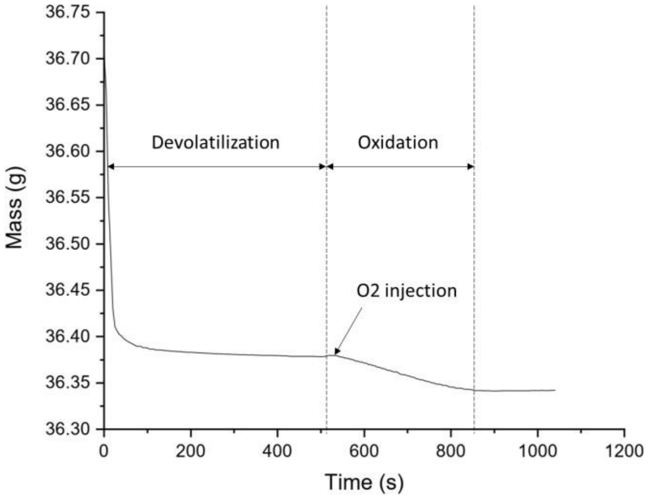

Figure 4. Illustration of the experimental procedure (in the case of oxidation of 0.5 – 1 mm char particles of beefwood inside under 3 % O_2/N_2 condition at 1000 °C)

Error of Calculation

The carbon conversion, X, during char oxidation was calculated followed the equation:

$$X = \frac{m_i - m}{m_i - m_{ash}} \qquad (1)$$

where m_i, m, and m_{ash} are respectively the initial mass of char, the mass at a certain time, and the mass of ash.

The conversion was plotted versus time. All experiments were carried out several times to check repeatability. A deviation of about 10 % for at least two tests under our condition was observed and the obtained results were an average value from experiments.

RESULTS

Effect of Reacting Temperature on Char Oxidation

The effect of temperature on conversion during char oxidation was investigated by setting the temperature 800 °C or 1000 °C. The results obtained for the oxidation of char particles under 3 % O_2/N_2 are shown in Figure 5 - Figure 9.

It is observed in the figures that there was a relatively large variation in initial carbon conversion. The burn out time shortens with the increase in temperature.

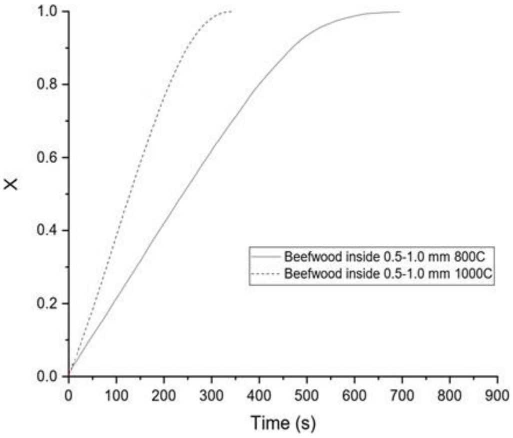

Figure 5. Oxidation of char particles of the inside part of beefwood under 3% O_2/N_2 at different temperatures

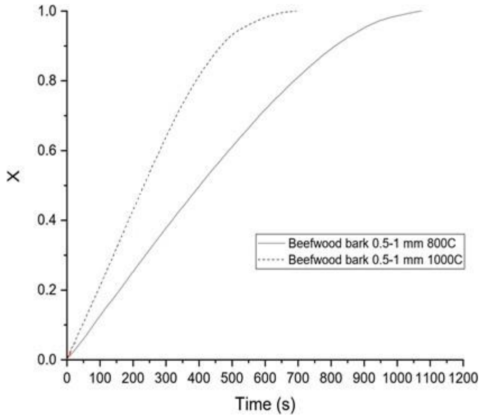

Figure 6. Oxidation of char particles of beefwood bark under 3% O_2/N_2 at different temperatures

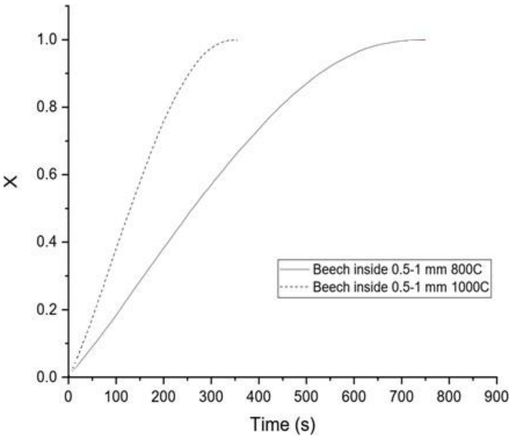

Figure 7. Oxidation of char particles of the inside part of beech under 3% O_2/N_2 at different temperatures

