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Experimental study on the combustion sensitivity parameters and pre-combusted changes in functional groups of lignite coal dust

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ABSTRACT

Sensitivity parameters are critical for safety management and risk assessment of coal dust combustion process. In this paper, in order to evaluate the combustion sensitivity parameters and reveal the mechanism of lignite coal dust, 20 L spherical explosion test apparatus and hot surface test apparatus were chosen to test the typical sensitivity parameters of lignite coal dust combustion. Results show that the limiting oxygen concentration of dust clouds (LOCC) was in the range of (13–14) %, and the minimum ignition temperature of dust layer (MITL) was in the range of (280–290) °C, respectively. The functional group variation law before combustion of lignite coal dust was tested by in-situ diffuse reflection Fourier transform infrared spectrometry (FTIR), and the proportions of functional groups in the lignite coal dust were analyzed from 30 °C to 290 °C. It is demonstrated that in coal dust combustion the key functional groups were —CH_3/—CH_2— and —OH.

1. Introduction

Dust combustion accidents occur very frequently in industries all over the world, and the potential danger in coal industry is particularly serious. Statistical data show that 79.93% of the coal seams in China have a potential for spontaneous combustion, and the data also indicate that more than 500 people have died in mine fires and explosion accidents resulted from the spontaneous combustion of coal during the period of 2001–2012 [1].

To understand the sensitivity parameters that are necessary conditions for coal combustion, in recent years, the limiting oxygen concentration of dust clouds (LOCC) and the minimum ignition temperature of dust layer (MITL) which are the typical sensitivity parameters have been studied considerably. For example, Mittal [2] investigated the LOCC by 20 L spherical explosion test apparatus and found that the level of coal dust combustion pressure decreased increasingly with the reduction of the oxygen concentration and the coal dust would not be ignited when the oxygen concentration reduced to a certain value. It demonstrated that the storage safety of the coal dust would be effectively improved by reducing the oxygen concentration. Janes [3] analyzed the self-ignition of a dust layer by a hot surface test apparatus, which demonstrated that the MITL gradually decreased with the increase of the thickness of the coal dust layer and suggested that the thickness of the coal dust layer had a certain effect on heat accumulation in the spontaneous combustion. Rangwala [4] studied the combustion temperature of coal dust layer with various thicknesses and revealed the reason of combustion is due to the heat obtained from the hot surface being higher than the heat loss.

The coal dust combustion results from the heat accumulation and is essentially a chemical reaction process of functional groups on the coal dust [5,6]. In order to further comprehend the temperature rising characteristic and chemical reaction mechanism of coal combustion, it is necessary to better understand the changes of these groups during coal temperature rising. The real-time change of coal dust active groups has been observed by using in-situ diffuse reflection Fourier transform infrared spectrometry (FTIR). For example, Qi [7,8] successfully designed an in-situ diffuse reflection FTIR system to test the real-time chemical variations during the coal reaction and concluded the presence of aliphatic groups on the coal varies with temperature. Wang [1,9–11] studied the distributions and concentrations of functional groups in coal during the oxidation process by the oxidation dynamic theories and quantum chemistry models.

However, to the best of our knowledge, as the previous testing methods are limited, the mechanism of the coal reaction is still unclear. Therefore, in this paper, we have selected lignite coal dust which is abundant in China as target. The two sensitive parameters, LOCC and MITL were investigated by 20 L spherical explosion and hot surface test apparatus, respectively. Furthermore, in-situ diffuse reflection FTIR was applied to analyze the variation law of functional groups

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Table 1
Proximate and ultimate analysis of the coal.

Sample	Proximate analysis (%)				Ultimate analysis (%)			
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C	H	O	N
Coal	3.54	14.46	41.75	40.25	57.05	4.43	37.4	1.12

M_{ad}: moisture content; V_{ad}: volatile matters; A_{ad}: ash; FC_{ad}: fixed carbon.

during lignite coal heat accumulation phase quantitatively, and the functional groups before the combustion of lignite coal dust were elucidated. The purpose of this work is to reveal the mechanism of lignite coal combustion by combining macroscopic sensitivity parameter tests with the microscopic molecular spectroscopy.

2. Experimental

2.1. Experimental materials

The proximate and ultimate analyses of the coal particles are summarized in Table 1. The lignite coal particles were sifted in a 200 mesh vibrating sieve and were desiccated in a vacuum drying oven at 30 °C for 24 h before the experiments. The median diameter of the lignite coal particles measured by laser particle size analyzer was 34 μm.

