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How to Design Efficient and Reliable Feeders for Bulk Solids

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A feeder is an extremely important element in a bulk material handling system, since it is the means by which the rate of solids flow from a bin or hopper is controlled. When a feeder stops, solids flow should cease. When a feeder is turned on, there should be a close correlation between its speed of operation and the rate of discharge of the bulk solid.

Feeders differ from *conveyors* in that the latter are only capable of transporting material, not modulating the rate of flow. *Dischargers* are also not feeders. Such devices are sometimes used to encourage material to flow from a bin, but they cannot control the rate at which material flows. This requires a feeder.

WHERE TO START

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.*, cu. ft./hr.). The four most common types of such feeders are screw, belt, rotary valve, and vibrating pan. 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. Examples include when the feed rate uniformity must be better than ±2%, or sample collection times must be less than about 30 sec. A gravimetric feeder should also be used when the bulk density of the material varies.

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 through the outlet of the upstream device - This is particularly important if a *mass flow* pattern [1] is desired, so as to control segregation [2], provide uniform residence time [3], minimize caking or spoilage in dead regions, etc.

4. Interface with the upstream device such that loads acting on the feeder from the upstream device are minimal - This minimizes the power required to operate the feeder, particle attrition, and abrasive wear of the feeder components.

Often, plant personnel prefer a certain type of feeder because of experience (good or bad), availability of spare parts, or to maintain uniformity for easier maintenance throughout the plant. Such personal preferences can usually be accommodated, since in general, several types of feeders, provided they are designed properly, can be used in most applications.

The major considerations in deciding which type of feeder to use are the properties of the bulk material being handled and the application. Tables I and II provide insight into which of four common types of feeders is best suited to each of these areas, and Table III provides typical design limits for these feeders.

SCREW FEEDERS

Screw feeders are well suited for use with bins having elongated outlets. These 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. In addition, its fewer moving parts mean that it requires less maintenance than a belt feeder. Screw feeders come in a variety of types, with the most

Table I: Feeder Selection Based on Material Considerations

Variable	Screw	Belt	Rotary Valve	Vibrating Pan
Max. practical particle size	Up to 1/3 of min. pitch[1]	6 in.	1/2 in.	12 in. and larger
Particles degrade (attrit) easily	Fair	Good	Fair	Good
Material is a dry powder	Good	Fair[2]	Excellent	Poor[2]
Material is sensitive to over-pressure	Fair	Good	Fair	Poor

[1] Depends on feeder robustness.
[2] When used with slide gate for initial fill.

Table II: Feeder Selection Based on Application Considerations

Variable	Screw	Belt	Rotary Valve	Vibrating Pan
Ability to tolerate direct impact	Fair	Poor	Poor	Good
Hopper outlet configuration	Square, round, or rectangular	Square, round, or rectangular	Square or round[3]	Square or round[4]
Gravimetric or volumetric operation	Volumetric	Either	Volumetric	Volumetric
Ability to seal against gas pressure	Poor[5]	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[6]	Good	Fair[6]	Good
Tolerance to tramp metal	Fair	Good	Poor	Good

[3] Rectangular if a star feeder is used.
[4] Rectangular if feeding across narrow dimension of outlet.
[5] Can be designed with moving plug at discharge end.
[6] Good if designed for quick assembly.

Table III: Design Limits

Variable	Screw	Belt	Rotary Valve	Vibrating Pan
Max. temperature	1000˚F	450˚F	1000˚F	1000˚F
Maximum ton/hr (□=100 lb/ft^3)	750	3000	500	500
Feeder speed	2-40 rpm	5-100 ft/min	2-40 rpm	0-80 ft/min (sloping down), 0-50 ft/min
Max. inlet length-to-width ratio	6[7]	Dictated by bed depth	N/A[8]	Unlimited
Turndown	10:1	10:1	10:1	10:1 or more

[7] 10 to 12 when using special designs.
[8] 2 or 3 when using star feeder.

