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SHAPA TECHNICAL PAPER 12

Discharge Aids

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Introduction

A wide variety of bulk solids are processed and handled throughout industry, from very fine powders, as pigments, clays, talc, to coarse granules, flakes and fibrous products.

Bulk material, such as agricultural grains, have been stored in silos since the ancient Egyptian civilisation. Vessels of many shapes and sizes have since been built though a process of trial and error, to store a huge range of bulk materials in virtually all spheres of industry. Particle technology has evolved considerably over the last 50 years, to produce a coherent set of theories and design guidelines for practitioners in the industry, (1). However, there are many challenging materials whose behavior cannot be easily accommodated by current theories. For instance, it is difficult to design a reliable storage system based solely on gravity flow for fibrous, spring-like, wet / moist, stick & tacky, visco-elastic, highly compressible, caking prone and very fine bulk materials. For these types of materials, applications where conventional design does not provide an acceptable solution and retrofit situations where operating difficulties are encountered, discharge aids or discharge systems are often used to secure discharge and empty the contents of silos

These devices are almost invariably selected based on past industrial experience or by a process of trial & error. Selection must take into account constraints that are imposed by the process and the available space. There is usually a significant economic penalty for incorrect or sub-optimal choice of a discharge system in terms of extended commissioning costs, production delays and interruptions, loss of output, product wastage, loss of quality, increased maintenance and manual attention cost.

The objective of this paper is to summarise information on dischargers that are currently prevalent in industry. An effort is also made to provide guidelines for their selection and specification as part of an integral design, or for retrofit to overcome operating problems.

Mined Minerals	Chemicals	Plastics	Agricultural Products	Food
Coal	Pigments	Plastic powders (PE, PP, PET, PVC)	Wood Chips & Shavings	Flour
Clays	Portland Cement	Rubbery pellets and crumbs	Animal Feeds	Bran
Flourspar	Detergents	Plastic chips and flakes	Grains	Cereal
Gypsum	Carbon Black	Rubber chips	Diary feed	Corn Starch
Perlite	Metal Oxides	Shredded recycle	Dried milk	Powdered Sugar
Diatomaceous Earth	Calcium Carbonate	Soft and tacky pellets	Hulls (rice, cottonseed, oat)	Chocolate
Talc	Herbicides		High oil and fat	Ground grains
Alumina	Cellulosic derviates		Shredded straws and stalks	
Iron Ore	Pharmaceutical powders			
Lime	Sludge			
Soda Ash	Fertilizers			
Bentonite				
Phosphates				

Table 1. Examples of challenging bulk materials used in various industries

Background

Discharge aids may be defined as devices that stimulate or improve bulk solids flow out of bulk storage container. Items may be installed downstream of discharge aids to provide a means to shut off or regulate the flow of bulk solids. Slide gate valves and feeders are examples of discharge controllers. A discharge system can either be integrated with the silo or installed as an add-on, depending on the design and reason for its inclusion. [2].

It is important to distinguish between the basic objectives of discharger aids and those of feeders to avoid misapplications. The primary purpose of a discharger aid is to promote flow, not necessarily to regulate it, and without regard to the order of zone discharge. A feeder, on the other hand, depends on the material flowing reliably to its inlet. Feeders influence the flow regime developed in the storage container and will not function if flow in the bin is unreliable. A feeder and its supply hopper are therefore an integral system.

Types of Flow Problems

The more common forms of flow difficulty are concerned with the restriction of flow, either complete or erratic stoppages, or a delivery rate less than that required. Circumstances also arise where the discharge rate is in excess of requirements, uncontrollable, in an unsuitable condition for handling, process or use or is incomplete.

These difficulties arise for a number of different reasons, such as: -

- **Arching, where the product forms a blockage over the outlet and flow ceases. Two basic types of arch can create a stable obstruction over a hopper outlet. One is that created by the bulk strength of a cohesive material being able to span the dimension of the opening. The other is when lumps come together to make a continuous structural across the orifice by virtue of the contact points offering a static relationship that makes a continuous load path as in a bridge.**
- **Piping, where material empties from a central core above the outlet up to the surface level of the stored material but no further product collapses into the empty flow channel.**
- **Irregular flow, where the discharge rate is erratic or subject to cyclic variations, that is not compatible with the specific process requirements of the operation.**
- **Flushing, a form of uncontrollable flow, generally due to the presence of excess air or gas in the voids that dilates the bulk material to a weak condition with virtually zero shear strength.**
- **Static zones of storage that subsequently offer problems due to deterioration of flow property or product quality because of extended residence time.**
- **Residue unable to discharge by gravity.**
- **Segregation, that leads to flow or processing difficulties or loss of quality.**
- **Particle attrition causing operation problems, hazards or loss of quality.**

Designing for Reliable Flow

A scientific design based on best practice, measured properties of the bulk material and knowledge of various special techniques can avoid most of these problems. However, apart from the awkward nature of some bulk materials, many storage units are constructed on standard forms that are convenient for manufacture but do not take appropriate account of the bulk material properties. Whereas these serve well with many materials that have good flow characteristics, they can fail badly with various fine, damp or lumpy products and others that are of a poor flow nature or are sensitive to various aspects of bulk storage.

