BIOMASS AND BIOENERGY 35 (2011) 4124–4133

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Kinetic and diffusive data from batch combustion of wood chars in fluidized bed

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ARTICLE INFO

Article history:
Received 2 April 2009
Received in revised form
13 May 2011
Accepted 2 June 2011
Available online 8 September 2011

Keywords:
Experimental data
Fluidized bed combustion
Modeling
Wood char
Kinetic constant

ABSTRACT

In this work it is studied the combustion of batches of wood char particles in a shallow fluidized bed at laboratory scale. Commercial and recarbonized chars from nut pine and cork oak parent woods were burned for bed temperatures of 600–750 °C and particle sizes range of 1.8–3.6 mm. A combustion model based on the two-phase theory of fluidization is presented to evaluate the global combustion resistance. Sherwood numbers and kinetic constants for the heterogeneous phase reaction are also assessed. Through the comparison among theoretical and experimental results, conclusions are drawn on the combustion mechanism as well as on the combustion controlling resistance. The Arrhenius law is proposed to predict the kinetic constants for the studied chars.

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1. Introduction

The uncontrollable use of fossil fuels, that supported the development of industrial societies for the last two centuries, has lead to environmental damage that is now becoming visible. Either in academic or industrial surroundings there is a continuous search for new energy sources and one of the new sources that has been deserving some attention is the energy from biomass. Patzek and Pimentel [1] made a very thorough thermodynamic analysis at the energy production from biomass, demonstrating that large scale energy production from biomass is frequently unsustainable and that the best option is the locally-produced electricity using acacia or sugar cane plantations. Obernberger [2] refers that biomass combustion in fluidized bed burners is an interesting approach due to the burner flexibility, as far as particles size and moisture content are concerned. However, Palchonok et al. [3] recognize that it is necessary to study the different phenomena taking place during the combustion stages of biomass inside the bed.

Scala and Salatino [4] refer that the fundamental study for the comprehension of physical and chemical basic mechanisms taking place during biomass combustion in fluidized beds got much less attention to that which was given to the study of solid fossil fuels on the same type of reactors. They justify such situation by arguing that models which were developed for coal and coke combustion could easily be adopted for biomass derived fuels like wood chars. In fact, being this proposition true, this means that it will be necessary to carry out such procedure, and this is the reason for the present work, to assess the possibility of using a model suitable for coke to the wood char combustion in a bubbling fluidized bed reactor.

Since the publication of the first theory for the combustion of coke particles in fluidized bed, Avedesian and Davidson [5], there has been a large discussion on the subtleties concerning the explanation of the physical and chemical steps that take

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doi:10.1016/j.biombioe.2011.06.020

place inside the bed during the combustion of carbon particles, namely the relative importance of physical and kinetic effects upon the overall reaction rate.

Ross [6] says that the reaction $CO + ½O_2 \rightarrow CO_2$ is responsible for 72% of the heat released when burning 1 mol of carbon and thus it is necessary to know the correct placement of this homogeneous phase reaction. If it is close to the particle, its temperature will raise leading to a higher rate of reaction, whereas if this reaction takes place far from the surface of the particle, the temperature of the particle will be closer to the bed temperature and the reaction rate will be smaller.

Garbett and Hedley [7] refer that combustion models should combine a combustion mechanism with a model of the bed hydrodynamics, and that the combustion model can be a purely diffusive model or a combination of diffusive and kinetic terms. They adopted a combustion model based upon the two-phase theory of fluidization, or alternatively a three-phase model as postulated by Gibbs [8]. They conclude that the experimental results presented in Avedesian and Davidson [5], which were interpreted as a pure diffusion phenomena, could be interpreted according to the combined diffusive and kinetic resistances.

La Nauze e Jung [9] made a revision of the models available for the fluidized bed combustion of fossil coal particles published so far and realize that the proposed models are limited because they have some critical parameters whose determination cannot be done with rigor. They also refer that many of the models are based upon some assumptions experimentally unchecked.

