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Transportation characteristics of gas–solid two-phase flow in a long-distance pipeline

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ABSTRACT

In this study, experiments on fly ash conveying were carried out with a home-made long-distance positive-pressure pneumatic conveying system equipped with a high performance electrical capacitance tomography system to observe the transient characteristics of gas–solid two-phase flow. The experimental results indicated that solids throughput increased with increasing solids–gas ratio when the conveying pipeline was not plugged. Moreover, the optimum operating state was determined for the 1000 m long conveying pipeline with a throttle plate of 26 orifices. At this state the solids throughput was about 12.97 t/h. Additionally, the transportation pattern of fly ash gradually changed from sparse–dense flow to partial and plug flows with increasing conveying distance because of the conveying pressure loss. These experimental results provide important reference data for the development of pneumatic conveying technology.

Introduction

Coal production and consumption in China continue to increase rapidly, with annual raw coal production rising from 1.16 billion tons in 2001 to 3.52 billion tons in 2011. Roof control in mines using traditional caving methods causes a number of geological hazards and social environmental problems. These include ground collapse, substantial pressure deviations in the mine, spontaneous combustion of residual coal in the gob area, and destruction of underground systems, which can seriously degrade the ecological environment. Backfill technology using pneumatic conveying of powder materials is one way to control the gob area and thus help ecological environment recovery. However, long-distance pneumatic conveying of powder materials is very challenging. With the increase in conveying length, conveying pressure obviously decreased (Liang et al., 2012; Tomita, Agarwal, Asou, & Funatsu, 2008), requiring an understanding and mastery of the characteristics of gas–solid two-phase flow during the process of long-distance pneumatic conveying.

Electrical capacitance tomography (ECT) technology can monitor the characteristics of gas–solid two-phase flow in a pipeline in real time without interrupting the ongoing flow. ECT has been used for monitoring dense-phase flow and fluidization characteristics (Dyakowski, Luke, Ostrowski, & Williams, 1999; Fuchs, Zangl, & Wypych, 2007; Jaworski & Dyakowski, 2001; Lee, Quek, Deng, Ray, & Wang, 2004; Rautenbach, Melaaen, & Halvorsen, 2013; Zhu, Rao, Wang, & Sandaresan, 2003). A twin plane ECT system (Azzopardi et al., 2008) was employed to monitor the flow rate of premium coal, where coal was transported in a pipeline at a rate measured by CT images. Cong et al. (2012) studied the flow mode of vertical dense-phase pneumatic conveying of coal powder. By studying plunger flow of coarse-grain material, Mi and Wypych (1994) determined the minimum superficial gas velocity required by the plunger movement in a horizontal pipeline, and revealed through experiments that plunger velocity has a linear relationship with superficial gas velocity. Azzopardi, Teixeira, and Pulford (1999) and Giddings, Azzopardi, Aroussi, and Pickering (2007) supplemented the authors' studies on gasometry and the flow velocity of solid sparse-phase conveying. In recent years, the ECT technique has been extensively investigated as a visualization technique for measuring and imaging two-phase/multi-phase flows in real time (Liu et al., 2005; Wang, Tang, & Cui, 2009; Wang, Yang, Wang, Cui, & Gao, 2013; Yang, Zhou, Xu, & Wang, 2011).

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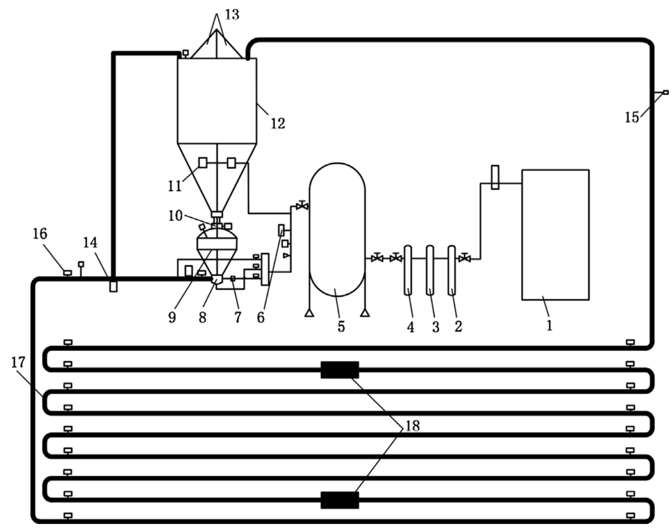

Fig. 1. Pneumatic conveying experimental system. 1. air compressor; 2. separation filter; 3. main pipeline filter; 4. effective oil-removal filter; 5. gas holder; 6. gas flow meter; 7. multi-orifice plate; 8. weighing instrument; 9. material sender; 10. feed valve; 11. gasification device; 12. storage bin; 13. gas–solid separator; 14. blocking remover; 15. solid flow meter; 16. pressure transmitter; 17. conveying pipeline; 18. capacitance sensor.