Fig. 1: Mass Flow Screw Feeder

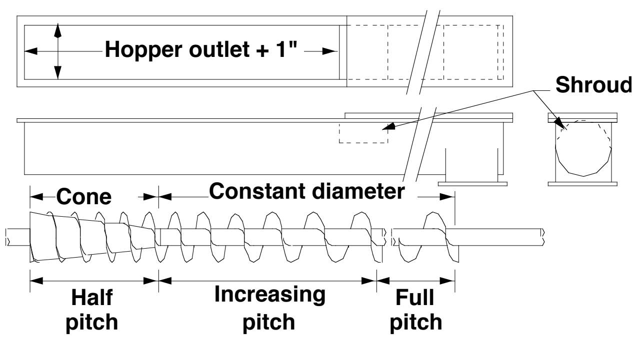
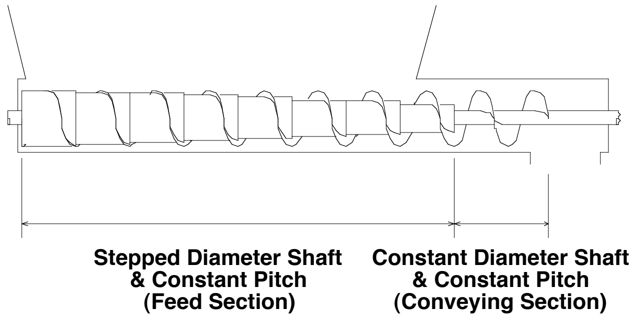


Fig. 2: Stepped Shaft Diameter Mass Flow Screw



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. 1.

Uniform discharge through the hopper outlet opening is accomplished through a combination of increasing pitch and decreasing diameter of the conical shaft. Approximate capacities of various size screws are given in Table IV.

Design Guidelines

A number of guidelines useful in designing screw feeders for optimum performance have been developed over the years. While these techniques are useful for design of a wide range of screw feeders, they are most applicable to design of solid flight screws having a diameter of four inches or larger.

- Specify the pitch tolerance to the screw manufacturer and closely inspect the screw to ensure that this fabrication tolerance is being met. In order to minimize problems with pitch tolerance, a good rule of thumb when using mass flow screws having a tapered shaft and a variable pitch is to limit the length of the screw under the hopper outlet to no more than about six times the screw diameter. Stepped shaft diameter mass flow screws (Fig. 2) can have lengths under the hopper outlet of up to 12 times the screw diameter.

- Use a U-shaped trough. This provides control of the flow pattern in the hopper, which is usually not possible with a V-shaped trough because the latter’s shallow sides tend to hold up material.

- Use a bolted flanged connection and size the hopper outlet width equal to the screw diameter. (Note: This dimension must be

Table IV: Typical Capacities of Mass Flow Screw Feeders

Screw Dia, in.	Cu ft/hr per rpm	TPH at 40 rpm (100 pcf 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

large enough to prevent arching of the material over the hopper outlet.) With screws designed to CEMA (Conveyor Equipment Manufacturers Association) specifications [5], the inside dimension of a U-shaped trough is one inch larger than the screw diameter. Therefore, sizing the hopper outlet width equal to the screw diameter allows a nominal half-inch increase in the inside dimension of the trough. This minimizes the possibility of a ledge, which could hold up material in the hopper at this point.

- Keep screw speed between roughly two and 40 rpm. Below two rpm, the discharge from the end of a screw is irregular, and the cost of the reducer becomes excessive. Above 40 rpm, screw efficiency decreases, causing increases in the power required to operate the screw, abrasive wear on the screw flights, and particle attrition.

- Use a shroud in the trough just beyond the hopper outlet. This effectively converts a U-trough into a circular pipe section, thereby limiting the capacity of the screw to the screw diameter and providing better control of screw efficiency. The length of this shroud usually does not need to be any longer than the diameter of the screw.

- Use only end bearings to support the screw. Internal hanger bearings are troublesome because a mass flow screw feeder operates between 90% and 100% full. Thus, a hanger bearing becomes immersed in material and wears out quickly. It also provides an impediment to material discharge and thereby upsets the mass flow pattern desired in the hopper section. Using only end bearings avoids this problem, but the length of the screw becomes limited by deflection of the screw between the end bearings. As a practical matter, screw lengths are typically limited to approximately 12 ft. unless an extra-strong shaft is used to support the screw.

- Use rugged materials of fabrication. Stainless steel and carbon steel are typically used for most industrial applications.

- Choose a smooth surface finish on the screw flights; the surface finish on the trough should be rough.

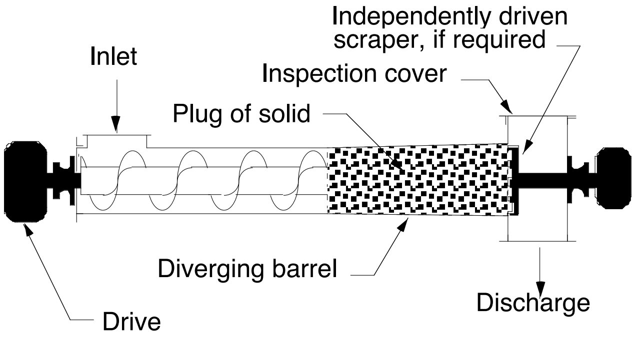
- Use a sufficient conveying length after the hopper outlet to prevent material dribbling out of the screw discharge opening when the screw is stopped. The minimum conveying length is determined from the angle of repose of the bulk material.