Various types of flow patterns develop in bin/silos, depending on the shape of the converging section and the particle-wall friction. (3). Of particular interest are 'Mass Flow', where all the contents are in motion during discharge, 'Expanded Flow' where contents in the outlet region are all in motion, but static zones form in higher regions, and 'Non-Mass Flow', where there is no slip of material on the walls of the bin. A Mass Flow pattern has benefits in providing best conditions for flow through small outlets and avoiding indeterminate storage periods for products that are time-sensitive. Expanded Flow offers the flow benefits of Mass Flow, but is not suitable for products that deteriorate with time, unless the bin is fully emptied before being refilled. Non-Mass Flow bins are adequate for free flowing products that similarly do not that deteriorate with time, and may even be used with products that do degrade or exhibit time-dependent problems, provided the bin is fully emptied every time before these difficulties arise.

The first and most important decision in hopper selection is to choose a flow pattern for discharge that is compatible with the nature of the bulk material to be stored. Measurement of contact friction then allows the required wall slope of a chosen shape to be determined for slip in Mass Flow, or establish ultimate self-clearing in non-mass flow. A design procedure for testing bulk materials enables an outlet size to be determined that secures reliable flow in hoppers of different shapes, with circular, square or slot-shaped openings. It is good practice to first explore the prospects of a design that work by gravity without additional assistance, as this offers operational simplicity and minimum maintenance.

Salient points to keep in mind are -.

- **The 'Angle of repose' is NOT a basis for silo design**
- **Measurement of the materials flow properties and wall friction angle are basic design parameters. A 'representative' sample must be obtained and tests conducted in appropriate process conditions. Note - All 'worst' conditions must be considered.**
- **Mass flow design results in a more predictable flow pattern and requires a smaller outlet size compared to a non-mass flow design.**
- **Selection of the converging bin section shape, cone, pyramid, wedge or chisel, has a major influence on the design. It is difficult to secure mass flow with a pyramid shape because product tends to stick in converging corners. Wedge shape is best for flow, but a feeder is usually required to extract from the whole outlet area.**
- **The feeder design and hopper interface must not inhibit the required flow pattern within the silo. A feeder MUST extract product across the entire cross-section of a hopper outlet to enable Mass Flow.**

Before considering a discharge aid to address a bin/silo flow problem, it is prudent to examine the bulk material nature and its flow properties in relation to the existing design. Hopper modifications may provide a more suitable solution, especially if the problem stems from an unsuitable flow pattern. Such alternatives may comprise: -

Steeper Hopper: **Replacing a shallow hopper with a steeper hopper section is the most positive way to obtain reliable mass flow, if sufficient headroom is available. Replacing the region near the outlet forms an 'Expanded Flow' construction to secure the flow benefits of mass flow, but will not elimination 'dead' regions of storage in higher regions of the hopper.**

Liners and Coatings: **It may be practical to reduce wall friction by the use of liners (e.g. UHMWPE, polished or 2B finish stainless steel or various types of epoxies and plasma coatings). It is essential that such changes are based on measured values of friction.**

Hopper Shape: **Replacing a pyramid or conical section with a plane flow hopper, even one that applies only to a relatively small outlet region, can secure a significant flow benefits. More involved geometry can secure even better flow benefits, but these require some specialised expertise.**

Flow Inserts: **Hopper inserts are fitted for a host of different reasons, [4]. Some are of proprietary design or require particular expertise but others are relatively simple in principle and require only limited knowledge of bulk technology. It must be emphasised that any fitting that is placed within the flow path of a bulk material may be exposed to high forces, wear and will be responsible for changes to the flow pattern. Detailed consideration must therefore be given to the security of the item and the effects that will be created.**

Flow Aids: **The addition of flow aids, for example fumed silica, is sometimes used to reduce the cohesive strength of difficult to handle products. Similarly, anti-caking, desiccant, antistatic and lubricating additives are used for various applications.**

There remain many circumstances where gravity flow design is not feasible. For such applications, a discharge system must be used to achieve reliable discharge. For example: -

- **Where the poor flow nature of the material requires a larger outlet size than is compatible with the feeder of choice or the downstream process. Fibrous, interlocking, spring-like, wet / moist, stick & tacky, visco-elastic, highly compressible, soft, caking-prone and very fine powders exemplify such materials.**
- **Uncontrolled variability in the material flow properties makes it difficult to ensure a reliable design.**
- **Where current space constraints, usually headroom and especially in retrofit situations, do not allow the use of steep walled hoppers.**
- **The discharge rate of the size of hopper outlet needed for reliable flow is either too high, too low or needs to be controlled to suit subsequent equipment.**

Ideally, the prospect of using a discharge system should be identified at the initial design stage of storage silos and details appropriately factored into the structure, including stress calculations and headroom for installation and maintenance. Failure to do so may seriously impede the choice of initial equipment or seriously limit the options for retrofit. It is good practice to include some spare headroom, wherever practical.

