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INVESTIGATION OF ENERGY CONSUMPTION AND WEAR IN BYPASS PNEUMATIC CONVEYING OF ALUMINA

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ABSTRACT: Dense phase pneumatic conveying is critically dependent on the physical properties of the materials to be conveyed. However, many materials, such as alumina and coarse fly ash, which are highly abrasive, do not have dense phase conveying capacity. Bypass pneumatic conveying systems provide a dense phase capability to non-dense phase capable bulk materials. These systems also provide the capacity of lower the conveying velocity and therefore lower pipeline wear and lower power consumption occurs. The objectives of this work were to study the energy consumption and wear of bypass pneumatic transport systems. Pneumatic conveying of alumina experiments were carried out in a 79 mm diameter main pipe with a 27 mm inner diameter bypass pipe with orifice plate flute arrangement. High speed camera visualizations were employed to present flow regimes in a horizontal pipe. The experimental result showed the conveying velocity of bypass system is much lower than that of conventional pipelines, thus specific energy consumption in the conveying process is reduced. The service life of the bypass line has also been estimated

KEY WORDS: Pneumatic conveying; Bypass system; Wear; Energy consumption; Alumina

1. Introduction

Pneumatic conveying systems provide flexibility and efficiency in their space requirement without generating environmental problems. Therefore, they are widely employed in the aluminum industry for its materials handling processes. There are two types of pneumatic conveying systems: dilute phase and dense phase. Dilute phase conveying process uses relatively higher mass flow of air (low solid loading ratios) which generates high conveying velocities. Material remains suspended in the conveying air throughout the conveying process. Unlike dilute phase conveying systems, Material is conveyed in much denser concentration of bulk solids at relatively low velocities through a conveying line. In dense phase mode material will not be suspended in conveying air at least some part of the conveying line. Alumina is a very abrasive material. As a result, erosive wear of pipelines are significant in the process of dilute phase conveying of alumina. Dense phase conveying is critically dependent on the physical properties of the materials to be conveyed. Alumina does not have the natural dense phase capability to be transported in the conventional conveying pipelines. The solutions for these particulates to be conveyed in dense phase can be provided through the use of bypass pneumatic conveying system. Bypass systems can reduce conveying velocity thus lower power consumption and pipeline wear due to erosion. For this reason, bypass pneumatic conveying systems have been widely used in process industry for the last few decades.

Pavoni [1] summarized the technology of Fluidstat bypass systems and the advantages over conventional pipelines. Möller et al [2] conducted alumina conveying tests to investigate the advantages of 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. In order to investigate conveying characteristics of powder materials for a plant pneumatic conveyor, Ramkrishnan et al. [3] used a closed loop dense phase pneumatic conveying system incorporating a Turbuflow bypass system. Four different types of powder materials (cement, fly ash, pulverized coal and raw meal) were transferred and the conveying energy consumption for a given volume of solids was assessed. The results showed the specific power consumption reduced with increasing phase density. Barton et al [4] 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.

Figure 1. Internal and external bypass pneumatic conveying systems

There are two basic types of bypass systems; internal bypass and external bypass as shown in Figure 1. One of the major problems with internal bypass systems is the unpredictable life of the bypass line due to wear. Material such as alumina is inherently abrasive by nature. As the bypass line is constantly in contact with these particles, pipeline is gradually worn out and reduces the effectiveness of bypass conveying system. Once the bypass line is eroded, material will be conveyed in similar mode of the conventional pipeline. It is important to be able to predict the life cycle of the bypass line so that the material can be conveyed within the designated parameters and modes of flow. Understanding of the particles contacts play a crucial role in determining the wear of the bypass line.

In order to obtain more detailed information of the solid phase during pneumatic conveying process, noninvasive flow visualization techniques have been employed in the past. An internal bypass pneumatic system was investigated experimentally and the internal flow pattern was visualized through electrical capacitance tomography (ECT) by Xu et al. [5]. The slug flow with a stationary bed revealed a wavy manner. No information on the bypass flutes area can be extracted from the ECT results. High speed video camera (HSVC) has already been used to observe and analyze material flows in the pneumatic conveying pipeline through a glass section in some investigations, e.g. for the examination of slug and dune formation [6]. Chen et al [7] employed high speed camera to visualize flow regimes in a horizontal conveying of fly ash and explain material blockages inhibition in an internal bypass system. Cenna et al [8] studied the flow structures in different bends while conveying alumina, sand and fly ash [9].

Generally, research are carried out to investigate bypass pneumatic conveying systems with little attention being paid to compare the energy consumption and wear of pipelines of alumina in between bypass systems and conventional pipelines. Visualization of the operation of bypass pneumatic transport of alumina using HSVC is also studied in this paper.

