



Oxidation behavior of particulate matter sampled from the combustion zone of a domestic pellet-fired boiler



Ulisses Fernandes ^a, Marta Guerrero ^b, Ángela Millera ^b, Rafael Bilbao ^b, María U. Alzueta ^b, Mário Costa ^{a,*}

^a Mechanical Engineering Department, Instituto Superior Técnico, Technical University of Lisbon, Avenida Rovisco Pais, 1049-001 Lisbon, Portugal

^b Aragón Institute of Engineering Research, Dept. of Chemical and Environmental Engineering, University of Zaragoza, Río Ebro Campus, 50018 Zaragoza, Spain

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ABSTRACT

This article describes an experimental investigation of the oxidation behavior of particulate matter (PM) sampled with the aid of a rapid dilution probe from a number of measurement positions located in the near the burner region of a domestic wood pellet-fired boiler. Morphology and chemical composition of the collected PM samples were examined in a scanning electron microscope equipped with an energy dispersive X-ray spectroscopy detector. To evaluate the oxidative reactivities of the PM samples, experiments were performed in a quartz reactor with an inlet oxygen concentration of 500 ppm in a nitrogen flow, a temperature of 900 °C, and a flow rate of 1000 mL/min (STP). Results obtained from the oxidation tests indicated that the PM samples collected from locations near the visible flame boundary were significantly less reactive towards O₂ than those sampled from locations along the burner axis. This fact may be due to the higher temperatures occurring near the visible flame boundary, resulting in PM samples with a higher degree of material organization and a lower availability of active sites.

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1. Introduction

Emissions of fine particulate matter (PM) can seriously affect human health [1]. Among the major contributors of fine PM to the atmosphere are the small-scale biomass-fired boilers, which are widely used around the world. In biomass combustion fine PM is produced from incomplete combustion (i.e., unburned matter and/or soot) and from vaporization and condensation of easily volatile ash elements. In principle, the presence of PM in the flue gas can be minimized through combustion modifications that lead, for example, to longer residence times of the combustible PM within the higher temperature regions in the combustion chamber of the boiler and/or to higher temperatures in the fuel bed. The latter strategy may, however, enhance the vaporization of the easily volatile ash elements, which may originate higher ash based PM emissions. Consequently, an important challenge regarding the fine PM formation and emission in domestic applications is to design burners/boilers capable of satisfying both the requirements of increasing the combustible PM oxidation rates and decreasing the vaporization rates of the inorganic materials present in the biomass fuels. To accomplish this, knowledge on the oxidation behavior of PM in such devices is

required and this work represents the initial effort of an on-going project targeted at obtaining such essential information.

There are a number of studies on soot reactivity related with conventional gaseous and liquid fuels, which have elucidated well the fundamentals of the soot oxidation processes [2–5]. For example, Seong and Boehman [3] carried out studies of oxidative reactivity of n-heptane-derived soot using a diffusion flame burner and concluded that the soot reactivity decreases with the increase of the oxygen concentration in the oxidizer stream and the increase of the flame temperature. They also observed that soot derived from an oxygenated fuel (mixture of 70 vol.% n-heptane and 30 vol.% monoglyme) is more reactive than n-heptane soot, and that the degree of soot crystalline order is inversely related with the soot reactivity. Abián et al. [4] studied the reactivity of soot produced from ethylene pyrolysis at different temperatures and CO₂ atmospheres towards O₂ and CO₂ using a thermogravimetric analyzer. The authors observed that the soot samples formed at lower temperatures have higher reactivity towards both O₂ and CO₂ than the soot samples obtained at higher temperatures, regardless of the environment history of the soot samples.

Analogous studies centered on the oxidative reactivity of PM formed in biomass combustion are, however, still missing. In this work, PM samples were initially sampled with the aid of a rapid dilution probe from a number of measurement positions located in the near the burner region of a domestic wood pellet-fired boiler. These PM samples were subsequently subjected to oxidation experiments in a quartz reactor to evaluate their reactivity. To the best of our knowledge, information

* Corresponding author at: Mechanical Engineering Department, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. Tel.: +351 218417186.

E-mail address: mcosta@ist.utl.pt (M. Costa).

