

Granular Attrition due to Rotary Valve in a Pneumatic Conveying System

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Abstract

The rotary valve is a widely used mechanical device in many solids-handling industrial processes. However, it may also be responsible for most of the attrition effects occurring in a typical process. In this study, the attrition effects occurring in a rotary valve operating as a stand alone device and as part of a pneumatic conveying system are investigated. The Gwyn's correlation was found to fit the experimental data obtained in the former case and at high air flow rates in the latter.

Introduction

Granular material is widely used as a raw material in the chemical industries. During transportation through long pipelines and other devices in a processing facility, granular material may be severely degraded as a result of inter-particle collisions and wall impacts. This may lead to significant changes in physical characteristics and subsequently flow behavior of the granular material in the system.

The most important mechanism responsible for granular material degradation is shearing (Ouwerkerk, 1991). As such, a number of techniques that produce shear strains have been proposed. Among the various types of devices used, the annular shear cell test has become a widely used testing method. Bridgwater and co-workers have investigated (1983 a, b, 1994, 1999) the effects of stress and strain extensively for a wide range of materials such as urea prills, sodium chloride particles, molecular sieve beads, and alumina extrudates in various forms. Ghadiri (2000) studied the dependence of attrition in an annular shear cell on the applied normal load and shear strain in detail for porous spherical catalyst carrier beads. More recently, Bridgwater et al. (2003) used particles made of the same material but with different shapes in an annular shear cell to investigate the effects of stress, strain and particle shape on particle attrition.

The rotary valve is a widely used volumetric type feeder in the food, chemical, cement and textile industries (Mehmet, 2004) and has also been used in our research laboratory for studies on pneumatic conveying of granular materials (Rao et al., 2001; Zhu et al., 2003, 2004; Yao et al., 2004). During its operation, the rotary valve has been observed to cause significant attrition effects in the granular material used.

The present work aims to study attrition effects in a rotary valve operating either as a stand alone device or as part of a pneumatic conveying system. The experimental data obtained are fitted with Gwyn's correlation and the corresponding parameters at various rotary valve speeds and gas flow rates are obtained.

Rotary valve

The rotary valve presented herein has 8 pockets (General Resource Corp., Hopkins, Minnesota) as shown in Figure 1. In order to get various rotary valve speeds, a three phase frequency inverter (HF-320 Series, Sumitomo Heavy Industries, Ltd.) was used to change the power frequency and three different speeds could then be obtained: 15.8 rpm, 25.0 rpm and 30.4 rpm. PVC particles were used throughout the experiments.

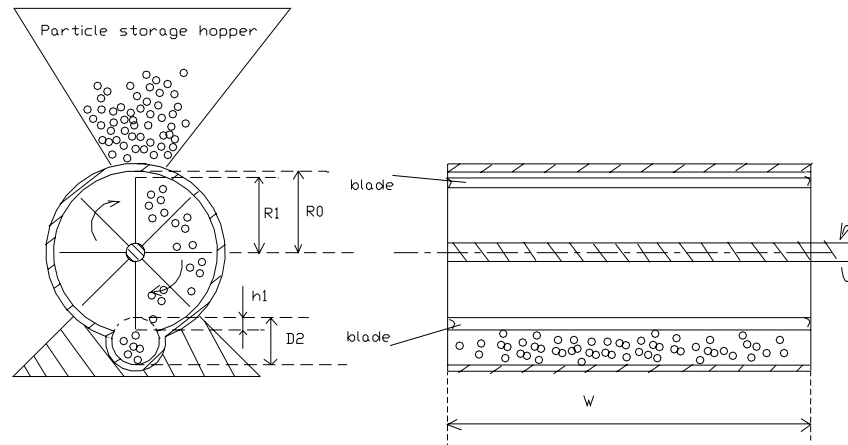


Figure 1. Attrition apparatus: rotary valve (R_0 : 140mm; R_1 : 120 mm; W : 248 mm; h_1 : 25 mm; D_2 : 70mm)

The following experimental procedures were used to investigate attrition effects arising within the rotary valve while operating as a stand alone device. The bottom pipe (Figure 1) inside the rotary valve vessel was filled with granular material to a level just below the vanes. The rotary valve was then run at a constant speed and granular material was added slowly to maintain the amount of material at the same level. At pre-defined time intervals, the rotary valve was stopped and all granular material removed for weight-size distribution analyses by sieving. The whole process was repeated for different rotary valve speeds.