2. EXPERIMENTAL SET-UP AND PROCEDURES

The bypass pneumatic conveying test was conducted on a 6.5 m bypass system to obtain experimental data for the operation of a bypass system as shown in Figure 2 (a). The material is fed into the system from the bottom of the feed bin which is a positive pressure blow tank. The discharge rate of materials from feed bin was controlled by adjusting the proportion of total air flow directly into the blow tank and changing the position of feed pipe. The receiving bin is mounted on load cell for measuring the mass flow rate. The main pipe is 80NB and the bypass pipe is 25NB. The inner bypass pipe was designed using orifice plate approaches, which is shown in Figure 2 (b).

(a) Schematic diagram of the bypass system

(b) Arrangement of bypass pipe

Figure 2. Bypass pneumatic conveying test rig used in the current study

The bypass configurations in terms of bypass flute sizes and flute spacing are shown in Table 1. In order to monitor real time behavior of the system, pressure transmitters are used to measure the gauge pressure. A Lab-view program is used to monitor and record the data at an acquisition rate of 50Hz.

Table 1
Bypass configurations

Main pipe ID, m	Bypass pipe ID, m	Bypass flute spacing, m	Orifice plate diameter, m	Angle of bypass opening, °
0.079	0.027	0.4	0.007	45

A glass section used in the main pipe allowed flow visualization by HSVC. HSVC Phantom 5 with 105mm lens is used to obtain detailed information of solid phase flow behavior in pneumatic conveying pipelines. The image sample rate was up to 1000 frames per second and the exposure time was 990 μ s. Alumina has been used in the test and the detailed physical properties of alumina are shown in Table 2.

Table 2
Physical properties of material

Material	Mean diameter, μ m	Particle density, kg/m ³	Bulk density, kg/m ³	Permeability , 10 ⁻⁷ m ² /(Pa·s)	Minimum fluidization velocity, mm/s
Alumina	76.7	4088	1003	3.6	17.7

3. RESULTS AND DISCUSSION

3.1 Flow visualization

Visualization of flow in dense phase pneumatic conveying of alumina in bypass system and conventional pipeline were conducted in this study. Figure 3 presented the flow patterns observed in conventional pipeline at different solids and air mass flow rates. The conveying parameters for these experiments are presented in Table 3, where SLR represents solids loading ratio. It has been demonstrated that for certain solids loading ratios alumina formed a stationary layer at the bottom and the particles flow on top of the layer at a higher velocity. With increased solid loading ratio, it is apparent that the stationary layer at the bottom becomes fluidized and changes the flow characteristics to moving bed flow. Alumina is a non-dense phase material which cannot normally be conveyed in dense phase in the traditional pipeline. However the study showed a remarkable characteristic of alumina conveying and a very high solids loading ratio. It is possible that this is a particular case of pneumatic conveying for a shorter pipeline without any bends. It would be worthwhile to investigate the effect of solid loading ratio on dense phase conveying of alumina in the straight pipe varying the length of pipeline in the future work.

Figure 3. High speed camera visualization of pneumatic conveying of alumina in conventional pipe
(Flow direction is from left to right)

Figure 4 presented the flow characteristics in the bypass pneumatic conveying of alumina over a range of superficial air velocities. The observation area including two bypass flutes is about 0.7 meters in length, and the positions of the bypass flutes are shown in Figure 4 (a). Figure 4(b) – 4(c) presented the flow characteristics of alumina conveying in a bypass system for different conveying parameters. The conveying parameters including the solids loading ratios for by pass system are presented in Table 3. Figure 4 (b) represents the flow pattern of alumina for a SLR of 66. Visual observation of the flow showed an immature dune flow. At higher solid loading ratios, the

flow pattern reveals a slug flow. The slope at the front of the slug is steeper than the back of the wave as shown in Figure 4 (c). The shape of the slug described by Konrad [10] is that the slope of slug front is less than that of the back. The difference of the phenomenon is caused by the properties of materials used in the tests. For the granular materials with high permeability in the Konrad's experiments, materials from stationary bed was picked up by the slug and then dropped behind the slug and finally form a stationary layer again. For fine powder in our tests, the rigid alumina slug was not formed as the gas cavity can be observed in the slug. In the bypass system, the pressure before the orifice plate in the bypass pipe is higher than that in main pipe as a result of orifice plate flow resistance. Therefore, air come into main pipe and aerated the material continuously.

