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Effect of gas temperature and oxygen concentration on single particle ignition behavior of biomass fuels

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Abstract

This work focuses on single particle ignition behavior of biomass fuels. Five biomass fuels were studied, namely, wheat straw, kiwi branches, vine branches, sycamore branches and pine bark. Coal was also tested for comparison purposes. Tests were carried out in an optical flat flame McKenna burner able to produce a confined laminar flow of combustion products, in which single particles were injected upward through a central hole. The equivalence ratio and the thermal input of the burner were adjusted to yield the following operating conditions in the ignition zone: five mean temperatures (1500, 1575, 1650, 1700 and 1800 K) and three mean dry oxygen concentrations (3.5, 5.1 and 6.5 vol. %). The ignition mode and the ignition delay time were evaluated through the analysis of images obtained by means of a CMOS high-speed camera. The effects of gas temperature and oxygen concentration on the ignition mode and ignition delay time were assessed. For the studied conditions, the ignition of the biomass particles generally occurred in the gas-phase, although surface ignition was also observed in some cases. The results suggest that the critical diameter for the ignition mode transition varies with the fuel type. All particles show a consistent trend of decreasing ignition delay time with increasing gas temperature, with the biomass particles presenting slightly higher values than the coal tested. The estimated drying times were subtracted from the total ignition delay time and the trends shifted, with the pine bark and wheat straw presenting a lower remaining time than the coal. Finally, for the studied oxygen concentration range, its variation did not have a significant impact on the ignition mode and delay time at high temperatures.

Keywords: Biomass; Single particle; High-speed imaging; Ignition delay time; Ignition mode

1. Introduction

In the context of the current world energy crisis and increasing CO_2 emission constraints, alternatives to conventional coal combustion, such as coal-biomass co-firing, are becoming more common. Co-firing arises as an alternative that allows the use of biomass fuels in existing power plants, thus making it an attractive technology. Biomass is a highly reactive fuel and has a high volatile matter content, resulting in lower ignition temperatures for coal-biomass blends than for pure coal [1], helping with flame stability. Additionally,

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emissions of SO_2 and NO_x are typically reduced [2]. Despite some successful long-term demonstrations [3], there are still many open questions on the combustion process, particularly in the area of particle ignition behavior.

The ignition process has a critical influence over flame stability, and is, thus, crucial in the design of boilers. Depending on the conditions, ignition can result from the interaction between the volatiles released from the particles and the oxidizing gas in the gas-phase, i.e., homogeneous ignition, or it can result from direct oxidation of the particle surface, i.e., heterogeneous ignition [4]. Most studies on ignition focus on ignition mode and ignition delay time and the parameters that affect them, namely, size and composition of the particle, and combustion atmosphere (temperature and composition). Despite the importance of the ignition process, its definition is ambiguous and depends on the diagnostic methods used. Early studies of Howard and Essenhigh [5] defined the ignition event based on the percentage of loss of carbon and volatiles during the early moments of combustion; however, since then most works have used optical diagnostics to characterize this event. Molina and Shaddix [6] defined the onset of ignition of bituminous coal diluted jets based on the CH^* chemiluminescence. In a more recent work, Shaddix and Molina [7] measured the ignition delay time of individual coal particles by capturing the visible light signal emitted by igniting particles, and defined the ignition onset as the point at which 60% of the maximum luminosity intensity was reached. Yuan et al. [8] used a similar criterion to characterize the ignition of streams of coal particles. In their work, the ignition delay time is defined as the time between injection and the instance when the luminosity intensity reached 10% of the maximum peak.

Studies on the ignition of biomass fuels are very scarce, with most works focusing on coal [4–10]. Ignition studies on coal have shown that different types of coal have completely distinct ignition and combustion behaviors [4,9], but generally ignition delay times (i) decrease with increasing temperature [8], (ii) decrease with increasing oxygen concentration [4,6,7,9], and (iii) decrease with decreasing particle size [10]. Even though the behavior of coal is relatively well characterized, some differences may arise when the transition to biomass fuels is made. In fact, Riaza et al. [11] studied the combustion of four biomass fuels under different atmosphere conditions and found significant differences between biomass fuels and the coals previously studied by Khatami et al. [4,9].

In this context, the main objective of this study is to characterize the single particle ignition behavior of biomass fuels, particularly for temperatures higher than those reported in literature, under atmosphere conditions much closer to the ones that occur inside industrial boilers. The tests were performed in an optical flat flame McKenna burner and the ignition events were captured with a CMOS high-speed camera. In this study, the ignition behavior is characterized in terms of ignition mode and ignition delay time.

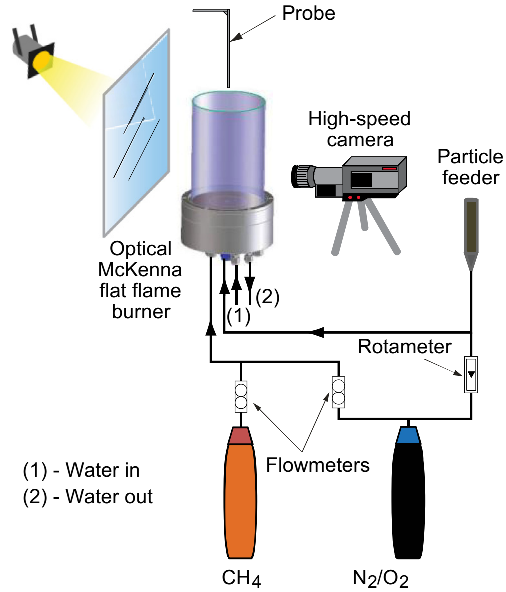

Fig. 1. Schematic of the experimental setup.

2. Materials and methods

2.1. Experimental setup

Figure 1 shows a schematic of the experimental setup used. It consists of a biomass feeding unit, a McKenna flat flame burner, a gas feeding system and an image acquisition system. The biomass feeding unit consists of a rotameter (to measure the transport air flow rate), a 10 ml syringe and a vibrating motor. The biomass particles stored in the syringe were fed (by gravitational force) into the stream of transport air and injected upward through the central hole of the burner (I.D. 1.55 mm) into the ignition zone. The vibrating motor avoided the clogging of particles in the syringe hole and ensured a low feeding rate.

The Mckenna flat flame burner consists of a stainless-steel cylinder enveloping a water-cooled bronze porous sintered matrix of 60-mm diameter. Two mass flowmeters allowed the control of the methane and primary air flow rates to the burner. In addition, cooling water was fed to the burner through copper tubes (labeled 1 and 2 in Fig. 1). Above the burner, a high-grade fused quartz of I.D. 70-mm, height of 500-mm, and thickness of 2-mm confined the flow and avoided the entrainment of ambient air, while providing optical access.