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Investigation on characteristics of pulverized coal dense-phase pneumatic conveying under high pressure

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Abstract−Experiments of dense-phase pneumatic conveying of pulverized coal were carried out in a test facility with a conveying pressure up to 4 MPa. The influence of fluidization nitrogen flow rate, the flow rate of supplementary nitrogen, and the pressure difference between sending hopper and receiving hopper on the solids to gas ratio and the solid mass flow rate was investigated. Test results indicate that with the increase in fluidization nitrogen flow rate, the solid mass flow rate increases, and the solids to gas ratio increases at first and then declines. When the fluidization of pulverized coal in the sending vessel becomes intensive, with the increase in supplementary nitrogen flow rate, the solids to gas ratio declines and the solid mass flow rate increases. And the solid mass flow rate increases linearly with the increase in pressure difference between two hoppers. The experimental results provide a database for the design and operation of a dense-phase pneumatic conveying system.

Key words: Pneumatic Conveying, Dense Phase, Pulverized Coal, High Pressure, Two Phase Flow

INTRODUCTION

The industrial application of pneumatic conveying technology began in the late 19th century and grew enormously during the early and middle 20th century, especially because it is a dust-free transportation of a variety of products from granular solids to dry powdered and is very flexible in routing and distribution. At the early stage, almost all of the pneumatic conveying systems were dilute phase systems. For dilute phase systems, however, the wear of equipment and degrading of conveyed solid particulates are not avoided due to the high velocity of conveyed particulates. Also, because of the high conveying velocity, the pressure loss is high [1], which in turn determines either high power consumption or limitation in conveying distance, while reducing the conveying velocity might cause the system to become plugged up [2-4].

Dense phase pneumatic conveying technology, which has advantages of low energy consumption, low wear and abrasion of equipment, low particle degradation, high solids to gas ratio, high mass flow rate, seems attractive and has been studied by some researchers since around the 1970s [5,6]. There are also some successful applications of dense phase pneumatic conveying technology in industry, such as fluidization stable flow [7] and plug flow with gas knife. However, the previous works are mostly related to ambient pressure.

Coal gasification technology provides a clean and efficient way to utilize coal. Syngas produced from coal with coal gasification technology could be used for electricity generation and raw material for chemical production, transportation fuel, hydrogen and substitute for natural gas. It is generally acknowledged that the entrained pulverized coal gasification technology is one kind of promising large-scale coal gasification technology.

In this paper, one kind of high pressure and dense phase pneumatic conveying technology is researched, which will be used in the development of an entrained pulverized coal gasification technology with financial support from the National Key Program of Basic research in China.

In the present study, the influence of the fluidization nitrogen flow rate, the supplement nitrogen flow rate and the pressure difference between sending hopper and receiving hopper on the conveying

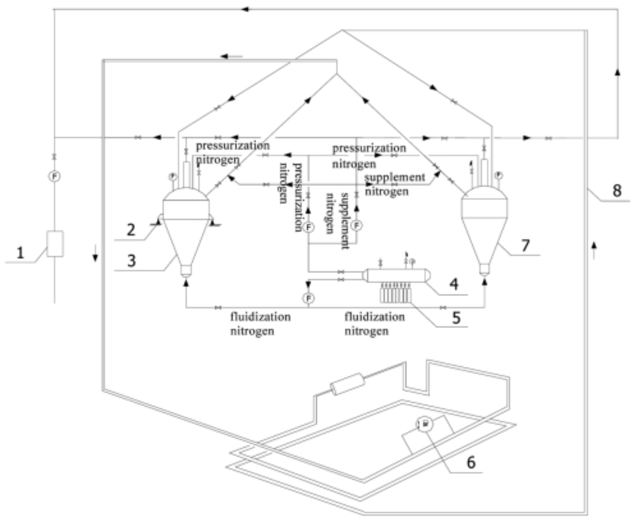

Fig. 1. System of high pressure and dense phase pneumatic conveying of pulverized coal.
1. Electromotive control valve
2. Weight cell
3. Pressure hopper 1#
4. Buffer tank
5. Nitrogen cylinder
6. Pressure drop sensor
7. Pressure hopper 2#
8. Pipeline

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solid mass flow rate and solids to gas ratio was investigated experimentally. The test results presented in this paper provide a base for further experimental and theoretical research on high pressure and dense phase pneumatic conveying technology.