Table 3
Parameters used in conventional and bypass conveying of alumina

Conventional pipe					Bypass pipe				
Case No.	Ma, kg/s	Ms, kg/s	SLR	Vs, m/s	Case No.	Ma, kg/s	Ms, kg/s	SLR	Vs, m/s
1	0.0681	2.87	42	15.2	6	0.0681	2.78	41	18.1
2	0.0595	2.10	35	13.5	7	0.0417	2.76	66	10.1
3	0.0556	2.29	41	12.2	8	0.0317	2.99	94	7.3
4	0.0681	0.85	12	23.4	9	0.0157	2.82	180	3
5	0.0595	0.44	7	21.4

Figure 4. High speed camera visualization of pneumatic conveying of alumina in bypass pipe
(Flow direction is from left to right)

The visualization of the blockage clearance mechanisms is presented in Fig 5. Figure 5(b) showed that the stationary alumina bed almost filled the whole cross-section of the main pipe. When the aerating process of alumina bed started in the bypass line, the cracks in the materials can be seen in Figure 5 (c) which was similarly observed in the experiments of conveying fly ash in horizontal bypass pipelines by Chen et al [7]. The rigid full bore plug was not formed because air came out through the bypass openings into main pipe to penetrate into the material volume. The material is then fluidized slowly and blockage is cleared from the blocked location as seen in Fig 5(c).

(c) aerating the material bed

Figure 5. High speed camera visualization of aerating the material bed

3.2 Specific Energy

Specific energy is the energy needed to convey unit mass of material for a given pressure difference. It provides a simple measure for comparison between competing conveying methods. The specific energy consumption can be given by the Eq. (1) [11].

$$\text{Specific Energy} = 2RT \frac{M_a}{M_s} \ln \left(\frac{p_1}{p_2} \right) \quad (1)$$

where M_a is air mass flow rate (kg/s); M_s is solid mass flow rate (kg/s); R is universal gas constant (0.287 kJ/kg/K); T is absolute temperature (288K); P_1 is conveying line inlet absolute pressure, P_2 is conveying line outlet absolute pressure.

The specific energy for both bypass system and conventional pipeline has been measured for the conveying tests carried out for visualization of flow structures. The results are presented in Figure 6. For both bypass and conventional pipes, the results show that the specific energy decreases with the decrease of mass flow rate of conveying air. The difference in specific energy consumption between two conveying systems reduces with the decrease of conveying velocity. From the experimental results, it can be seen that the bypass pipeline consumes more energy than conventional system when using the same air mass flow rates. However, one of the advantages of bypass system is the ability to convey at lower velocities. With reduced velocity, the specific energy consumption is also reduced as supported by Möller et al. [2]. The pressure drop of bypass system is higher compared to conventional pipeline for same air mass flow rates, due to the increase of wall friction and flow resistance of a number of orifice plates. From Eq. (1), the specific energy rises with an increase of pipeline inlet pressure while other parameters remain the same. More energy is consumed in bypass system compared with conventional pipeline for same mass flow rates of solids and air.

Figure 6. Comparison of specific energy transportation between bypass system and conventional pipeline

3.3 Assessment of Wear of Bypass Line

One of the primary concerns of bypass system is the wear of the bypass line. For internal bypass system, there is no way to monitor the state of the bypass tube while in operation. On the other hand, if the bypass line failed in operation, blockage of pipeline is inevitable. The plant can operate without the bypass line at higher air mass flow rates whereby increasing the conveying velocity. This reduces the service life on the pipeline drastically. As a result a predictive model for service life of bypass tube could save unscheduled breakdown keeping the reliable operation of the plant.

The particle velocity in the pipeline has been measure from the high speed video of the flow. Figure 7 presented the measured average particles velocities around bypass pipe over a range of air mass flow rates in both conventional system and bypass pipeline. Based on the models developed for the assessment of service life of pneumatic conveying pipelines, the thickness loss of bypass tube has been estimated. It has been estimated that for a

wall thickness 3mm of a bypass tube, it can make a hole in 2.5 years if the particle velocity 3 m/s whereas the bypass tube can be worn out in about 4 months if the particle velocity increases to 10 m/s. As the wear rate depends on the particle velocity together with other factors such as particle size, particle angularity, particle flux as well as the surface characteristics, the assessment of 'time to failure' for bypass tube needs a better understanding of the total operation of the system.

Figure 7. Alumina particles average velocities

4. CONCLUSIONS

The bypass pneumatic experimental system was built with a main pipe of 79mm in diameter and a bypass pipe of 27 mm inner diameter with orifice plate flute arrangement. The results showed that bypass system consume more energy than conventional system when using the same air mass flow rate due to the increased friction. The difference in specific energy consumption between two conveying systems reduces with the decrease of conveying velocity. The specific energy consumption is much reduced as the conveying velocity of bypass system is much lower than that of conventional pipelines. High speed video camera visualization allowed the measurement of particle velocity in the pipeline. Based on the particle velocity, service life of the bypass line has also been estimated.

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