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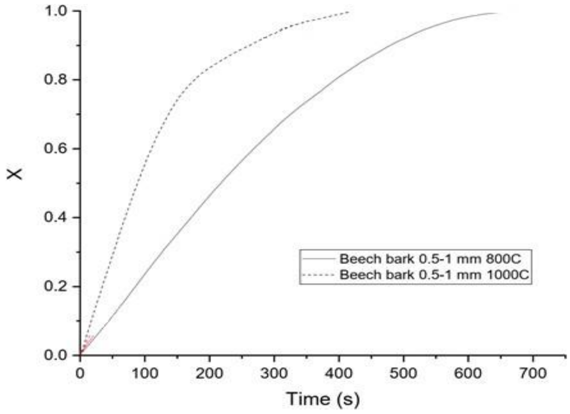

Figure 8. Oxidation of char particles of beech bark under 3% O_2/N_2 at different temperatures

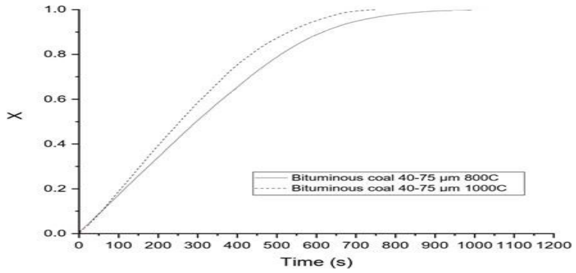

Figure 9. Oxidation of char particles of bituminous coal under 3% O_2/N_2 at different temperatures

Effect of Particle Size on Char Oxidation

The effect of particle size on the conversion of char oxidation was investigated by setting particle size of 0.5 – 1.0 mm or 1.0 – 2.0 mm (in case of coal, it was 45 – 75 µm or 100 – 300 µm). The results obtained for the oxidation char particles at 1000 °C temperature are shown in Figure 10 - Figure 14

In general, the rate of carbon conversion decreases with increase in particle size. And, it can be seen that the time required for char oxidation with the increase in particle size.

There were some results which show the burn out time of larger particle is shorter than that of the smaller one (Figure 10 - Figure 12). This might be partly explained by the arrangement of particles on the surface of the basket shown in Figure 3. That causes the contact between the particles leading to slow down of the external heat and mass transfer, and morphological structure of samples in the order of several millimeters. As shown in Figure 15, it can be seen that the chars maintained part of the biomass fibrous structure. At the same temperatures, the surface structure of 1.0 – 2.0 mm char particles was stronger defragmented resulting in the formation of large cavities and pores due to the significant release of volatiles compared to 0.5 – 1.0 mm char particles.

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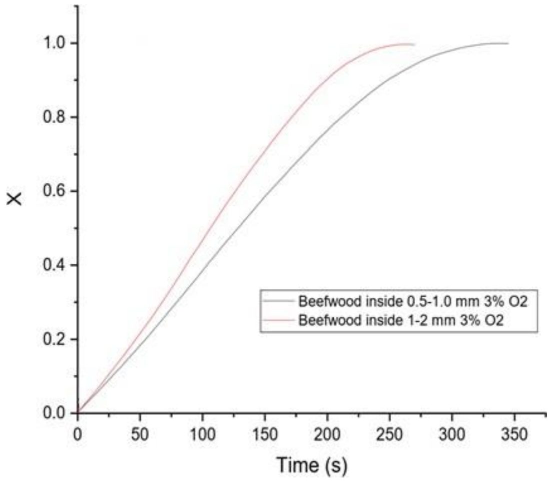

Figure 10. Oxidation of different particle sizes at 3 % O_2 concentration of char particles of the inside part of beefwood inside at 1000 °C

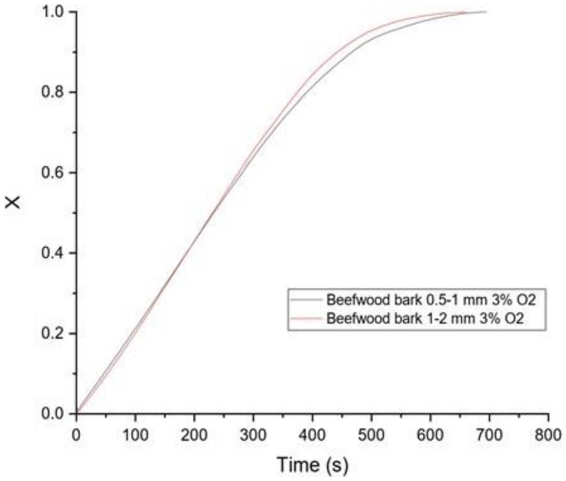

Figure 11. Oxidation of different particle sizes at 3 % O_2 concentration of char particles of beefwood bark at 1000 °C

