Dosing of Powders into Processes

Is Your Process Control Screwed?

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Many industrial operations include powder additions to dry blends or wet processes as a key value adding step. The value adding of such processes can be severely impaired in the event that these dosing operations provide an inconsistent or unreliable flow of product.

The market for dosing systems is expansive, and yet despite the wide range of devices that are available to industry, many processes are typified by unpredictably variable powder flow into processes. This article will therefore consider some of the most commonly found installation and design errors that contribute to poor dose control.

1. Defining Poor Accuracy

An important aspect of defining dose variations on a process is to correctly understand the magnitude of the variation. Many contractual issues are known to have arisen from suppliers and end users incorrectly specifying the accuracy that is required by the process. In some instances the misunderstanding is derived from the desire for a "high" accuracy system – without having fully determined beforehand exactly what level of accuracy is required by the process to deliver an in specification product.

Other instances of mis-specification have resulted from ambiguity over the period of scrutiny over which the accuracy is to be measured – the implication being that a requirement for a minimum 3% weight variation over 10 minutes can require a quite different approach (and CAPEX penalty) than the same accuracy over 2 minutes. It follows that time spent early in the project in considering in detail what the actual accuracy (as opposed to perceived accuracy) for a process is, can bring about useful cost savings in the short term and avoid extended commissioning periods pursuing the unnecessary.

2. The Implications for Process Equipment

In instances where the period of scrutiny is large or the process accuracy requirements generous, some degree of instantaneous powder flow variability can usually be tolerated by the process. In such instances, many standard types of buffer hopper and dosing arrangements may be adequate provided that reliability of powder flow is established and supported by the design of the equipment.

However, as higher accuracy (i.e. consistency and repeatability) is sought the equipment design should shift towards the incorporation of geometrical parameters derived from the measurement of flow properties for the worst case powders to be handled through the process. In most cases such "worst case" powders may be found to exhibit significant cohesion and / or wall friction. In some cases though, the powders may be free-flowing, but exhibit a tendency to segregate (de-blend) during handling through the system. Both genres of powder behaviour can have the potential to cause variation in dosing accuracy – whether batch or continuous operation is considered. Fig. 1 illustrates a common problem (rat-holing) when handling cohesive powders through dosing systems.

The key requirement for any dosing system (whether operating on volumetric or gravimetric principles) can basically be reduced to that of consistency of powder flow into the dosing apparatus. The main parameters in this respect relate to the bulk condition

Fig. 1: An example of unreliable flow of a cohesive powder.

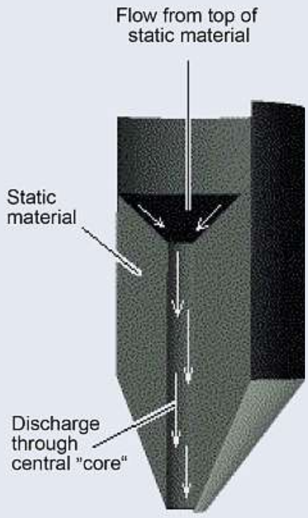

Fig. 2: Core flow.

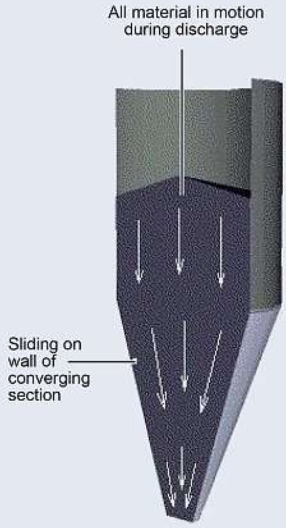

Fig. 3: Mass flow.

of the powder and its flow properties (these two aspects being inter-related). If we consider the basic components of a typical dosing installation the importance and influence of these parameters on dose accuracy can be easily considered.

3. Feed hopper

Obtaining a consistent feed rate and bulk density delivery into a dosing system is a primary requirement and is strongly influenced by the geometry of the feed hopper. In many instances the geometry of the buffer is defined by the use of "standard" convergent angles and surface finishes.

For many free-flowing products this may not necessarily present an issue (a segregating material being the exception) with regards to supporting a reliable feed of material. However, for finer materials the likelihood for erratic flow and bulk density variation is considerable unless the feed hopper is designed to specifically support the flow of such powders.

