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A NOVEL APPROACH TO ROTARY VALVE VENTING

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ABSTRACT Venting of pocket carryover and leakage air from rotary valves is a perennial problem. Unless this air is controlled its only escape route is up through the drop tube leading into the feeder. This causes a counter flow to the product falling into the rotary valve restricting the throughput of the system.
This paper discusses the design and implementation of an in-line cyclone to obviate the disadvantages of the traditional methods employed for rotary valve venting.

1 INTRODUCTION

The amount of rotary valve air leakage present depends on many factors, such as system pressure, rotor clearances, material being handled, head of product above the valve and whether venting is used or not. Disregarding leakage at the design stage of a pneumatic conveying system can result in incorrect sizing of the prime mover (viz. fan, blower or compressor). An oversized prime mover can result in higher transport velocities, reduced solids throughput, increased abrasion and/or erosion of the plant, an increase in product degradation and/or unnecessary over-expenditure. An undersized prime mover can result in insufficient transport velocities causing increased operating pressures, unstable flow, system shutdown and/or pipeline blockages [1].

Other consequences of air leakage include: fluidising the product above the rotary valve and hence, reducing its bulk density; hindering the flow of product into the valve. Either consequence will result in a reduction of the feed rate capacity of the valve. This situation is exacerbated for rotary valves that wear out over time, resulting in increased internal clearances and hence, air leakage. This paper discusses the design, evaluation and application of a novel in-line cyclone to obviate the disadvantages of traditional methods employed for rotary valve venting.

2 TYPES OF AIR LEAKAGE

Labyrinth leakage occurs if there is poor sealing between the rotor shaft and the side plates of the casing. This leakage can be minimised by using suitable seals [2].

Carry-over leakage, Figure 1, occurs when compressed air is “carried” up into the feed hopper through the returning empty pockets of the rotary valve. This type of leakage can be reduced by venting air from the returning pockets before coming in contact with the feed material [2]. However, venting also will tend to increase the total amount of air leakage for a given valve and operating condition.

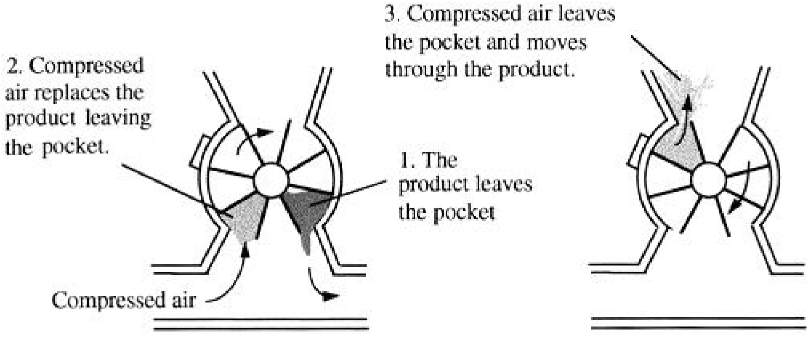

Figure 1 Rotary Valve Carry-Over Air Leakage

Clearance leakage, Figure 2, occurs when air leaks through the gaps between the moving rotor and the housing. To minimise this form of air leakage, small clearances can be used between the rotor and the valve housing. Manufacturers also have experimented with such things as spring-loaded, flexible and adjustable rotor tips [2] (i.e. to minimise rotor tip clearance).

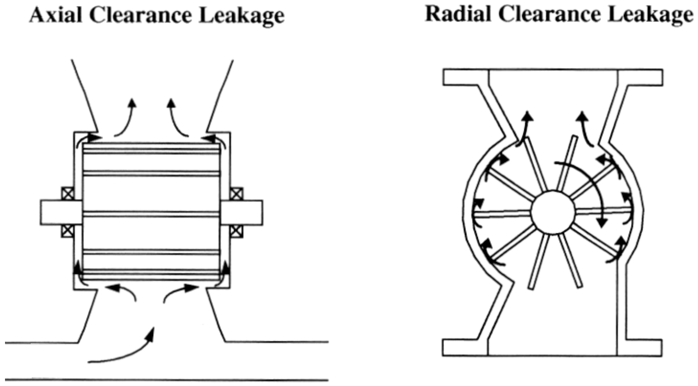

Figure 2 Rotary Valve Axial (End Plate) And Radial (Rotor Tip) Clearance Air Leakage.

