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# Characteristics of nanoparticles emitted from burning of biomass fuels

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ABSTRACT

The characteristics of the particles of the smoke that is emitted from the burning of biomass fuels were experimentally investigated using a laboratory-scale tube furnace and different types of biomass fuels: rubber wood, whole wood pellets and rice husks. Emitted amounts of particles, particle-bound polycyclic aromatic hydrocarbons (PAHs) and water-soluble organic carbon (WSOC) are discussed relative to the size of the emitted particles, ranging to as small as nano-size (<70 nm), and to the rate of heating rate during combustion. differential thermal analysis (DTA) and thermogravimetric analysis (TG) techniques were used to examine the effect of heating rate and biomass type on combustion behaviors relative to the characteristics of particle emissions. In the present study, more than 30% of the smoke particles from the burning of biomass fuel had a mass that fell within a range of <100 nm. Particles smaller than 0.43 μm contributed greatly to the total levels of toxic PAHs and WSOC. The properties of these particles were influenced by the fuel component, the combustion conditions, and the particle size. Although TG–DTA results indicated that the heating rate in a range of 10–20°C did not show a significant effect on the combustion properties, there was a slight increase in the decomposition temperature as heating rate was increased. The nano-size particles had the smallest fraction of particle mass and particle-bound PAHs, but nonetheless these particles registered the largest fraction of particle-bound WSOC.


## Introduction

Biomass energy is a solution to the increasing demand for renewable energy that can reduce carbon dioxide ($CO_2$) emissions, which is necessary to address the issue of global warming. However, the burning of biomass has a considerable regional and global impact on both the chemical properties of the atmosphere and the radiative balance of the Earth (Andreae and Merlet, 2001).

Although biomass fuel has carbon-neutral characteristics, biomass burning can be a significant source of ambient

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nanoparticles. The emission of fine particles in the atmosphere constitutes a serious concern for human health and contributes to photochemical smog. Fine particles play a particularly important role in health since this size distribution penetrates deeper than larger particles and causes damage to the most critical components of the respiratory system (Andrea, 2009). This is because the deposition site of inhaled particles changes with particle size, and the clearance time of the deposited particles varies depending on the deposition sites, leading to differences in toxicity, even for the same composition of particles. Therefore, it is necessary to determine the chemical composition of particles with respect to particle size, particularly for nanoparticles. In addition, how the characteristics of nanoparticles vary during the combustion process has not been investigated in detail.

Polycyclic aromatic hydrocarbons (PAHs) and water soluble organic carbon (WSOC) are typical components emitted during the burning of biomass (Mayol-Bracero et al., 2002; Furuuchi et al., 2006; Bignal et al., 2008; Tekasakul et al., 2008; Chomanee et al., 2009). Some PAHs are known to be carcinogenic (IARC, 1982), and exposure to high levels of PAHs has produced immunosuppressive effects (Leo, 2005). WSOC compounds are a matter of interest not only because WSOC in an aerosol form exerts climate effects such as contributing to cloud condensation nuclei generation (Redemann et al., 2001; Andreae and Merlet, 2001; Kundu et al., 2010), but because WSOC is a major environmental concern due to the presence of natural organic carbon in water that interact with trace amounts of pollutants when transferred into a natural water environment. Dissolved organic carbon has been recognized as a major carrier of trace metals and persistent organic contaminants that are relatively insoluble and immobile (Jonnalagadda and Nenzou, 1996). Furthermore, dissolved organic carbon in water is believed to be one of the important precursors for the generation of trihalomethanes and other chlorinated products (Tao, 1996), which have produced carcinogenic effects in various test organisms.

Investigation into the physicochemical properties of smoke particles from the burning of various kinds of biomass fuels have indicated that biomass combustion can be a significant source of fine particles and gaseous matter in ambient air, which then leads to environmental loads and serious health risks (Sippula et al., 2007), and most PAHs are associated with fine particles (Choosong et al., 2007; Furuuchi et al., 2006, 2007a,b; Tekasakul et al., 2008; Hata et al., 2009b).

Variations in the emission of smoke PAHs depend on the type of biomass fuel, the combustion process (Oanh et al., 2005), the biomass blending ratio, the excess air ratio, and on the moisture content of the fuel used in the combustion process (Chao et al., 2008; Chomanee et al., 2009). However, current understanding of the effects of the combustion parameters on PAH formation of particulate emissions from biomass combustion remains to be at the initial information stage and is rarely used either for source identification or for risk evaluation. In particular, information surrounding the physicochemical characteristics of smoke particles in the nano-size range is of particular importance in order to gain an understanding of the impact that burned biomass has on ambient air that can enter the respiratory system and affect the general health of an individual.

In the present study, a laboratory-scale electric tube furnace was used to examine the characteristics of particulate matters emitted from the combustion of different biomass fuels, rubber wood, whole wood pellets and rice husks—all examples of biomass fuels that are typically not used in Asian societies. The emitted amount of particles per unit of fuel mass was evaluated for different sizes of particles down to the nanosize range (<70 nm). Particle-bound PAHs and WSOC are discussed here relative to the contributions of different sizes of particles. The influence of the heating rate during combustion also is discussed.

## 1. Experimental

### 1.1. Tested biomass fuels and their thermal properties

The characteristics of biomass fuels are listed in Table 1, where the moisture content as well as the carbon, hydrogen, nitrogen and sulfur contents of biomass fuel were measured using a moisture analyzer HB43 (Mettler Tolede, Greifensee, Switzerland) and a CHNS analyzer vario III (Elementar Analysensysteme GmbH, Hanau, Germany).

Fig. 1 shows the TG/DTA TG8120 (thermogravimetric/differential thermal combined analyzer, Rigaku, Tokyo, Japan) analysis results of 4.0–6.0 mg of tested biomass samples at different heating rates of 10, 15 and 20°C/min to determine the differences in reaction steps from weight loss and exothermic change between heating rates under a temperature program. The results showed that thermal decomposition started at 280°C, and pyrolysis was essentially completed at 500°C. Above that temperature, there was no further weight loss. As shown in Fig. 1, the TG curves shifted to higher temperatures as the heating rate increased. The results from the TG and DTA curves of the pyrolysis process appeared to be divided into 3 weight-loss phases during the heating process: drying at 150°C, charring at 200–350°C, and calcining at more than 350°C (Hu et al., 2000). Based on those results, the following combustion test temperature was set at 700°C, which was deemed to be high enough for combustion.

### 1.2. Experimental setup and procedure

A schematic diagram of the experimental setup is shown in Fig. 2. A selected amount of biomass fuel, was added to a tube furnace that consisted of a quartz glass tube (I.D. = 45 mm, O.D. = 50 mm, L = 500 mm) installed in an electric tube furnace that had a heating zone with a diameter of 50 mm and a length of 300 mm.

**Table 1 – Contents in tested fuel samples.**

| Sample | Component (%) | | | | Moisture (%) |
|---|---|---|---|---|---|
| | C | H | N | S | |
| Natural rubber wood (NRW) | 40 | 2 | 2 | 3 | 43.9 ± 4.3 ($n$ = 6) |
| Rice husks | 34 | 4 | 0.4 | 0 | 9.9 ± 0.5 ($n$ = 5) |
| Whole wood pellets | 47 | 7 | 1 | 0.3 | 11.0 ± 1.0 ($n$ = 5) |

$n$: sample numbers.