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Prediction of the combustion process in fluidized bed based on physical–chemical properties of biomass particles and their hydrodynamic behaviors

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ABSTRACT

The utilization of biomass in fluidized bed reactors is due to alternatives created by the carbon credit market and to environmental concerns. This fact calls for an accurate determination of physical–chemical properties and hydrodynamic studies on biomass-inert binary mixtures. In bubbling fluidized bed combustion processes, the inert material mass is approximately 95% of the total mass of the bed material, and an effective mixture between biomass and inert particles is desired to improve the efficiency of the process. In this study, binary mixtures, composed of biomass and sand as an inert material, were used. Thermal and physical–chemical properties of five biomass samples (sugarcane bagasse, pine sawdust, coffee husk, Tucumã seed, and rice husk) were experimentally evaluated. The morphology of the samples was determined by SEM, and the thermal properties were found by thermogravimetric analysis (TG) and differential thermal analysis (DTA). The hydrodynamic study was carried out in a fluidized bed at room temperature and local atmospheric pressure, in which the minimum fluidization velocity and voidage of the biomass-inert binary mixture were evaluated. The arrangement of the physical–chemical characteristics of biomass and the hydrodynamics of the binary mixture are equally important for predictions of the biomass behavior in fluidized bed combustors.

1. Introduction

The increasing demand for energy has claimed for improvements in energy generation processes. The carbon credit market has created good opportunities for the use of biomass in fluidized bed reactors in industrial processes for combustion, gasification, and pyrolysis. Fluidized bed reactors are characterized by high conversion efficiencies and low emissions of atmospheric pollutants. The use of biomass in fluidized bed reactors is still restricted due to the lack of knowledge regarding biomass particle properties and their hydrodynamic behavior. Such information is important for predicting the behavior of these biomasses when they are applied to fluidized bed reactors and contributes to enhance the industrial equipment performance.

The high consumption of coal worldwide and the consequent environmental pollution problems have required the generation of a clean energy [1]. Many studies have been conducted on energy generation from biomass for environmental reasons, and fluidization is considered the most promising technology to be applied due to its good performance parameters, such as excellent fluid mixing, high heat and mass transfer rates, as well as temperature uniformity. Moreover, fluidization can operate at various regimes, depending on parameters, such as temperature, pressure, gas velocity, particle diameter, riser diameter, and gas/particles properties.

Several studies have focused on biomass particles characterization, whose knowledge is important for the improvement of the performance of such materials in thermal processes [2–7]. Within this purpose, thermal analysis techniques – thermogravimetry (TG/DTG) and differential thermal analysis (DTA) – have been used for the appraisal of the thermal behavior of the biomass providing useful information about the thermal degradation of lignocellulosic contents [8–12].

On the other hand, very few attempts have focused on the influence of physical–chemical properties of biomass materials on fluidized bed performance, probably due to the lack of sufficient data on those properties. Regarding binary mixtures involving biomass and sand particles, an effective mixture inside the bed must be achieved for a better

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performance of the reactor [13]. However, more experimental studies on the hydrodynamic behavior of fluidized beds containing binary mixtures of biomass and sand particles are still required, although plenty of research has been carried out over the past four decades [14–17].

These studies have shown that the values provided by equations of the minimum fluidizing velocity (U_{mf}) for binary mixtures with biomass particles are far from the experimental ones due to the segregation phenomena, irregular shapes of biomass and the formation of preferential channels inside the bed. Despite all efforts devoted, the combination between hydrodynamic studies of biomass-sand mixtures in fluidized beds and studies on physical–chemical properties of biomass still have not been analyzed.

In this context this paper investigates five biomass samples (sugar cane bagasse, pine sawdust, coffee husk, Tucumã seed and rice husk) based on the thermal and physical–chemical properties and hydrodynamic behavior of biomass–sand binary mixtures. The fluidization process of the binary mixture in the fluidized bed is conducted by using air at room temperature and local atmospheric pressure. The arrangement of the physical–chemical properties of biomass and hydrodynamic behavior enables the prediction of the fluidized bed combustors when the biomass is used. Such attempts are expected to lead to a better utilization of the biomass samples in thermal processes.

2. Materials and methods

2.1. Solid particles

The five biomass samples studied were collected from different regions in Brazil: sugarcane bagasse, pine sawdust, and coffee husk from São Paulo State, Tucumã seed from Amazonas State and rice husk from Maranhão State. All biomass particles were ground by either a hammer mill or a slicer to obtain particle sizes smaller than 2800 μm, except for rice husk. This preparation followed the ASTM Standards (E1757-01).

