# Feeding of Bulk Solids: A Review

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## 1. Introduction

The benefits of mass flow have long been recognized: elimination of ratholing, controlled flow of fine powders without flooding, minimization of segregation, defined and predictable residence time for processing applications, no stagnant regions where particles can degrade, etc. Design techniques developed by Jenike [1] have been proven over the last 40 years in thousands of applications around the world in virtually every industry.

Jenike's work primarily focused on how to design the hopper section of a storage or processing vessel. By selecting proper hopper angles, geometry and materials of construction, conditions conducive to developing mass flow are present [2]. Unfortunately, mass flow doesn't always result even when these parameters are all met. The problem is often related to the feeder and the manner in which it withdraws material from the hopper outlet.

Consider, for example, a hopper with an elongated outlet which employs a screw feeder to control discharge. If a constant pitch, constant diameter helical screw is used, flow will be confined to the back end of the screw. As shown in Fig. 1, this preferential flow pattern will propagate up into the hopper above, enforcing a funnel flow pattern even if the hopper design meets the requirements for mass flow.

In this paper, common feeders used for bulk solids applications will be reviewed, and some of the common mistakes as well as proper design techniques will be pointed out.

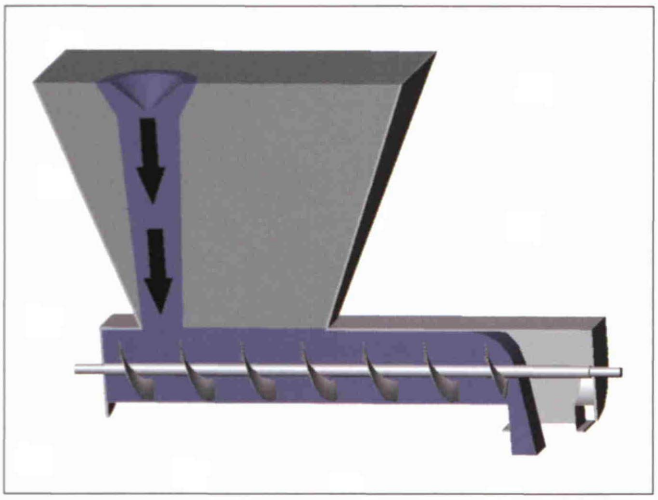

Fig. 1: Constant pitch and diameter screw results in funnel flow pattern developing

## 2. Volumetric or Gravimetric?

There are two basic types of feeders used in industrial plants: volumetric and gravimetric. As its name implies, a **volumetric** feeder modulates and controls the volumetric rate of discharge from a bin (e.g., $ft^3$/h). The three most common types of such feeders are screw, belt, and rotary valve. A **gravimetric** feeder, on the other hand, modulates the mass flow rate. This can be done either on a continuous basis (the feeder modulates the mass per unit time of material discharge) or on a batch basis (a certain mass of material is discharged and then the feeder shuts off). The two most common types of gravimetric feeders are loss-in-weight and weigh belt.

Gravimetric feeders should be used whenever there is a requirement for close control of material discharge. Typically this means requiring a feed rate uniformity of better than about ±2%, or sample collection times of less than about 30 sec. Another application for a gravimetric feeder is when the bulk density of the material varies.

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## 3. Criteria for Feeder Selection

No matter which type of feeder is used (volumetric or gravimetric), it should provide the following:

1. Reliable and uninterrupted flow of material from some upstream device (typically a bin or hopper).
2. The desired degree of control of discharge rate over the necessary range.
3. Uniform withdrawal of material over the outlet of the upstream device. This is particularly important if a mass flow pattern is desired, so as to control segregation, provide uniform residence time, minimize caking or spoilage in dead regions, etc.
4. Minimal loads acting on it from the upstream device. This minimizes the power required to operate the feeder as well

as minimizes particle attrition and abrasive wear of the feeder components.