EXPERIMENTAL SETUP

Fig. 1 shows schematically the system of a high pressure and dense phase pneumatic conveying test facility. The pulverized coal, with average particle diameter of 37 μm, true relative density of 1,350 kg/m^3 and sphericity of 0.63, was alternately conveyed between two pressure vessels via a 53.4 m long and 10 mm inner diameter pipe, and the pressure in conveying pipeline is up to 4 MPa.

The high pressure nitrogen was first loaded to a buffer vessel in which the maximal pressure was maintained at 4.8 MPa, and then divided into three parts. The first part, named fluidization gas, fluidizes the pulverized coal at the bottom of sending pressure vessel, and then drives the pulverized coal into the conveying pipe. The second part, named supplement gas, could adjust the nitrogen flow rate in a wide range and prevent solid slugs to guarantee continuous and long distance transport of pulverized coal. And the third part, named pressurization gas, is to maintain the stabilization of pressure in the sending vessel; otherwise, the pressure would decline while the pulverized coal was gradually discharged from the sending vessel. The three above nitrogen flow rates were controlled by metal rotor flow meters. The pulverized coal mass flow rate was measured by a foil electronic balance, which was installed at the sending pressure vessel. The pressure drops along the pipe were measured by the PD-23 pressure drop meters (Keller Corp.) with a precision of 0.3%. A computer data acquisition system was employed to record the data of flow rates and pressure drops.

EXPERIMENTAL RESULTS AND DISCUSSION

1. Effects of Fluidization Gas Flow Rate (M_{gf}) on the Characteristics of Dense-phase Pneumatic Conveying

In the experiment, the M_{gf} was changed from 0.1 m^3/h to 0.7 m^3/h, while the other parameters such as the pressure in two pressure vessels, the supplement gas flow rate and pressurization gas flow rate were kept constant. The two experimental conditions are listed in Table 1.

1-1. The Effect of M_{gf} on Coal Mass Flow Rate

The effect of M_{gf} on coal mass flow rate is shown in Fig. 2. It can be seen that with the increase in M_{gf}, the coal mass flow rate increases while the increase rate declines later. The pulverized coal in the sending pressure vessel is part fluidized when M_{gf} is low, so the coal mass flow is small. When the M_{gf} is increased, the pulverized coal is further fluidized and more is driven into conveying pipe, so the coal mass flow rate increases. However, when the pulverized coal has been fully fluidized, the increase rate of the coal mass flow rate declines with further increase in M_{gf}.

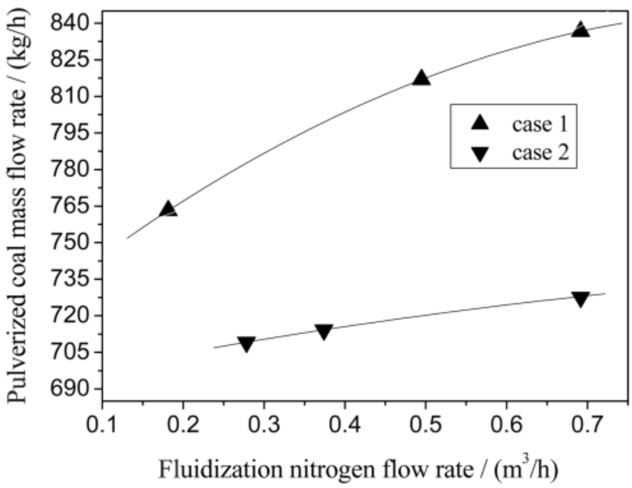

Fig. 2. Pulverized coal mass flow rate versus fluidization nitrogen flow rate.

