Manufacturing tablets and capsules involves several powder handling steps, including blending, transfer, storage, and feeding. This article identifies powder handling problems, discusses the powder and equipment properties that cause the problems, and offers some solutions.

A full understanding of powder flow behavior is essential when designing new equipment or when developing corrective actions for existing equipment. This article provides an overview of common bulk solids (powder) handling problems that can occur in pharmaceutical manufacturing processes and the key powder and equipment properties that relate to them.
The importance of reliable powder flow

Powder that doesn't flow reliably adversely affects process robustness and other areas of your operation, including

1. Production costs. These increase because the flow problems reduce production rates (e.g., tabletting/encapsulation rate limitations, required operator intervention), restrict raw ingredient selection (e.g., amount of lubricant in a formulation), limit the manufacturing methods available (wet granulation vs. dry granulation vs. direct compression), limit equipment selection (type of blender, bin, tablet press), and reduce overall yield.

2. Product quality. The properties of the tablets and capsules (weight, hardness, etc.) vary and are subject to segregation and/or content uniformity concerns.

3. Time to market. A product launch may be delayed because of problems with product or process development, validation, or commercial batches. You may not be aware of the potential for these problems until scale-up.

A designer's understanding of the key powder properties (flow properties) and equipment parameters that affect common flow problems can reduce these risks. Although it's beyond the scope of this article, there is a substantial amount of literature regarding the measurement of key powder flow properties [1-5]. In cases where segregation of the final blend is a concern, a designer can also make use of the substantial literature devoted to minimizing the effects of segregation and maintaining blend uniformity in pharmaceutical processes [6, 7].

Defining flowability

A bulk solid (powder) is defined as a collection of discrete solid particles, and the concepts discussed in this article apply to many types of bulk solids. In fact, bulk solids are often referred to as powders, and this article uses the two terms interchangeably. The terms refer to dusts, granulations, and granules, whether they comprise a single substance or a multi-component blend of fine and coarse particles.

Flowability describes the ability of a powder to flow through equipment reliably. There is a tendency to define flowability as a one-dimensional characteristic (flow property), usually ranking the powder on a scale from free flowing to non-flowing. A single parameter, however, is not sufficient to fully define a powder's handling characteristics or to provide the design parameters needed to address the common handling concerns of formulators and equipment designers. That's because bulk solids flow behavior is multi-dimensional, and therefore the full range of flow properties must be measured to characterize the bulk solid [2]. Flow properties (plural) are the specific bulk characteristics and properties of a powder that affect flow and that can be measured.

In addition, the flowability of a given bulk solid is often a function of the equipment and flow properties. A poor-flowing powder can be handled reliably in properly designed equipment. Conversely, a good-flowing powder may develop problems in improperly designed equipment.

Therefore, a more accurate definition of flowability is the ability of powder to flow in the desired manner in a specific piece of equipment. Clearly, then, the flow properties of the bulk solid must be measured so that they have meaning with respect to a specific application. Furthermore, the flow properties should provide quantitative and scalable design parameters for developing new equipment or for evaluating potential corrective modifications to existing equipment.

One of the first steps in assessing potential flow problems is to determine the flow pattern that will occur during gravity discharge of powder through the handling equipment. There are two primary flow patterns that occur in bins: funnel flow and mass flow. See Figure 1. In funnel flow, an active flow channel forms above the outlet, which is surrounded by stagnant material. This is a first-in, last-out flow sequence. It generally occurs in equipment with relatively shallow hoppers, often including hopper geometries such as the asymmetric cones common to tablet press feed hoppers and rectangular-to-round transitions (Figure 2).
In funnel flow, as the level of powder decreases, stagnant powder may fall into the flow channel, provided the material is sufficiently free flowing. If the powder is cohesive, a stable "rathole" may develop.

In mass flow, all the powder moves when any is withdrawn. Powder flow occurs throughout the bin, including at the hopper walls. Mass flow provides a first-in, first-out flow sequence, eliminates stagnant powder, provides a steady discharge with a consistent bulk density, and provides flow that is uniform and well-controlled. Therefore, designing handling equipment (bins, transfer chutes, feed hoppers) for mass flow provides many benefits. Achieving mass flow requires 1) an outlet large enough to prevent arch formation and 2) hopper walls that are steep and smooth enough to allow the powder to flow along them. The flow properties tests and calculations used to determine these design parameters are reviewed elsewhere [1].

The next section discusses the possible effects that the flow pattern can have on common flow problems encountered in the feed systems of tablet presses and encapsulators.