Often, personnel at a plant have a preference for a certain type of feeder because of past experience, availability of spare parts, or to maintain uniformity so as to make maintenance easier throughout the plant. Such personal preferences can usually be accommodated, since, in general, several types of feeders can be used in most applications provided they are designed properly.

The two major considerations in deciding on the type of feeder to use are: the properties of the bulk material being handled, and the application [3]. Tables 1 and 2 provide insight into which of four common types of feeders is best suited in each of these areas, and Table 3 provides typical design limits for these feeders.

| Variable | Screw | Belt | Rotary valve | Vibrating pan |
|---|---|---|---|---|
| Max. practical particle size | Up to 1/3 of min. pitch[1] | ≅ 6 inch | ≅ 1/2 inch | 12 inch and larger |
| Particles degrade | Fair | Good | Fair | Good |
| Material is a dry powder | Good | Fair[2] | Excellent | Poor[1] |
| Material is sensitive to over-pressure | Fair | Good | Fair | Poor |

[1] Depends on feeder robustness
[2] Performance improved if slide gate used for initial fill

Table 1: Feeder selection based on material considerations

| Variable | Screw | Belt | Rotary valve | Vibrating pan |
|---|---|---|---|---|
| Ability to tolerate direct impact | Fair | Poor | Poor | Good |
| Hopper outlet configuration | Square, round or rectangluar | Square, round or rectangular | Square or round[1] | Square or round[2] |
| Gravimetric or volumetric operation | Volumetric | Either | Volumetric | Volumetric |
| Ability to seal against gas pressure | Poor[3] | N/A | Good | N/A |
| Amount of return spillage | None | A problem | None | None |
| Ability to control dust | Good | Poor | Good | Good (if enclosed) |
| Ease of cleanout | Poor[4] | Good | Fair[3] | Good |
| Tolerance to tramp metal | Fair | Good | Poor | Good |

[1] Rectangluar if a star feeder is used
[2] Rectangluar if feeding across narrow dimension of outlet
[3] Can de designed with moving plug at discharge end
[4] Good if designed for quick disassembly

Table 2: Feeder selection based on application considerations

## 4. Screw Feeders

Screw feeders are well suited for use with bins having elongated outlets. Such feeders have an advantage over belts in that there is no return element to spill solids. Since a screw is totally enclosed, it is excellent for use with fine, dusty materials. With fewer moving parts than a belt feeder, it requires less maintenance.

Screw feeders come in a variety of types, with the most common using a single helicoidal or sectional flight screw shaft, which is a fabricated weldment.

The key to proper screw feeder design is to provide an increase in capacity in the feed direction [4]. This is particularly important when the screw is used under a hopper with an elongated outlet. One common way to accomplish this is by using a design as shown in Fig. 2. Uniform discharge over the hopper outlet opening is accomplished through a combination of increasing pitch and decreasing diameter of the conical shaft. Unfortunately, normal tolerances of fabrication are such that extending the length under the hopper outlet to greater than about six to eight times the screw diameter often results in a poorly performing screw. This length can be extended with special design and fabrication techniques, such as a stepped shaft, variable pitch screw as shown in Fig. 3.

Approximate capacities of various size screws are given in Table 4. It is wise to limit the rotational speed to no greater than about 40 rpm in order to prevent significant abrasive wear or excess power requirements. Low rpm's (2 or less) often require large, expensive reducers. Nonuniform discharge may also be a

