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Experimental investigation on the flow characteristics of rice husk in a fuel-rich/lean burner

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HIGHLIGHTS

- The separation performance of rice husk in an impact-block-type burner was investigated.
- Effects of block height and inlet particle concentration on the separation performance were studied.
- The impact block had greater effect on larger particles.
- The separation behaviors of rice husk were opposite to coal particle with increase of inlet solid concentration.
- The rich/lean concentration ratio of rice husk was always larger than that of coal particle.

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ABSTRACT

The particle dispersion mechanisms of rice husk in a fuel-rich/lean burner with an impact-type concentrator were investigated by both digital imaging technique and sampling method. In the experiments, a model burner with a scale ratio of 1/2.708 was studied employing an optical measurement system which consisted of a charge-coupled device (abbreviated as CCD) camera and a laser sheet for illumination. Effects of different impact block heights and inflow particle concentrations on the distribution of rice husk were studied. The distribution of husk particles was obtained by measuring local particle appearance frequency ratio (abbreviated as AFR) within the field of view. Then the size distributions and mass ratios of particles collected from the solid-rich and solid-lean sides were obtained by sampling methods. Increasing the impact block height resulted in a great increase of the rich/lean ratio of particle appearance frequency (abbreviated as RL) at the exit of the burner, as the ratio of 1.66, 5.21 and 9.55 for the block height of 40 mm, 50 mm and 60 mm. Similar tendency was observed when increasing the inflow particle concentration (9.55, 10.57 and 11.87 for 0.1, 0.2 and 0.3 kg/kg). The mean size of particles on solid-rich side was always larger as compared with that on the solid-lean side.

1. Introduction

Coal plays a dominant role in China's primary energy structure, and is one of the largest sources for the production of electricity worldwide. Coal accounted for 69% of the total energy consumption in China. The total coal consumption of the world was nearly 8.19 billion tons in 2012, and China consumed nearly as much coal as the rest in the world combined with a coal consumption of 3.89 billion tons [1]. However, combustion of coal adds a great amount of pollutants to the atmosphere such as NOx, SO_2, CO_2, and fine particulate matter. In 2012, China emitted about 8106 million tons of CO_2 to the atmosphere, which intensified the greenhouse effect [2]. At the 2009 United Nations Climate Change Conference held in Copenhagen, China promised to reduce its CO_2 emissions by 40–45% between 2005 and 2020. So it's urgent to find a proper way to reduce the coal consumption.

As a substitute to fossil fuel in coal-fired utility boiler, biomass fuel has attracted a lot of attention. Biomass is a renewable energy source with low content of sulfur and nitrogen, leading to less emissions of SO_2 and NOx compared with coal [3,4]. Besides, biomass is considered to be CO_2-neutral due to the photosynthesis of plants. Firing biomass in thermal power plants has advantages in reduction of coal consumption, CO_2, NOx, SO_2 and fine particles emissions [5–9]. Biomass can be pulverized using the existing mill system without any additional equipment and introduced into the furnace from the existing combustors. As a consequence, it is very convenient to combust biomass in existing furnaces [10].

The amount of rice husk is very abundant in China. In 2013, 203.6 million tons of paddy rice was produced. Rice husk is the

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outer cover of the rice and on average it accounts for 20% of the paddy produced, on weight basis. In recent years, many studies have focused on combustion characteristics of rice husk in different combustors. Fang et al. [11] reported a research in which fluidization and burning characteristics of rice husk were investigated in circulating fluidized bed. Their results indicated that it was hard to fluidize the rice husk particles alone. Armesto et al. [12] investigated the combustion efficiency and CO emissions of rice husk in a 30 kW/h bubbling fluidized bed, and the properties of ash were also studied. Madhiyanon et al. [13] also investigated the combustion of rice husk in a fluidized bed, and the results indicated that increasing excess air could cause the increase of CO and NOx emissions. Su et al. [14] performed experimental studies to evaluate the reburning properties of rice husk in a single-burner furnace, and NO reduction efficiency of 58% was achieved. As is known, the flow characteristics of pulverized fuel out of the burner have great effects on the combustion process. Many burners with different structures have been developed to concentrate pulverized coal to form a reasonable gas–particle structure. However, how biomass particle would behavior in these burners was rarely investigated.