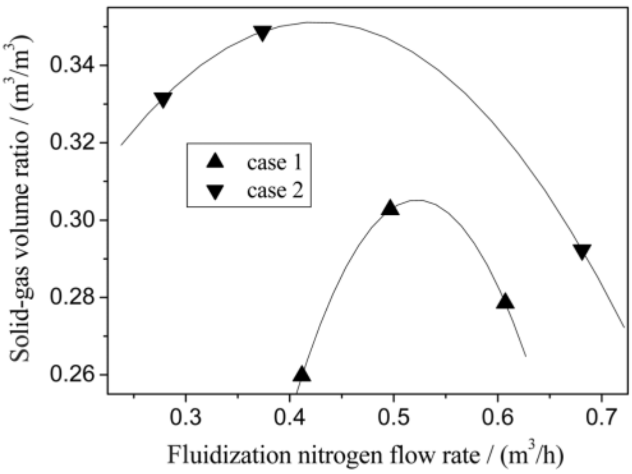

Fig. 3. Solids to gas volume ratio versus fluidization nitrogen flow rate.

1-2. The Effect of M_{gf} on Solids to Gas Volume Ratio

Solids to gas volume ratio is affected by following parameters, such as the particle properties (diameter, shape, density, viscosity, etc.), pipe diameter and length, conveying pressure and gas flow rates [8].

The solids to gas volume ratio α is defined as:

$$\alpha = \frac{M_c/1{,}350}{\left[p_s * \left(M_{gt} - \frac{M_c}{1{,}350}\right)\right]/p} \tag{1}$$

where 1,350 is the true relative density of coal (kg/m^3).

Table 1. Experimental conditions - The effects of fluidization gas flow rate on the characteristics of dense-phase pneumatic conveying

Condition	Buffer tank pressure P_b/(MPa)	Sending hopper pressure P_s/(MPa)	Receiving hopper pressure P_r/(MPa)	Pressurization gas flow rate M_{gp} (m^3/h)	Supplement gas flow rate M_{gs} (m^3/h)
Case 1	4.0	3.76	2.9	1.21	0.5
Case 2	4.0	3.72	3.1	1.14	0.39

Fig. 3 shows that the solids to gas volume ratio first increases and then declines with increase in M_{gf}. When the fluidization nitrogen flow rate is low, with the increase in M_{gf}, the pulverized coal above the grid plate is gradually fluidized, and the average distance between coal particles becomes larger. Thus, the energy consumption related to the moving of coal particles is lower, and more pulverized coal can be conveyed by per unit of nitrogen gas and lead to an increase in gas-solid volume ratio. While the M_{gf} is further increased, the average distance between coal particles becomes even larger and induces larger gas void, so the solids to gas volume ratio is reduced.

2. Effects of Pressurization Gas Flow Rate (M_{gp}) on the Characteristics of Dense-phase Pneumatic Conveying

In this experiment, the M_{gp} is changed from 0.8 m^3/h to 1.5 m^3/h, while the other parameters are kept constant as below:

pressure in the buffer vessel: 4 MPa
pressure in the sending pressure vessel: 3.65 MPa
pressure in the receiving pressure vessel: 3.1 MPa
fluidization gas flow rate: 0.47 m^3/h
supplement gas flow rate: 0.38 m^3/h

2-1. The Effect of M_{gp} on Conveyed Coal Mass Rate

Fig. 4 shows that the coal mass flow rate increases linearly with M_{gp} while the other parameters remain constant. In the present experiment, the pressurization nitrogen flow rate is at a high level compared to other conditions, and part of the pressurization gas would flow through the pulverized coal layer to the bottom of the sending pressure vessel and then enter the conveying pipe acting as transportation gas. So, the coal mass flow rate increases with M_{gp}.