Fig. 2: Mass flow screw feeder draws uniformly from the entire outlet

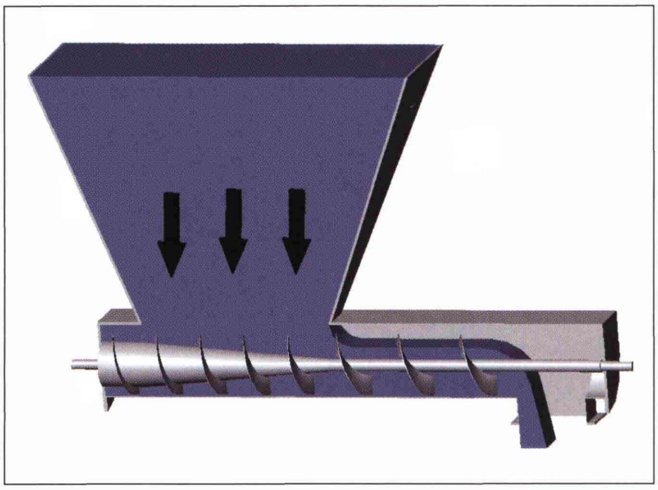
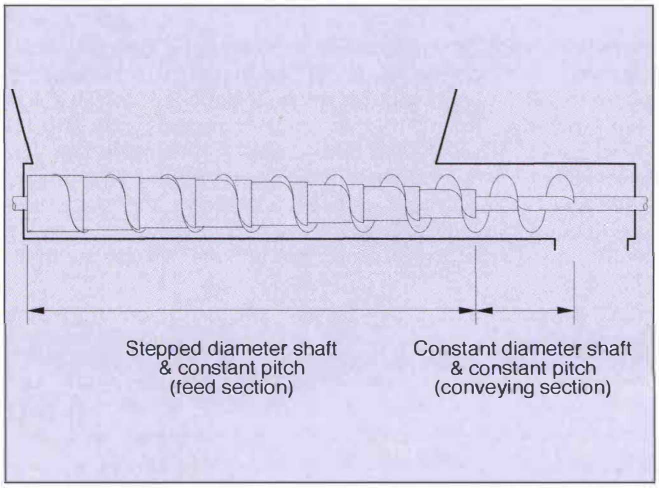


Fig. 3: Stepped shaft screw feeder



| Variable | Screw | Belt | Rotary valve | Vibrating pan |
|---|---|---|---|---|
| Max. temperature | 1000°F | 450°F | 1000°F | 1000°F |
| Max. t/h (100 lb/ft³ bulk density) | 750 | 3000 | 500 | 500 |
| Feeder speed | 2 to 40 rpm | 5-100 ft/min | 2-40 rpm | 8-80 ft/min (sloping down), 0-50 ft/min (horiz.) |
| Max. inlet length-to-width ratio | 6 to 8[1] | Dictated by bed depth | N/A[2] | Unlimited[3] |
| Turndown | 10:1 | 10:1 | 10:1 | 10:1 or more |

[1] 10 to 12 when using special designs
[2] 2 or 3 when using star feeder
[3] Feeder pan must be oriented to feed across narrow dimension of slot

Table 3: Design limits

| Screw diameter inch | ft³/h per rpm | t/h at 40 rpm (100 lb/ft³ bulk density |
|---|---|---|
| 4 | 1.5 | 3 |
| 6 | 4 | 9 |
| 9 | 16 | 33 |
| 10 | 22 | 44 |
| 12 | 37 | 74 |
| 14 | 61 | 122 |
| 16 | 92 | 185 |
| 18 | 133 | 267 |
| 20 | 183 | 365 |
| 24 | 320 | 640 |

Table 4: Typical capacities of mass flow screw feeders

problem at low screw speeds, particularly with cohesive bulk solids. Special flights can be added to the discharge end of the screw to minimize this problem.

Internal hanger bearings should not be used, since a typical screw feeder operates in the range of 90 to 100% full throughout most of its length. A U-trough should be used rather than a V-trough in order to minimize buildup outside of the screw flights which can cause flow problems in the hopper above. Typically the hopper outlet width should be equal to the screw diameter in order to prevent an upward facing lip, which can prevent material from flowing along the hopper walls.

Through special design techniques, a moving plug can be formed at the discharge end of the screw, allowing material to be fed into a higher pressure environment while minimizing leakage back into the feed bin [5].