- Extend screw flights no more than one inch over the discharge opening. This minimizes the chance of material being conveyed past the screw opening and plugging the region of the end bearing.

Special Designs

When large hopper outlets are required, multiple screws are sometimes used (for example, to overcome arching, to decrease screw speed, or to obtain a high discharge rate). It is important to remember with such screws that, if mass flow is required, tolerances of fabrication govern the maximum length-to-diameter ratio of a *single* screw. Therefore, while multiple screws allow wider hopper outlets, they usually do not allow longer ones. The direction of rotation of the screws must also be taken into consideration. Twin screws, which rotate towards each other (when viewed from above), tend to withdraw material preferentially from along hopper walls. This is desirable if flow along the walls is questionable. On the other hand, twin

Fig. 3: Compaction Screw



screws, which rotate opposite each other, tend to withdraw material preferentially from the center of the hopper. This is helpful if the bulk material is pressure sensitive. In calculating screw torque, the head of material associated with the full hopper outlet width, not that associated with just a single screw, must also be used.

Special screws can be used to provide compaction of the bulk material and thereby seal against adverse pressure gradients [6, 7]. An example of such a screw is shown in Fig. 3.

Spokes and/or blades are sometimes used near the discharge end of a screw to break up the material and thereby provide more uniform discharge. This usually requires terminating the screw flights at a greater distance from the discharge opening.

Cut flight and ribbon flight screws present special design problems. They are useful in breaking up material but are far less efficient with respect to feeding than a solid flight screw.

Inclined screws also require special design considerations. At 0° (horizontal), a mass flow screw feeder, designed according to the principles described in this article, will have an efficiency close to 100%. As a screw's inclination varies from 0° to 30°, its efficiency decreases. At angles of inclination between approximately 30° and 60°, the efficiency of a screw feeder is very low. Above 60° its efficiency increases again as the inclination becomes greater. Obviously, the effect of inclination on screw efficiency must be taken into consideration when calculating the required rpm of a screw feeder.

BELT FEEDERS

Like screws, belt feeders can be an excellent choice when there is a need to feed material from an elongated hopper outlet [1]. Belt feeders are particularly useful when handling cohesive (*i.e.*, non-free-flowing), friable, coarse, fibrous, elastic, and/or sticky bulk solids. In addition, since the idlers of a belt feeder can be mounted on load cells, a belt feeder can be used in either a volumetric or gravimetric application. Belt feeders generally can handle a higher flow rate than enclosed feeders (*e.g.*, screws or rotary valves).

Belt feeders are generally not as good as enclosed feeders in handling of fine, dusty materials, although with careful design of the feeder and control of the bin level above it, belt feeders have been successfully used for such applications [8]. Belt feeders have more moving parts and therefore generally require more attention and maintenance than a well designed screw or vibrating pan feeder. They usually also require more installation space than screws.

As with screw feeders, the key to proper belt feeder design is to provide increasing capacity (draw) along the length of the hopper 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. This provides expansion in both plan view and elevation (see Fig. 4).

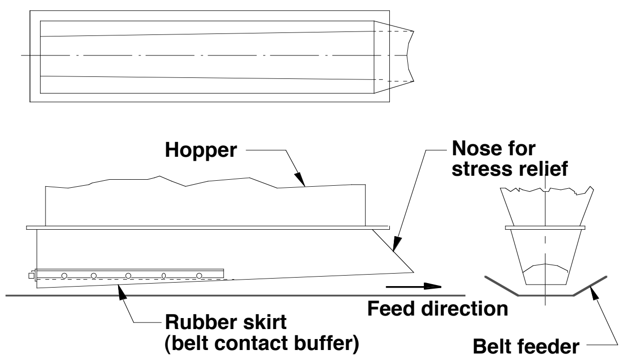
The major features of this design are:

- Calculated taper in both plan and elevation to achieve uniform material withdrawal
- A slanted "nose" and/or an arch-shaped "lip" to provide stress relief and prevent stagnation at the discharge end
- A flexible rubber or plastic buffer at the back end to allow a typical half-inch gap for uniform material withdrawal without belt or interface damage
- The ability to use conventional belting, flexible side wall belts, or aprons (steel pans)
- Spillage skirts that expand slightly in the direction of belt travel and that are remote from the feeder interface - This prevents the skirts from interfering with uniform material withdrawal. Such skirts may not be necessary with flexible sidewall belts or some apron feeders.

In order to prevent blockage it is important that the bed depth of material at the front of the hopper outlet be equal to at least 1.5 to 2 times the largest particle size.

