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Effects of fuel properties on the natural downward smoldering of piled biomass powder: Experimental investigation

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ABSTRACT

To validate the modeling of one-dimensional biomass smoldering and combustion, the effects of fuel type, moisture content and particle size on the natural downward smoldering of biomass powder have been investigated experimentally. A cylindrical reactor (inner size Φ26 cm × 22 cm) was constructed, and corn stalk, pine trunk, pyrolysis char and activated char from corn stalk were prepared as powders. The smoldering characteristics were examined for each of the four materials and for different moisture contents and particle sizes. The results revealed the following: 1) The maximum temperature in the fuel bed is only slightly affected by the fuel type and particle size. It increases gradually for original biomass and decreases slowly for chars with the development of the process. 2) The propagation velocity of the char oxidation front is significantly affected by the carbon density and ash content and nearly unaffected by moisture content and particle size. 3) The propagation velocity of the drying front is significantly affected by the moisture content, decreasing from over 10 times the propagation velocity of char oxidation front to about 3 times as the moisture content increased from 3 to 21%.

1. Introduction

Biomass combustion comprises over 90% of the total global bioenergy [1]. The advantages of using large particles (the particle size is equivalent to the diameter of the biomass stem) [2] have led to their current, and likely future, wide use in biomass utilization and waste (biomass) incineration. Modeling the combustion of large biomass particles can deepen our understanding of the process and, thus, is important for its application.

One-dimensional (1-D) modeling of this process [3–7] is popular due to the complexity of the process. However, due to the difficulties with the measurement of parameters inside a particle and the influence of strong buoyancy in many furnaces, 1-D biomass combustion experiments are scarce. In contrast, 1-D smoldering experiments are relatively easily implemented [8,9], and detailed, accurate information can be obtained inside the fuel bed (temperature field, mass loss rate, primary gas products, shrinkage). The natural downward smoldering of piled biomass powder is described in the lower part of Fig. 1. Like the combustion of biomass particles, natural downward smoldering involves chemical and physical changes; heat, mass and momentum transfer in porous media; and the shrinkage of the fuel bed. Except for the boundary conditions, the governing equations for the

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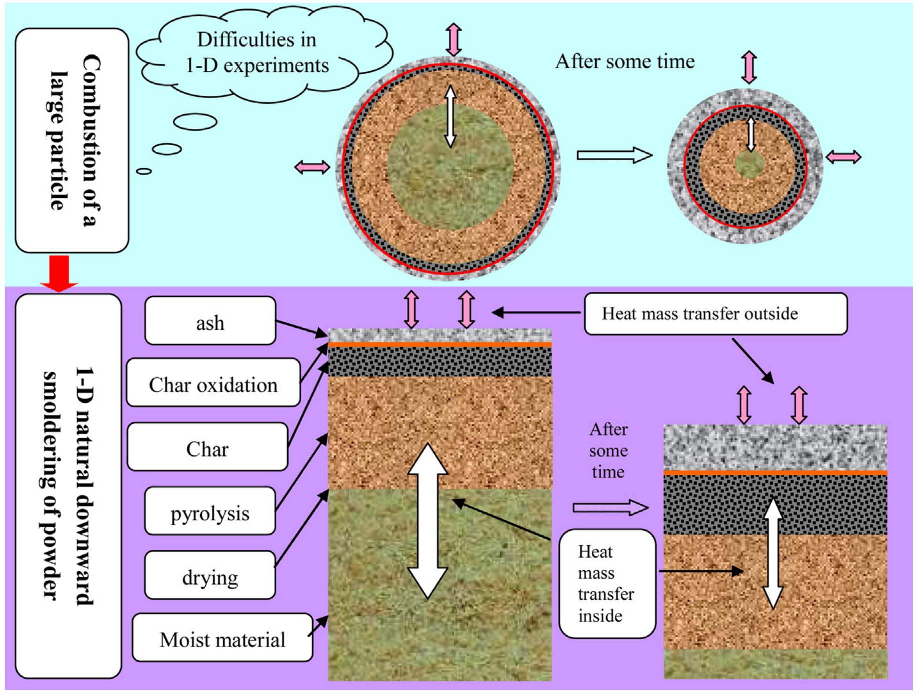

Fig. 1 – Comparison of biomass particle combustion and natural downward smoldering.

smoldering and combustion of biomass are not intrinsically different [3,5,10–15]. Thus, there is a great potential for using smoldering experiments to validate the governing equations of combustion.

Smoldering also occurs in fires and in many thermo-conversion processes. It is an important hazard but also a novel technological concept under development [16]. The experimental study of smoldering may provide important information for fire safety and the development of new technology.

Broad experimental investigations of biomass smoldering have been performed. Palmer [17] examined the smoldering process of piled dust (cork, deal, grass) and rigid combustible boards to evaluate the safe storage of these substances. Specifically, the effect of the air flow velocity above the fuel bed on propagation, the minimum fuel layer thickness required for sustained smoldering and the propagation of upward smoldering were investigated. Kinbara et al. [18] examined the downward smoldering of thin bunches of materials (rolled paper, incense sticks, strips of cardboard) and piles of cardboard tightly bound with thread. The smoldering propagation velocity was successfully correlated with the physical characteristics of the fuel and the environmental parameters. Ohlemiller and Lucca [9,19] investigated 1-D forced and 2-D natural smoldering. The effect of the air flow rate inside the fuel bed on the propagation velocity of 1-D smoldering wave was analyzed [9]. The 2-D profiles of temperature, oxygen mole fraction and residual organic material have been measured [19]. Frandsen [20] investigated the influence of the moisture and mineral soil content on the smoldering limits of forest duff. Recently, Carvalho et al. [21] studied the effect of temperature and air supply in a tunnel apparatus on the smoldering speed of wood logs. Pastor et al. [22] investigated the smoldering temperature inside piled charcoal (after the field fire of cutting debris was extinguished). He and Behrendt [8] investigated the natural upward and downward smoldering of char powders. Despite these works, there have been few studies on the natural downward smoldering of biomass powders in terms of the modeling validation of smoldering and combustion.

This paper presents the effects of fuel type, moisture content and particle size on the natural downward smoldering of biomass powders. The results are useful for validating smoldering and combustion modeling and providing an improved understanding of this process.

2. Method

2.1. *Experimental set-up*

A small experimental set-up was constructed, as shown in Fig. 2. It includes a cylindrical reactor (inner size $\Phi 26\ cm \times 22\ cm$) to contain the fuel and a hood to evacuate the flue gas. The inner wall of the reactor is made of a 10-cm-thick high-aluminum aluminum-silicate blanket for insulation. The hood is positioned 40 cm above the top surface of the reactor to avoid disturbing the air flow above the fuel bed. The biomass powder is poured into the reactor via a filling funnel. A thin rod is used to stir the fuel bed after loading the fuel, and the reactor is vibrated to avoid bridging, maintain as uniform a bulk density as possible and smooth the top surface of the fuel bed. After the fuel bed is ignited from the top by a round heater (600 °C, 5 min, 1 cm above the top surface of the fuel bed), the smoldering propagates downwards.

The temperatures are measured by 9 K-type thermocouples (Φ1 mm, KMTXL-040-G) in the positions shown in Fig. 2. The bed depth decreases by as much as a factor of 5 during