Classification of Discharge Aids

Reviews of discharge aids are given by Reed, [5] and Woodcock, [6]. They can be broadly classified into two categories based on the form of flow promoting mechanism employed:

1. Active devices:-

These devices can be grouped into three types -

- **Pneumatic**
- **Vibratory**
- **Mechanical**

2. Passive devices:-

- **Hopper shape and construction, - plane flow hoppers, hopper design with one-dimensional convergence (e.g. DiamondbackTM hopper), Sigma Two relaxation, low friction liners.**
- **Insert systems, - 'Cone-in-Cone, Compaction shields, Inverted cone, 'Hoops stress cutters', Flow modifiers.**

All discharge aids work using one or more of the following principles: -

a) Dilate the material to enhance flow. The flow function of dilated material exhibits significantly lower unconfined yield strength (see Figure 3) thereby making it flow better. (Air injection may be used to dilate the bulk or inhibit time consolidation due to settlement).

b) Induce stresses that exceed the strength of the bulk material. (Vibration and mechanical agitators may be used to deform the bulk).

c) Reduce the friction between particles and the wall of flow channel. (Change the surface finish to a contact friction of lower value)

d) Modify the flow regime to one more favorable to flow.

e) Alter the bulk material flow properties by additives or surface modifiers. (Inhibit particle to particle adhesion or 'caking').

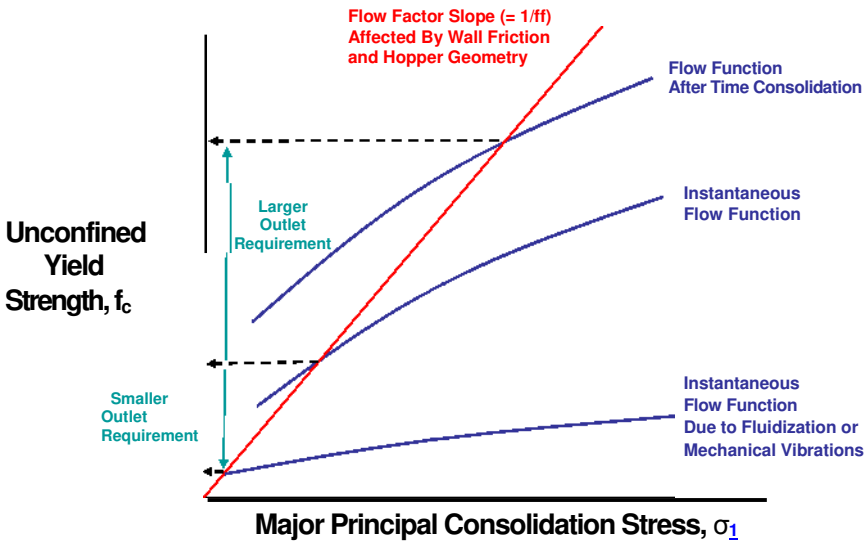


Figure 3. Relationship between 'flowability' and outlet size for mass flow bins/hoppers based on Jenike analysis

Pneumatic Discharge Aids

A wide range of pneumatic discharge aids are available in the market, namely

- **Aeration or fluidising pads, fluidising hoppers**
- **Directed air-jet type (continuous and pulsed)**
- **Pneumatically inflated dischargers or air pillows**
- **Air cannons**

Aeration or fluidising pads and fluidising hoppers

These discharge aid rely on dilation of bulk material (increase in inter-particle separation) by injecting air in the interstitial space between the particles. Powders tend to behave like fluids when fully aerated, but total fluidisation is not essential to promote the flow of fine particulate material, in fact doing so can result in the powder being difficult to control or not be in a suitable state for packing. Bulk materials comprised of particles of size less than 75 microns (-200 mesh), or with at least a 25% fraction less than 75 microns, (-200 mesh), are suitable candidates for aeration. However, powders with particles mostly less than 10 microns are very slow to settle, but difficult to re-fluidise, since they then exhibit channeling behavior. Good air dispersion may be re-achieved by pulsing large airflow rates that creates shock waves to cause massive agitation.

There are two main techniques of employing product aeration:

1. **Air injection during discharge – This works by reducing the materials bulk strength and particle wall friction, particularly near the outlet region.**

2. Continuous air injection during storage – This works by inhibiting de-aeration and the gain of bulk strength of the whole mass due to time settlement.

It should be determined whether the bulk material has a tendency to flush/flood or flow uncontrollably in fluidised state. In such cases, option #2 is more suitable. The amount of air required to avoid high strength gain of fine powders due to time settlement is very small, but the technique is not appropriate for products that rapidly de-aerate (particle size greater than 200 microns).

Excessive fluidisation can result in bubbling and the elutriation of fines. It can also aggravate the segregation of coarse and fine fractions within the hopper.

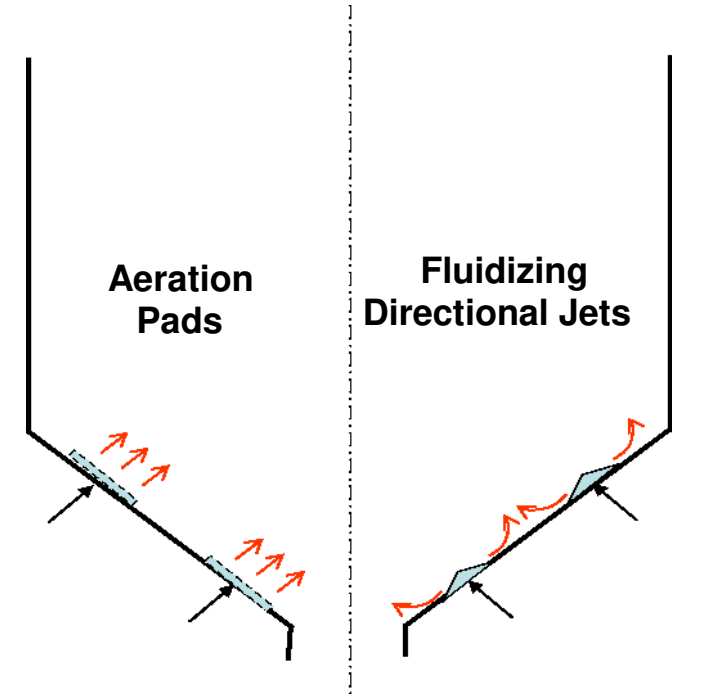
Aeration or fluidisation pads are easily mounted on existing hoppers as retrofits (Figure 4). Sintered media, multi-layer metal mesh or woven media is typically used as air distributor. Uniform air distribution is achieved by maintaining a large pressure drop across the media. The air consumption is typically 10 ft^3/min per square foot of pad area. These inject air only when discharge is required. They generate a pressure differential between the injection pint and the hopper outlet, providing both a driving force and a supply of air to satisfy the void demand of bulk expansion for flow.