To achieve lower NOx emissions and higher combustion efficiency, various kinds of fuel-rich/lean-type burners have been widely used in power plants in China. The fuel–air mixture is separated into two streams by the concentrator, and injected into different zones in the boiler. The fuel-rich stream is close to the center of the boiler to provide fuel for combustion and ensure the flame stability. The fuel-lean zone locates between the fuel-rich zone and the furnace waterwall, hence oxidizing zone is formed near the waterwall. The oxidizing atmosphere leads to the raise of ash fusion temperature, thus ash deposition and corrosion can be reduced. In addition, the nonstoichiometric combustion leads to the reduction of NOx emissions [15,16]. The present work is concerned with a collision-block-type burner with height and width of 120 and 160 mm, as shown in Fig. 1. The scale ratio of the burner model is 1/2.708. The concentration ratio between the solid-rich side and the solid-lean side can be regulated by adjusting the block height. In our previous works, experiments have been conducted to investigate the separation characteristics of coal particles (modeled by talcum powder particles) [17,18]. However, few experiments have been conducted to investigate the separation performance of this kind burner using rice husk as the conveyed material.

To describe how the concentrator separates the gas–particle mixture, the distribution characteristics of particles need to be measured. Different optical techniques have been reported in many investigations to measure gas–solid two-phase flow. Fiber-optic probe was employed to measure the concentration and size distributions of fine particles [16–18]. Yan and Rinoshika [19] reported an investigation in which polyethylene particles were conveyed in a horizontal pipeline with dune model. The profiles of velocity and concentration of particles were obtained by high-speed particle image velocimetry technique. An important observation was that the dune model had greater impact on larger particles. Wu et al. [20] developed a trajectory imaging based method for measuring the velocity and diameter of coal particles, and the results agreed with those obtained by particle image velocimetry and shadow imaging method. Carter and Yan [21] combined the digital imaging sensor and electrostatic sensor to measure the concentration and velocity of the particles. Gao et al. [22] employed three lasers of different wavelengths to illuminate the biomass particles, and three sub-images of different channels were separated from an single image to obtain the size and shape data.

The aim of this work is to investigate the solid-rich/lean separation behaviors of rice husk in the burner mentioned above. A laser sheet and a CCD camera were employed to 'freeze' particles that appear at various cross-sections of the model. The particle appearance frequency was then determined through the digital image processing. In addition, sampling method was also employed to further evaluate the separation performance. Particles from both the solid-rich side and solid-lean side were collected by filter bags. The two influence factors of the impact block height and solid concentration were taken into consideration.

2. Experimental

2.1. Test facility

The flow characteristics of rice husk were investigated in a pneumatic conveying test facility which consisted of feeding, collecting and measuring system, as showed in Fig. 1a. An electromagnetic vibrating feeder was used to discharge rice husk particles into the pipeline. Various inflow solid concentrations were obtained by adjusting the vibration frequency of the calibrated feeder. The arrangement of the image acquisition system and the positions of measured cross-sections are illustrated in Fig. 1b. Three different cross-section positions of 460, 600, and 720 mm were selected to gain detailed information about the flow characteristics. A continuous laser beam, with maximum power up to 4 W, was transformed into a lase sheet by special lens. A CCD camera was used to capture the images of particles at the illuminated cross-sections. The angle between the laser sheet and the model axis was kept as 45°, and the camera axis was perpendicular to the laser sheet. Sampling method was employed to collect rice husk from both solid-rich side and solid-lean side by specially designed filter bags. The pore size of the filter bags was small enough to collect the rice husk. To eliminate the disruption of the two-phase flow, the filter bags were made long enough and the feeding amount was controlled to a reasonable magnitude. Then mass and size distributions of collected particles were analyzed.

2.2. Material

The rice husk investigated in the present work was made from indica type rice produced in Ningbo, China, with bulk density of 102.45 kg/m^3 and true density of 500 kg/m^3. Particle size distributions in various cases obtained by traditional sieving analysis were compared to evaluate the separation performance. The size distribution of rice husk particles is illustrated in Fig. 1c.

2.3. Experimental conditions

The major influence factors investigated were the impact block height and the solid concentration in the primary air. Three various block heights of 40, 50, 60 mm, and solid concentrations of 0.1, 0.2, 0.3 kg/kg, were investigated in this work. The experimental parameters are listed in Table 1. In order to study the difference with the real operation conditions, the important dimensionless numbers should be considered, such as the Reynolds number Re and particle Stokes number St. They are defined as:

$$Re = \frac{\rho U D}{\mu} \quad (1)$$

$$St = \frac{\rho_p d_p^2 U}{18 D \mu} \quad (2)$$

where ρ is the air density, U is the flow velocity, D is the characteristic length scale, ρ_p is the particle density, d_p is the particle diameter, and μ is the fluid dynamics viscosity.