Sand particles whose size ranged between 150 μm and 1000 μm were selected for hydrodynamic experiments and subjected to both particle and bulk density experimental analyses. However, smaller particles were required for porosimetry and thermal analyses. In those cases, particles of 460 μm were used, but previously washed, dried at 80 °C for 18 h, grounded, and then sieved. The average size of 460 μm was obtained by the arithmetic mean of two consecutive ASTM laboratory sieves whose mesh apertures ranged between 420 and 500 μm. Pictures of the biomass samples after the preparation are shown in Fig. 1.

2.2. Physical–chemical analyses

Ultimate analysis, higher heating value (HHV) and porosity tests were carried out to characterize the biomass samples. The ultimate analysis of the samples was conducted with a CE Instruments analyzer — model EA1110-CHNS-O. HHV was determined on a bomb calorimeter (IKA C200) according to the ASTM D-2015 standard test method and using samples weighing (1.0 ± 0.1)g in three replicate experiments.

The samples were dried in an oven for approximately 24–120 h under a temperature of 110 °C prior to the porosimetry tests conducted in a Micromeritics porosimeter (ASAP-2020). Samples of (1.0 ± 0.3)g were used in all experiments. Under the Degas conditions, the samples were heated at a 10 °C min^{-1} up to 70 °C rate and subjected to an evacuation rate of 10 $mmHgs^{-1}$ to 10 μmHg, remaining under these conditions for 240 min. Under the analysis conditions, the samples were immersed in liquid nitrogen and maintained in isothermal conditions at −196 °C during all experiments. The porosimetry analysis was performed under vacuum at an evacuation rate of 5 $mmHgs^{-1}$ to 10 μmHg, remaining under these conditions for 6 min. Then, a P/P_0 programming for 42 points was applied (27 points for adsorption and 15 points for desorption). P/P_0 is the ratio between the applied pressure (P) and the saturation vapor pressure of the adsorbed gas (P_0), i.e., nitrogen.

The morphological structures of the biomass samples were analyzed by Scanning Electron Microscope (SEM) in a LEO Electron Microscopy 440 (ZEIZ/LAIKA).

2.3. Thermal analyses

The thermal properties of the samples were determined by both thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The TG technique determines the changes in the sample mass as the temperature increases and DTA determines the enthalpic transitions by means of endothermic and exothermic peaks [18]. The experiments were performed in a thermogravimetric balance and in a

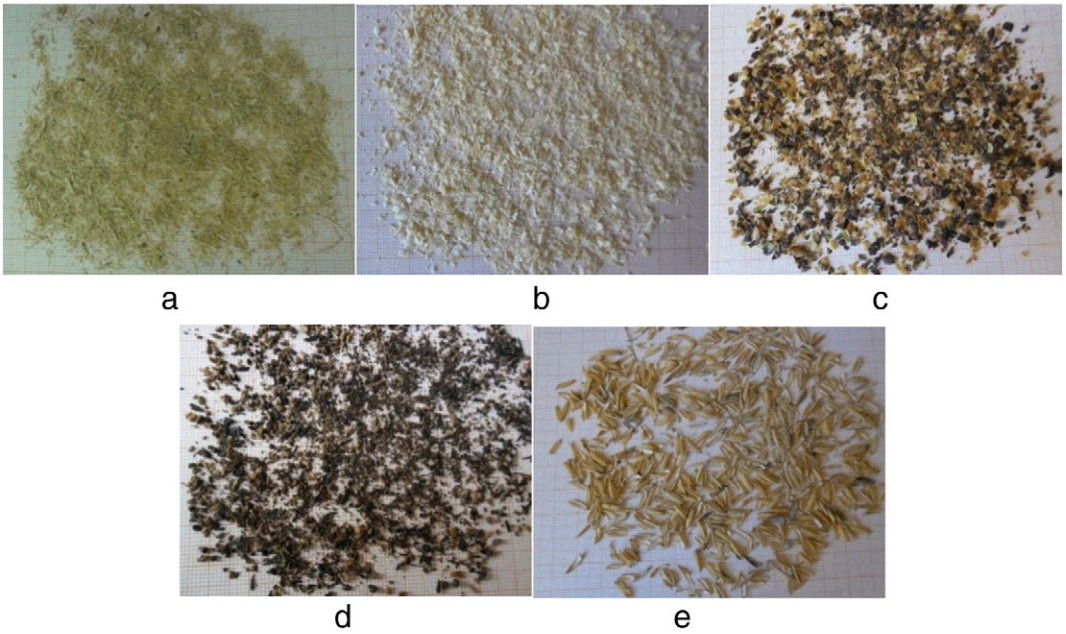

Fig. 1. Samples of the five biomasses studied: (a) sugarcane bagasse; (b) pine sawdust; (c) coffee husk; (d) Tucumã seed and (e) rice husk.