Bulk control can be achieved by use of an aeration pad that covers the whole container base. Dilatation of the bulk improves the materials 'flowability' by reducing both wall friction and inter-particle cohesion. Activation of the entire hopper section allows a shallow hopper design to be employed (Figure 5). This may be supplied with a low, controlled-volume injection during storage, to stabalise the flow condition whilst the material is static, and increase the degree of aeration by injecting a higher rate of air for discharge. It is critical to supply oil free, clean and dry air for aeration to avoid product contamination. Appropriate arrangements must also be made to exhaust excess air and contain entrained dust at the top of the bin/silo.

Directed air jets

Directed jets can be effective in using the kinetic energy of air-jets to dislodge material from surrounding hopper wall and provide better gas dispersion through turbulence generation (Figure 4). The effective radius of these jets is limited to 1- 2 feet. Therefore, the jets must be placed in effective locations or multiple units need to be installed on the hopper wall to avoid dead zones. These jets can be timed and pulsed to minimise gas consumption. It is critical to supply oil free, clean and dry air to avoid contamination and prevent plugging of fine nozzles.

The crucial flow region for discharge is that near the outlet, because the smaller span at this location is the most likely place for stoppages to form. Clearing this region, or part of the periphery of the orifice, is equivalent to having a larger opening that can be sufficient for the remaining contents to discharge.



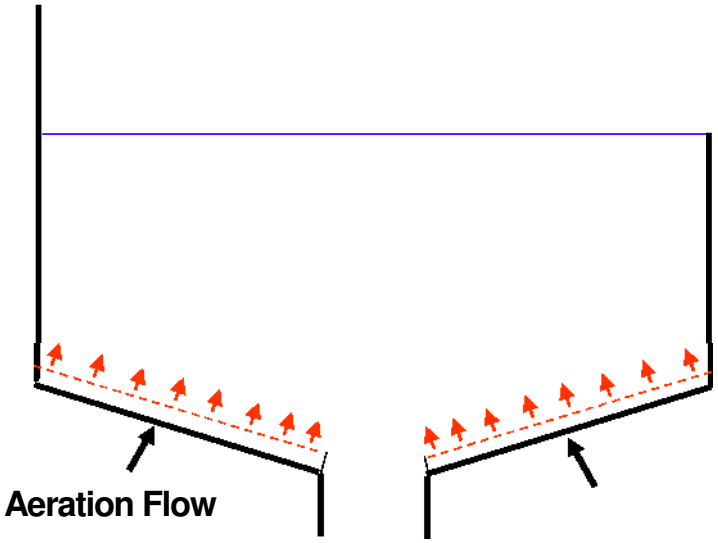


Figure 4. Aeration or fluidisation discharge aids

Figure 5. Fluidising hopper

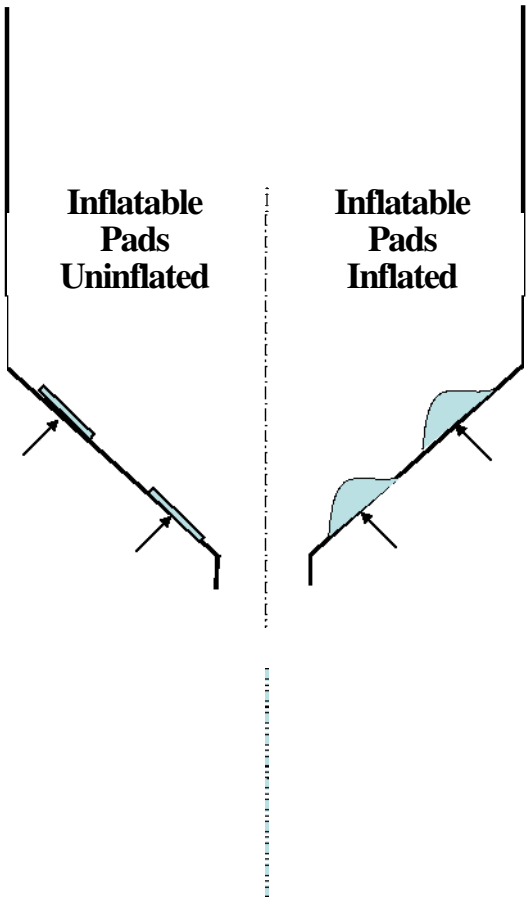


Figure 6. Operation of inflatable pads

Pneumatically Inflated Dischargers or Air Pillows

These are flexible bladders mounted on the cone or inclined walls of the bin/silo. Upon pressurisation (typically 1 to 3 bars), the flexible bladders expand and force the material towards the center (Figure 6). They are helpful in breaking ratholes or "brittle arching". These devices should not be used when the hopper outlet is closed or where the material is unable to flow, as local compaction will aggravate the flow difficulties, or with sharp or abrasive products that can puncture or wear through the flexible diaphragm.

