

## **Char Burnout Characteristics of Various Vietnamese Woody Biomass: Effect of Lean and Rich Oxygen Concentration on Char Conversion**

Le Duc Dung<sup>†</sup>, Pham Anh Minh<sup>†\*</sup>, Nguyen Huu Linh<sup>†</sup>, Nam Nguyen Hong<sup>‡</sup>, Emi Ohno<sup>†‡</sup>,  
Hiroki Ishii<sup>†‡</sup>, Laurent Van De Steene<sup>††</sup>

<sup>†</sup>School of Heat Engineering and Refrigeration, Hanoi University of Science and Technology, Hanoi, Vietnam

<sup>‡</sup>University of Science and Technology of Hanoi, Vietnam

<sup>†‡</sup>IHI Corporation, Japan

<sup>††</sup>CIRAD, UPR BioWooEB, France

\*Corresponding Author Email: minh.phamanh@hust.edu.vn

**ABSTRACT:** The influence of oxygen concentration on the char burnout characteristics of the coniferous tree (beefwood) and broadleaf tree (beech), which are abundantly available in Vietnam under-reacting temperature of 800 °C, and 1000 °C was investigated using Macro TG. The obtained results showed that in rich O<sub>2</sub> concentration, the particle size has little effect on char oxidation. However, the carbon conversion rate and the whole time of conversion decreases with an increase in particle size. There were some excepted cases contracting to this trend, mainly due to the difference in char samples' morphological structure at different sizes and operating temperatures in lean O<sub>2</sub> concentration. The characteristics of biomass strongly affect the char oxidation rate. In all experiments, the conversion rate of char oxidation of the inside part of beefwood is higher than the bark's conversion rate. The oxidation rate of beech bark is higher than the one of the inside parts of the beech. There is no significant difference in char oxidation rate between the inside part of the beefwood and beech wood bark. However, all kinds of biomass in this study have a faster rate of oxidation than coal.

**KEYWORDS:** Biomass, Combustion, Char, Oxidation, Renewable.

### **INTRODUCTION**

To prevent global warming, it is critical to reducing CO<sub>2</sub> emissions from coal-fired power plants [1][2]. It is expected to utilize woody biomass as fuel since the amount of net CO<sub>2</sub> emissions will not increase because woody biomass is carbon neutral [3][4][5]. Co-firing of coal with biomass is a friendly approach for dealing with problems associated with coal burning [6]. Although woody biomass has many advantages such as advanced ignition and burnout, low pollution, there are still several current biomass combustion issues in the furnace, particularly low thermal efficiency, heat load instability, and slagging [7][8][9]. Besides, the difference in fuel properties between biomass and coal might cause complicated fuel mixture preparation and combustion when co-firing biomass with coal in the existing coal-fired boilers [10][11]. Thus, it is necessary to understand the essential combustion characteristics of woody biomass regarding the feasible operation and properly design combustion equipment.

Combustion of solid fuels such as coal and biomass in low oxygen (O<sub>2</sub>) atmosphere exists widely in industrial processes, as O<sub>2</sub> decreases from 21% in fresh air to 3 – 4% at the boiler's furnace outlet [4]. For many advanced swirl burners, the intense recirculation of hot combustion products to the primary reaction zone quickly dilutes the oxygen concentration [12]. The corresponding ignition and burning processes occur in a low O<sub>2</sub> atmosphere. This phenomenon also appears in developing combustion technologies such as oxygen-enriched combustion and pure

oxygen combustion [13]. In existing coal-fired power plants, it is possible to utilize many kinds of woody biomass in the future. However, there are little data about woody biomass fuels' combustion characteristics, especially char burnout in low oxygen concentration. Hence, better expertise and understanding of biomass combustion in this condition require biomass to better organize the furnace combustion and effectively improve combustion efficiency. Therefore, this study aims to clarify the effect of biomass characteristics, the particle size of char of the coniferous tree (beefwood) and broadleaf tree (beech) abundantly growth in Vietnam on oxidation rate.