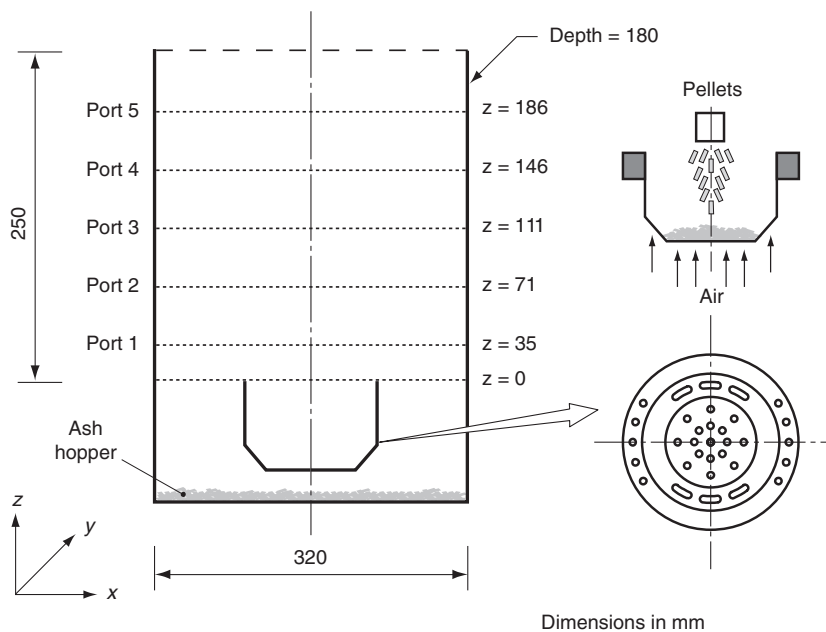


Fig. 1. Schematic of the combustion chamber, showing the burner and the measurement traverses (ports 1 to 5).

on near burner region PM oxidative reactivity is absent from the literature and its importance in the context of fine PM control strategies cannot be overemphasized.

2. Materials and methods

The PM samples examined in this study were collected from inside the combustion chamber of a domestic wood pellet-fired boiler [6]. Fig. 1 shows a schematic of the rectangular combustion chamber and burner. The pellets are manually loaded into a hopper with a capacity of 45 kg and are fed to the burner through a screw feeder that works by impulses. The feeding rate of the pellets is regulated by the boiler load and the pellets consumption rate is measured with the aid of a loss-in-weight technique, for which the boiler is mounted on a weighbridge.

The combustion of the pine pellets takes place within a hemispherical basket (brazier) with a diameter of 120 mm. The basket is top-fed with pellets by the screw. Ignition is accomplished with the aid of an electrical resistance placed close to the basket and the primary air is

supplied by a dedicated fan to the basket through several small orifices located across the basket bottom. A short cleaning period of the basket is programmed to occur once every 11.5 min. During the cleaning process the fuel supply decreases and the air supply increases for a few minutes in order to remove the ashes accumulated at the bottom of the basket (bottom ashes). The resulting hot gases from the combustion exchange heat with water circulating in a heat exchanger located at the top of the combustion chamber. The heat transferred to the water in the boiler is dissipated through a plate heat exchanger with the aid of an external water circuit.

For the present study, the combustion chamber was modified to allow the introduction of probes inside the rectangular combustion chamber. The probes could be inserted horizontally inside the combustion chamber through five ports located along the middle of the side wall so that measurements were taken in a horizontal plane cutting through the burner axis (see Fig. 1).

Local mean temperature measurements were obtained using 76 μm diameter fine wire platinum/platinum: 13% rhodium (type R) thermocouples. The hot junction was installed and supported on

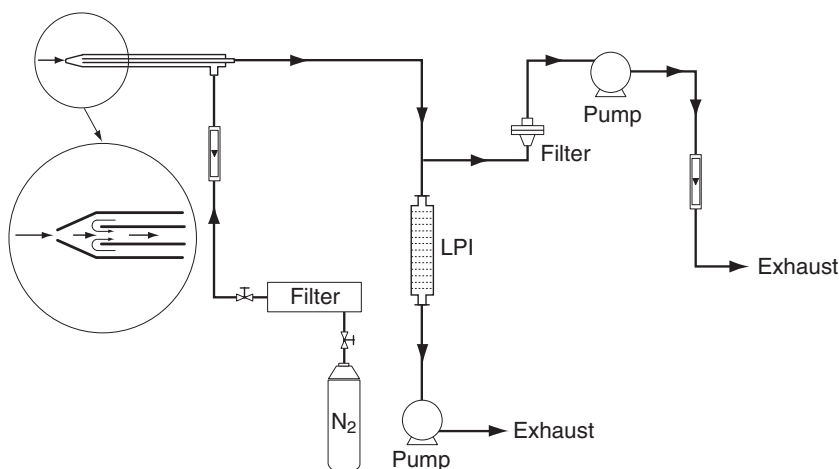


Fig. 2. Schematic of the PM sampling probe and associated sampling system.

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