Air Cannons

Air cannons (or blasters) are designed to inject blasts of high pressure gas, (up to 10 bars), in a short duration (typically fractions of a second). The shockwave traveling through the bulk solid provides a substantial force to break an arch or a rathole (Figure 7). Air cannons must be located where the stored material can be moved into an empty flow channel. Typical application includes use with sticky, wet, adhesive, fine, caking and fibrous materials. These devices are also used to knock sticky or adhesive materials and residual pockets of material from the walls of a bin/silo.

The force created by discharging air cannons is directly proportional to the reservoir pressure. The duration of the pressure pulse depends on both the size of the reservoir and

the initial air pressure.

The blast from air cannons or blasters can be directed either tangentially, (along the wall), or into the bulk material at various angles. Various shapes of nozzles are available to create

different dispersion patterns. When operating multiple air cannons, those at the bottom should be fired first, and the other moving progressively upwards at regular intervals. These devices should not be used for continuous operation. They are most useful for restarting flow after long downtime, after a process upset or for terminally clearing the bin after gravity flow has cleared what will discharge of its own accord.

Every blast causes a reactionary force on the silo wall, so reinforcement of walls near the blasters fittings must be considered, especially for retrofit situations. Large chunks of caked or consolidated material may be dislodged from a wall, arch or rathole, to generate significant impact stresses within the silo. The silo and any associated equipment must accommodate such conditions.

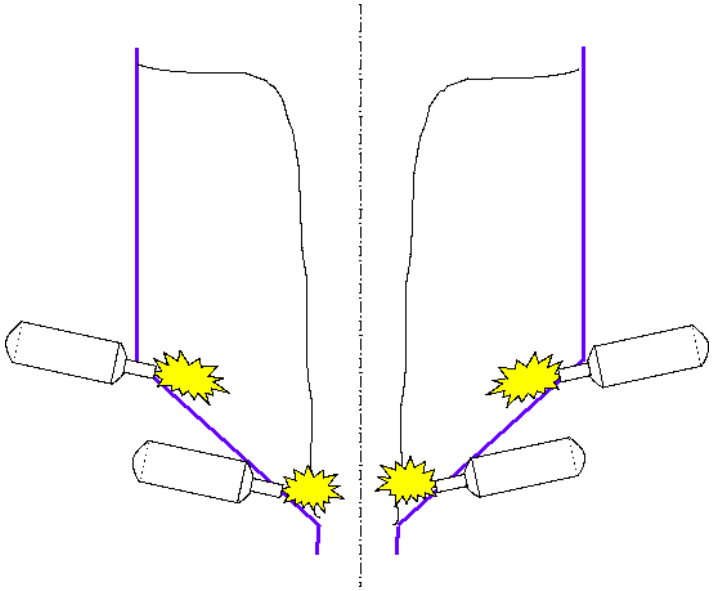


Figure 7. Air Cannon or air blasters

Vibratory Discharge Aids

Metal bars, mallets and sledge hammers are primitive discharge aids that are commonly found in solids handling plants. Unsightly deformations and dents, ('hammer rash'), is very commonly seen on hoppers that are used to handle difficult flow products. While the practice of mechanical vibrations is old, research on pressure wave propagation in within bulk materials and the effect of vibrations on flowability is limited and of mixed effect, [7].

The information provided here is a combination of fundamental research, empirical knowledge and best practices based on experience.
Vibratory discharge aids can be attached externally to the shell of a bin/silo as near as practical to the outlet or attached to elements/internals directly in the path of material flow (see Figure 8). These devices are used to address flow problems (arching, bridging or ratholing) or incomplete material withdrawal due sticking on hopper walls.