## MATERIALS AND METHODS

### Sample preparation

For this study, beefwood and beech, widely planted in the North of Vietnam, and Indonesian bituminous coal were selected. Bark was separated from the inside of a tree in each biomass fuel. Then, conventional analysis, including a determination of proximate analysis, ultimate analysis, and heating value, were conducted, as shown in Table 1. 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  $\mu\text{m}$  and 100 – 300  $\mu\text{m}$  for coal.

**Table 1.** Proximate and ultimate of coal samples

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
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  $\text{O}_2/\text{N}_2$  with oxygen concentration of 3 % and 21 %. The total flow rate of reaction gas was 5 NL/min. Table 2 shows test conditions in this study.

### Experimental Device

Our macro-TG (MTG) reactor's general principle consists of holding a sample inside a reactor at atmospheric pressure, swept by the oxidizing agent in  $\text{N}_2$ , and at a controlled temperature. The weight of the sample is continuously monitored to follow the conversion of the sample. The MTG reactor and its principle are shown in Figure 1.

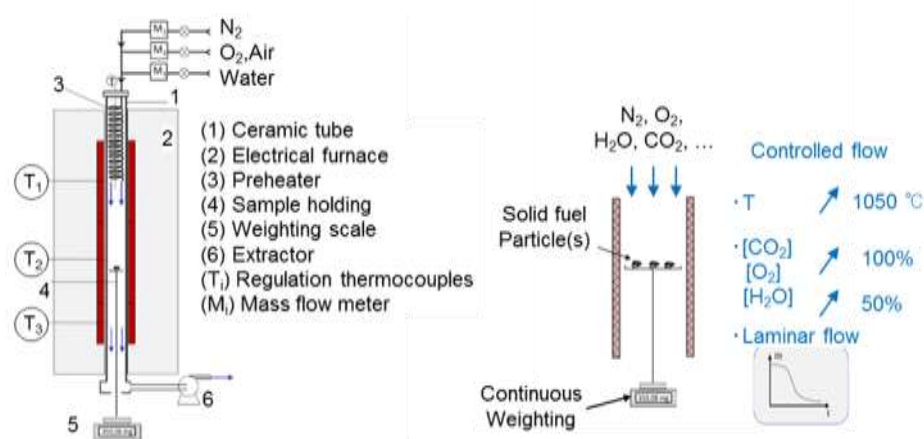
The reactor consisted of a ceramic tube, 111 cm in length, with an internal diameter of 7.5 cm (1), placed in an electrical furnace (2). Heating was ensured by three independently controlled heating zones ( $T_1$ ,  $T_2$ , and  $T_3$ ), ensuring the temperature was uniform throughout the reactor. The furnace can provide a maximum temperature of 1200  $^{\circ}\text{C}$  for the reactor. The reaction atmosphere was generated by a mixture of  $\text{N}_2$  and a reacting gas ( $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,

or O<sub>2</sub>) in selected proportions. Each gas was controlled by mass flowmeters (M<sub>1</sub>, M<sub>2</sub>, and M<sub>3</sub>). The gas mixture was preheated in a 2 m long coiled tube (3) located in the reactor's upper heated part. At the reactor's outlet, the gas flow was sucked by an extractor (6) and flown outside.

A weighting system comprised an electronic scale (5) having an accuracy of  $\pm 0.1$  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 weight recording disturbance. All the samples and the holder were weighted and monitored continuously in the computer with monitoring software. The reliability of this system has been proven by a series of previous tests [14].

**Table 2.** 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 <sub>2</sub> conc. 1	3 %				
O <sub>2</sub> conc. 2	21 %				
TEMP. 1	800 °C				
TEMP. 2	1000 °C				



**Figure 1.** MTG reactor and its principle

### Experimental Procedure

Raw masses of around 400 mg for wood samples and about 200 mg for coal samples, which makes the char mass of 100 mg after devolatilization, were spread out on the whole surface of the 46 mm diameter platinum plate the weighting system as shown in Figure 2.

