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Online monitoring and characterization of dense phase pneumatically conveyed coal particles on a pilot gasifier by electrostatic-capacitance-integrated instrumentation system

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ABSTRACT

The transportation of pulverized coal in gasification system needs to be carefully monitored and regulated with respect to the operation stability, gas quality and energy efficiency. In this paper, an integrated instrumentation system is developed to continuously monitor the pulverized coal flow within a 30 mm horizontal pneumatic pipe on a pilot coal gasifier at low pressure. The instrumentation system calculates the mass flow rate of pulverized coal by measuring the particle mean velocity with two ring-shaped electrostatic sensors and particle concentration with a helical capacitance sensor. The system is calibrated and optimized before the field experiments, especially the optimal structure of the helical capacitance sensor with a homogeneous sensitivity distribution is achieved by static tests to minimize the influence of the uneven particle concentration distribution on the particle concentration measurement accuracy. Experiments are carried out under various operation conditions to characterize the flow of pulverized coal particles using the integrated instrumentation system. The regulating effects of the operation parameters of the pneumatic conveying system (the angle valve opening, the fluidized gas and supplement gas flow rates, the pressure within the feeding tank) on the particle velocity, concentration and mass flow rate are experimentally studied. Results demonstrate that the integrated instrumentation system can effectively monitor the dense phase pneumatically conveyed coal particles flow on the pilot coal gasifier. Both the angle valve and the pressure within the feeding tank are effective to control the mass flow rate via regulating the particle concentration. The supplement gas can regulate the particle velocity and concentration simultaneously.

1. Introduction

Gasification fed with dry pulverized coal fuel particles is a process that converts coal into syngas, a mixture consisting primarily of carbon monoxide, hydrogen, carbon dioxide, methane and water vapor. This is achieved by concurrently reacting the coal particles with steam and oxygen or air in suspension at high temperature [1]. For satisfactory operation of the gasification system with respect to operation stability, gas quality and energy efficiency, it primarily requires a good control of fuels and air or oxygen to achieve a reasonable matching for optimal reaction state in the gasifier.

Dense phase pneumatic conveying could be certainly adopted to feed dry pulverized coal particles into gasifier in the coal chemical industry [2]. However, the flow characteristics of the conveying process in the gas-solid system is still not fully understood because of the inherent flow randomness and instability especially for the dense phase flow, where the particle concentration is very high, ranging from 30 kg/m^3 up to 500 kg/m^3. The regulation of the particle mass flow rate highly relies on the practical tests for a given gasification system. Besides an accurate regulation to achieve the required gas production of the gasifier, both particle velocity and concentration are expected to be flexible to guarantee the conveying stability, minimize the piping abrasion and achieve the required fuel reactivity. Therefore, online monitoring techniques for coal particles flow are desirable for the real-time regulation of the pneumatic conveying system.

Many techniques have been developed for gas-solid flow measurements [3,4], while only a few could measure the dense-phase pneumatically conveyed solid particles flow because it is an unsteady and complex non-linear dynamic system with high particle concentration. Among them, electric methods, mainly including electrostatic and

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capacitance sensing techniques, have the advantages of non-invasiveness, simple structure, low-cost, high reliability and non-radiation. Especially, the electrostatic sensing technique is very practical for particle velocity measurement and the capacitance sensing technique is better applicable for higher concentration cases. Great advances have been made in particle velocity measurement in gas-solid flow by using electrostatic sensor along with signal processing algorithms. Applying cross-correlation or spatial filtering techniques, inspiring velocity measurement results have been obtained in both laboratory and field experiments [5–14]. Besides, the velocity measurement is not subject to the particle concentration provided the particles can get charged in the flowing process. Although electrostatic sensor can indicate the particle concentration in dilute phase conditions [14,15], it cannot quantify the pulverized coal concentration and mass flow rate. It is because the magnitude of the electrostatic charge carried on the pulverized coal particles highly relies on the particle properties (size and shape, work functions, moisture content, permittivity, etc.) and flow conditions (velocity and concentration distributions, pipe size, bending, wall roughness, temperature, pressure, etc.) [16–18].

On the other hand, capacitance method has been successfully employed for the phase concentration measurement in gas-liquid and gas-solid two-phase flows with optimized sensor structures [19–22]. It has been proved that the helical capacitance sensor has a more homogeneous sensitivity and a good potential for the particle concentration measurement. However, the re-optimization for the sensor structure is essential when the particle materials and the pipe size change. Thus, the re-calibration of the sensor for concentration measurement is also required. It should be noted that experimental tests are still essential to obtain the optimal sensor structure, although the numerical optimization can be carried out [21]. Capacitance sensor combined with cross-correlation method also can measure particle velocity [23]. Nevertheless, it is difficult to accurately measure the particles flow if the concentration is relatively low.