The key issues presented by the discharge behaviour supported by the buffer are that if a standard design of bin is used then it is likely that it will discharge in core flow (Fig. 2), in which case a central flow channel will develop above the point on the dosing apparatus that offers a transport capacity.

If the vessel is designed to operate in mass flow, then it will have the capability to support an even draw down of material (enabling a first in, first out flow of product) – provided that the dosing equipment and interface is designed to be capable of drawing down from the cross-sectional area of the hopper outlet.

The importance of vessel design for mass flow (as opposed to no special design considerations), is that the flow channel formed above the dosing equipment is coincident with the walls (Fig. 3). For a dosing system the establishment of this flow pattern has some very useful benefits.

- Outlet dimensions to avoid arching and rat-holing are substantially smaller than for a standard vessel.
- Gravity discharge is achieved (with recourse to very low levels of air introduction for very cohesive powders in exceptional cases).
- Velocity profile across the outlet area is constant.
- First in, first out flow permits a controlled residence time for freshly introduced materials.
- All vessel volume is "live" capacity.
- Bulk density at the outlet is very consistent – even in response to falling inventory levels.

In contrast a vessel that is operating in core flow is typified by a preferential flow channel whose diameter is defined by the transport capacity availability of the selected dosing apparatus. Thus, typically, such a vessel may exhibit a fairly large outlet of which less than 10 % area may actually be active during flow. This scenario is very likely to give rise to the following issues:

- Substantial storage volume is taken up with material that is not flowing – hence increasing the risk of agglomeration or spoiling if the vessel is not drained down regularly.
- Increase incidence of flow stoppage (arch or rat-hole).
- Freshly introduced material is drawn straight down to the dosing apparatus – leading to density fluctuation or uncontrolled flow (for air retentive materials).
- All of the dosing rate is drawn down through the flow channel – hence relatively high flow velocity with a resulting reduction (and variation) in bulk density.
- Bulk density variation with changes in inventory level.

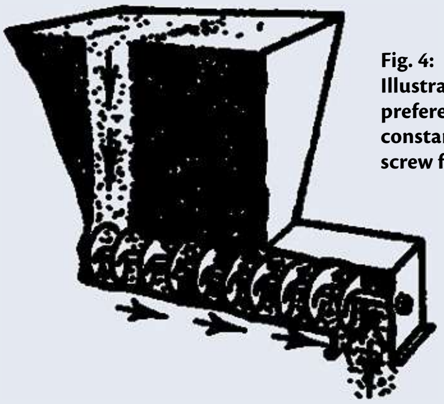

Fig. 4: Illustration showing preferential draw for a constant capacity screw feeder.

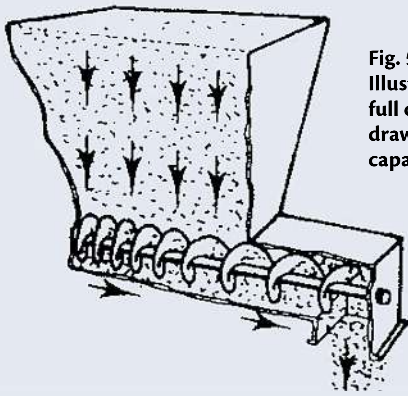

Fig. 5: Illustration showing a full cross-sectional draw for an increasing capacity screw feeder.

4. Interface

In order to support reliable flow from a vessel, the maximum wall half angle, wall surface finish and minimum outlet dimension should be derived from the measured flow properties of the "worst case" powder sample. In instances where this design criteria is applied, the minimum outlet dimension must be complied with in order to support reliable (gravity) flow. It follows that whatever the feeding device, the flow channel that it generates must also suit this critical dimension in order to support mass flow discharge from the vessel (i.e. using a screw as an example, the width of the screw should preferably be slightly wider than the minimum outlet dimension used on the vessel).

In the case of a metering screw feeder this could entail the use of a larger than standard diameter unit – the draw back of which being that the delivery of material from the screw would exhibit a greater instantaneous fluctuation. A reduction in the magnitude of pulsation is possible through double flighting at the delivery end of the screw. For many processes this may be acceptable (subject to the period of scrutiny for which the accuracy has been stipulated), however for some higher accuracy applications there may be a need to opt for a multiple screw set (arranged 180° out of phase for a dual arrangement) which would deliver smaller fluctuations in dosed weight. These are the design details that would apply to a screw feeder designed for optimal performance.