## 5. Belt Feeders

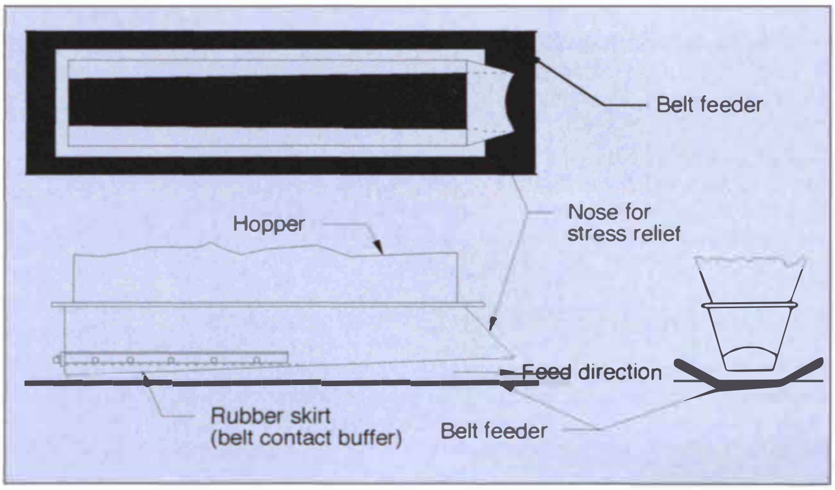
Belt feeders can be an excellent choice when there is a need to feed material from an elongated hopper outlet. They are particularly useful when handling cohesive (i.e., non-free flowing bulk solids). In addition, since the idlers of a belt feeder can be mounted on load cells, such a device can be used in either a volumetric or gravimetric application. Belts are generally not as good as enclosed feeders (e.g. screws or rotary valves) when handling fine, dusty materials, but through careful design of the feeder and control of the bin level above it, belt feeders have been successfully used for such applications. Belt feeders have more moving parts and therefore generally require more attention and maintenance than a well designed screw or vibrating pan feeder.

As with screw feeders, the key to proper belt feeder design is to provide increasing capacity (draw) along the length of the bin outlet. Without this, material will channel at one end of the hopper and disrupt mass flow.

An effective way to increase capacity is to cut a converging wedge-shaped hopper in such a way that it is closer to the feeder at the back of the outlet than at the front [6]. This provides expansion in both plan and elevation (see Fig. 4). It is important that the bed depth of material at the front of the outlet be at least 1.5 to 2 times the largest particle size to prevent blockage.

With small belts (e.g., 12 inch wide or less), flat idlers can be used. However, with larger belts, sag between the idlers forces a rhythmic movement of material up into the hopper as it passes over each idler. This increases power and belt wear and may cause particle attrition. It is therefore better to use troughing idlers for these larger sizes, if possible. One exception would be if the belt is a weigh feeder, in which case a flat belt may be required.

Fig. 4: Typical mass flow belt feeder interface




There are three types of troughing idlers – equal length, unequal length, and picking – and at least three standard idler angles (from horizontal); 20, 35, and 45°. Of these, 35° equal-length troughing idlers are the most common, although unequal-length and picking idlers often allow the use of narrower belts for the same capacity.

## 6. Rotary Valves

Rotary valves are generally limited to being used with hoppers having circular or square outlets. Thus they are not as useful when handling cohesive bulk solids as, for example, a screw or belt feeder. However, an elongated rotary valve, called a star feeder, can be used to feed across the narrow dimension of a slotted outlet. As with a screw, a rotary valve is enclosed and therefore can be used with fine powders. It can also be used as an air lock when feeding into a higher or lower pressure environment, such as a pneumatic conveying line.

Two common problems that are often experienced when using rotary valves – and their solutions – are:

1. Material flowing faster from the hopper on the upside of the rotary valve. This tendency can be reduced or eliminated by

adding a short vertical section having a height of about 1.5 outlet diameters between the hopper outlet and rotary valve inlet, or by offsetting the valve.