With small belts (*i.e.,* 12 in. or less), flat idlers or a slider plate 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 usage and belt wear and may cause particle attrition. It is therefore better to use troughing idlers for large belts, if possible. If the belt is a weigh feeder, a flat belt may be required.

Fig. 4: 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° [9]. 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.

The flexibility possible in design of belts allows them to be used in various ways. Some special applications are briefly discussed below.

Weigh Feeders

Belt feeders can be operated in gravimetric mode, allowing the mass moved per unit time to be monitored and controlled. Generally, in order to achieve the type of feed rate uniformities expected of such devices, the belt must be flat, not troughed. Very small belt feeders are sometimes mounted completely on a load sensing device, which is satisfactory provided the material pressures at the bottom of the interface are constant.

If an accurate measurement of *instantaneous* flow rate is not required, a weigh idler can be used with either flat or troughed belts to measure the *total* mass of material going across the belt in a given period of time. In this case, the weigh idler can be placed on the conveying portion of the belt at some point beyond the material's angle of surcharge from the bin outlet. This idler must also be upstream of any detroughing section since the stiffness of a belt changes rapidly over this region.

Sloped Belts

These can be designed to feed material uniformly from a slotted outlet provided the coefficient of friction between the belt and material is great enough to prevent slippage, and the slope of the belt is less steep than the material's angle of surcharge. In some cases, shallow belt cleats can be used to prevent slippage. These may be necessary with wet materials that lubricate the belt or freeze and slide off. With inclined belts, the additional power required to elevate the material must be considered. With declined belts, the feeder interface may need to be tilted downward in order to prevent the slot from narrowing in the direction of belt travel.

Multiple Feed and/or Discharge Points

The optimum interface cannot readily accept material from more than one hopper outlet; consequently, it is better to use individual belt feeders for each outlet and use a common collecting conveyor. In some instances, such as self-unloading ships, feed from more than one hopper opening onto a single belt is necessary, and this can be achieved using a special gate and interface design. Multiple discharges can be accomplished using a reversing belt with a pivoting interface, a belt tripper, a side discharge plow on a flat portion of the conveying section, a splitter in the trajectory stream, or a downstream splitter.

ROTARY VALVES

Rotary valves are generally limited to use with hoppers having circular or square outlets. Thus, in handling of cohesive bulk solids, rotary valves are not as useful as, for example, screw or belt feeders. 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 with a pneumatic conveying line.

Two problems commonly encountered in the use of rotary valves, and the solutions thereto, are discussed below:

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. The result is that the material discharge rate from the hopper outlet is reduced, and arching may 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 material discharge rates are high or the bulk material is impermeable to air.

VIBRATORY FEEDERS

Vibratory feeders can provide a nearly continuous curtain of material discharge. Electromagnetic vibratory feeders are extremely rugged and simple in construction; thus, they are well suited for use in hostile and dirty environments. Like screw feeders, vibratory feeders can be enclosed to eliminate dusting and product contamination. They are, however, essentially limited to feeding from round, square, or slightly elongated hopper openings, unless they are oriented to feed across the narrow dimension of a long slot [10]. This kind of feeder may require several drives to accommodate extreme hopper widths, although the drives will be small because of the feeder's short length.

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

AGITATED AND FLEXIBLE WALL HOPPERS

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

Another technique sometimes used with 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 agitated hoppers described above.

ROTARY PLOW FEEDERS

Because of lower capital and operating costs, as well as greater ease of maintenance, rotary plow feeders instead of belt feeders or a series of small hopper outlets are often used under large stockpiles. This system can be used to move minerals - ranging from coal to iron ore - stored at mine sites, processing facilities, and power plants.

The mechanism by which a rotary plow moves material is as follows: When a rotary plow begins operating, it loosens material in a narrow vertical channel above it. If twin plows are used and both are operating, two channels will form independent of each other. The pressures exerted on the material adjacent to the channels are generally low and proportional to the size of the flow channel.
If a plow does not traverse under the stockpile, and if the material has sufficient cohesive strength, the channel eventually empties out, forming a rathole. However, as a plow traverses, the narrow flow channel lengthens. Whether material on either side of it remains stationary or slides, depends on the wall friction angle along the sloping wall, the wall angle, and the head of the material.

If the material slides, it does so for only a short distance, since, as the material in the flow channel is compressed, the pressure it exerts on the adjacent material increases, resulting in a stable mass. If the side material does not slide, the level of material in the flow channel drops and material sloughs off the top surface.

Even if the side material does not start sliding immediately, it may start when the level of material is reduced because of the lesser support offered from the material in the flow channel. Likewise, the side material may stop sliding at a lower elevation if the relative support offered to it by the walls becomes greater.