For many systems the undeniable economics of purchasing standard designs dominate the decision making process and thus most common types of screw feeder tend to feature large cross-sectional area inlets onto the screw feeder in which flow is maintained through agitation of the bed – typically through the use of rotating agitators. The issue with this type of arrangement can be that although the volume of the chamber above the screw is swept to prevent consolidation of material, the flow channel will still be dictated by the available transport capacity of the screw feeder. Fig. 4 illustrates this effect for a standard design of screw feeder.

Since virtually all industrial screw feeders feature a constant pitch spacing (either in conjunction with a constant shaft diameter or in a shaftless form), this dictates that irrespective of how large the outlet of the vessel is, the proportions of the flow channel will be dictated by the available capacity of the feeder.

The establishment of a preferential flow channel effectively ensure that the vessel will operate in core flow (even if designed for mass flow) and, as discussed earlier, this will encourage a draw from the upper region of the vessel. Thus, not only does material that has had a minimal residence time (to mature by de-aeration or cooling) get drawn into the screw, but additionally this material will be in a highly dilated state (as a function of the screws volumetric transfer rate being achieved through a flow channel that is small relative the vessel outlet area).

These two effects result poor particle packing in the screw and thus a low (and variable) bulk density fill of the pitch – giving rise to dose inconsistency. As inventory levels reduce in the feed vessel it is not unusual to find that the bulk density can drop significantly. In order to obtain an activation of the cross-sectional area of a vessel it is necessary to ensure that the feeder is designed such that it can offer an increase in transport capacity along the length of the outlet from which it is drawing material. Fig. 5 shows the flow channel development for such a screw design. In the case of a screw feeder, this is achieved through the construction of design that combines and increase in pitch spacing in conjunction with a reducing shaft diameter.

The simple design feature of increasing the transport capacity enables a complete drawn down to develop – which is a prerequisite for supporting mass flow. Thus is a mass flow vessel interface, the flow pattern will allow first in – first out stock rotation and by virtue of the flow channel now being the full area of the outlet, bulk density variation is minimal and segregation effects are significantly reduced. A very important benefit relating to the establishment of mass flow discharge onto a screw feeder is that the particle packing in the screw feeder will have the potential to be more consistent than for material fed through a system that relies on agitators rotating along the axis of the screw feeder.

An example of the potential for inconsistent particle packing would exist where a variable speed screw (i.e. for fast and trickle feed functions) is used in conjunction with a fixed speed agitator. In such a situation the proximity of the agitator blade to the material already being transported within the screw can transmit additional stress into the powder. At high feed rates (with the screw operating at higher RPMs) the frequency of compaction effects will be relatively low, however at trickle feed conditions (lower RPMs) the compaction frequency will be higher –

giving rise to some fluctuation in weight (dependant upon the accuracy required). This cyclic additional packing of material into the feed screw is likely to contribute towards a build up of material on the screw (if the geometry employed is not favourable) – which in turn leads to the need to run the screw faster to obtain a comparable transfer rate over time, which decreases the consistency of particle packing if the draw is preferential – giving rise to greater inaccuracy.

5. Summary

It is hoped that this very brief look at some of the problems associated with accuracy in feeder operations may provide an insight into some of the more common issues in processes. Some of the principles discussed are transferable to other types of controlled feeding systems (such as belts), but space limitations preclude presenting this information in a single article.

In summary, the importance of considering powder flow characteristics before specifying (or purchasing equipment) cannot be over stated enough. Time spent considering the integration of process elements to operate together with the objective of delivering an accurate and repeatable output before the start of a project will invariably pay dividends when the time comes to produce consistent quality products with reliability. ■

About the Author

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Richard Farnish holds an MPhil from the University of Greenwich and has worked extensively on consultancy projects ranging from pneumatic conveying, silo design and segregation problems. He has recently completed his thesis „Effect of flow channel profiles on repeatability of discharge rates from dispensing heads used for flow control of particulate materials in bulk“. His research interests are in optomising packaging and tanker filling systems.

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