2-2. The Effect of M_{gp} on Solids to Gas Volume Ratio

It can be seen from Fig. 5 that the solids to gas volume ratio decreases with increase in M_{gp}. When M_{gp} is high, some pressurization gas would flow through the pulverized coal layer to the bottom of the sending pressure vessel and mix with the fluidization gas. In this condition, increase in M_{gp} will lead to increase in M_{gf} equivalently, and the solids to gas volume ratio will decrease with increase in M_{gp} for the same reason given in Section 1.2.

3. Effects of the Pressure Difference Between Two Pressure Hoppers (ΔP_h) on the Characteristics of Dense-phase Pneumatic Conveying

Fig. 6 and Fig. 7 present the effects of ΔP_h on the characteristics

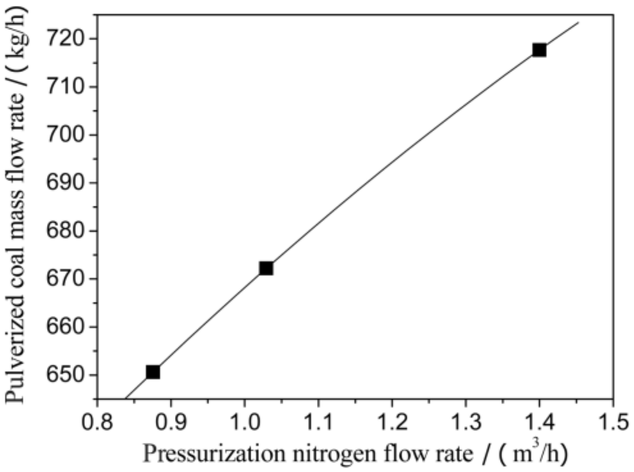

Fig. 4. Pulverized coal mass flow rate versus pressurization nitrogen flow rate.

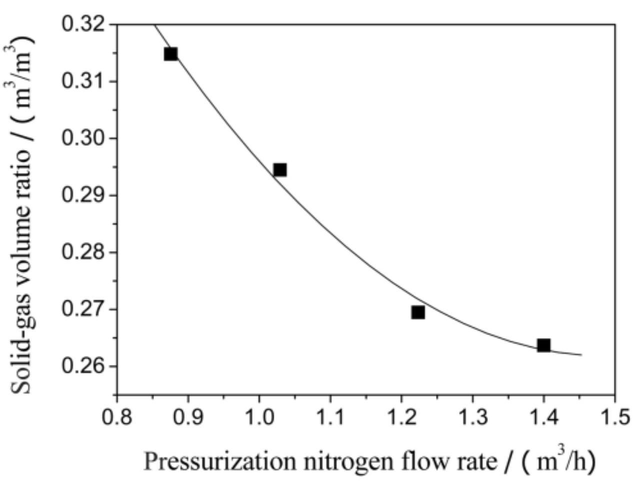

Fig. 5. Solids to gas volume ratio versus pressurization nitrogen flow rate.

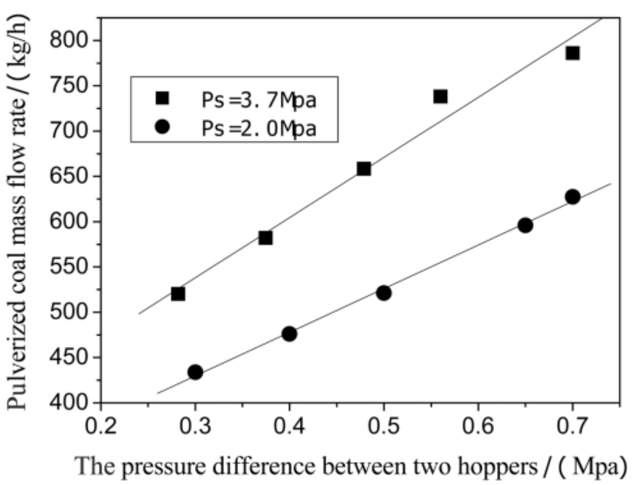

Fig. 6. Pulverized coal mass flow rate versus the pressure difference between two hoppers.