Conventional rotary valves used for dilute-phase conveying (where operating pressures are typically < 100 kPag) usually have both axial and radial clearances and hence, air leakage. Special high-pressure rotary valves used for dense-phase conveying (where operating pressures are typically < 350 kPag) usually have axial seals and hence, only radial clearance air leakage.

3 VENTING

Body venting of carry-over and clearance leakage is a method used to reduce the feed hindering effect of gas leakage. The gas rising through the valve escapes through a vent on the return side of the valve body instead of forcing its way through the head of product above the feeder. Body venting, when applied can initiate other problems. For example, the clearance leakage resistance created by the rotor blades is reduced as there are fewer blades "in contact" with the return side of the valve. The effects of this can be seen in Figure 3.

The vent line from the venting ports commonly acts as a relatively small pneumatic conveying system. Particles can escape through the body vent ports and convey elsewhere in the system. Common practice for the vent line is to return it to the supply bin. This method solves the loss of product associated with body venting but does not assist with the overall system capacity.

Body venting reduces the amount of gas entering the hopper, yet does not stop it. Clearance leakage travelling up the feed side continues to enter the hopper. This can also be seen in Figure 3.

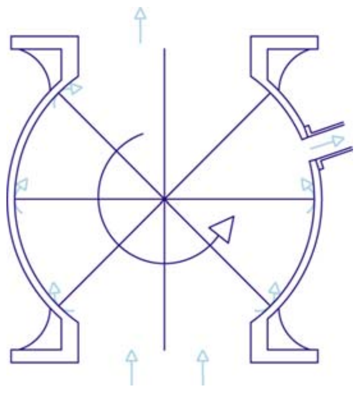

Figure 3 Clearance Leakage and Body Venting

4 FEEDING CHARACTERISTICS

The feeding of product into the pockets is a very complex area. Different bulk solids may behave differently (i.e. how they flow, how easily they aerate and how the rotary valve speed affects the product). The geometry of different feeders will also alter the feeding characteristics, including the amount of time each pocket is exposed to the material. There are several methods that can be used to estimate the feeding performance of a certain system, including the complete pocket filling model and the Reed et al. methods [3,4].

4.1 Complete Pocket Filling

This method is the simplest method for calculating the mass flow of solids through a rotary feeder. It assumes the pockets are completely filled with product at the loose-poured bulk density. The method should be used more as a "limiting" value rather than a reliable estimate of product throughput, as pockets will rarely completely fill, especially as the rotor speed increases. Equation (1) displays the method for calculating the mass throughput.

$$m_s = \psi\ \rho_{bl}\ N / 60 \qquad (1)$$

5 VENT HOPPER DESIGN

The vent hopper, see Figure 4, was developed to increase the mass flow rate of solids passing through the rotary feeder. The design consists of three main areas. Firstly the vertical standpipe, this consists of a vertical section of pipe connected to the feed bin hopper and terminating just above the rotary feeder blades. Secondly the cyclone section surrounds the vertical standpipe and is used to separate the solids from the air exiting through the body vent ports, reintroducing them it into the rotary feeder. The body vent line enters the vent hopper tangentially to promote the cyclonic effect around the body and the exhaust line exits tangentially in order to maintain the cyclonic action. Finally, the hopper section was designed to aid in the separation of the particles whilst reducing the diameter of the body to suit the rotary feeder inlet port. The annular area between the hopper section and the vertical standpipe was minimised to increase product flow, yet the area had to be large enough to ensure the velocity of the leakage air was not too high.

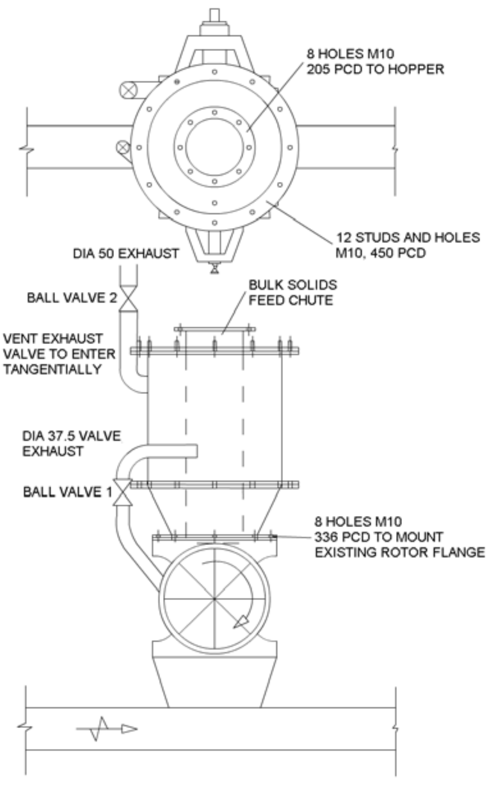

Figure 4 Diagram of the Venting Hopper Arrangement

5.1 Body Venting Alternatives

To test the efficiency of the vent hopper, four valve switching orientations were used:

