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A further study on effect of gas type on pulverized coal discharge

Haifeng Lu, Xiaolei Guo, Shunlong Tao, Xin Gong *

Key Laboratory of Coal Gasification and Energy Chemical Engineering of Ministry of Education, Shanghai Engineering Research Center of Coal Gasification, East China University of Science and Technology, Shanghai 200237, PR China

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ABSTRACT

In this paper, a large-scale loop feeding system including pneumatic conveying and hopper discharge was set up; fine pulverized coal was used as the experimental material and four different procedures were designed; discharges of pulverized coal under the action of both gravity and aeration were carried out to further study the effect of gas type on hopper discharge. The experimental results were compared with each other and the effect of powder bulk state as well as feeding and aerating gases on hopper discharge was discussed. Compared to air, CO_2 is hard to escape from the adsorbed pulverized coal and thus CO_2 feeding corresponds to higher gravity solid discharge rates. The effect of gas type on hopper discharge is much more complicated than previously reported especially when feeding and aerating gases are different. It was concluded that aerating gas determined the discharge characteristics to a large extent and feeding gas would compound the problem. The state of gas–solid fluidization prior to the opening of the hopper outlet was discussed to help understand the differences between discharge results. Experimental results showed that when feeding and aerating gases were air and CO_2, respectively, defluidization occurred during aeration in the hopper and discharge ability was weakened resulting in a low solid discharge rate.

1. Introduction

Hoppers are widely used in many engineering processes. In most industrial situations where hoppers are used, it is of interest to know how the powder will flow from the hopper as it empties under gravitational forces only [1]. The safety and stabilization of hopper discharge are of great economic significance. Of course, reliable and controllable discharge of powders from hoppers is always a necessary requirement for successful operation of most processes. However, the discharge of fine powders is not so reliably predicted due to either fluid dynamic interactions or cohesive interparticle interactions, which acting in static and flowing solids can give rise to powder consolidation, arching phenomenon and discontinuous flow [2].

In this paper, pulverized coal used in entrained-flow gasification was taken as the experimental material. The entrained-flow gasification process of pulverized coal [3, 4], characterized with large-scale, high efficiency, and cleanness, has been developed around the world. It operates with the pulverized coal having a particle size on the order of 90% smaller than 100 μm diameter to ensure high efficiency of carbon conversion inside the gasifier. Such fine pulverized coal belongs to Group C powders [5], and discharge from the hopper is not easy without careful engineering [6]. Aeration, with the advantages of lower cost and less noise, is often applied to ensure a steady discharge in many applications [7]. It is regarded as a valuable technique for improving flow properties of powders [8]. By introducing gas, it is possible to obtain a 10-fold or even higher increase of the discharge rate. For Group C powders, such as fine pulverized coal, the effect of aeration is to promote the flow which does not occur at all at zero gas flow rate. In our previous study, the discharge of pulverized coal from an aerated hopper under several gas flow rates was analyzed; four flow regions were proposed and three prevailing effects of aeration on the hopper discharge were discussed and all verified by the experiments [9].

It is known that either N_2 or CO_2 can be used as the carrier gas to feed pulverized coal into the gasifier in the entrained-flow gasification process, while CO_2 is more desirable because of its attractive effects as a gasification agent. This technology has been paid more and more attention with wide applications [10, 11]. A previous study on effect of gas type (air, He, H_2 and CO_2) on discharge of pulverized coal was carried out to support this technology; it was found that CO_2 always corresponded to the smallest solid discharge rate under the same conditions [12]. However, in the above studies as well as other reports published about aerated discharge, the gas mentioned is only fixed as a single one, while in the entrained-flow gasification process using CO_2 as carrier gas the situation is a little more complicated. Fig. 1 shows the schematic diagram of entrained-flow gasification process using CO_2 as carrier gas; at the initial stage, N_2 has to be employed as the carrier gas to feed pulverized coal; later, CO_2 from the rectisol unit will replace N_2 when the system is running after a period of time and the recycled production of CO_2 is enough. It can be seen that, there is a gas switching from N_2 to CO_2 at the early stage. The exchanged gas makes the powder discharge certainly not straightforward or easily

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* Corresponding author. Tel.: +86 21 6425 2521; fax: +86 21 64251312.
E-mail address: gongxin@ecust.edu.cn (X. Gong).

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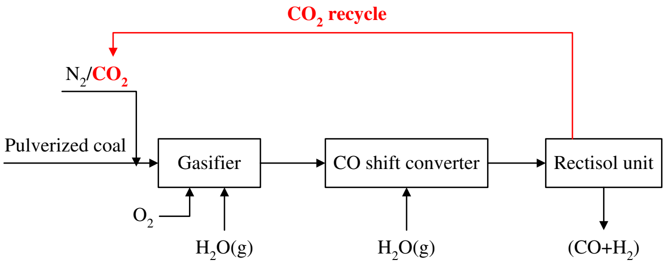

Fig. 1. Schematic diagram of entrained-flow gasification process using CO_2 as carrier gas.

predictable. It is important and necessary to understand what will happen to the hopper discharge if the introduced gas is exchanged. Up to now, there is no relative report and it seems that the studies on the hopper discharge are still far from enough and lack of the ready-made conclusions for reference.