INTERFACES

Gates

To make it easier to perform maintenance on a feeder, slide gates are often used to isolate the feeder 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. The gate must be operated only in a fully-open or fully-closed position so it does not affect 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 to minimize the additional head pressure on the feeder.

Sometimes, particularly with long slotted outlets above screw or belt feeders, it is more practical to use spile bars (closely spaced bars or pipe) than a slide gate for a maintenance cut-off. Although it is usually impossible to ensure complete stoppage of material with spile bars, they can generally provide sufficient restriction of material flow to allow feeder maintenance. As with slide gates, it is important that spile bars not be used to attempt to control flow and that they not present any protruding ledges into the flow channel.

Bolted Flanges

Usually the housing of a feeder or, in the case of a belt, its interface section, is bolted to the hopper section of a bin. If the inside dimensions of this housing or interface are identical to those of the hopper outlet section, there invariably will be a mismatch on one or more sides when the two are bolted together. An inwardly protruding lip at this point can be destructive of mass flow.

An approach, which easily circumvents this problem, is to oversize the inside dimensions of the lower flange. Usually a one-inch oversize (half an inch on each side) is sufficient to prevent problems in this area.

SPECIAL CONSIDERATIONS

Flow Rate

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 [11].

Considerations of the Bulk Solid

As noted at the beginning of this paper, feeders must be designed for the actual bulk solid being handled to ensure that the feeder will operate reliably and provide the required rate of discharge and power consumption. If the bin is being designed for mass flow, the three most important flow properties are the minimum hopper outlet sizes required to prevent arching, the hopper wall angles needed to force the bulk solid to flow at the walls, and the hopper outlet sizes needed to achieve the desired flow rate [11]. These properties can be determined from laboratory tests of the bulk solid [12], using a small (typically five-gallon) representative sample at expected values of moisture, temperature, and time of storage at rest. Once these properties have been determined, they can also be used for the design of the feeder.

Special precautions need to be taken when the bulk solid is hygroscopic or hydrophilic. Since this sensitivity to moisture can have a major effect on flow properties, laboratory tests need to be conducted under an environment that takes this into account. Often with such materials, an enclosed feeder such as a screw is much better than an open belt because the former minimizes ingress of moisture through the outlet region of the hopper.

Adhesive and viscous bulk solids also deserve special attention. Not only may they build up on hopper walls, they may also coat feeder components such as the flights and shaft of a screw feeder, or they may require scraping from a belt.

Elastic, flaky, and/or stringy particles are also difficult to handle with feeders, in part because of the inability of such particles to form sharply defined shear planes. Unusually large hopper outlets and increases in feeder capacity along a hopper outlet are often required for reliable operation with these types of materials.

Any of the above factors, unless careful attention is paid to their effects, can result in poor operation of an otherwise well-designed bin and feeder.

Design Coordination

It is important that the engineer who develops the conceptual design of a bin and feeder follow through all subsequent steps in order to ensure that critical design details are incorporated. Otherwise, problems may arise in the transfer of conceptual designs to written specifications, to engineering drawings, and finally to hardware.

CASE HISTORIES

Silo Discharge Problems Solved at Pet Products Plant

This west coast plant produces various dry, premium pet foods. Raw ingredients - whole corn, soybean meal, soybean hulls, rice, whole rice, and high and low ash poultry mixes - are stored in silos that hold approximately 400,000 to 500,000 lbs. each. Two smaller silos handle ground rice and ground corn.

Material spoilage had occurred in the silos, necessitating their frequent complete emptying and cleanout. Since only one silo is available to store each product, cleaning the silos often creates production stoppages. This problem was acute in the whole corn silo. Since production requires corn on a frequent basis, the operators attempted to keep the silo nearly full. Consequently, material along the walls below the lowest material level remained there indefinitely and spoiled. This necessitated periodic cleanout about every two weeks, resulting in lost material, lost production, and increased labor costs.

The whole corn silo is 15 ft. in diameter and 56 ft. in total height, with a 60° from horizontal conical bottom, terminating at a 5 ft. diameter. Below this is a circular-to-rectangular slot transition hopper with vertical end walls extending down to a 12 in. wide by 5 ft. long slot. Corn discharge used to be controlled by a 6 in. diameter half-pitch screw.

<u>Analysis</u>*:* The corn was found to be flowing in a funnel flow pattern (*i.e.*, material at the walls remained stationary). Corn was feeding only from the back end of the screw in a narrow flow channel that extended upward to the top

surface of the silo. (This is a typical flow pattern when using a constant pitch screw.)