a. Body vent closed, exhaust vent closed
b. Body vent closed, exhaust vent open
c. Body vent open, exhaust vent closed
d. Body vent open, exhaust vent open

The product used throughout this testing was corvic powder, (ρ_{bl} = 522 kg m^{-3}, ρ_s = 1488 kg m^{-3} d_{50} = 115 μm). The first orientation attempts to simulate a rotary feeder only situation, the air that exits through the rotary valve must exit the system through the vertical standpipe carrying the product. The second switching orientation opens the vent hopper vent valve. The gas leaks through the valve in the traditional manner, but then exits the system through a separate line, minimising the flow of gas through the falling product. The third orientation allows the carry over leakage and the return side clearance leakage to travel through the body vent. The air then enters into the vent hopper and exits through the vertical standpipe, this orientation aims at investigating whether eliminating the puffing effect commonly associated with carry over leakage will improve the mass flow rate. The final orientation allows the vent hopper to operate as designed. The body vent is active reducing the puffing effect, and the vent is open allowing maximum separation of the product and the gases. A schematic of the four different orientations with their principal air flows can be seen in Figure 5. Figure 6 shows the results achieved from testing the four different alternatives.

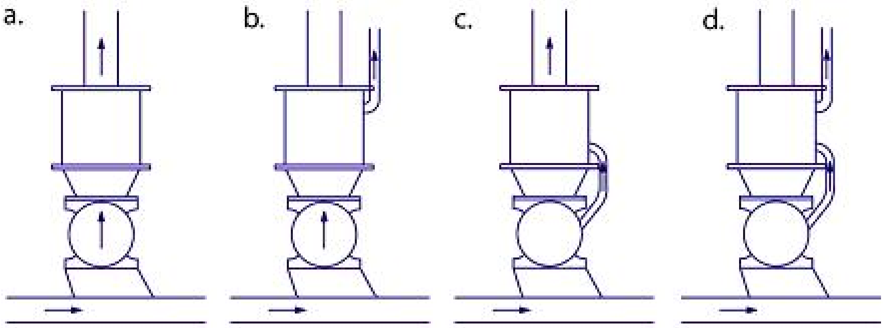

Figure 5 Body Venting Alternatives

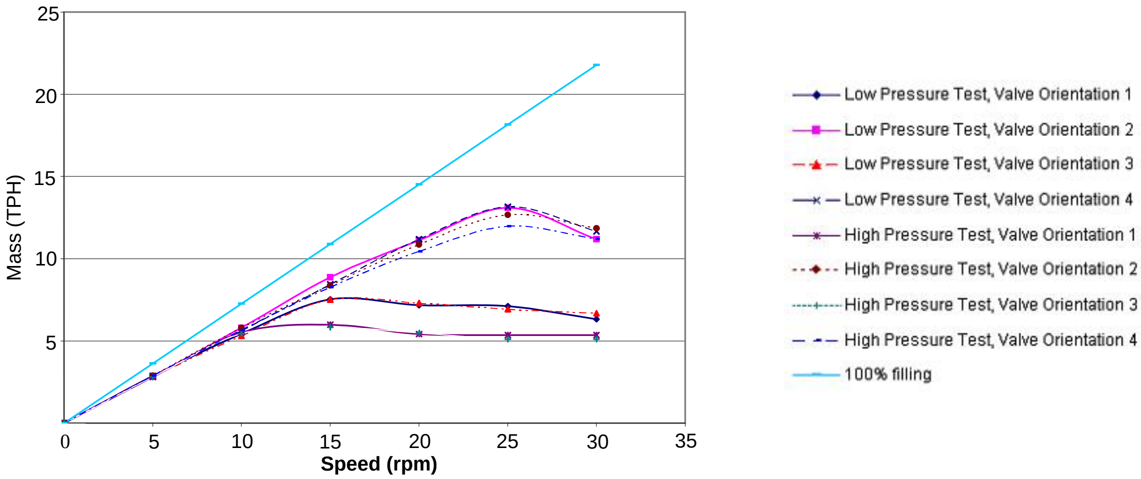

Figure 6 Product and Air Feed Rate Test Results
(low pressure = 10 kPa; high pressure = 100 kPa)