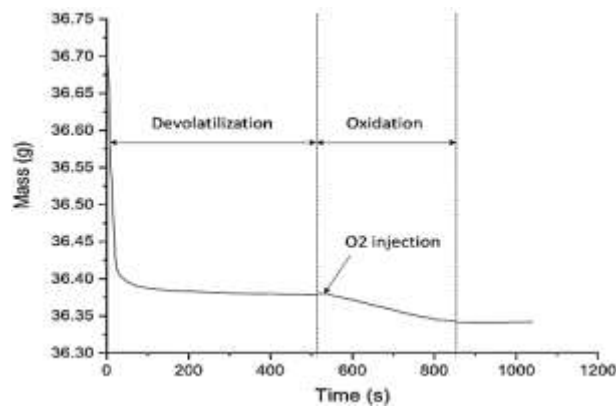
For each experiment, the reactor was first heated to the desired operating temperature (800 °C and 1000 °C). The sample holder was then lifted from the bottom of the reactor to the desired position (which is at the oxidation temperature) for less than 20 seconds and maintained under a flow of N<sub>2</sub> to carry all moisture and volatile matter out of the sample. It 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 the 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 depicted in Figure 3.

The MTG system allowed recording char mass at frequencies from 1 – 10 seconds. In this present work, the charred mass was recorded at 5 seconds intervals. The data were afterward smoothed to 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 char samples' structure.



**Figure 2.** Sample arrangement



**Figure 3.** An illustration of the experimental procedure

#### Experimental Procedure

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

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

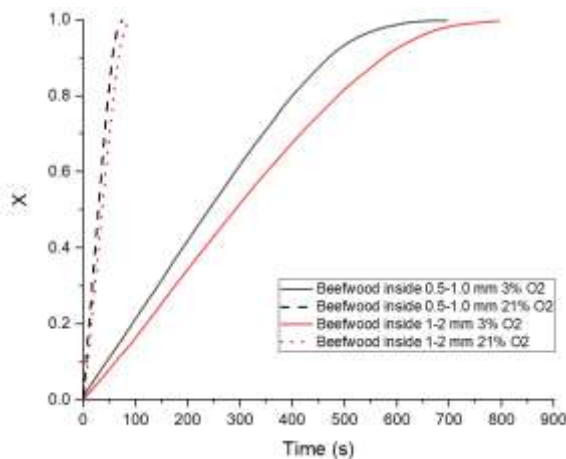
Where  $m_i$ ,  $m$ , and  $m_{ash}$  are the initial mass of char, the mass at a certain time, and the mass of ash. The conversion was plotted versus time. All experiments were carried out several times to check repeatability. A deviation of about 10 % for at least two tests under our condition was observed, and the obtained results were an average value from experiments.

#### RESULTS AND DISCUSSION

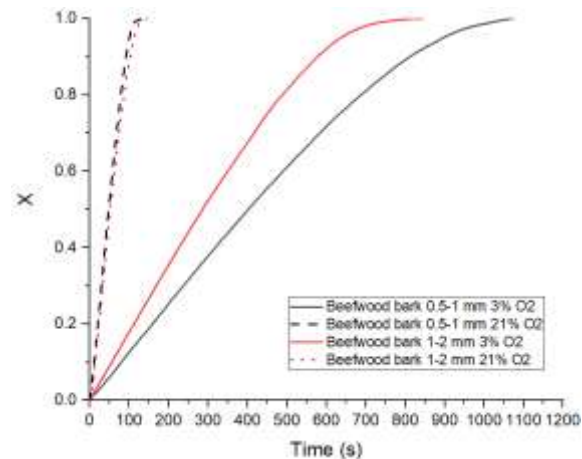
##### The effect of particle size at different $O_2$ concentrations on char oxidation

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 at  $O_2$  concentrations of 3%  $O_2/N_2$  and 21%  $O_2/N_2$ . The results obtained for the oxidation char particles at 800 °C and 1000 °C are shown in Figure 4 - Figure 11.