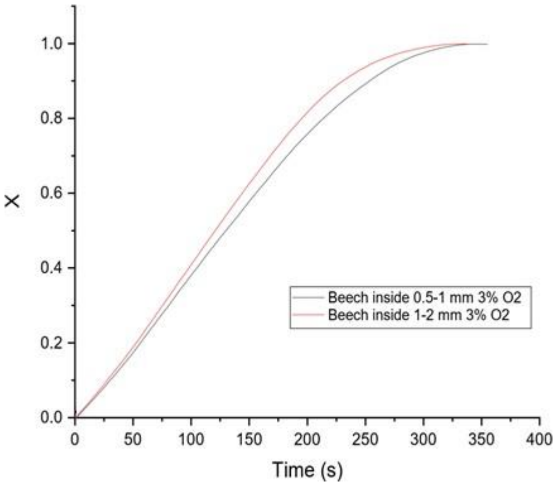

Figure 12. Oxidation of different particle sizes at 3 % O_2 concentrations of char particles of the inside part of beech at 1000 °C

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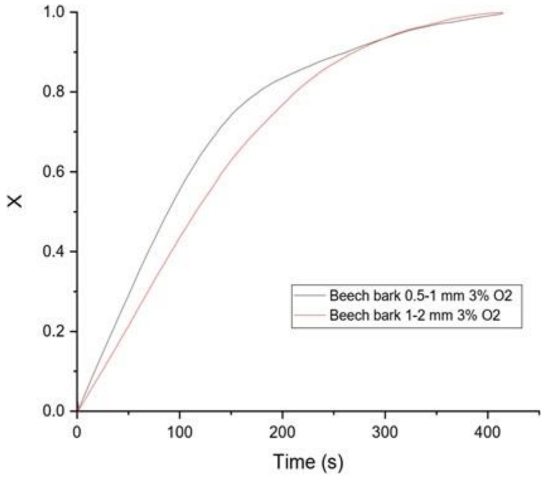

Figure 13. Oxidation of different particle sizes at 3 % O_2 concentration of char particles of beech bark at 1000 °C

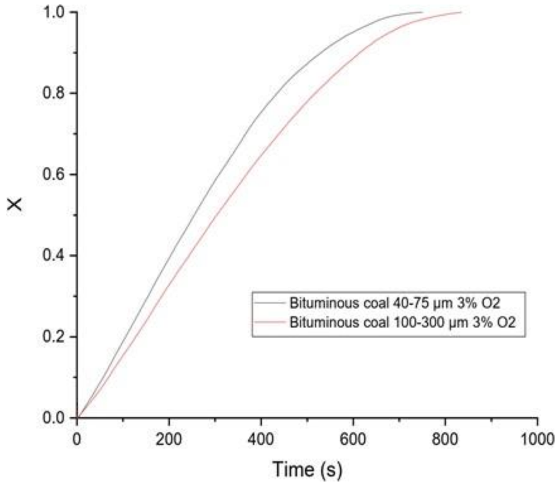

Figure 14. Oxidation of different particle sizes at 3 % O2 concentration of char particles of bituminous coal at 1000 °C