5.2 Displacement Leakage

This leakage is caused by the product entering the valve pockets and displacing an equal volume of gas. For a given test, m_s = 3.62 kg s^{-1}, the leakage was estimated to be 0.00298 kg s^{-1}. This mass flow rate of air exiting the valve is small, even much less than the air only tests measured with only 10 kPa below the valve. Yet if the leakage is added to the curves in the air only tests it represents an increase of around 17% at low pressures and an increase of 4% at 110 kPa. This increase in leakage may be important when designing for gas entering the feed bin. However, it should be noted that this leakage does not relate to a loss of supply gas, and so for prime mover selection this mode leakage should not be considered.

5.3 Puffing

The effects of puffing could be seen through the perspex viewing windows located on the top of the vent hopper when the body vent valve was closed. This rush of gas is caused by a combination of carry over leakage and a short period of excess clearance leakage and can be seen as a puff of product partially or fully filling the cyclone section of the vent hopper. The annular region surrounding the vertical standpipe allowed the high pressure gas to expand before it "entered" the feeding product. Whilst some product was accelerated away from the feeding pockets, such as it would be without the vent hopper, the product was still allowed to fill the pockets effectively, and there was no significant difference in the conveying capacity of the system. Opening the body vent valve dramatically reduced the visual effect of puffing, yet made little to no difference to the feeding efficiency of the system. Modifying the vent hopper so that the standpipe is not concentric may increase the efficiency further, by enlarging the vertical standpipe and moving it closer to the feed side of the rotary feeder will increase the pocket filling time and allow for additional gas expansion.

5.4 Body Venting

Allowing leakage to exit through the body vent did increase the total leakage through the valve. The average leakage when the body vent valve was open was 4% greater than when it was closed. This increase in leakage is small, yet significant and if not estimated correctly when designing and commissioning a plant, it could be detrimental to the process and the equipment. The Woods' model [5] can be manipulated to calculate body venting, and can yield quite accurate results although it was not designed to predict this effect.

Introducing the body vent alters the dynamics of the rotary feeder, firstly the restriction to flow is decreased, this effect can be seen directly when evaluating the rotary feeder statically, and secondly the puffing characteristics ,when investigating dynamically. This transformation of flow could not be measured directly by the apparatus used, as the percentage of leakage travelling through the body vent could not be measured. The air exiting the system when the body vent valve was opened was far more constant than when the vent was closed, possibly due to the carry over leakage and a percentage of the clearance leakage exiting prematurely through the body vent.

Opinion is divided on the effectiveness of body venting on rotary feeders [6] and the results obtained compliment both arguments. Whilst the testing did not show any differences when the body vent was open or closed, it did show dramatic differences when the vent hopper exhaust was open. The industry standard configuration for body venting is currently to have the vent line return the gas and any entrained product to top of the feed bin, or a separate bin and filter. Some of the gas therefore does not exit through the central product line, and the rotary feeder efficiency should increase. This method will reduce the puffing effect that will displace product when the rotary feeder is fully flood fed. This certainly is a different argument than that previously mentioned, that is, that body venting increases the rotary feeder efficiency solely by reducing puffing, but is congruent with the idea that body venting does increase feeder efficiency.

5.5 Vent Hopper Exhaust

The vent hopper exhaust allowed gas at pressures above atmospheric in the vent hopper to flow away from the feeding product. The fluid and solids mixture then travelled vertically to where it entered into the top of the feed bin. Opening the vent hopper exhaust promotes maximum separation of the gases. Whilst the mass flow rate of fluid measurements were not taken it can be seen that virtually all of the gas did exit through the vent hopper exhaust, this is caused by the negligible resistance to flow through the vent hopper exhaust line when compared to the substantial resistance through the product.