2.2. Experimental apparatus

2.2.1. 20 L spherical explosion test apparatus

As seen in Fig. 1, this test system consists of a 20 L spherical explosion chamber, a dispersion system, an ignition system, a control and a data acquisition system. A pyrotechnical igniter of 2 kJ energy prepared according to the standard [12] is located in the center of the explosion chamber, and the chamber is vacuumed to −0.06 MPa (gauge pressure). A two phase valve is mounted under the bottom of the vessel, and is driven by compressed gas. A dust chamber of 0.6 L is connected to the two phase valve and pressurized to 2 MPa. After opening the two phase valve, the lignite coal dust sample is dispersed into the explosion chamber and formed into dust clouds by compressed gas through the dispersion nozzle. When the pressure in explosion chamber increases to 0 MPa (a standard atmospheric pressure), the pyrotechnical igniter is detonated to ignite the dust clouds. The dynamic pressure during the lignite coal dust combustion is recorded by the pressure sensor, and the LOCC can be obtained.

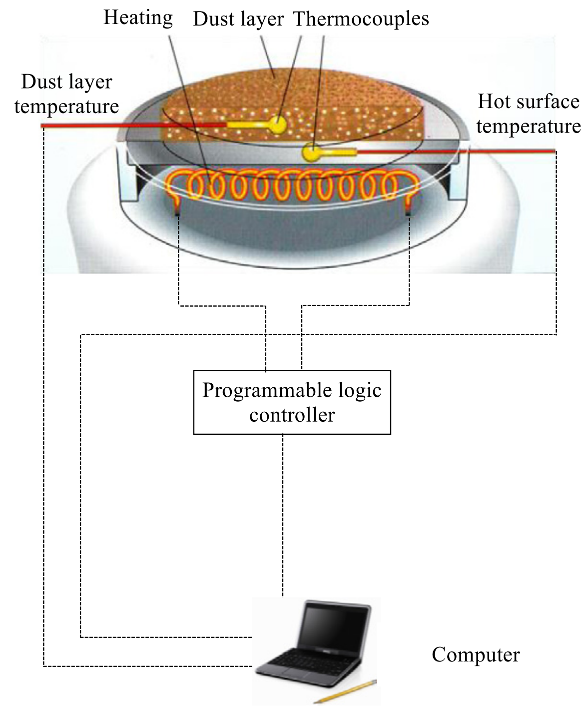

Fig. 2. Schematic diagram of hot surface test system.

2.2.2. Hot surface test apparatus

MITL is tested in hot surface test apparatus, which is schematically shown in Fig. 2. The sample is placed within a metal ring on the top of a hot plate presetting to a constant temperature, and to form a 12.7 mm [13] thickness of the lignite coal dust layer within 2 min. The temperatures of the hot surface and the dust layer are monitored by

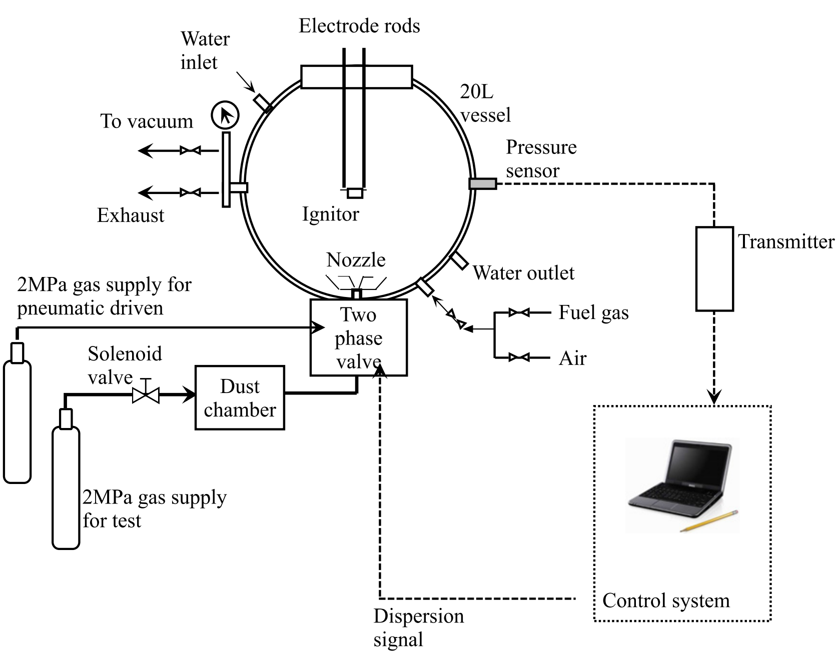

Fig. 1. Schematic diagram of 20 L spherical explosion test system.