Common flow problems and the powder and equipment parameters that affect them

What follows is a review of the basic design techniques used to provide consistent, reliable flow of gravity-fed powders, with particular attention paid to

1. Designing bins for reliable funnel flow (while preventing a rathole) and
2. Designing bins for reliable mass flow.

But first it should be noted that another common source of flow problems is adverse two-phase (powder and interstitial gas) flow effects. These effects can limit tabletting and encapsulation rates and/or result in out-of-specification variation in the tablet/capsule properties (weight, thickness, hardness, dissolution). Two-phase flow behavior, where the blend starts to behave in a liquid-like manner due to the interaction between the powder and the interstitial gas, is most common with fine powders (i.e., mean particle size of 150 microns or less). A thorough discussion of two-phase flow behavior, the flow properties that affect it, and the problems it can cause is available elsewhere [2].

Now let's review the key equipment parameters and flow properties related to the two design objectives cited above: reliable funnel flow and mass flow.

Reliable funnel flow design: Preventing a rathole

Whether the equipment being designed is a bin, transfer chute, or feed hopper, a crucial first step in designing a reliable feed system is determining the flow pattern and designing accordingly. This section focuses on preventing ratholing in a funnel flow bin, but the design techniques can also be applied to preventing ratholing in a flooded-load transfer chute with a converging cross-sectional area or a feed hopper. These techniques can be applied to any powder, including the API, excipients, and/or blends held in a bin upstream or downstream of the final blender.

A funnel flow bin design can be considered if all of the following design criteria are met:

1. Segregation is not a primary concern. Since a funnel flow bin will discharge in a first-in, last-out flow sequence, any side-to-side segregation that occurred when the bin was filled will often be exacerbated in funnel flow discharge. This topic is outside the focus of this article but is discussed more thoroughly elsewhere [7].

2. The final blend has relatively low cohesive strength. In this case, the formation of a stable rathole is not a concern. This is discussed in more detail below.

3. Flooding due to a collapsing rathole is not a primary concern. Flooding can result in a highly aerated (low-density) powder being fed from the bin to the tablet press or encapsulator, which may adversely affect the tablet or capsule properties (weight, hardness, dissolution variation). This is a two-phase flow effect that is not discussed in this article, but is covered elsewhere in the literature [2].

4. Non-uniform feed density is not a primary concern. Since tablet presses and encapsulators use volumetric feeding, variation in the density of the feed into the feed frame of a tablet press or the bowl of an encapsulator can result in variation of tablet/capsule weight. A funnel flow bin will typically have a more non-uniform feed density than a mass flow bin, since the blend in the funnel flow bin will be subjected to different consolidation pressures, depending on where in the bin it is discharged from. For instance, the portion of the blend located at the bottom of the bin at the hopper walls (outside the flow channel) may be more consolidated and have a higher density than the portion of the blend within the flow channel.

If all these design criteria are met, a funnel flow bin design can be considered. If a funnel flow bin design is acceptable, the first concern is the outlet diameter, which must be greater than the critical rathole diameter (Df) to ensure that a stable rathole will not form. (See Jenike for the calculation.) If the diameter of the funnel flow bin is less than Df, it's possible that a stable rathole will form. You can seek to reduce the likelihood of a stable rathole forming by following these steps:

1. Enlarge the bin opening. This may require using a slotted outlet, which would require a feeder capable of feeding uniformly across the entire outlet (e.g., a mass flow screw feeder). Simply using a larger outlet diameter may not be practical or feasible, since the opening may need to be so large (e.g., more than 12 inches!) that it would no longer mate with downstream equipment, such as the tablet press hopper or the inlet to the encapsulator.

2. Reduce the material load in the bin. Df typically decreases with a reduction in the effective head (EH in Jenike),
which depends on the fill height. Therefore, a reduction in the fill height can be considered, but that may lead to using multiple smaller bins.

3. Use an internal, mechanical agitator. It may be practical to add an internal mechanical agitator, such as one with "arms" that rotate about a central vertical shaft (Figure 4). That modification is likely most practical on a small scale, such as in a tablet press hopper. It is likely less practical in large-scale bins because of motor size and cleaning concerns. A discharge valve might also offer an effective means of causing a stable rathole to fail, but that option would require full-scale trials to assess its effectiveness [8].

The flow properties that govern whether a powder is prone to ratholing include cohesive strength, wall friction, and bulk density [1-5]. Changing (reformulating) the powder to reduce the cohesive strength and wall friction, however, may reduce the likelihood of ratholing. Common methods to improve the flow properties of a powder include increasing the particle size distribution, lowering the moisture content, and using a lubricant or glidant.

In addition to ratholing, there are several adverse effects of using a bin that discharges in funnel flow. They include first-in, last-out flow, non-uniform feed density, and exacerbation of segregation. As noted above, the options available to prevent a rathole may be infeasible or impractical for a given application. Therefore, another common design technique for preventing ratholing is to redesign the bin for mass flow. A mass flow bin will not rathole because the powder moves along the bin walls. The following section discusses the design techniques for mass flow.

