Fuel 218 (2018) 49–58

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Morphological and structural evolution of bituminous coal slime particles during the process of combustion

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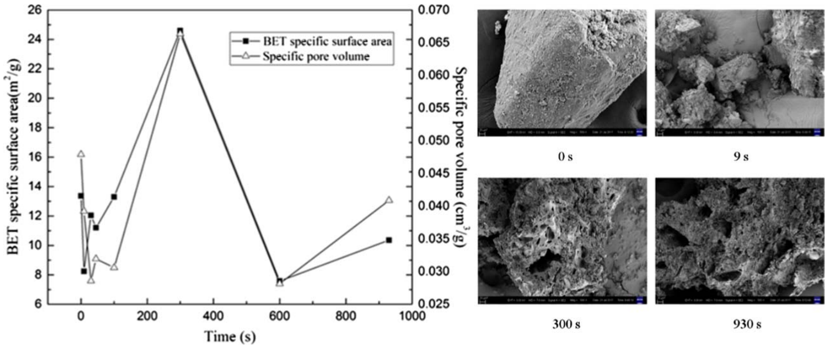
GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Coal slime
Combustion
Morphology
Structure

ABSTRACT

The evolution processes of the structure and morphology of coal slime spherical particles in the process of combustion in an air atmosphere are examined in this work. A high-definition camera was used to capture changes in the macrostructure of the particles in the process of combustion, and a large amount of educt at the stage of homogeneous combustion was studied. The main component of the educt was graphite, as determined by X-ray diffraction(XRD),which demonstrated the process whereby the organic carbon molecule structures are transformed from a complicated and disordered condensed aromatic nucleus macromolecular structure to ordered graphite molecules with simple structures inside coal slime particles. Using a conducting N_2 adsorption test and analysis, this study found that there were a number of mesopores and a handful of micropores inside the coal slime particles. The pore structures experienced a process that varied from complicated at the initial moment to simple, to complicated and finally to simple. Scanning electron microscope (SEM) photos proved the change process of the above pore structures and found the phenomenon whereby pyrolytic products filled the pores at the stage of homogeneous combustion.

1. Introduction

Coal is an important energy source in China and accounting for more than 60% of the country's energy consumption, which has already reached 3.41 billion t/y in 2016 [1,2]. The worldwide excessive exploitation and use of coal leads to problems such as worsening coal quality and aggravating environmental pollution, health problems [3–6] and then results in increasing quantities of coal preparation. Coal slime is a by-product of the process of coal preparation. Due to its special generation process, coal slime, whose particle sizes are less than

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https://doi.org/10.1016/j.fuel.2018.01.022
Received 11 October 2017; Received in revised form 26 December 2017; Accepted 6 January 2018

1 mm in general, is characterized by high water holding capacities, high ash and low heat values [7,8]. Because of the above characteristics, coal slime is mostly abandoned directly or sold to local residents. The improper utilization mode of coal slime leads to resource waste, water, soil, and air pollution [9,10]. In those cases, the value of coal slime cannot be fully embodied. Circulating fluidized bed (CFB) boiler shave advantages that include extensive adaptability and low pollutant emissions [11–13], Therefore, CFB boilers are among the best ways to use coal slime. It is of great importance for the combustion and utilization of coal slime to study the evolutionary processes of the morphology and structure of coal slime in the process of combustion.

Wang et al. [14] studied the structural and morphological change of a coal-water slurry combusted in a bench-scale fluidized bed, removed coal water slurry particles at different moments to conduct an SEM analysis on their micro-morphologies and adopted the method of nitrogen adsorption to analyze changes in their porosities. The results showed that the porosities of the particles experienced a process of decrease after increasing and that the micro-morphologies also experienced a process whereby they evolved from simple to complicated and finally to simple [15,16]. After 15 s, the release of volatile components in the coal-water slurry gave rise to particle breakage and the formation of numerous pores. Due to the breakage of particles, flames burst into the interior of the particles and the particles burned, which produced cavities inside them. Liu et al. [17] used thermogravimetry, XRD, SEM, Raman spectra and other techniques to study the structure and dynamics of coal coke under a CO_2 gas condition. Based on research employing BET and SEM, it was found that the pore structure of the coal coke increased rapidly with the development of the conversion rate and collapsed quickly when the conversion rate reached up to 90%. From the XRD and Raman spectral analyses, it was found that graphite and amorphous carbon in the skeleton structure of the carbon witnessed an increase in proportion to the increase in conversion rate. Lee et al. [18] studied the relationship between the changes in the pore structure of two kinds of coal and temperature during the processes of pyrolysis and gasification and illustrated the relationship between pore structure and combustion reactivity. They found that coal with high BET specific surface areas was caused by the ash pore structure. The distribution of ash content was relatively dispersed, which resulted in more developed pore structures and surface areas and then increased combustion reactivity. Yi et al. [19] studied the changes in the carbon content and surface and pore structures of char in different atmospheres and under a condition of high water content. Fan et al. [20], took advantage of the XRD technique to analyze the impact of temperature and rate of temperature increase on coal structure and used the program proposed by Shi et al. [21] to calculate the structural parameters of carbon crystals; it was found that the XRD showed two peaks in the graphitization and ordering of carbon crystal structure in the process of pyrolysis. Predecessors have conducted numerous works on the structure of coal in the process of pyrolysis, gasification and combustion [22–26], but structural changes in coal slime in the process of combustion have been seldom studied.