Pneumatic conveying system

The experimental setup used in the study was the same as the pneumatic conveying system used by Yao et al. (2004). Granular material was introduced into the rotary valve and entrained by air flowing from the compressor mains. The conveying pipe was made of transparent PVC material and had a wall thickness of 5 mm. Visual observations of the various solid flow patterns which arise during the experiments were facilitated through the use of transparent pipes. The entire configuration was held in position using metal castings and supports with various pipe segments joined by connectors and reinforced by silicone gel. Air from the compressor mains flowed through the rotary feeder, driving the granular material through the conveying system. A control valve and rotameter which allowed a maximum flow rate of 2000 liters/min were used to adjust the air flow rate. Air humidity was controlled by the dryer (silica gel with indicator-blue) at $RH = 5\%$ and ambient temperature was controlled between $28 \sim 30 \text{ }^\circ\text{C}$.

The experimental procedure is summarized as follows. A specific air flow rate was used to transport a sample of granular material through the pneumatic conveying system for a given amount of time (about 60 minutes for each test). At pre-defined time intervals, the granular material was emptied from the system and a weight-size analysis was carried out by sieving on a representative sample of the material. The procedure was repeated for different air flow rates using fresh granular material samples for each separate experiment.

Physical analysis of granular attrition due to rotary valve

Three possible mechanisms by which particle attrition may take place in a rotary valve are proposed as follows. Firstly, particles may be crushed between the vanes of the rotary valve and its casing wall as they enter or leave the device. This was verified through visual observations during the experiments where granular material was seen to accumulate at both the entrance and exit of the rotary valve due to low air flow rate and weak particle flowability. Secondly, particle attrition may also result from direct impacts with the vanes of the rotary valve with higher impact speeds leading to more extensive particle damage. Thirdly, inter-particle collisions may also contribute to the attrition effects occurring within the rotary valve.

Results and discussion

Rotary valve

From the experiments performed, it was found that the size of attrition product including the debris and mother granules were mostly in the range 0 – 3.35 mm. Using the golden section principle, sieve cuts were chosen at 1.18 mm, 2.00 mm, 2.36 mm, 2.80 mm, and 3.35 mm.

Gwyn approach

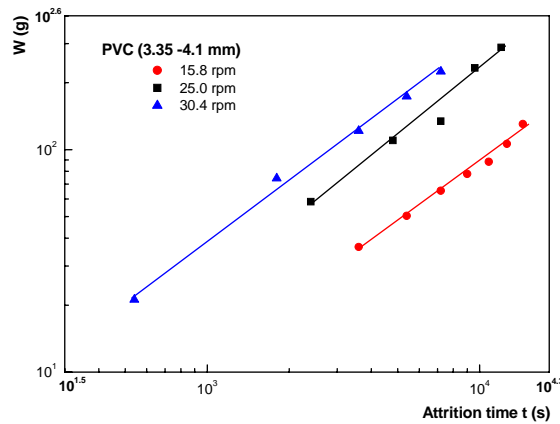


Figure 2 Gwyn plots for sieve particles: sample mass PVC (3.35 – 4.41 mm), 742.42 g.

Gwyn (1969) proposed a means of describing attrition of a bed of solids held in a cylindrical vessel into which an air jet was injected at high velocity. He stated that the attrition of initially single-sized particles could be described empirically by:

$$W = Kt^m \quad (1)$$

where W is the mass that has undergone attrition at time t and m is an empirical constant. K is another constant which he argues is a function of particle size. Paramanathan and Bridgwater (1983b) attempted a theoretical explanation of the equation in a model of the process of surface abrasion.

Figure 2 shows that the experimental data for particle attrition effects in a rotary valve operating as a stand alone device could be correlated adequately with equation (1). The corresponding Gwyn parameters obtained from the correlation for different rotary valve speeds are shown in Table 1.

Table 1 Summary of attrition data using the Gwyn approach PVC 3.35 – 4.1 mm

| Rotary valve speed (rpm) | Parameters from Gwyn function | |
|--------------------------|-------------------------------|--|
| | m(-) | K/ 10 ⁻⁴ (s ^{-m}) |
| 15.8 | 0.8388 | 0.52 |
| 25.0 | 0.9158 | 0.64 |
| 30.4 | 0.9381 | 0.76 |

It may be observed that the parameter m is approximately constant over the range of rotary valve speeds investigated and so may be dependent only on the type of granular material used. This is consistent with the findings of Neil and Bridgwater (1994, 1999).