Some corn remained on the silo walls after the silo had been cleaned, and the cone walls were rusty, indicating that flow was not occurring along the walls of the cone.

Solution: The silo was converted to a mass flow pattern, in which all material in all regions within the silo flowed whenever corn was withdrawn from the outlet. This resulted in a first-in-first-out sequence of material flow such that no material resided in the lower portion of the silo for long periods.

Achieving mass flow is dependent on several important factors:

1. The hopper section must be steep enough and there must be sufficiently low friction between it and the material to allow flow along the walls. From tests on this corn, it was found that 60° rusty carbon steel hopper walls would not achieve mass flow. Luckily, in the case of this whole corn, lining the hopper with a particular type of UHMW plastic liner made it sufficiently smooth so that mass flow was achieved. The transition hopper below the 5 ft. diameter was also made smoother with the application of a common air-temperature-cured epoxy.

2. Withdrawal from the silo outlet must be along the entire slot. This cannot occur with a constant pitch screw, which simply withdraws material from the outlet's back end. So, the screw was replaced by a 10 in. diameter, mass flow screw. This screw, which consists of a combination of varying shaft size and pitch, has increasing capacity in the direction of withdrawal.

Jenike & Johanson structural engineers checked the silo to make sure it could withstand mass flow loading, and then the mass flow screw feeder was fabricated and installed.

Results: This modified silo and feeder have been in operation now for many years. According to the plant manager, "We haven't had a spoilage problem in our corn silo since we made the conversion on the hopper."

Mass Flow Coal Feed System Results in Large Cost Savings to Cement Company

In recent years, a major trend in the cement industry has been the switch from oil to coal as kiln fuel. Shortly after the changeover to coal, a Canadian cement company encountered many of the flow problems typical of coal handling operations.

The system: During the shipping season, coal is shipped from the eastern U.S. across Lake Ontario and stockpiled outside the plant for year-round use. It is retrieved by front-end loader, dumped through a grizzly, and screened. The oversize fraction is crushed and returned to the fine coal stream, which is then conveyed to a bucket elevator and deposited into a silo.

The 33 ft. diameter slip-formed concrete silo had a conical steel hopper with a 31° wall angle (from vertical) and a 4 ft. diameter outlet. Below the opening was a custom designed vibrating feed box with a 12 in. wide by 22 in. long rectangular outlet.

The problem: Coal flow from the silo was poor. Almost constant poking and hammering were required to maintain feed. Although air blasters had been installed on the conical hopper, they were not effective.

The solution: Coal samples were tested for instantaneous flow properties at total moisture contents of 8.3% and 9.6%. The poorer flowing sample was also tested at 15% moisture content after eight hours' storage at rest.

Jenike & Johanson technicians ran wall friction tests on a variety of possible bin wall liner materials, including 2B finish stainless steel, epoxy coatings, and UHMW polyethylene.

Through these tests, it was learned that the coal was cohesive, moderately sensitive to vibration and pressure, and very sensitive to storage time at rest. The critical rathole diameters predicted from the tests were very large, indicating that a funnel flow silo design was not suitable. Arching dimensions during continuous flow were moderate, but became large after storage at rest or exposure to extreme pressure. Tests showed that UHMW polyethylene was an excellent hopper lining material for this application.

The lower portion of the existing funnel flow cone and belt feeder was replaced with a 20 ft. diameter mass flow transition hopper lined with UHMW polyethylene and a 42 in. wide weigh belt feeder. Jenike & Johanson engineers performed the detailed structural and mechanical design and procured the equipment.

Results: The new mass flow system has been in operation for many years. According to the plant engineer, the results have been exceptional. “Large operational cost savings resulted from the silo and feeder modifications,” he explained. “The feeding operation became completely automatic, thus saving labor costs. In addition, now that flow stoppages due to hangups have been eliminated, fuel costs have been reduced since gas is no longer used as a backup fuel.”

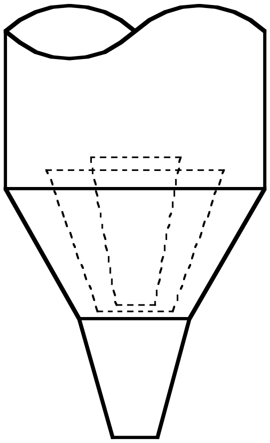
BINSERT® System Prevents Flow Problems at Copper Mine Modernization Project

Part of a modernization project for a copper mining company in the southwest involved new bins for copper concentrate, flux, and slag. The design called for four 12 ft. diameter copper concentrate bins, two 12 ft. diameter slag bins, and four 7 ft. 9 in. diameter flux bins, all with 35° (from vertical) conical hoppers. An air injection system and a pinch valve in the bottom of each hopper were intended to control flow onto an impact flow meter. The material would then be transferred by screw conveyor to the process.

