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An experimental approach to thermochemical conversion of a fuel particle in a fluidized bed

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HIGHLIGHTS

- Chemical Conversion and hydrodynamics of fuel particle is studied simultaneously.
- The effect of bed temperature is investigated on the devolatilization rate.
- Pyrolysis time of particle is measured at different ranges of fluidization velocity.
- Mass loss of the fuel particle is recorded due to the devolatilization.

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ABSTRACT

Measuring the temperature of a fuel particle during the thermochemical process inside the fluidized bed is of great importance in order to obtain detailed knowledge of the conversion behavior of the fuel particle and so optimize the combustion performance. In this study a number of experiments were done in order to register the temperature and hydrodynamics of a biomass fuel particle in a fluidized bed during the devolatilization process of a biomass particle. The experiments were done in a 2D fluidized bed with a front transparent window in order to use the particle image velocimetry (PIV) method to obtain information on the hydrodynamics of the fuel particle and inert bed material inside the bed. A thermocouple was also used to measure the temperature of the particle during the conversion. Experiments were done at a fluidized bed temperature and fluidization velocity in the range of 350–450 °C and 0.2–0.6 m/s, respectively. The effect of the bed's temperature and fluidization velocity on the drying and devolatilization process of the biomass fuel particle was investigated. The results indicate that the bed's temperature and fluidization velocity have a significant effect on the mass and heat transfer between the fuel particle and the bed during the conversion process.

1. Introduction

Restrictions to do with reducing greenhouse gas emissions cause by the combustion of traditional fossil fuels has received great interest lately and has encouraged industries to use other kinds of energy resources. Biomass and organic waste are good alternatives for energy production due to their reduction of CO2 and sulfur emissions. Fluidized bed combustion is one of the technologies for thermochemical conversion of biomass and has lots of advantages compared to other methods. Higher thermal and combustion efficiency and reduction of nitrogen oxide formation, thus reducing air pollution and enabling the combustion of different low-grade fuels, are just a few benefits of a fluidized bed combustor [1]. As a consequence, fluidized bed combustion is used widely for getting energy from biofuels, even those with high amounts of moisture.

When a biomass particle is introduced to a hot fluidized bed, it undergoes a thermochemical conversion process containing different number of processes. The main stage of a biomass combustion is drying and devolatilization since the fixed carbon content is only 10–30 wt.% of the particle mass in this case [2]. Drying is the process whereby all the moisture leaves the particle. The devolatilization process involves a rapid thermal decomposition during which the biomass decomposes into light gases, tars and a highly carbonaceous solid called char. The amount of each component developed during this stage depends on the composition of the original sample and the environment temperature. Because of the high content of volatiles in biomass fuels, devolatilization is considered a very important and effective stage in the process of heat generation and includes heat and mass transfer, as well as several

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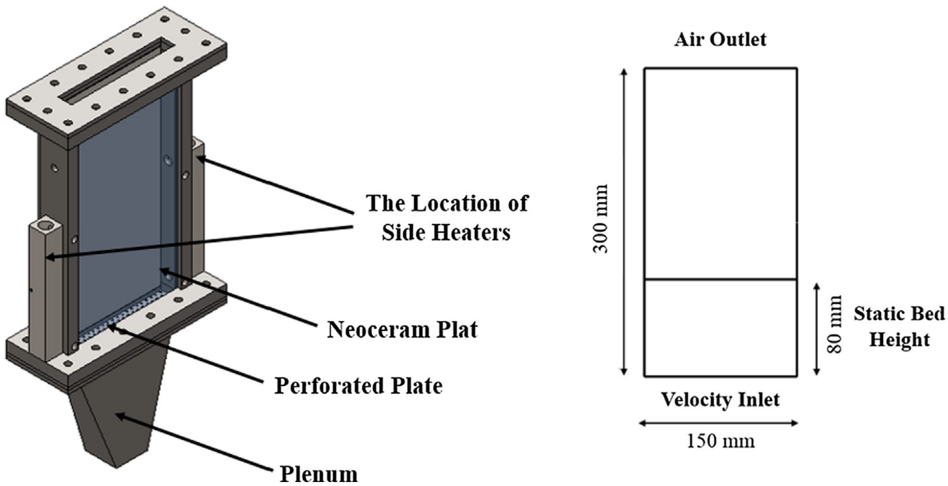

Fig. 1. Schematic and sizing diagram of the fluidized bed.

