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Combustion and emission characteristics of a domestic boiler fired with pellets of pine, industrial wood wastes and peach stones

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ABSTRACT

This study evaluates the combustion and emission characteristics of a domestic boiler fired with pellets of pine, industrial wood wastes and peach stones. Initially, the boiler performance, firing pine pellets, was evaluated as a function of the thermal input. Subsequently, the influence of the pellets type on boiler performance was also examined. The results reveal that the type of pellets affects significantly the boiler emissions characteristics, with the pine pellets performing significantly better than the pellets of industrial wood wastes and peach stones. The boiler thermal efficiency is not negatively affected when fired with the pellets of industrial wood wastes and peach stones. Typical operating conditions of the boiler are not suitable for the use of wood wastes and peach stones pellets as CO and HC emissions are superior. The pellets of industrial wood wastes and peach stones have, however, an attractive potential for use in domestic boilers, through the optimization of the boiler operating conditions, being this a sustainable means of energetic valorisation of residues with no specific use.

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1. Introduction

In recent years, the use of pellets in the domestic space and water heating market has increased rapidly driven by the growing maturity of the technology and financial incentives for the acquisition of heating systems. Currently, this market is already well established in countries such as Germany, Sweden, Austria, Switzerland and Italy [1]. Domestic pellet fuelled boilers typically use wood derived pellets, but the limited availability of wood biomass for energy purposes [2], along with its high demand from other industrial sectors, is putting an enormous pressure on the forest resources. Under these circumstances, it is important to broaden the raw materials for pellet production in order to secure pellet supply, particularly to small-scale customers, and to ensure price stability in the future [3]. Agricultural and industrial waste residues have the potential to be used in domestic boilers in the form of pellets; however, these raw materials often have characteristics that may compromise the combustion conditions and the operation and maintenance of the boiler [4]. Therefore, it is important to evaluate the combustion behaviour of pellets produced with different raw materials in order to assess their effective potential.

Related previous studies [5–17] showed that the characteristics of the boiler, the fuel properties and the operating conditions affect significantly the combustion process and the pollutant emissions. The emissions of products from incomplete combustion from pellet boilers, in particular CO and unburned hydrocarbons (HC), are lower when combustion conditions that promote the oxidation of the unburned species leaving the fuel bed are fulfilled. Mixing limitations and low temperatures inhibit oxidation leading to increased emissions of CO [5,7,10,13,15]. Disturbances of the fuel bed, occurring during intermittent operation and in top-fed burners, deteriorate combustion conditions temporarily, originating peaks of CO and HC emissions [10,13]. Pellets produced from different sources and in different making conditions have distinct chemical and physical characteristics and their combustion behaviour will differ at identical operating conditions. These characteristics affect strongly the pollutant emissions, although the effect on boiler thermal efficiency is small [5–7,9]. In small domestic boilers, the temperature in the combustion chamber is typically below 1300 °C and, therefore, NO formation via the fuel mechanism is expected to be the main source of NO_x emissions [10]. It is well established [5,9–11] that NO_x emissions are strongly dependent of the fuel nitrogen content, confirming the importance of the fuel-NO mechanism. Furthermore, the specific combustion conditions may have an effect on the conversion of HCN and NH_3 released during devolatilizaton to NO, particularly the excess air level, mixing, turbulence and temperature, influencing the total

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NO_x emissions [9,16]. Biomass has generally a low content of fixed carbon, and, thus, NO_x emissions from char-nitrogen reaction paths from the fuel-NO mechanism are minimal [18].

The main objective of the present article is to evaluate the potential of using industrial wood wastes and peach stones as raw materials for pellet production by examining its combustion and emission characteristics in a domestic boiler. To accomplish this goal, initially, we examined the performance of a domestic boiler firing pine pellets, which are currently available in the market. Subsequently, we evaluated the performance of the same boiler firing the industrial wood wastes and peach stones pellets, which were made specifically for this study. Finally, to broaden the assessment to other raw materials originated from residues, data selected from the open literature from similar studies was compared to the present results in order to assess the potential of using pellets from sustainable origin in domestic boilers.