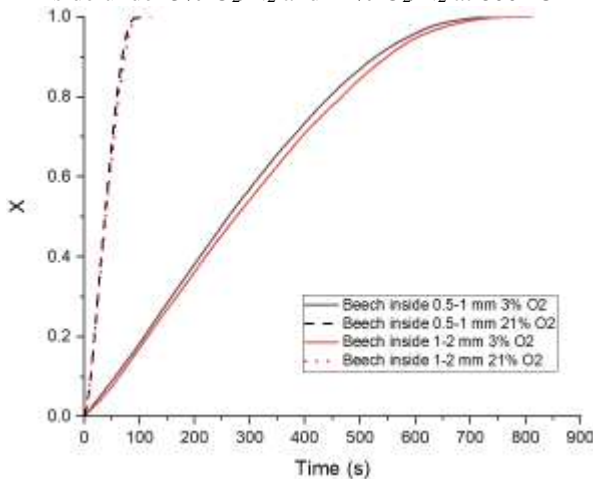
The carbon conversion rate decreases with an increase in particle size at  $O_2$  concentrations of 21%  $O_2/N_2$ . It can be seen that the time required for char oxidation increases with particle size increase. However, the difference due to particle size is insignificant. In contrast, particle size strongly affected char particles' carbon conversion at low  $O_2$  concentration. Some results show that larger particles' burnout time is shorter than that of the smaller one, mainly beefwood bark (Figure 5) and beefwood inside (Figure 8). This might be partly explained by the arrangement of particles on the basket's surface shown in Figure 3. That causes the contact between the particles leading to the slow-down of the external heat and mass transfer and morphological structure of samples in the order of several millimeters. As shown in Figure 12 and Figure 13, it can be seen that the chars maintained part of the biomass fibrous structure. At the same temperature, the surface structure of 1.0 – 2.0 mm char particles was more robust defragmented, resulting in large cavities and pores' formation due to the significant release of volatiles compared to 0.5 – 1.0 mm char particles. Additionally, the rate of carbon conversion increases with an increase in oxygen concentration.



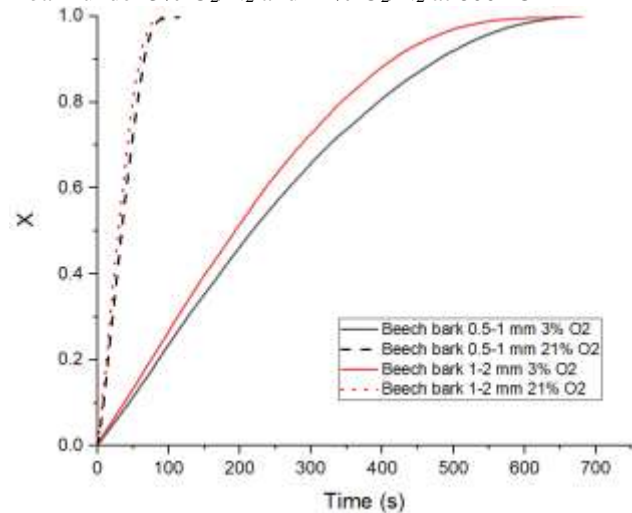
**Figure 1.** Oxidation of char particles of beefwood inside under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 800 °C



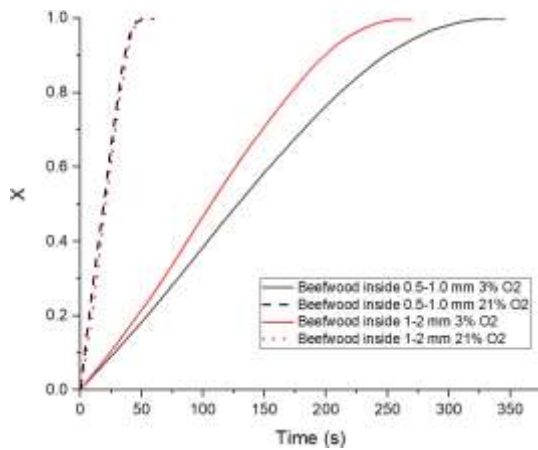
**Figure 2.** Oxidation of char particles of beefwood bark under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 800 °C