Although the use of ECT for gas–solid flow measurement has been significantly developed, the characteristic of pneumatic conveying of fly ash in long-distance pipelines has not been fully investigated. By taking advantage of the high performance ECT system, comparative studies on fly-ash conveying and its fluctuating flow characteristics at different pipeline positions (200 and 800 m) with various conveying pressures, were performed in this study. The relationship between gas inflow, throughput, and material-gas ratio under different conveying pressures and gas mass-flow rates was studied, to make a contribution to the understanding of long distance gas–solid flow characteristics.

Experimental

Set-up and instruments

The system performs pneumatic conveying using a storage bin under positive pressure, which features a simple structure, high impermeability, and large conveying capacity. The experimental set-up consisted of a gas-supply system, a gas–solid mixing system, a pipeline conveying system, a gas–solid separation system (dedusting system), a control system, and a monitoring system (see Figs. 1 and 2).

The conveying pipeline was 1000 m long, arranged at five vertical levels. Twenty-one 90° elbows there were at the bending points of the conveying pipeline. The steel-ceramic composite elbows made these points wear-resistant. The radius of curvature at the bending points was 1 m, and the pipe diameter was 120 mm.

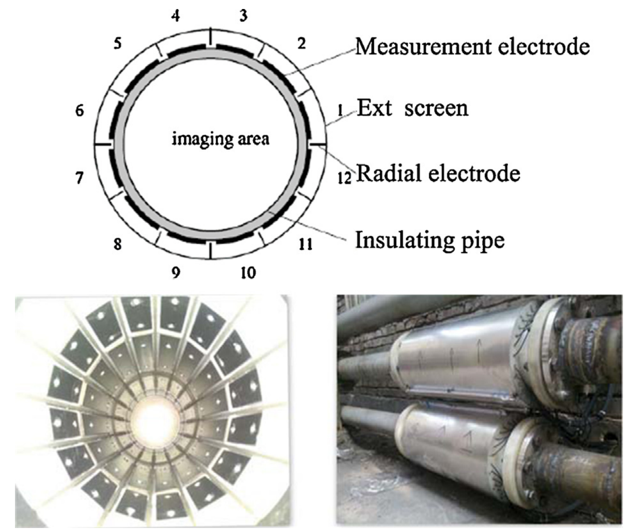

Fig. 3. Capacitance sensors for gas–solid two-phase flow measurement.

Two twin-plane ECT sensors with the same diameter, i.e. 125 mm, were installed on the pipeline. The distance between the two sensors was 600 m. Each ECT sensor was powered using a dedicated data acquisition system. The data acquisition systems were field-programmable gate array (FPGA) based and communicated with the host PC via a USB link, with a data acquisition rate of 800 frames per second (fps) (Cui, Wang, Chen, Xu, & Yang, 2011; Cui, Yang, Sun, & Wang, 2014). To avoid possible mutual interference between the two data acquisition systems, through the metal pipeline, different excitation frequencies were assigned to the two systems. In this way, the digital phase sensitive demodulator eliminated interference from the signals other than its reference signal frequency. The measured capacitance signals were sent to the host PC via USB and were stored and processed using the ECT software either online or offline. In fact, the duration of ECT measurement in an experiment mainly depended on the disk space of the host PC, i.e. up to tens of hours.

The ECT sensor was composed of 12 measurement electrodes, as well as 12 radial electrodes, an external earthed screen and an axial end screen for better measurements (Fig. 3). Flanges were used for pipeline installation. The axial length and width of the measurement electrodes were 12 and 2.6 cm, respectively. By interrogating the inter-electrode capacitances for all possible electrode combinations, the data acquisition system was able to obtain 66 capacitance measurements for each sensor plane, which were sent to the host PC for image reconstruction and data analysis. The reconstructed images presented details of the ongoing gas–solid flow. Several image reconstruction algorithms were applied in the software, e.g. linear back-projection, Landweber pre-iteration, and Newton–Raphson (Yang & Peng, 2003). The spatial resolution of the reconstructed image was relatively low. However, it offered better temporal resolution and could satisfy spatial resolution required

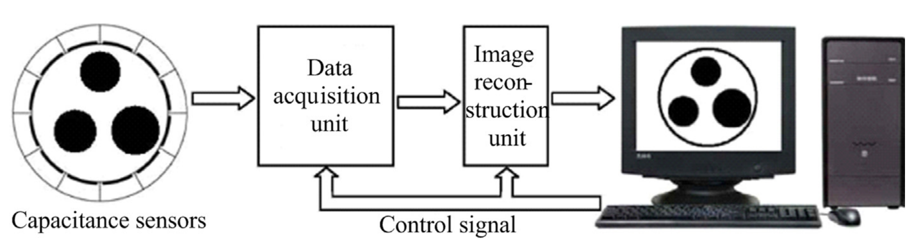

Fig. 2. Schematic of the ECT system.