2. Experimental

2.1. Boiler description

The present tests have been performed in a domestic wood pellet-fired boiler with a maximum thermal capacity of 22 kW, with forced draught. Fig. 1 shows a schematic of the experimental set-up. 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. The flow rate of combustion (primary + secondary) air is automatically regulated by the boiler control system.

The combustion of the 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 (see Fig. 1). The secondary air is supplied through a vertical tube, located slightly above the basket, which injects the air in the same direction as the exiting flow of the basket. It should be pointed out that 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 during 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 the circulating water in a heat exchanger 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.

Currently, the present type of boilers have design, manufacturing, safety, performance and emissions requirements that are subject to the EN 14785 approved by the European Committee for Standardization (CEN) in 2006 [19]. Specifically, the standard limits the CO emissions to 400 ppm@13% O_2 for nominal boiler thermal inputs and 600 ppm@13% O_2 for reduced boiler thermal inputs. These regulations are necessary to protect inhabitants from negative health impacts and to encourage the manufacturers to optimize their products for the lowest possible emissions.

2.2. Pellet fuels

Three types of pellets were used in this study, namely, pellets of pine, industrial wood wastes and peach stones. The pellets of pine are currently manufactured and commercialized in Portugal, while the pellets of industrial wood wastes and peach stones were made specifically for this study by a Portuguese company named Casal & Carreira Biomassa, Lda, located in Alcobaça, Portugal. The pine pellets are made of sawdust residues from the Portuguese wood industry and the industrial wood wastes pellets are made of residues from Portuguese wood products at the end of their life cycle, mainly pallets, furniture and construction work residues. Peach stones are residues produced by the Portuguese fruit transformation industry.

The pelletization process of the industrial wood wastes and peach stones followed the same steps as the typical pine pellets manufacturing process in the following order: milling, decontamination, drying and pelletization. The peach stones were pulverized to a mean diameter of 0.6 mm and did not require any further treatment, proceeding immediately to the drying stage. In contrast, the industrial wood wastes required a pre-treatment step of

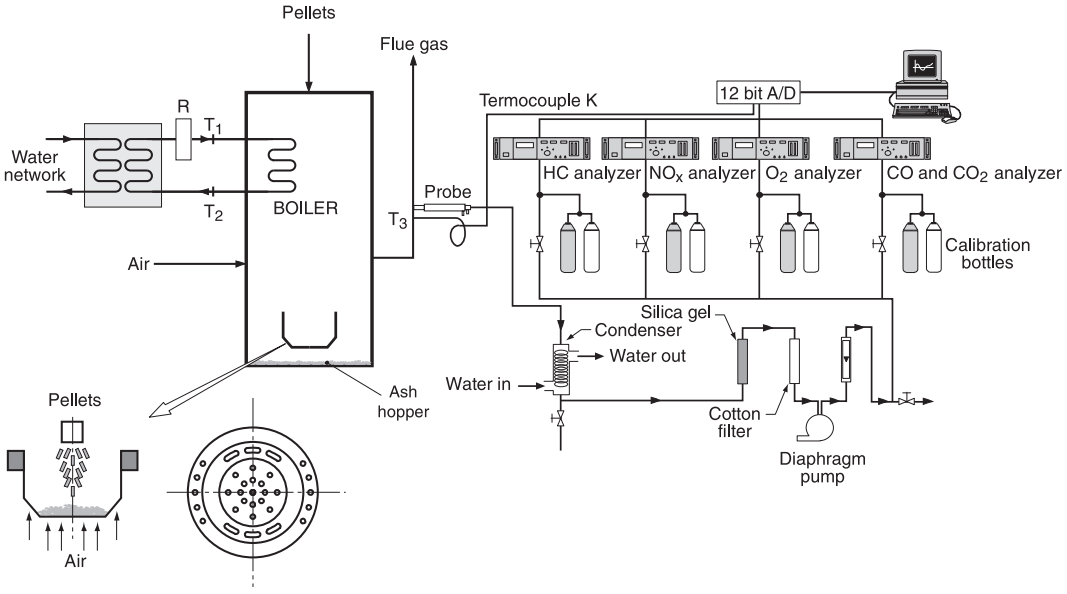

Fig. 1. Schematic of the experimental set-up.

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