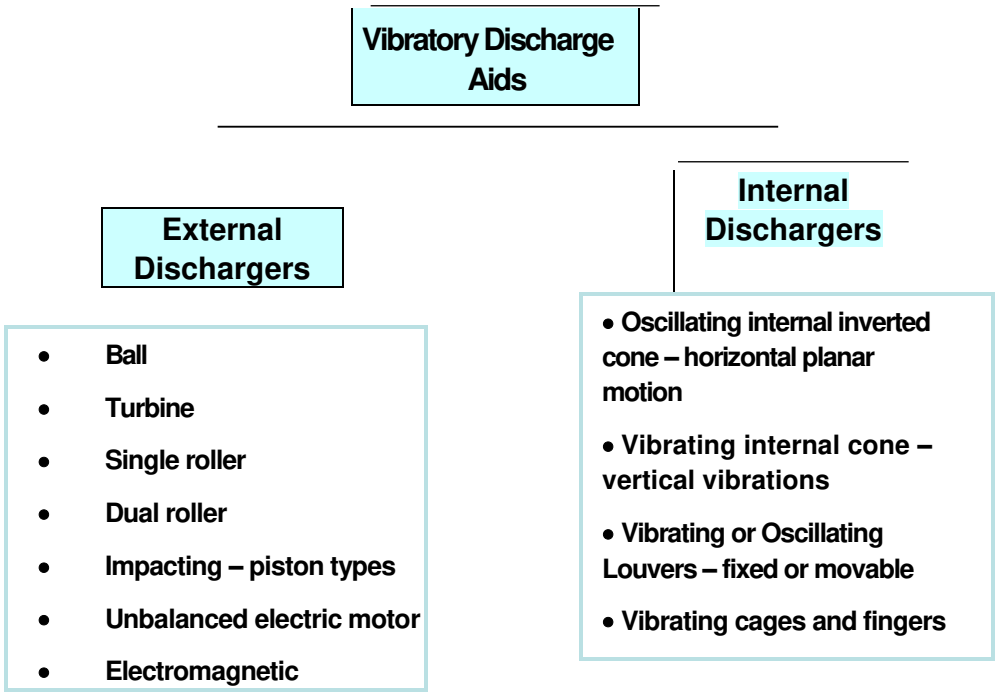


Figure 8. Classification of vibratory discharge

aids External Vibratory Dischargers

A wide range of vibratory aids is commercially available. Their versatility is partly due to their ease of installation as a retrofit. They may be classified based on the type of energy source (compressed air or electricity) and further on the basis of type of motion generated (Figure 9).

Linear vibrators produce vibrations that are perpendicular to the wall of the hopper, act similar to beating the hopper wall with a hammer, whereas rotary vibrators produce components of force both perpendicular and parallel to the hopper wall. Rotary vibrators typically run at higher frequencies and have lower amplitudes than linear vibrators. Twin rotary vibrators mounted in a parallel axis arrangement will tend to run in synchrony and cancel the forces acting in one plane, to produce a linear type oscillating force.

The resulting forces produced by vibratory devices are functions of their mass, amplitude and frequency. Frequencies ranging from 10 Hz to 500 Hz are used, depending on the energy source. Resulting forces are normally limited to 10 g for most applications.

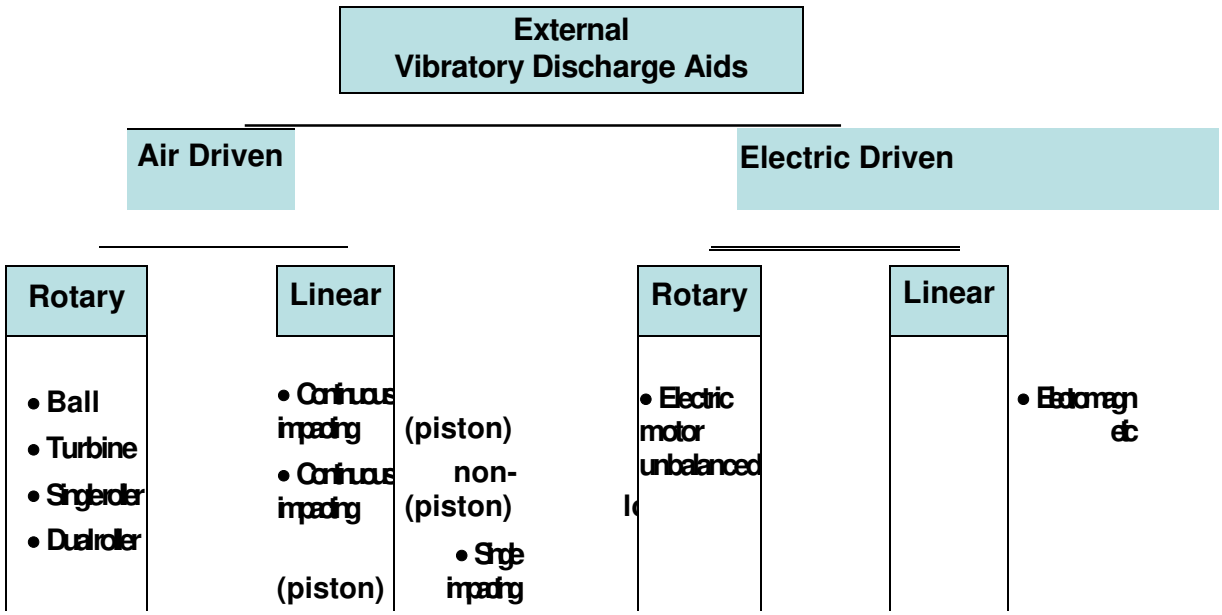


Figure 9. Classification of external vibratory discharge aids

A useful formula [5] relating peak acceleration (g force) to frequency and amplitude is given below:

'g' force = 0.1022 x amplitude (inches) x frequency (cycles / sec)

Air driven devices need a lubricated, compressed air supply. The frequency, amplitude and air consumption are proportional to the supply pressure.

Selection of Vibration Type Based on Application

Linear versus Rotary:

Rotary vibrators are recommended for dry, cohesive products that tend arch or form ratholes. These types of vibrators are mounted on hopper walls with rigid mounting techniques. Linear impacting and non-impacting vibrators are used for sticky or wet products. Linear vibrators are most effective when the hopper walls can flex to some extent. There is however, a significant overlap in the application uses of rotary and linear vibrators. Acceptable noise levels in the process area may inhibit the type of vibrator that can be used. Vibrators should never be run with the discharge valve closed and material is in the hopper as it is likely to result in severe compaction of the product, especially with a fine powder. Rotary vibrators may incur resonant transitions during startup and as they more slowly run down, so may not be suitable for applications where frequent on/off cycling is required.

