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Experimental Investigation of Pressure Drop in Bypass Pneumatic Conveying of Fly Ash

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Abstract: Bypass pneumatic conveying systems provide a passive capability to reduce conveying velocity and therefore reduce attrition and abrasion in the process of conveying many fragile and erosive particulate solids. Because of these capabilities, bypass pneumatic conveying systems have been used in coal-fired power stations for removing fly ash for the last couple of decades. In bypass systems, the differential pressure between bypass pipe and main pipe as well as the pipeline pressure drop are two of most significant parameters as differential pressure represents the aeration mechanism within the pipeline while pressure drop is an essential parameter for bypass pneumatic conveying system design. In bypass systems, these two parameters are determined not only by the turbulent mode of the gas solids two-phase flow but also by the bypass configurations. The objective of this study was to experimentally investigate the differential pressure between bypass pipe and main pipe as well as the pressure drop during the bypass pneumatic conveying of fly ash.

Pneumatic conveying tests in bypass systems and a conventional pipeline were carried out in this study. The bypass pipeline was a 79 mm diameter main pipe with a 27 mm inner diameter bypass pipe with orifice plate flute arrangement. Fly ash was discharged to the system from the bottom of a positive pressure blow tank. The receiving bin was mounted on load cells for measuring the mass accumulation. In order to monitor real time behavior of the system, pressure transmitters were used to measure the gauge pressure. Differential pressure transmitters were employed in the system for measuring the pressure difference between the bypass pipe and main pipe.

Differential pressure results between bypass pipe and main pipe in the process of conveying fly ash showed that the pressure before the orifice plate in the bypass pipe was higher than that in main pipe as a result of orifice plate airflow resistance. Therefore, air came into main pipe and aerated the material continuously. The differential pressure also illustrated that the particulate may go into the bypass pipe as pressure in the bypass pipe after orifice plate is lower than that in main pipe. The pipeline pressure drop results also showed that pressure drop was higher than in the conventional system when using the same operating parameters due to the increase of friction. The influences of bypass configurations on pressure drop of bypass system were also discussed.

Keywords: Pneumatic conveying, Bypass system, Pressure drop, Differential pressure, Fly ash.

Introduction

Fly ash is one of the main residues generated in the combustion of coal from coal-fired power plants. Considering flexibility and efficiency in their space requirement and environmental issues, pneumatic conveying systems become the most popular ash removal methods. A traditional pneumatic ash handling system operates on the dilute phase principle with low solid loading ratios and high conveying velocities which lead to both high energy consumption and significant erosive wear of pipelines. Therefore, dense phase pneumatic conveying systems have become the most popular ash removal method because of its advantage of energy efficiency and lower maintenance. However, due to an overly thick layer of material, the possibility of blockage increases in dense phase conveying pipeline. Also coarse ash, i.e. bottom ash,

does not have the natural dense phase capacity to be transported in conventional pipeline. Bypass systems provide an alternative method to transport such particulates in dense phase. The outstanding advantage is that bypass systems can decrease conveying velocity thereby reducing power consumption and pipeline wear.

Möller et al [1] conducted alumina conveying tests to investigate the advantages of a “Turbuflow” bypass system over conventional pipe line in the laboratory installation. The results showed that the pressure in the feeding vessel was more stable than the traditional system as segregation is prevented and the agglomerations are broken down. Barton et al [2] focused on overall performance of conveying alumina in bypass pneumatic conveying systems. Mathematical equations have been developed that describe how to determine the bypass pipe diameter and

flute spacing. An internal bypass pipeline pressure drop was experimentally investigated by Xu et al. [3]. There is little work on comparison of pressure drop between bypass pneumatic conveying systems and conventional conveying pipelines, which plays a key role in pneumatic conveying system design. Differential pressure data between bypass pipe and main pipe, caused by disks installed in bypass pipe, is also one of most significant parameters, which is considered to represent the work principle of bypass pneumatic conveying system. It is determined not only by the turbulent mode of the gas solids two-phase flow but also by the bypass configurations [4]. The performance of disks in bypass pipelines was claimed as turbulence intensifier by Möller [5]. Most recently, Chen et al [6] conducted some bypass system modelling work for predicting pressure drop and describing the mechanism of material blockage inhibition in bypass systems. The influences of bypass configurations and conveying materials properties on bypass system performance were also discussed.

Generally, research has been carried out investigating bypass pneumatic conveying systems with little attention being paid to describe the differential pressure around the orifice plates. The aim of this study was to experimentally investigate the differential pressure between bypass pipe and main pipe as well as the pressure drop in bypass pneumatic conveying of fly ash.

1. Experimental Set-up and Procedures

The pneumatic conveying tests were conducted in a 6.5 m long bypass system to obtain experimental pressure data as shown in Figure 2 (a). Fly ash was discharged to the system from the bottom of a positive pressure blow tank. The receiving bin was mounted on load cells for measuring the mass accumulation. The bypass pipeline was a 79 mm diameter main pipe with a 27 mm inner diameter bypass pipe with orifice plate flute arrangement which is shown in Figure 2 (b). The bypass configurations in terms of bypass flute sizes and flute spacing are shown in Tab. 1. The properties of the fly ash are shown in Tab. 2.