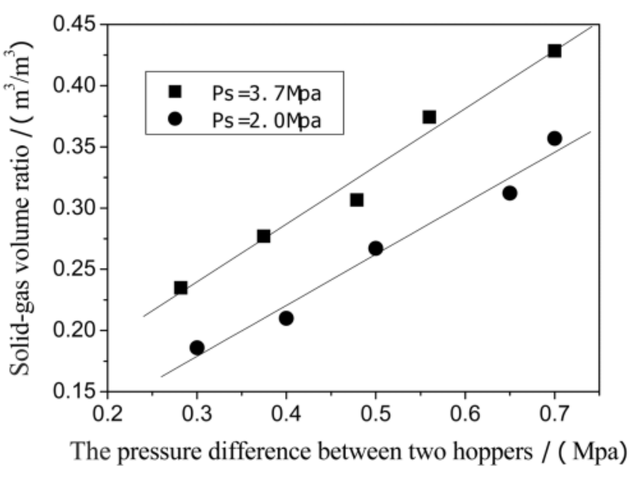

Fig. 7. Solids to gas volume ratio versus the pressure difference between two hoppers.

of pulverized coal dense-phase pneumatic conveying under high pressure while the other parameters remain constant.

3-1. The Effect of ΔP_h on Coal Mass Flow Rate

As shown in Fig. 6, the coal mass flow rate increases linearly while ΔP_h is increased from 0.3 MPa to 0.7 MPa. ΔP_h is the power source of the pneumatic conveying system and it determines the transportation energy of the conveying gas. When the ΔP_h is increased, the transportation energy of the conveying gas is increased, and more pulverized coal can be carried by the conveying gas. It can also be found from Fig. 6 that when the ΔP_h is increased from 0.3 MPa to 0.7 MPa, the coal mass flow rate is increased by 220 kg and 140 kg, respectively, for the conditions of the conveying pressure at 3.7 MPa and 2.0 MPa, indicating that the effect of ΔP_h on the coal mass flow rate is more significant at higher conveying pressure.

3-2. The Effect of ΔP_h on Solids to Gas Volume Ratio

Fig. 7 shows that the solids to gas volume ratio increases with increase in ΔP_h. When the ΔP_h is increased, the coal mass flow rate increases while the conveying gas mass flow rate remains constant, leading to an increase in solids to gas ratio.

CONCLUSIONS

Experiments were performed to study the transport characteristics of a high pressure and dense phase pneumatic conveying of pulverized coal system. The conclusions of the present study can be drawn as follows:

1. The coal mass flow rate and solids to gas volume ratio can be changed in a wide range, by means of changing fluidization gas flow rate, pressurization gas flow rate and the pressure difference between sending hoppers and receiving hopper.
2. The coal mass flow rate increases with the increase in fluidization gas flow rate and pressurization gas flow rate.
3. The solids to gas ratio increases first and then declines with the increase in fluidization gas flow rate.
4. The solids to gas volume ratio declines with the further increase in pressurization gas flow rate, when the pulverized coal has already been fully fluidized.
5. Both the coal mass flow rate and solids to gas ratio increase linearly with the increase in pressure difference between two hoppers ΔP_h. Furthermore, the effect of ΔP_h on the coal mass rate is more significant at higher conveying pressure.

ACKNOWLEDGMENT

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NOMENCLATURE

M_c : coal mass flow rate [kg/h]
M_{gf} : fluidization gas flow rate [m^3/h]
M_{gp} : pressurization gas flow rate [m^3/h]
M_{gs} : Supplement gas flow rate [m^3/h]
M_{gt} : total volume flow rate of conveying gas [m^3/h]
P : average pressure in conveying pipe [MPa]
P_b : buffer tank pressure [MPa]
P_r : receiving hopper pressure [MPa]
P_s : sending hopper pressure [MPa]
ΔP_h : pressure difference between two pressure hoppers [MPa]
α : solids to gas volume ratio

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