The flow properties of the concentrate, flux, and slag were determined, each at two moisture contents. The tests showed that much steeper hoppers (13° from vertical) would be required to ensure mass flow. Without mass flow, semi-stable ratholes could form even with low moisture contents, causing erratic flow. If the moisture content increased above the maximum design value due to a disturbance in the dryer, arching and ratholing could be expected. Some of these problems had been experienced at another operating plant of similar design.

A straight mass flow cone inclined at 13° from the vertical would have required a substantial increase in headroom. The solution was to modify the bins with a triple cone BINSERT® system [13] as shown in Fig. 5. This converted the bins to mass flow with no increase in headroom. Discharge is controlled by a mass flow screw feeder, the speed of which is varied by a signal from the impact flow meter.

Fig. 5: Binsert® System to Convert Funnel Flow to Mass Flow



Although some of the materials are abrasive, screw feeders are viable for this situation because of their enclosed design and because of the low flow rates required. A screw feeder wear evaluation showed that a reasonable screw wear life could be expected.

Jenike & Johanson engineers performed the structural design calculations and prepared engineering drawings for the modification, including the mass flow screw feeders. Then they reviewed the bin and feeder construction in the fabrication shop and again on-site after installation to ensure that the design was properly executed. Special shut-off slide gates were designed, for use when performing maintenance on the bins.

The bins have been used for a number of years and they have operated extremely well.

Screw Feeder and Compactor Cuts Maintenance in Half

Production of elemental phosphorus by a chemical company plant in the northern plains involves calcining phosphate ore in a rotary kiln. In this process, carbon monoxide gas, a furnace by-product, is the primary fuel for firing the kiln, with pulverized coal being used to provide the balance of fuel requirements.

Typically, coal pulverizers are fed with enclosed volumetric or gravimetric belt feeders. Sealing against mill air pressure is accomplished by a vertical standpipe, typically 10 to 15 ft. in height, between the coal storage bin and belt feeder. However, vertical height was limited in this installation, so some other feed and seal arrangement had to be found.

Screw feeders with compacting sections were designed for the original installation, but the results were unsatisfactory. The compacting section was created at the discharge end of the screw by omitting a short segment of flights which forced the screw to run full of coal at this point. However, compaction was inadequate, resulting in air flowing back into the feeder section. In addition, coal backed up from the compacting segment into the storage bin, which caused feed from the storage bin to the pulverizers to be nonuniform. Coal would arch above the feeder section, requiring frequent prodding and rapping of the bin to resume flow. The kiln firing rate was upset because of intermittent coal feed. Frequent overloading of the screw drives occurred, especially when the coal was wet.

Flow property tests were run on the coal, and the design parameters of the compacting screw were determined on a model test stand. A special concern was that the compacting screw be able to feed coal to two ball-type pulverizers from a common storage bin and seal against 15 to 20 in. w.c. air pressure created by the pulverizer blowers.

The new feeder/compactor screw conveyor provides adequate sealing against mill pressure and requires far less vertical space, a critical factor at the plant. Additionally, the initial cost was significantly less than it would have been for a belt feeder. Moreover, by adding a revolution counter, the screw can be calibrated and used for volumetric measurement.

Since the feeder/compactor was installed over a decade ago, no interruptions in coal feed due to arching have been experienced. Mass flow from the storage bin to the screw feeders has been achieved, and coal feed to the pulverizers is uniform. Motor overload problems have been eliminated.

Plant engineers consider the unit to be completely successful. With the unit operating approximately 310 days per year, screw life is about 1-1/2 years with hard facing applied to the flights.

It would be difficult to estimate the actual savings in production cost and labor resulting from the use of the new units. However, feeding problems, which were virtually a constant daily problem with the original feeders, have been eliminated, and maintenance costs were reduced by approximately one-half.

Charging a Loss-In-Weight System at High Rates

A Loss-in-Weight (LIW) system consists of a hopper and feeder mounted on load cells. Such systems are commonly used for precise metering of powders and other bulk solids. When operated in a continuous discharge mode, accurate gravimetric operation is achieved by controlling the speed of the feeder in order to provide a constant decrease in the weight of the feed hopper.

The problem: A Canadian manufacturer of LIW systems needed a surge bin to reliably handle pulverized lignite and coal. Their customer required that the surge bin have a capacity of 60 metric tons and a maximum diameter of 5 m. System requirements made it necessary for the LIW feed hoppers to be filled with 88 cu. ft. of material in 10 seconds. At a bulk density of 38 lb. per cu. ft., this corresponds to an instantaneous discharge rate from the surge bin of approximately 600 tph!