Occasionally the product failed to flow when the exhaust valve was closed. The mass flow of air was enough to cause a product blockage in the standpipe. The pressure below the valve, combined with the ability of the product to restrict flow causes this dramatic problem. This situation can occur in industry, but is far less likely when the valve is flood fed through its entire inlet port. This is due to both the increased surface area reducing the stress on the product and the effect of puffing breaking the cohesion or arching between the particles.

A visible amount of product was conveying through the exhaust line to the top of the feed bin. Although the product returning up the line could not be measured it was could be seen to be very dilute, and hence a small percentage of the total product being conveyed. Increasing the height of the vent hopper or installing a filter before the product exits the vent hopper, or both, could be used to reduce this effect. Installing the filter may cause feeding problems over time if correct measures are not taken to clean the filter. The vent line must remain free from blockages at all times, if product blocks the line the gas is again forced to travel up through the standpipe and hence reduce the effectiveness of the system. To ensure product does not build up inside the vent line, the vent line should be as close as possible to the vertical.

6 Perlite Testing

Perlite is a light fluffy material typically used as an insulator in large cooling towers and has a very low loose-poured bulk density of 55 to 60 kg m^{-3}. Although perlite is a good candidate for pneumatic conveying this makes it extremely difficult to feed to a rotary valve, as the leakage air travelling up through the rotary valve restricts the flow of the light fluffy product. This product was tested through a vent hopper equipped test rig and the vent hopper was found to dramatically increase the mass flow into and through the rotary valve. For example, for a constant air flow of 0.107 kg s^{-1} and a rotary valve speed of 30 rpm, the mass flow of solids was increased from 750 kg h^{-1} to 2300 kg h^{-1}. The results of a series of tests are shown in Figure 7.

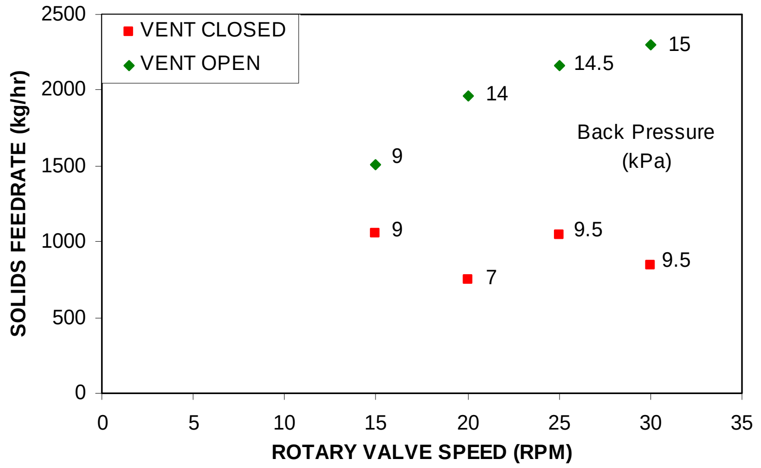

Figure 7 Change in Mass Flow of Solids with Vent Hopper Exhaust Open and Closed

7 CONCLUSIONS

Based on the results and findings presented in this paper, the following conclusions can be made.

Rotary valve air leakage is an important issue that needs to be addressed in the design and operation of dilute- and dense-phase (positive-pressure) pneumatic conveying systems. This leakage can be significant for high-pressure dense-phase systems and even for dilute-phase systems, where relatively small diameters of conveying pipeline are employed.

A new feeding aid for rotary valve feeders has been developed and tested. The vent hopper was designed to efficiently separate the leakage gas from the feeding material, and allow body venting to occur without product loss. The vent hopper was tested under various conditions and proved that it did increase significantly the mass flow of product through the rotary feeder, especially for light and fluffy materials. The vent hopper however did not behave exactly as expected, opening the body vent did not influence the feeding potential of the system, due to the annular region between the standpipe and the hopper reducing the puffing, and effectively short circuiting the body vent.

The head of material above the valve does reduce the amount of leakage as Reed et al. [3,4] and Woods [5] suggest. This material blockage effect could be seen during testing, yet it was not measured. For use in accurate modelling, further testing similar to that originally completed by Reed et al. [3,4] will need to be carried out, as the blockage factors he determines are only specific to his methods of leakage calculation.

8 NOMENCLATURE

m_s	Mass flow rate of product	kg s^{-1}
n	Number of pockets in rotary valve	
N	Speed of rotary valve	rpm
ρ_{bl}	Loose-poured bulk density	kg m^{-3}
Ψ	Swept volume	m^3

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