Frequency and Amplitude:

The force imparted by a vibrator is a function of its frequency and amplitude. The frequencies may range from (10 Hz to 500 Hz) and amplitudes may range from 0.01 inches to 0.5 inches.

Electromagnetic and linear (piston type) vibrators are generally capable of producing frequencies in the range of 20 to 120 Hz. Rotary (electric) type vibrators operate between 10 to 60 Hz. Very high frequencies, ranging from 100 to 500 Hz, are generated by air operated roller, ball or turbine type vibrators.

Table 2. Selection of vibrations based on application

Type of Vibration	Application
Low Frequency (<30 Hz) – High Amplitude Vibrations	Coarse or large particles, material sticking to wall, electrostatic problem, wet materials
Medium to High Frequency (30 Hz to 60 Hz) and Low Amplitude	Compacting materials, discharge of fine dry powders, reduces wall friction to create mass flow
Very High Frequency (> 60 Hz) and Low Amplitude	Hopper cleaning, chute flow, de-aeration, discharge of fine dry powders

Force Requirement:

A rule of thumb often quoted in the industry is to – "Use 1 lb. of force for every 10 lb. of dry material in the slope portion of the bin". This is a good starting point. Higher level of force is required for bins with thick walls (pressure vessels) or materials that absorb vibrations (e.g. rubber crumbs, soft plastic pellets).

Installation of Vibrators

Proper Mounting:

Improper mounting of vibrators can result in fatigue and failure of hopper wall or the mount itself thereby resulting in safety incidents. Most vendors agree on the following guidelines for installation:

- **The transmission channel (see Figure 10) should be approximately 2/3rd of the length of the sloped wall**
- **Always use stitch weld to mount the transmission channel or a stiffener plate to the hopper wall. A stitch weld of one to two inches with an equal spacing between the welds is recommended. Leave the ends free of weld. Continuous weld creates brittleness and results in failures.**

- **Avoid welding at the corners or break edges of all stiffeners at the corner**

areas. ***Noise Control:***

Externally mounted vibrators can be very noisy. Linear impacting vibrators, which have hammer like action, can be as loud as 115 decibels (dB). Other rotary vibrators can radiate noise levels up to 95 dB. Amongst rotary vibrators, the turbine and electric vibrators are least noisy with noise levels up to 75 dB.

Various measures can be undertaken to minimise the noise produced by a vibrator:

1. **Using an exhaust muffler**
2. **Proper mounting**
3. **Operating at lower speed, use larger vibrator at lower speeds**
4. **Changing the location of the vibrator**
5. **Sound insulation**
6. **Using thicker wall material and avoiding operating near resonant frequency of the structure**

Multiple Vibrators:

When bin diameter exceeds 10-12 feet, consider using more than one vibrator to distribute the vibrations more effectively. If two vibrators are used, the second vibrator should be mounted at 90 degrees from the first and further up the cone. (see Figure 10 for heights).

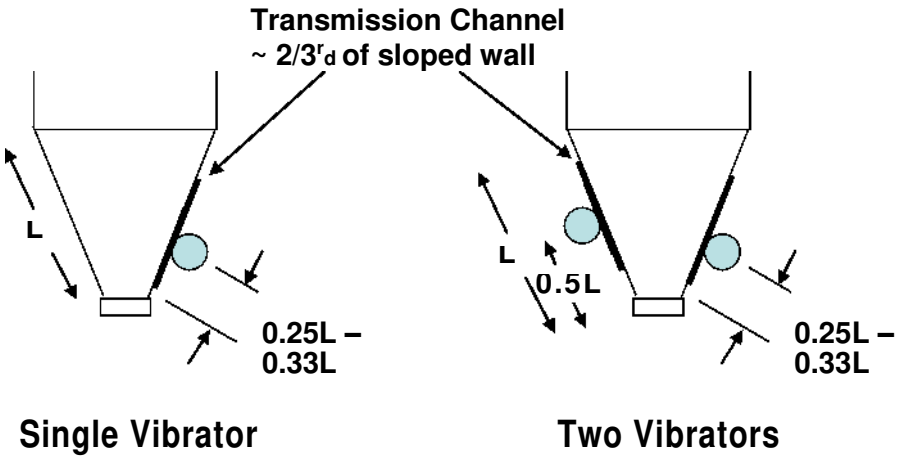


Figure 10. Installation guideline for vibrators on hoppers/bins

Internal Vibratory Dischargers

Bin Activators

A bin activator consists of an inverted cone or baffle suspended across the outlet hopper with supports (Figure 11). There is an annular space between the inverted cone and the outlet hopper through which the material from the bin/silo can flow towards the outlet hopper. The entire assembly oscillates in a horizontal elliptical plane at frequencies ranging from 10 to 50 Hz (typically 30 Hz) and amplitudes ranging from 1/16 to $^1/_2$ inch. Single or dual exciters can be used to impart vibrations. The inverted cone serves three purposes: -
a. Imparts force into the bulk to break potential arches.
b. Reduces stresses in the outlet region by shielding flow over the outlet
c. Provides a slot-like outlet and pseudo-plane flow, offering a favorable flow shape.

Some vendors provide additional baffles or venting in the outlet hopper to assist flow and prevent compaction.