The solution: The first step in designing this surge bin, as it should be with any bulk solids storage system, was to determine the flow characteristics of the material to be handled. Representative samples of the pulverized lignite and coal were sent to one of Jenike & Johanson's laboratories for analysis. Flow tests were run at the maximum expected moisture content (3% for the lignite and 5% for the coal) and at both 72° and 150°F (the maximum expected temperatures of the materials in the surge bin). By simulating the worst-case conditions in the laboratory tests, a design that would reliably handle the materials under those conditions could be provided.

Both the lignite and coal were found to have little cohesive strength. This meant that both these materials would flow through a relatively small outlet in a mass flow bin without forming a stable arch. Hopper wall angles required for the materials to flow in a mass flow pattern were also determined.

It is important to have a mass flow pattern when handling materials such as coal, which can spontaneously combust in a storage bin. In mass flow, all of the material in a bin is moving when any is discharged. The first material placed in the bin is the first material out, resulting in a uniform residence time. The alternative is a funnel flow pattern, where an active flow channel develops over the outlet, but material around the periphery of the bin remains stagnant. This flow pattern is undesirable because stagnant material will remain in the bin for an extended period until the bin is completely emptied. It is this stagnant coal, which is most likely to spontaneously combust.

The parameters for mass flow were calculated and the design requirements to achieve an instantaneous discharge rate of 600 tph were determined. Pulverized lignite and coal are typical of most fine powders in that they will deaerate if given sufficient time in a storage bin. As the powder reaches the outlet of a mass flow bin, the solids pressure decreases, causing the voids to expand and a vacuum to develop just above the outlet. This tends to create a counter-current air flow that holds up the material and severely limits its discharge rate from the bin.

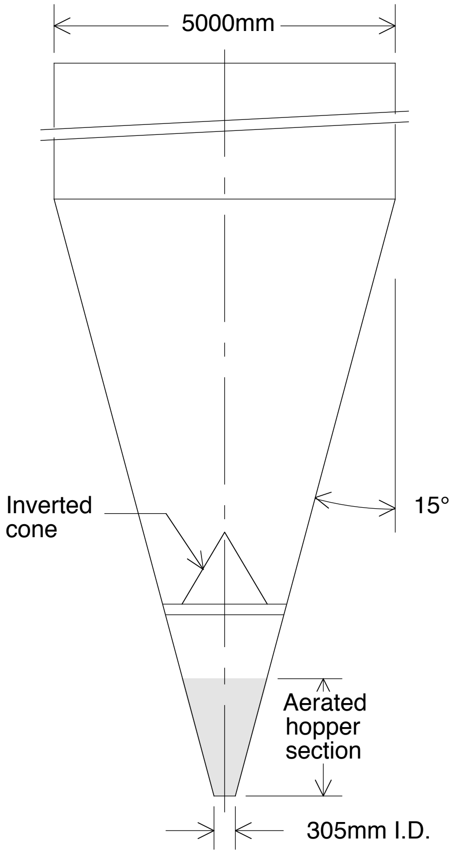
Limiting flow rates were calculated for various outlet dimensions based on the powders' compressibility and permeability (*i.e.*, how readily air passes through the voids). These tests indicated that both materials to be handled in this system are relatively impermeable; hence achievement of the desired flow rates would require special design considerations. A computer analysis indicated that both powders would aerate readily and deaerate rapidly.

Based on the test results and computer analysis, the surge bin shown in Fig. 6 was designed. It consists of a 5 m diameter cylinder above a carbon steel cone with walls sloped at 15° from vertical. The cone outlet diameter is 305 mm. This design provides mass flow and the required capacity.

In order to achieve the required discharge rate with a reasonably sized outlet, it was decided that the material must be aerated. Several air pads were positioned on the lower hopper walls (below the inverted cone shown in the figure) to aerate only the material near the hopper outlet. Calculations indicated that air at 250 cfm, turned on for 5 seconds prior to material discharge, would be sufficient to aerate the material below the inverted cone, and that this volume of material would be enough to fill the LIW feed hopper. The inverted cone would aid in aerating the material by relieving the pressure at the bottom of the bin and providing space (under the cone) for the aerated material to expand.

Another important aspect of the design was to ensure that the heel of material in the LIW hopper did not become fluidized during rapid refill. Fluidization of the material could lead to flooding and loss of control of the feed rate. To prevent this, a deflector plate was placed in the hopper. While such a plate could create dust problems, these are easier to deal with than flooding.

Fig. 6: Mass Flow Surge Hopper for Loss-In-Weight System



The system was installed and has worked as intended for over seven years.

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