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Particle charging and conveying characteristics of dense-phase pneumatic conveying of pulverized coal under high-pressure by N_2/CO_2

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A B S T R A C T

The particle charging and conveying characteristics of pulverized coal under high-pressure dense-phase pneumatic conveying were investigated experimentally using CO_2 and N_2 as carrier gas, respectively. A novel sensor was designed through a combination of EST sensor and ECT sensor to simultaneously obtain the information of the electrostatic charge and volume concentration of pulverized coal. Experimental results indicated that the increment of the conveying pressure difference could cause the changes of flow pattern from laminar flow to suspension flow for both CO_2 and N_2. The volume concentration of pulverized coal conveyed by CO_2 was greater than that by N_2 under the same conveying pressure difference, and the same conclusion can be obtained for the mass flow rate. The significant difference with CO_2 and N_2 as carrier gas was found and defined in term of the charging characteristics of pulverized coal. The change of charging intensity of pulverized coal exhibited the converse trend for CO_2 and N_2, which indicated that the carrier gas played an important role in the particle charging of dense-phase pneumatic conveying. A comparison was made further for the relationship between volume concentration and charge intensity of pulverized coal, which was proved to be negative correlation for both CO_2 and N_2.

1. Introduction

Pneumatic conveying has been widely used in the industrial and agricultural fields. It is generally divided into two categories, dense-phase conveying and dilute-phase (or lean-phase) conveying [1]. Dense-phase pneumatic conveying has the characteristics of high solid–gas ratio (300–600 kg/m^3) and low gas velocity. Its typical patterns observed in the horizontal conveying of powder include slug flow, dune flow, stratified flow and suspension flow [2]. In dilute-phase conveying, particles usually exhibit the suspension flow with high gas velocity. Compared with dilute pneumatic conveying, dense pneumatic conveying has many advantages including the lower velocity and power consumption, higher solid-mass flow rate, and fewer abrasions on pipe. As the transport medium supplying flow power, carrier gas has significant influence on the flow characteristics of dense-phase conveying of pulverized coal under high pressure.

Some work has been done in the area of pneumatic conveying of pulverized coal using various gases. Liang et al. investigated the effects of coal type, particle size and moisture contention on conveying characteristics through conducting the experiments of dense-phase pneumatic conveying of pulverized coal using nitrogen. They found that the fluidizing gas flow rate had a significant effect on the mass flow rate of pulverized coal [3]. Liu et al. performed the experiments and validated that the dense-phase conveying of pulverized coal could be smoothly and controllably operated when using carbon dioxide as carrier gas [4]. Cong et al. investigated the conveying characteristics of pulverized coal pneumatic conveying using CO_2 and air respectively [5]. They found that the energy consumption with CO_2 was about 7.5% higher than that with air at the same gas flow rate, but the required energy with CO_2 was increased by about 20% than that with air at the same solid mass flow rate. Lu et al. studied the effect of gas type on hopper discharge of pulverized coal [6].They found that CO_2 was hard to escape from the adsorbed pulverized coal, and CO_2 achieved higher gravity solid discharge compared to air.

Moreover, particle charging of pulverized coal is an unavoidable and universal phenomenon in gas-solid two-phase flow due to the interactions and frictions between particle-particle, particle-wall and particle–carrier gas. It influences the flow behaviors of pulverized coal, and even causes dangerous explosion in some cases [7–9]. However, the powder particle charging can also be utilized to achieve measurements of some flow parameters of gas-solid two-phase flow in dilute pneumatic conveying. Zhou et al. designed an electrostatic sensor array to measure particle concentration downstream of a swirl burner [10]. The ability of the designed sensor in field measurement was validated in their work. Zhe et al. studied the velocity measurement with inserted electrostatic sensor in the gravity conveying rig and confirmed the feasibility of the method [11]. Wang et al. proposed a method to

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measure the particle velocity distribution in the pipeline of dilute horizontal pneumatic conveying [12]. Zhou et al. fused the data of ECT sensor and EST sensor to get more accurate charge distribution in gas–solid flow [13]. For dense-phase gas–solid flow, its flow process is characterized by the lower gas velocity compared with dilute-phase flow. Dong et al. have found that the electrostatic charge had significant influence on the hydrodynamics of the powder particles with lower gas velocity in the fluidized bed [14]. But fewer investigations have been made for dense-phase pneumatic conveying of pulverized coal under high pressure.

In this paper, the particle charging and conveying characteristics of pulverized coal under high pressure dense-phase conveying were investigated experimentally by using CO_2 and N_2 as carrier gas respectively. A novel sensor was designed to achieve the simultaneous acquisition of the electrostatic information and volume concentration of pulverized coal. The flow regime and conveying capabilities of pulverized coal were analyzed by means of ECT (electrical capacitance tomography) sensor and load cells. The electrostatic charge of pulverized coal was investigated with EST sensor. A comparison between the conveying processes considering two kinds of carrier gases, CO_2 and N_2, was made in terms of flow regime, conveying capability, particle charging characteristics, as well as the relationship between electrostatic charge and volume concentration of pulverized coal.