Reliable mass flow designs for the bin, chute, and tablet press hopper

The details of the wall friction tests and design charts used to determine whether a bin will discharge in mass flow or funnel flow are provided elsewhere [1]. The same literature also describes how to conduct the minimum required outlet diameter (Bc) or minimum slot width (Bp) to prevent a cohesive arch from forming in a mass flow bin (Figure 5).

No matter whether the equipment being designed for mass flow is a bin, transfer chute, or tablet press hopper, the same design criteria apply for obtaining mass flow discharge. Therefore, although this section focuses on design techniques for mass flow bins, these techniques may be extended in order to obtain mass flow in a transfer chute and tablet press/encapsulator hopper. Furthermore, the techniques can be applied to designing new equipment and to modifying existing equipment to provide mass flow.

When designing a bin to provide mass flow, follow these general steps:

1. Size the outlet to prevent a cohesive arch. This is done by making the outlet diameter equal to or larger than Bc (Figure 5). If a slotted outlet is used (with at least a 3-to-1 length-to-width ratio for the outlet), the outlet width should be sized to be equal to or larger than Bp (Figure 5).

The outlet may also need to be sized based on feed rate and two-phase flow considerations [2]. If the outlet cannot be sized to prevent an arch (e.g., because the tablet press hopper outlet must mate with a fixed feed frame inlet), an internal mechanical agitator could be considered, as discussed earlier.

2. Once the outlet is sized, design the hopper wall slope to be equal to or steeper than the recommended hopper angle for the given outlet size and selected wall surface. For a conical hopper, the walls should be equal to or steeper than the recommended mass flow angle for a conical hopper (σc). See Figure 5. If the bin has a rectangular-to-round hopper, the valley angles should be sloped to be equal to or steeper than σc. Planar walls should be equal to or steeper than the recommended mass flow angle for a planar hopper (σp). See Figure 5.

3. Pay careful attention to the interior wall surface finish. It is not sufficient to specify a type 304 or 316 stainless steel for the bin without specifying the interior finish, because the wall friction of the powder may vary significantly from one finish to another. Nor can you assume that the lower the average roughness (Ra) of the interior surface finish, the better the wall friction properties because there are fine powders that are more frictional against an interior finish with a lower Ra (e.g., electro-polished finish) than a higher Ra (320-grit finish). That can happen because there is more contact area between the fine powder and the lower Ra finish. Therefore, measure the wall friction of the powder against the interior surface finish being considered. The results will determine the required angles for mass flow (σc/σp).

4. Consider velocity gradients. Even when a bin is designed for mass flow, there still may be a velocity gradient...
between the material discharging at the hopper walls (moving slower) vs. the center of the hopper (moving faster), assuming a symmetric bin with a single outlet at the center. Depending on the application, the bin designer may want to increase the velocity gradient to enhance blending between vertical layers of material in the bin or reduce the velocity gradient to enhance side-to-side blending. The course of action depends on the segregation that occurs upon filling the bin and the effect on content uniformity. Making the hopper slope steeper with respect to the recommended mass flow hopper angle ($\theta_c/\theta_p$) reduces the velocity gradient. Changing the interior surface to reduce friction or using an insert (discussed further below) are other methods for controlling the velocity gradient. Asymmetric hoppers, which are common to tablet presses, are especially prone to velocity gradients because the material moves faster at the steeper hopper wall.

5. Avoid upward-facing lips or ledges. These often occur where flanges mismatch (Figure 6) or where there are level probes, view ports, or partially opened valves protruding into the flow path, especially in the hopper section. Ideally, devices that protrude into the interior are installed in the straight-sided section of the bin or hopper. There they are less likely to upset the mass flow pattern.

If you're modifying an existing funnel flow bin to provide mass flow, several different options are available:

1. Use a different interior surface finish. This can improve wall friction properties (lower friction). Conduct wall friction tests on alternative wall surfaces to assess if changing the surface finish (e.g., electro-polishing an existing 2B finish) while still using the existing bin geometry will convert the bin from funnel flow to mass flow. If changing the friction is sufficient to obtain mass flow, you have performed one of the most cost-effective modifications to obtain mass flow.

2. Use a flow-controlling insert. Figure 7 shows one such insert, called Binsert [9], that is used to obtain mass flow within a funnel flow bin. A properly designed insert can change the stresses that develop in the bin during discharge and thus can obtain mass flow at a wall where the material was previ-
ousy stagnant.

3. Modify the hopper geometry. If possible, change the hopper geometry (e.g., planar instead of conical walls) to obtain mass flow. If the hopper is modified to have a slotted outlet, it is crucial for the feeder that mates with the hopper to withdraw material across the entire outlet.

In conclusion, the key to avoiding costly powder flow problems is often a dose of preventive medicine: Measure the flow properties of the powder before designing or selecting the powder handling equipment.

**References**


8. One such valve is available from Matcon, Sewell, NJ. Website: www.matconibc.com

9. Available from Jenike & Johanson, Tyngsboro, MA. Website: www.jenike.com

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