Pneumatic conveying system

Gwyn approach

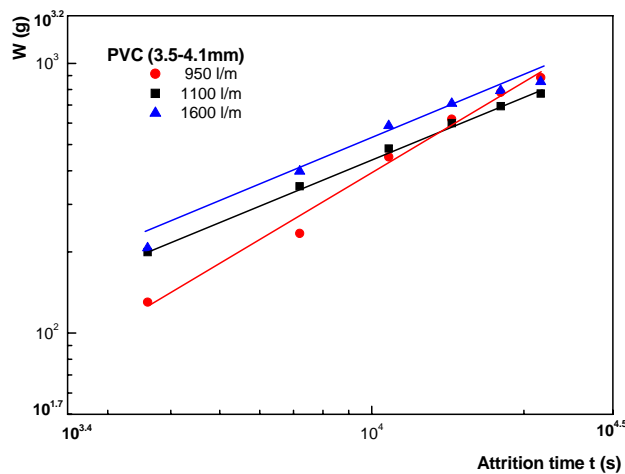


Figure 3 Gwyn plots for molecular sieve particles 3.35 – 4.1 mm as a function of air flow rate, sample mass 1100 g.

Similarly, it can be seen in Figure 3 that the experimental data for attrition effects in the pneumatic conveying system can be correlated with equation (1). The value of the parameter m remains substantially constant for the cases with air flow rates of 1100 L/min and 1600 L/min but is observed to be unusually large in the last case using 950 L/min (Table 2). Figure 4 also shows that the amount of attrition product produced using this latter air flow rate increases rapidly beyond the fourth hour of the experiment and eventually overtakes those using higher air flow rates (1100 and 1600 L/min) after six hours.

Table 2 Gwyn function parameter of the rotary valve in the pneumatic conveying system

| Air flow rate (liter/min) | Parameter from Gwyn function | |
|---------------------------|------------------------------|---|
| | m(-) | K / 10 ⁻⁴ (s ^{-m}) |
| 950 | 1.0613 | 0.2032 |
| 1100 | 0.8087 | 2.4086 |
| 1600 | 0.8907 | 1.2705 |

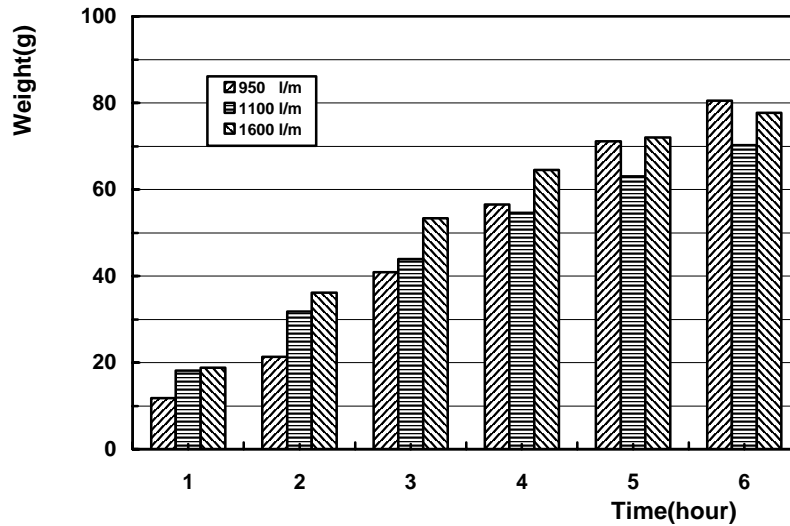


Figure 4 Attrition product weight via air flow rate in the pneumatic conveying system

This anomalous behavior may be explained based on the relationship between attrition behavior and transport velocities of the original particles and attrition product. Smaller-sized particles generated from attrition of the original particles are conveyed at higher velocities than their intact counterparts. This leads to more significant attrition effects in these fast moving particles and generation of more attrition product. Thus, as analogous to an autocatalytic chemical reaction, the amount of attrition product may increase rapidly after an initial period of time and this effect becomes more apparent at lower gas conveying velocities. In the rotary valve, it is also expected that a lower air flow rate would lead to accumulation of granular material and consequently more significant attrition effects.

It may be generally observed that the experimental data obtained at high air flow rates (1100 and 1600 L/min) are well fitted to the Gwyn's correlation shown in equation (1). This may imply that the mechanisms for attrition in such cases are well described by the physical principles inherently defined in the correlation. On the other hand, at the low air flow rate of 950 L/min, the attrition process may not be well described by the Gwyn's correlation as seen by the less adequate fitting and parametric values obtained above.

Conclusions

The attrition effects in a rotary valve operating as a stand alone device and as part of a pneumatic conveying system have been investigated in this study. In the former, the experimental data at various rotary valve speeds were well fitted to the Gwyn's correlation and a fairly consistent set of values for the parameters in the correlation were obtained. In contrast, when the rotary valve was operated as part of a pneumatic conveying system, the Gwyn's correlation was found to fit the attrition data obtained at high air flow rates but not otherwise. It is suggested that the attrition mechanisms at lower air flow rates may be different from that inherently defined by the correlation.

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