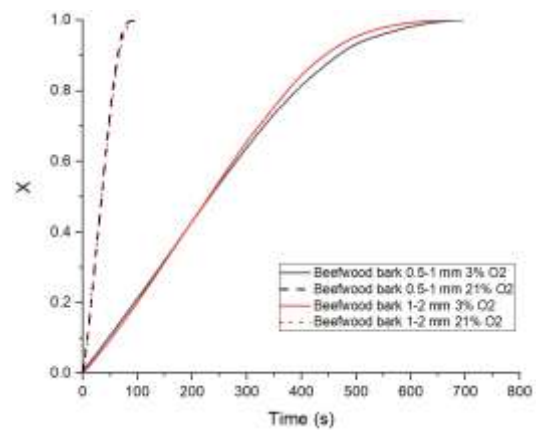
**Figure 3.** Oxidation of char particles of beech inside under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 800 °C



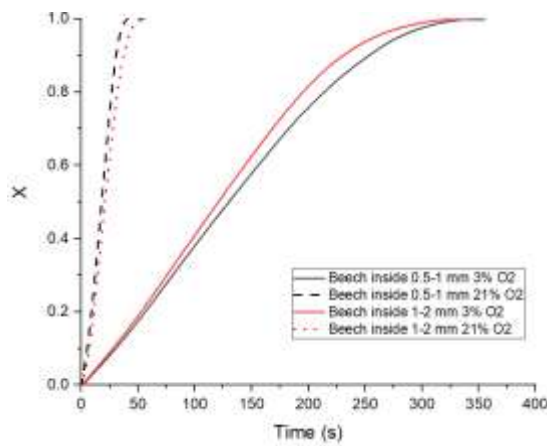
**Figure 4.** Oxidation of char particles of beech bark under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 800 °C



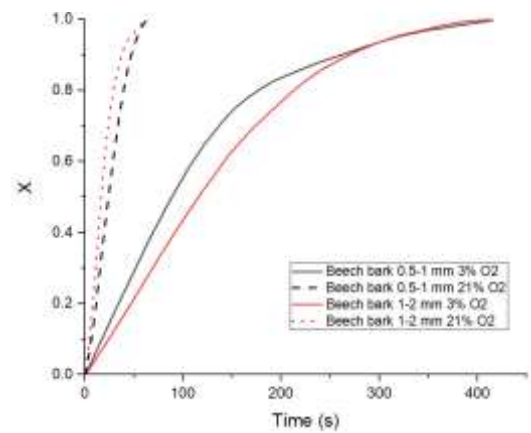
**Figure 8.** Oxidation of char particles of beefwood inside under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 1000 °C



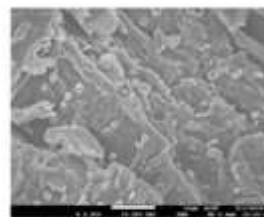
**Figure 9.** Oxidation of char particles of beefwood bark under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 1000 °C



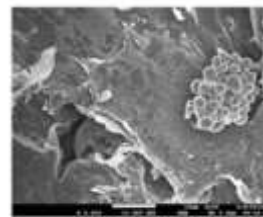
**Figure 10.** Oxidation of char particles of beech inside under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 1000 °C