2. Gas backflow from a downstream higher-pressure environment. For example, if material is being fed into a positive-pressure pneumatic conveying line, a non-vented rotary valve acts as an effective pump on the upside. Leakage across the valve adds to this gas backflow [7]. The result is that the material discharge rate from the hopper outlet is reduced, and arching may even occur. This problem can be effectively overcome by venting the valve on its return side and using a tight-seating valve. Venting is sometimes necessary even with rotary valves exposed to atmospheric conditions if the required rates are high or the material impermeable to air.

## 7. Vibratory Feeders

Vibratory feeders are excellent in providing a nearly continuous curtain of material discharge. Electromagnetic vibratory feeders are extremely rugged and simple in construction; thus they are well suited to being used in hostile and dirty environments. Like screw feeders, they can be enclosed to eliminate dusting and product contamination. They are, however, limited for the most part to feeding from round, square, or slightly elongated openings, unless they are oriented to feed across the narrow dimension of a long slot. This kind of feeder may require several drives to accommodate extreme width, although the drives will be small because of the feeder's short length.

Vibratory feeders should be applied cautiously when handling cohesive bulk solids because the vibratory motion may cause the material to pack in the hopper.

## 8. Agitated and Flexible Wall Hoppers

Sometimes an open helix auger, rotating shaft with paddles, or similar device is used to condition material or break up compacted material. Such devices are generally only practical for relatively small hoppers, because the power required to operate them becomes excessive if the hopper becomes too large. Also, one must remember that these devices are, at best, an aid to the feeder itself. In other words, they cannot control the discharge rate.

Another technique that is sometimes used in small hoppers is to make the hopper wall out of a flexible material and then cause it to oscillate using an external paddle. This technique is similar in effect to that of the agitator described above.

## 9. Special Applications

A moving hole feeder has been developed to feed biomass such as wood chips over elongated outlets. It has also been used successfully in self-unloading ships handling cohesive materials such as synthetic gypsum.

Another innovative feeder concept consists of an annulus which rotates slowly about a horizontal or vertical axis. Such feeders have been used successfully for coal, fine copper concentrate, and cohesive chemical powders.

## 10. Gravimetric Feeder Considerations

The key to ensuring high performance from a gravimetric feeder is to begin by following proper design principles outlined above for volumetric feeders. The electronics of a gravimetric can then be used to maximum advantage to refine and closely control the discharge rate.

The most accurate and robust type of gravimetric used today operates on the principle of loss-in-weight (or gain-in-weight). The major advantage of this type over other gravimetric feeders is that it is not a zero reference device. Therefore calibration and buildup problems are far less likely to affect performance.

The major problem when using a loss-in-weight feeder in continuous discharge mode is the need for fast refill. The reason is that, during refill, the feeder is in non-gravimetric (i.e., volumetric) mode. This need for high refill rates can be a major limitation, particularly when handling fine powders.

Loss-in-weight feeders using mass flow technology have the potential of providing an extremely high degree of flow rate control. For example, one application involved placing a series of "blobs" of detergent on a moving fabric. Each blob represented 300 milliseconds of discharge from the feeder. The mass of each blob was to vary no more than ±5% at three standard deviations. Through use of a mass flow hopper, vibrating louver feeder and loss-in-weight control, this requirement was successfully met.

## 11. Gates

To make it easier to perform maintenance on the feeder, various types of gates such as slide, butterfly or spile bar (pin gate) can be used to isolate it from an upstream bin. If the bin is designed for mass flow, it is vitally important that there be no protrusions into the flow channel when the gate is open. In addition, the gate must be operated only in a full-open or full-closed position, not to modulate the rate of solids flow. A protruding lip or partially opened gate will allow stagnant regions to form above it, resulting in a funnel flow pattern. The height of the gate should be minimized, so as to minimize the additional head pressure on the feeder.

## 12. Flow Rate Considerations

It is important to ensure that the maximum feed rate from the bin is always greater than the maximum expected operating rate of the feeder. Otherwise, the feeder will become starved, and flow rate control will be lost. This problem is particularly pronounced when handling fine powders, since their maximum rate of flow through an opening is significantly less than that of coarser particle bulk solids whenever a mass flow pattern is used [8].

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