Zhou et al. [27] studied the static combustion characteristics of coal slime particles in a drop tube furnace, explored the combustion characteristics of coal slime particles under conditions of different furnace temperatures, oxygen concentrations, and convection intensities, used a high-speed camera to capture combustion images of coal slime particles and divided the combustion behaviors of coal slime particles into the heterogeneous ignition of char, heterogeneous ignition of coal and homogeneous ignition of volatile matter. Yin et al. [28] adopted the method of numerical simulation to simulate the change rules of the motions, drying and temperatures of large coal slime particles in a CFB boiler. Wu et al. [29] adopted the method of thermogravimetric analysis to analyze the combustion parameters of three kinds of coal slime at different heating rates and used the distributed activation energy model (DAEM) and Ozawa–Flynn–Wall (OFW) methods to compute the dynamic parameters of coal slime, including combustion activation energy under different conditions. The above researchers mostly focused on studying the combustion characteristics of coal slime. The structural evolutionary characteristics of coal slime in the process of combustion remain to be explored.

This study analyzed changes in the macro-morphology of coal slime spherical particles in the process of combustion, conducted N_2 adsorption, XRD and SEM tests by removing coal slime particles at different moments in the combustion stage and analyzed the changes in the morphology and structure of the coal slime. Combustion process of coal particles is partially controlled by the internal diffusion of oxygen, which can be improved by structural changes, then influence burning rate, combustion efficiency and other characteristics further [30–32]. In this way, investigation of morphological and structural evolution of the coal slime particle can reflect change degree of internal conditions, then its combustion characteristics. Combustion conditions of this paper are set on purpose to be near CFB conditions, so the results can be used to give instruction for coal slime utilization in CFB boilers.

2. Experimental

2.1. Experimental system and method

The experiments were conducted on the experimental system shown in Fig. 1 [33]. The quartz tube of the horizontal furnace had an inner

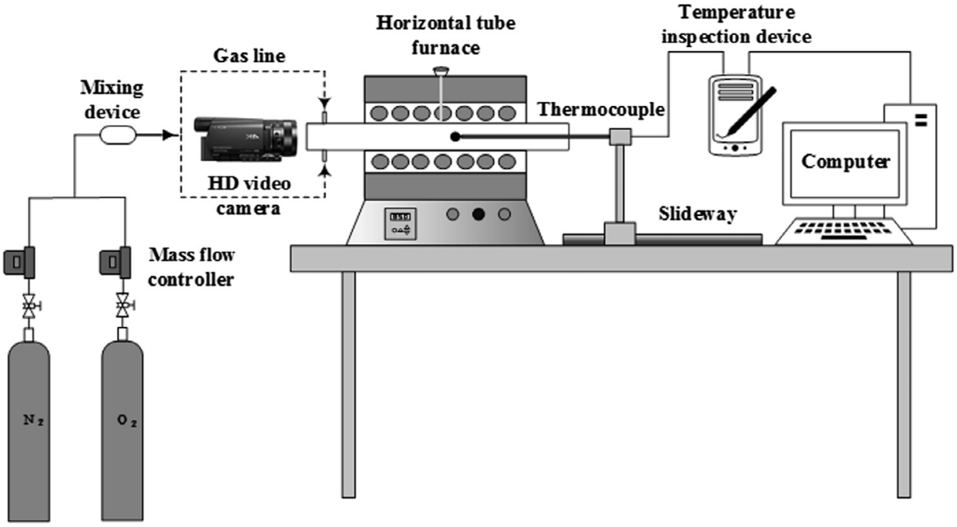

Fig. 1. Schematic diagram of the experimental device [33].