**Figure 11.** Oxidation of char particles of beech bark under 3%  $O_2/N_2$  and 21%  $O_2/N_2$  at 1000 °C

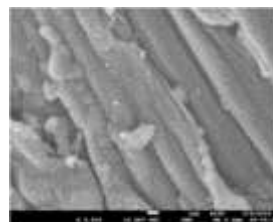


a) 0.5 - 1 mm

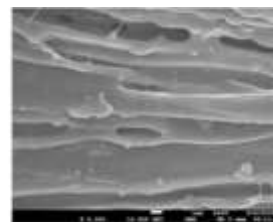


b) 1 - 2 mm

**Figure 12.** SEM of particle char of beefwood bark at 800 °C



(a) 0.5 - 1.0 mm



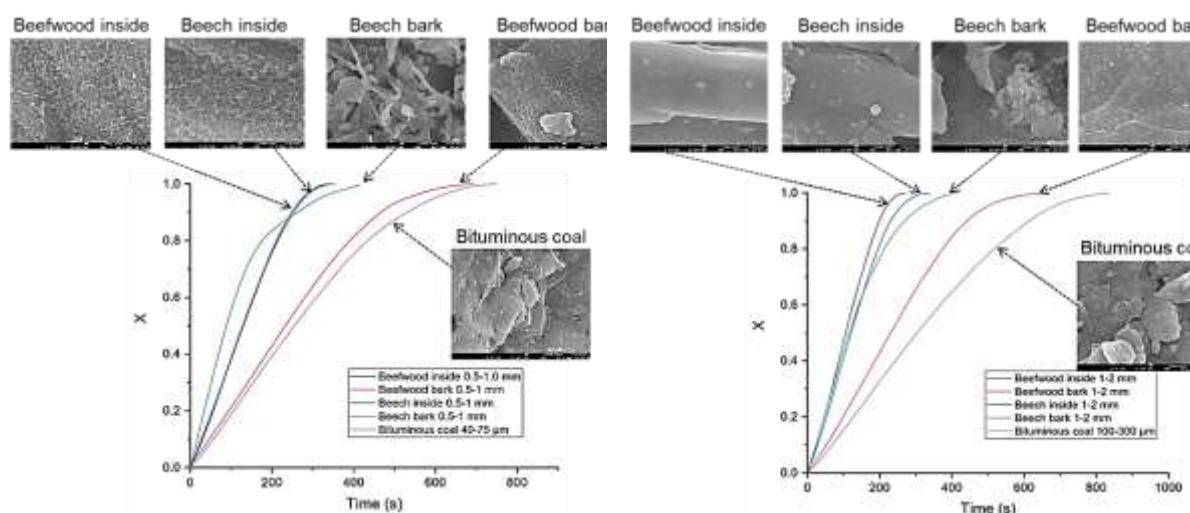
(b) 1.0 - 2.0 mm

**Figure 13.** SEM of particle char of beefwood inside at 1000 °C



## Spontaneous combustion of the blended coal

The characteristics of biomass also play an essential role in the oxidation of char particles. Figure 14 and Figure 15 compare the oxidation of different char particles at specific conditions. It can be seen that in all test conditions, the char particles of beefwood inside have 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. It could be partly explained by the differences in the morphological structure of inside and bark chars. SEM images of char samples in Figure 14 and Figure 15 suggest that char surfaces of beefwood inside and beech bark were more porous and formed larger cavities and pores due to the significant release of volatiles beefwood bark and beech inside. However, to evaluate the relationship between surface quantitatively and char oxidation, it is necessary to measure the surface area of char.



**Figure 14.** Oxidation of 0.5 – 1.0 mm char particles of biomass varieties in 3% O<sub>2</sub>/N<sub>2</sub> at 1000 °C

**Figure 5.** Oxidation of 1.0 – 2.0 mm char particles of biomass varieties in 3% O<sub>2</sub>/N<sub>2</sub> at 1000 °C

## CONCLUSION

The influence of particle size on char conversion has been investigated. In general, the carbon conversion rate and the conversion time decreases with an increase of particle size in a rich oxygen atmosphere. However, some excepted cases contracted to this trend at low oxygen concentration, mainly due to the difference in the char samples' morphological structure when considering different sizes and temperatures. As oxygen concentration increases, the influence of particle size on conversion was insignificant.

The characteristics of biomass strongly affect the char oxidation rate. In all experiments, the internal part of beefwood's conversion rate was higher compared to the one of beefwood bark. The conversion rate of the char is faster or nearly equal to the beech's internal part. There was no significant difference in char oxidation rate between the interior part of beefwood and beech wood bark. However, all kinds of biomass in this study have a faster char conversion rate than coal.

## ACKNOWLEDGMENT

This work was financially supported by Hanoi University of Science and Technology (HUST) under project number T2020-PC-034.

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