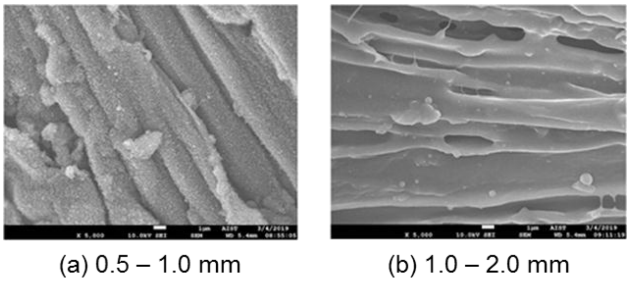
(a) 0.5 – 1.0 mm
(b) 1.0 – 2.0 mm

Figure 15. SEM of particle char of beefwood inside at 1000 °C

E on Char Oxidation

ffect of Various biomass

The characteristics of biomass also play an important

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role in the oxidation of char particles. Figure 16 and Figure 17 compare the oxidation of different char particles at specific conditions. It can be seen that in all test conditions, the char particles of the inside part of beefwood has a higher rate of char oxidation compared to that of beefwood bark. The char oxidation of beech bark char is faster than or nearly equal to that of beech inside. This could be partly explained by the differences in the morphological structure of inside and bark chars. SEM images of char samples in Figure 16 and Figure 17 suggest that char surfaces of the inside part of beefwood and beech bark were more porous and formed larger cavities and pores due to the significant release of volatiles compared to the that of beefwood bark and the inside part of beech. However, in order to evaluate quantitatively the relationship between surface area and char oxidation, it is necessary to measure the surface area of char.

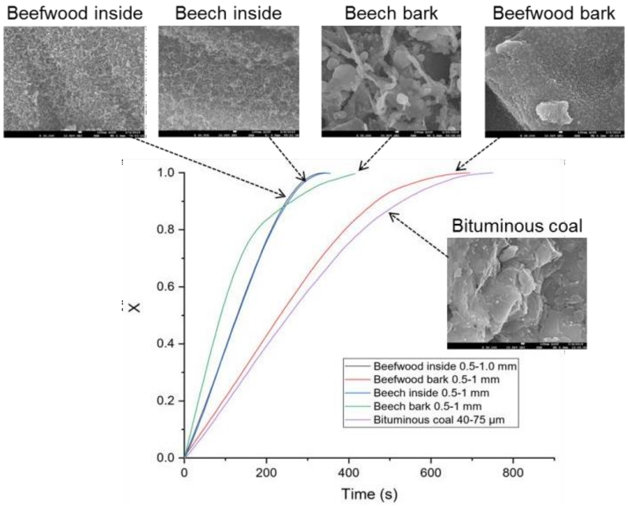

Figure 16. Oxidation of 0.5 – 1.0 mm char particles of biomass varieties in 3% O_2/N_2 at 1000 °C

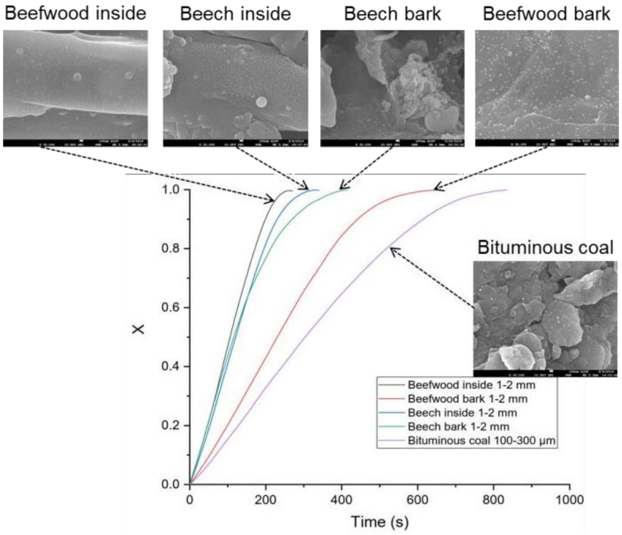

Figure 17. Oxidation of 1.0 – 2.0 mm char particles of biomass varieties in 3% O_2/N_2 at 1000 °C

CONCLUSION

The results obtained from oxidation experiments of char particles indicate that reaction temperature plays a significant role in the rate of char oxidation. The higher temperature takes significant shorter times to complete oxidation of char particles.

The effect of particle sizes on oxidation is not as large as that of temperatures. In general, the carbon conversion rate and theconversion time decrease with an increase of particle size. However, there were some excepted cases contrasting with this trend.It may mainly due to the difference in the morphological structure of the char samples when considering different sizes.

The characteristics of biomass strongly effect on the rate of char oxidation. In all experiments, the conversion rate of the insidepart of beefwood was higher compared to that of beefwood bark. The rate of char oxidation of beech bark is faster than or nearlyequal to that of the inside part of beech. There was no significant difference in the rate of char oxidation between the inside partof beefwood and beech wood bark. In addition, all kinds of biomass in this study have a faster rate of oxidation than that of coal.

Therefore, it suggests that we can design properly combustion instruments for a commercial plant if we get information aboutthe rate of char oxidation of biomass fuel in advance. However, in order to evaluate quantitatively the relationship between surface area and char oxidation, it is necessary to measure the surface area of char.

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