2. Experimental setup

2.1. High-pressure pneumatic conveying system

Fig. 1 shows the schematic diagram of the high pressure dense-phase conveying system, which consisted of four parts including gas source, hopper, conveying pipeline, sensors and data collection system. Two identical hoppers were arranged symmetrically, each of whose volume was 0.648 m^3. They can be treated as the feeding tank or receiving tank by switching the valve mounted on the conveying pipeline. The conveying pipeline was made of a smooth stainless steel with an internal diameter of 10 mm and total length of about 53 m. In the experiments, the fluctuation of the mass flow rate of pulverized coal was obtained by three load cells, which were attached below the left hopper. The ECT sensor and EST (electrostatic tomography) sensor were mounted on the horizontal testing part of the conveying system. Signals from all sensors were obtained by a multichannel sampling system and then were sent to the computer through a data collection card. The operational principle of the conveying system used in this paper was described by H. Zhou, et al. [15]. The pressure of the buffer tank was maintained to be 4 MPa in the whole conveying process.

2.2. Sensor

In this paper, a novel sensor was designed through a combination of ECT sensor and EST sensor, which is shown in Fig. 2. ECT sensor is sensitive to the particle distribution and concentration, while EST sensor is sensitive to the particle charging and velocity. Both of them have the similar sensing zone. Thus more information of gas–solid flow can be obtained by combination of two sensors. ECT sensor consisted of a capacitance sensor array with eight electrodes, and EST sensor consisted of an electrostatic sensor array with eight electrodes. A ring electrode between them was earthed for isolating the two sensor arrays and eliminating the mutual effects of each other. Two ring electrodes on both sides of the sensor arrays were earthed to eliminate the fringe effect. All electrodes were attached outside a quartz glass tube with an internal diameter of 10 mm and an outside diameter of 20 mm. The length of electrode of ECT sensor was 80 mm, and width was 5 mm. The length of electrode of EST sensor was 10 mm, and width was 5 mm. The capacitance measurement was implemented by AC method, its detail can refer to [16]. This configuration of the sensor minimized the distance between ECT sensor and EST sensor, and made it possible to approximate the measurement section of both sensors to be the solidification flow. Thus the information of the two sensors can be feasibly guaranteed to be consistent. The sensor worked with a sampling frequency of 1500 Hz for each electrode of EST sensor and 2072 Hz for ECT sensor, which can get 74 frame images per second. (2072/28 = 74 fps, 28 capacitance values per frame). Prior to the experiment, ECT sensor must be calibrated. After the outlet at the lower end was blocked, the full-sensor capacitance values were recorded by

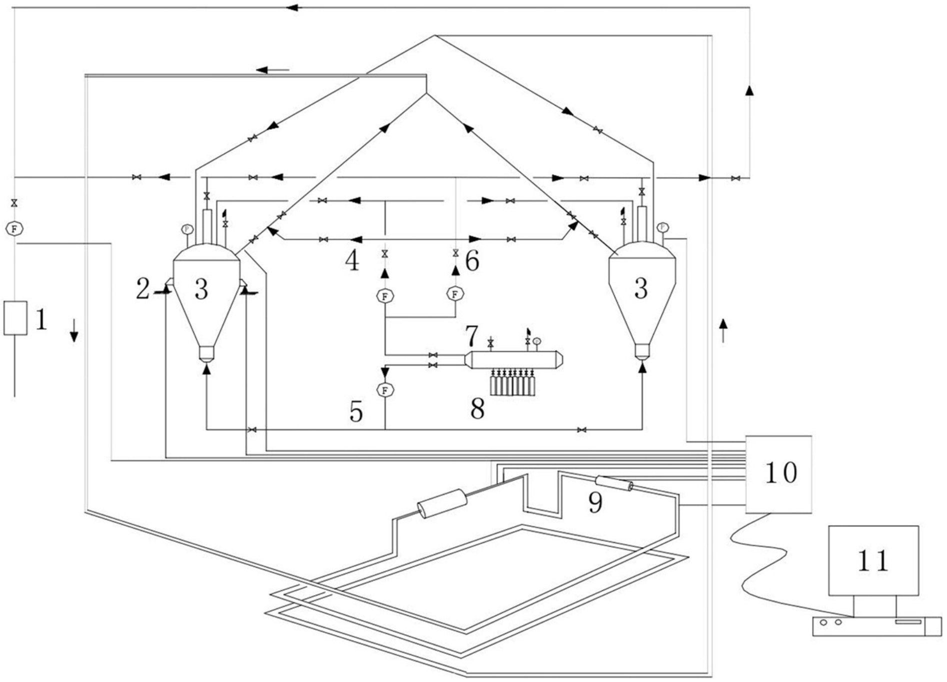

Fig. 1. Test rig schematic of dense-phase pneumatic conveying under high pressure. 1. Motor-drive control valve; 2. Weigh cell; 3. Hopper; 4. Pressurizing gas; 5. Fluidizing gas; 6. Supplemental gas; 7. Buffer tank; 8. Cylinders; 9. Horizontal test section; 10. Data acquisition; 11. Computer.