Guedes de Carvalho et al. [10] burned 1.3–22 mm diameter carbon particles in fluidized beds operating at 950 °C and refer that the experimental data obtained clearly stress that the CO oxidation takes place away from the carbon particles, outside the oxygen concentration boundary layer.

It is then necessary to implement an experimental study for the combustion of biomass chars in fluidized bed which should be concerned with the comprehension of the basic mechanisms that take place during the combustion of batches of particles.

Although fluidized bed combustion of coals takes place in the 800–900 °C temperature range, in the present work lower combustion temperatures were used (600–750 °C) in order to enhance the kinetic control of the combustion reaction. Fennell et al. [11] inform that it is difficult to measure with precision the reaction rates for temperatures equal or superior to 700 °C because of the shortness of the reaction time and suggest that, to get reliable kinetic data, experiments should be carried out at lower temperatures. This also makes sense in practical terms because in the combustion of chars produced from biomass the range of combustion temperatures can be wider (320–850 °C) than that found for the combustion of cokes [12]. A lower burning temperature for chars of vegetable origin can also be interesting for the reduction of pollutant emissions.

2. Experimental

2.1. Apparatus and considerations

Fig. 1 presents the experimental set-up. Batches of char particles were introduced in the reactor thorough a stainless pipe making 30 deg. with the vertical and positioned 250 mm above the distributor. To avoid gas leakage during the batch feeding process, the two ball valves shown in the feeding line were opened and closed sequentially. The bed was fluidized with air whose mass flow rate was measured with an orifice plate flow meter equipped with an Omega Engineering differential pressure transducer (PX-142) connected to a data acquisition system from Advantech (PCI-1710). The distributor, a stainless steel plate 3 mm thick, had 177 holes with 0.6 mm of diameter, and each hole was 4 mm apart. The bed riser was also a stainless steel pipe with 54.5 mm of internal diameter and its total height was of 2.5 m. The bubbling bed region of the reactor, of 250 mm height, was completely surrounded by an electrical heating system to guarantee the required operating temperature. The electrical heating system as well as the whole 2.5 m riser were thermally isolated with Kaowool ceramic blankets. Bed temperature measurements were done with K-type thermocouples.

During the experiments, the bubbling bed height was controlled through the measurement of the pressure drop by means of a capillary pressure probe with 1 mm internal diameter connected to a pressure transducer (PX-142). The average bed height H was of 100 mm, so taking into account the bed internal diameter D of 54.5 mm, the aspect ratio (H/D) was of 1.8 and the bed could be considered shallow. Bi et al. [13] refer that if $H_{mf}/D < 2$ the bed is considered as shallow. The bed was composed by silica sand particles with an average diameter of 225 μm (+200–250 μm, DIN) and 3000 kg/m^3 of density [14].

Applying a criterion cited in Bi et al. [13], where the definition of transition conditions from bubbling to the turbulent fluidization regime lead to a superficial velocity of 1.7 m/s, it was found that in the present work the bed always operated in the bubbling zone, because the fluidizing velocities were on the range of 0.4–0.6 m/s, for all studied cases.

The proximate analysis and density data for the tested chars are shown in Table 1. Density measurements were done with a mercury intrusion porosimeter, model Poremaster, from Quantachrome.

2.2. Procedure

Batches of 5 g of char particles were burned in the fluidized bed of sand particles and the evolution of the molar concentration of CO_2 in the exhaust gas flow was followed for each experiment. The tested particles were previously sieved with DIN standard sieve sizes and the following average particle diameters were tested, 3.6, 2.8, 2.2 and 1.8 mm. Four chars were tested; two commercially available in Portugal, nut pine (*Pinus pinea*) and cork oak (*Quercus suber*) chars, and two made in laboratory through the recarbonization of the two commercial chars previously referred. The recarbonized chars were obtained by the immersion of small batches of the two commercial chars in a bubbling fluidized bed at 850 °C, during 5 min. The fluidizing gas during the recarbonization process was nitrogen.

The combustion experiments were done at bed temperatures of 600, 700 and 750 °C, for fluidizing superficial velocities of 9 and 12 times the corresponding minimum fluidizing velocity (9 and $12U_{mf}$).

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