In this paper, an integrated instrumentation system based on electrostatic and capacitance sensors is integrated and optimized for the particle velocity, concentration and mass flow rate measurement [24]. Then, the integrated instrumentation system is utilized to monitor and characterize dense phase pneumatically conveyed coal particles flow within a 30 mm horizontal pipe on a pilot coal gasifier. Experiments are carried out under various operation conditions, and the regulating effects of the operation parameters of the pneumatic conveying system on the particle velocity, concentration and mass flow rate are systematically studied.

2. Experimental setup

The experimental setup of the pilot coal gasifier at low pressure is illustrated in Fig. 1. The coal bunker, lock hopper and feeding tank are vertically installed in sequence. The pulverized coal particles from the coal mill are stored in the coal bunker at ambient pressure. Then, they are transferred into the lock hopper before the feeding tank almost runs out of coals. The lock hopper is filled with nitrogen until its pressure reaches a requested level so that the coal particles in the lock hopper can be discharged into the feeding tank.

At the bottom of the feeding tank, a feeding device (Fig. 2) is utilized to control and transport the pulverized coal particles into the conveying pipe. The coal particles are fluidized by the fluidizing gas through porous medium. Then, the supplement gas is added into the pipe to improve the gas and solids mixture and enhance the conveying ability of the carrier gas. The following angle valve is used to control the mass flow rate of coal particles before entering the conveying pipe. Different from the normal operation, the coal particles are circularly send back into the coal bunker for cost saving. The switch is achieved by adjusting a three-way valve installed at the fuel inlet position of the burner. The vertical length of the conveying pipe is about 25 m with an inner diameter of 30 mm. The material properties of the coal particles used in the experiments are summarized in Table 1. Conventional instruments are equipped on the apparatus, such as pressure transmitters, gas flow meters and load cells.

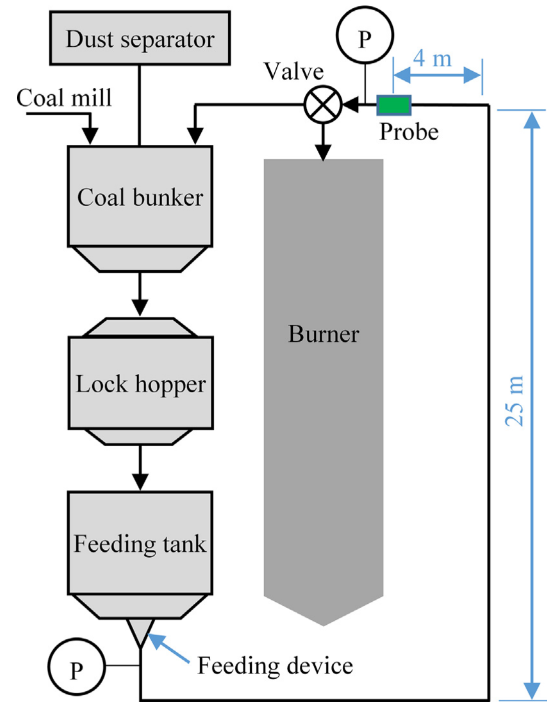

Fig. 1. Experimental setup of pilot coal gasifier.

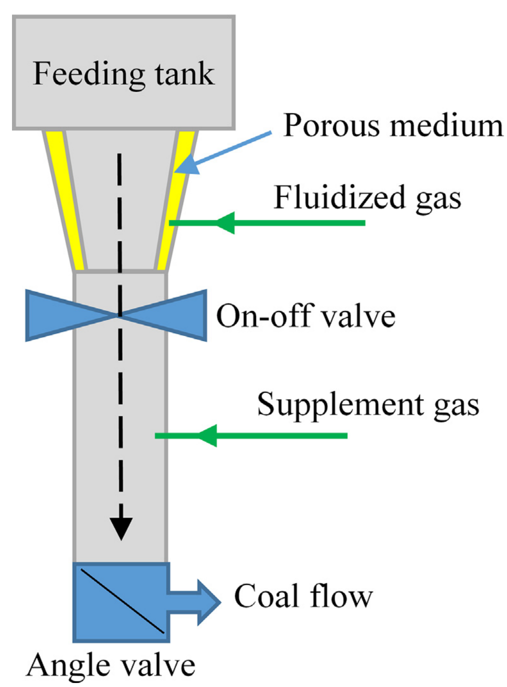

Fig. 2. Diagram of the feeding device.

Table 1
Material properties of coal particles.

Mean diameter	Density	Volatile content	Total moisture	Ash content	Fixed carbon content
75 µm	1450 kg/m^3	28.93%	6.53%	12.43%	52.11%