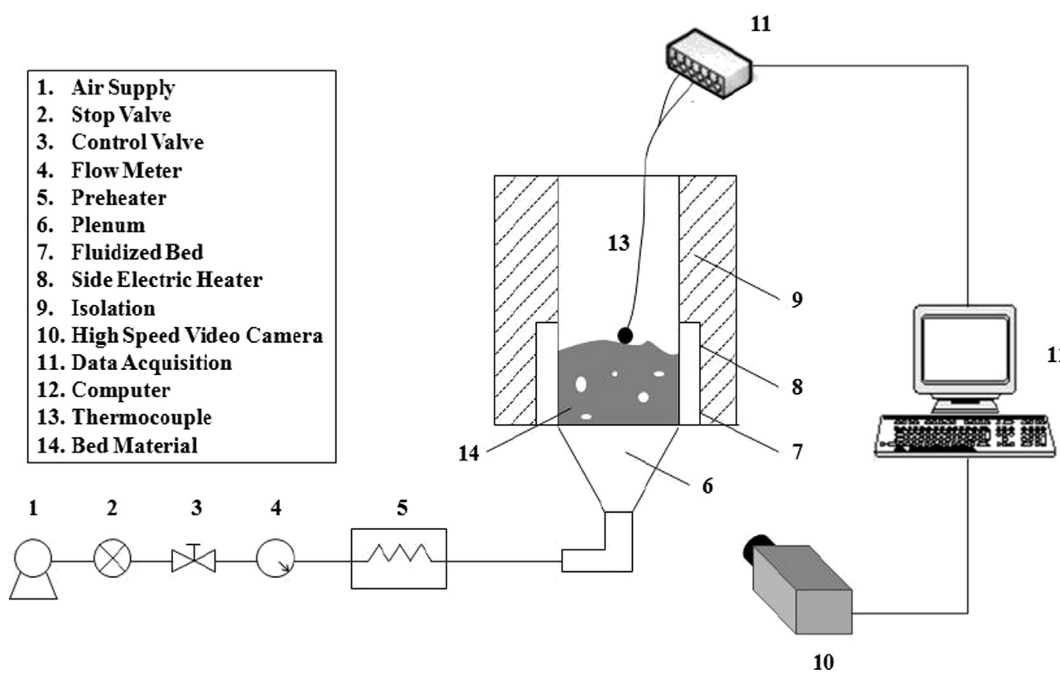

Fig. 2. Schematic diagram of the fluidized bed.

Table 1
Inert bed material properties used in the experiments.

Particle material	Glass beads
Particle density	2500 kg/m^3
Mean diameter	330 µm
Fluid heat capacity	1010 J/kg K

Table 2
The measurement instrument error of the experiment.

Instrument	Unit	Error
Thermocouple	°C	1.5 for T < 350 °C 0.004 T for T > 350 °C
PIV	m/s	0.006
Scale	mg	0.001

reactions resulting in the release of volatiles from the fuel particle to the ambient.

Because of the complexity and range of effective parameters, the devolatilization process of fuel particles is among the most studied subjects in the field of combustion. Stenseng et al. [3] investigated the influence of four different types of biomass particles with different sizes, ranging from 2 mg to 20 mg, on the pyrolysis process, using a thermogravimetric analysis and differential scanning calorimetry. Chen et al. [4] carried out an experiment on the pyrolysis of cubic Chinese fir wood with side lengths of 28 mm in a laboratory-scale turbulent fluidized bed reactor. The pyrolysis time of the particle in different bed temperatures ranged from 450 °C to 700 °C and was estimated using a CT scans method. Sudhakar and Kolar [5] did an experiment to investigate the effect of initial particle size and shape of the fuel particle on the devolatilization time and char yield in a hot fluidized bed. Fang et al. [6] studied the effect of bed temperature and fuel species on the thermochemical conversion process and devolatilization time in a fluidized bed. Shrinkages at different residence times were also measured using a computed tomography (CT).

Sreekanth et al. [7] conducted an experiment to measure the devolatilization time, wood char size and mass during the thermochemical