Tab. 1 Bypass configurations

Bypass pipe ID, m	Bypass flute spacing, m	Orifice plate diameter, m	Angle of bypass opening, °
0.027	0.4	0.007	45

Tab. 2 Physical properties of fly ash

d_p , μm	ρ_p , kg/m^3	ρ_b , kg/m^3	Permeability $10^{-7}\text{m}^2/(\text{Pa}\cdot\text{s})$	u_{mf} , mm/s
14.7	2093	775	6.6	84.7

In order to monitor real time behavior of the system, pressure transmitters were used to measure the gauge pressure with differential pressure transmitters employed in

the system for measuring the pressure difference between the bypass pipe and main pipe. The arrangement of the pressure transducer tap is shown as Fig.1 (c). The response time of pressure transducers is adjusted to the same value using three connection parts. Before the tests, the gauge pressure transmitters were calibrated using a Dead Weight Tester, while the differential transmitters were calibrated employing the water column manometer. A Lab-view program is used to monitor and record the data at an acquisition rate of 50Hz.

(a) schematic diagram of the bypass system

(b) arrangement of bypass pipe

(c) pressure transducer taps arrangement

Fig. 1 Bypass pneumatic conveying test rig used in the current study

2. Results and Discussion

2.1 Differential pressure

Differential pressure data between bypass pipe and main pipe is one of most significant parameters, which is considered to represent the work principle of bypass pneumatic conveying system. Fig. 2 illustrates the air only differential pressure results between bypass pipe and main pipe when the air mass flow rate is 0.0681 kg/s and the relevant air velocity at the pipe outlet is 12.2 m/s. In Fig. 2, the positive value means that pressure in the bypass pipe is higher than that in main pipe. While, the negative value represents pressure in the bypass pipe is lower than that in main pipe. It can be seen that the pressure before the orifice plate in the bypass pipe was higher than that in

main pipe. Therefore, air comes into main pipe as a result of orifice plate airflow resistance. The differential pressure also illustrated that air flowed into the bypass pipe after orifice plate. The pressure fluctuations were caused by the turbulent flow of air.

Fig. 2 Air only differential pressure results between bypass pipe and main pipe

Fig. 3 Differential pressure results between bypass pipe and main pipe in the process of conveying fly ash

Fig. 3 shows experimental results of differential pressure between bypass pipe and main pipe in the process of conveying fly ash under the operation condition of air mass flow rate of 0.0524 kg/s, solid mass flow rate of 0.87 kg/s and the superficial air velocity of 9.4 m/s. Due to the mixture of air and solids transferring in the pipeline, the differential pressure showed larger values compared to the air only data. These results agree well with our previous work [6], which was focused on modeling bypass pneumatic conveying systems. From the differential pressure data, it can be derived that air came into main pipe and penetrated into the particulate volume continuously before the orifice plate thus material blockages were inhibited. The differential pressure also illustrated that materials may go into the bypass pipe as pressure in the bypass pipe after orifice plate is lower than that in main pipe. The differential pressure after the orifice

plate showed more fluctuation than before the orifice plate because turbulence was generated by the acceleration of gas and material mixture thorough orifice plate.

2.2 Pipeline pressure drop

Fig. 4 Pressure signals recorded during a test

The bypass pneumatic conveying of fly ash experiments were carried out to obtain the pipeline pressure drop. Fig. 4 shows pressure signals recorded during a test where the correspondent differential pressure is shown in Fig. 3. The pressure signals at both the pipe inlet and outlet were relatively stable except the near the start and end of the test.

Fig. 5 Experimental results of pressure drop

Fig. 5 presents the pressure drop results in the bypass pneumatic conveying of fly ash for different solids mass flow rates. It has been found that pipeline pressure drop decreased with reducing the air mass flow rate until it reached pressure minimum point. After this point, the pressure drop increased with the decrease of air mass flow rate. This trend was also derived in the experimental work of Xu et al [3], which has been considered as a typical pneumatic conveying characteristic curve.

A series of tests were conducted to obtain the pressure drop in both bypass system and conventional pipeline. The results were compared as shown in Fig. 6. From the experimental results using our 6.5 m length test rig, it can

be seen that the bypass pipeline had higher pressure drop than conventional system when using the same air mass flow rate and solids mass flow rate. Compared to conventional pipeline, the existence of the bypass pipe caused the increase of wall friction and flow resistance of a number of orifice plates when bypass pipe is put inside of the main pipe. The difference in pressure drop between two conveying systems rose with the increase of conveying velocity as the flow resistance increased with the increase of conveying velocity.

Fig. 6 Comparison of pressure drop between bypass system and conventional pipeline

Fig. 7 Comparison of pressure drop between two bypass configurations

In Fig. 7, the experimental results from the pneumatic conveying of fly ash tests in two bypass systems showed that pressure drop in the bypass system with a 42 mm bypass pipe was higher than that with a 27 mm bypass pipe for the same solids and air flow rates. The main reason is that a 42 mm bypass pipe took up 2.4 times the circulation area as a 27 mm bypass pipe did, thus dramatically reducing the circulation area of the main pipe. Furthermore, the wall friction also was increased due to larger wall surface area. Pressure drop is also a dominant factor in

determining specific energy consumption. The specific energy rises with an increase of pipeline pressure drop while other parameters remain the same values. Therefore, it is important to choose the right bypass pipe diameter as a suitable diameter of bypass pipe can ensure good performance of bypass systems with lower energy consumption.

3. Conclusions

Pneumatic conveying tests in bypass systems and a conventional pipeline were carried out to obtain the differential pressure and pressure drop in this study. It has been derived from the differential pressure results that the mechanism of blockage inhibition in bypass system is that air flows into main pipe and aerates the material volume continuously as a result of orifice plate airflow resistance. The pipeline pressure drop results showed that pressure drop in the bypass systems was higher than that in the conventional system when using the same operating parameters due to the increase of friction. The difference in pressure between two conveying systems reduces with the decrease of conveying velocity. Compared to the bypass system with a 27 mm bypass pipe, pressure drop in the system with a 42 mm bypass pipe was higher because of the dramatically reducing circulation area of the main pipe and the increasing wall friction due to larger wall surface area, as a result, the energy consumption was increased.

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