A large-scale loop feeding system of pulverized coal was set up in this work, which included the processes of pneumatic conveying and hopper discharge. Air and CO_2 were used as the carrier gas to feed or discharge pulverized coal, where air was used to replace N_2 in order to simplify operations as they were proved to give approximately the same experimental results under the same condition. Gravity and aerated discharge were carried out based on different design procedures to further investigate the effect of gas type on pulverized coal discharge.

2. Experimental

In this work, pulverized coal taken from the industrial field of entrained-flow gasification was used as the experimental material. Physical properties of pulverized coal are provided in Table 1. Correlating powder flowability and some simple physical measures, Carr [13] suggested that angle of repose (AOR) below 30° indicated good flowability, 30°–45° some cohesiveness, 45°–55° true cohesiveness, and >55° sluggish or very high cohesiveness and very limited flowability. In addition, Geldart and Wong [14] developed the discrimination method of Hausner ratio (HR): powders having values of HR < 1.25 fell into Groups A, B, or D and those having values of HR > 1.4 belonged to Group C while powders of HR∈1.25–1.4 were in the transition zone of Groups A to C. As shown in Table 1, the pulverized coal used in this work has AOR of 47° and HR of 1.88, characterized by poor flowability and strong cohesive forces, typical powder of Group C.

Fig. 2 shows the complete set-up for the experiments. It is a loop feeding system of pulverized coal including two operation units, pneumatic conveying and hopper discharge. Prior to the experiment, about 200 kg of pulverized coal was stored in the feeding vessel; gas (named as feeding gas) was introduced from the bottom of the feeding vessel and the pulverized coal was transported to the hopper by the pneumatic conveying technology [15]; after the hopper was loaded, the feeding gas was shut off and the pulverized coal was then discharged from the hopper under the action of either gravity or aeration; the standpipe attached to the hopper outlet channeled the pulverized coal into the feeding vessel for the next loop.

The hopper, where gas (named as aerating gas) can be aerated near the outlet of conical section, has an outlet diameter of 40 mm and a hopper half-angle of 15°. Four pressure transducers were installed along the hopper wall, two in the cylindrical body (P_1, P_2) and three in the conical bottom (P_3, P_4, P_5), to measure the pressure inside the hopper. The pressure transducer used in the experiment is a diaphragm type, which measures a combination of the gas and solid pressure. More details about the hopper can be found elsewhere in the literature [9].

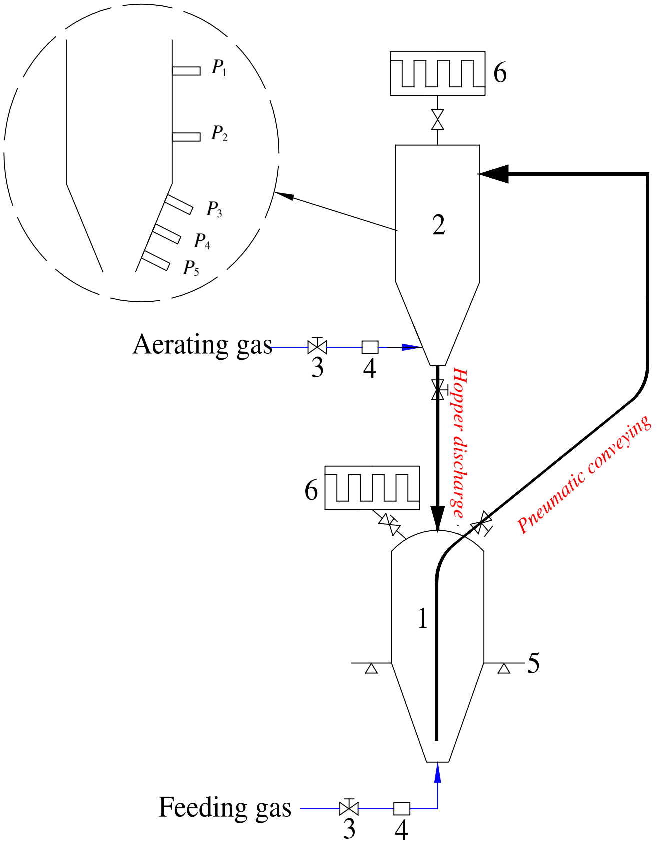

Fig. 2. Schematic diagram of loop feeding system of pulverized coal 1—feeding vessel; 2—hopper; 3—valve; 4—gas meter; 5—weighing cell; 6—dust catcher.

It should be noted that, the feeding gas was fixed as air and only the aerating gas was changed in the previous study [12], while both feeding and aerating gases are variable in this work. As shown in Table 2, they can be either air or CO_2. Consequently, four different procedures were formed and a more comprehensive comparison was conducted to investigate the effect of gas type on pulverized coal discharge. During the experiments, the gas flow rate was regulated by a valve and measured with a gas meter. Time series of pressure signals and the mass of discharged powder were acquired by a computer through a data acquisition board. The discharge rate was determined from the weight-versus-time curve of the feeding vessel.

3. Results and discussion

According to the process difference of hopper discharge, gravity and aerated discharge are discussed one by one. The former without any aerating gas thereby shows the effect of feeding gas while the latter gives a coupled influence of feeding and aerating gases on hopper discharge.

Table 1
Physical properties of pulverized coal.

Size distribution (μm)			Mean particle size d_{32} (μm)	Moisture content (%)	Particle density (kg/m^3)	Angle of repose (°)	Hausner ratio
d_{10}	d_{50}	d_{90}					
4.3	23.8	73.4	8.4	1.09	1532	47	1.88