The intensity of vibration can be changed by moving the eccentric weights on the drive motors. Desirable discharge rates can be achieved by suitable combination of width of annular space, outlet size, vibration frequency/amplitude and on-off cycles. There is lack of consensus amongst various vendors regarding on-off cycling of bin activators. On one hand, vibrating product for extended periods with the outlet closed can result in compaction and arching problem so is best avoided, but constant cycling of the unit can result in mechanical failures.
The resonant frequency of isolated assembly is usually lower than the operating frequency. Therefore, the unit will often pass through a resonant "shudder" when the motor is stopped and the machine is running down. For frequent cycling operations, a motor breaking control system is recommended. This will minimise resonant vibrations that can damage mechanical components and weigh cells (if installed).

Bin activators have been successfully adapted and applied to various industries:

Chemical Industry: Explosion proof motors, self cleaning design, corrosion resistant design
Agricultural Products: Steeper cones for deeper penetration into the bulk material for light and springy products
Diary/Food Industry: Smooth stainless material of construction, sealed cones, FDA compliant materials for flexible boot
Coal/Foundry Industry: Abrasion resistant design and high temperature components

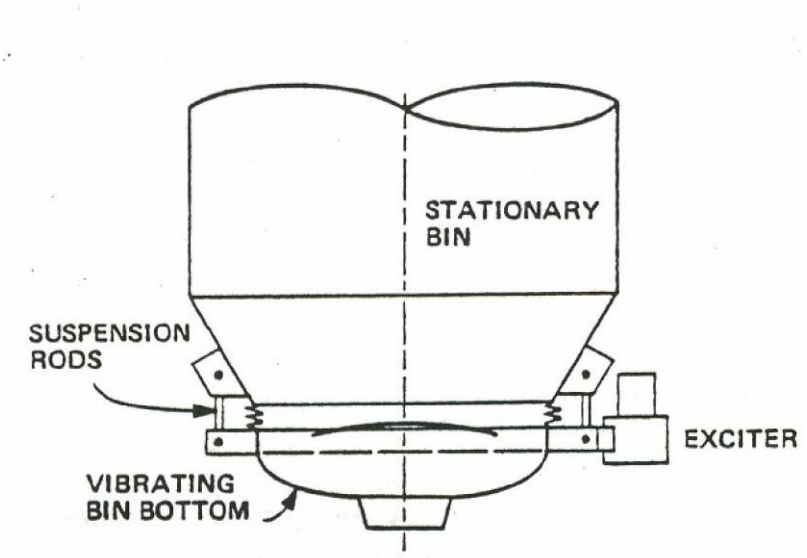
The advantages of bin activators can be summarised as follows:

- **Reduces effective outlet size as compared to gravity flow design. Makes it easier to interface with a feeder.**
- **Helps to restart material flow after long duration (time consolidation) or discharge caked material**

- **Reduces overall headroom requirement by using shallower cone**

Bin activators are typically sized based on guiding principles developed by various vendors through years of applications (and errors!!). Some general guidelines are shown in Table 3. However, we must caution the readers that flow properties (flow function / shear characteristics) of the material must always be measured to estimate arching and rathole dimensions. A bin activator would be ineffective if the arching or rathole dimension is larger than the diameter of the bin activator. The bin/silo design above the activator should still follow principles outlined by Jenike [1].

The bin activator should not be operated with the outlet valve closed or feeder turned off. It may result in compaction of material in the outlet cone. For applications where the bin activator is not discharging freely, and a feeder or flow control device is being used. The outlet must be fully 'live' and the discharge rate not restricted to less than a third of the bin activators uninhibited discharge capacity. Where low feed rates are required, the discharger should empty to a surge hopper with the feeder and a high level probe to stop the flow when the surge hopper is full.



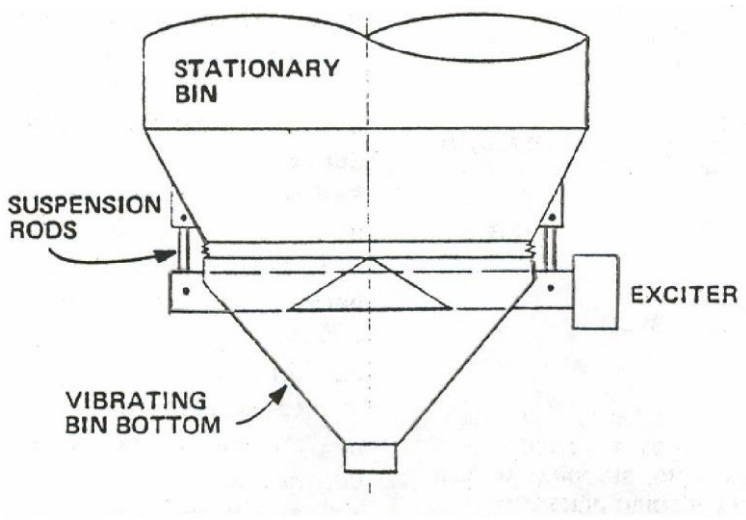


Figure 11. Typical bin activator designs

Table 3. Preliminary sizing of bin activator based on material properties

Material Description	Bin Activator / Bin Diameter Ratio
Normally granular free-flowing. Bridging caused by temperature and humidity	1/4 -+ 1/3
Sluggish powder; slightly cohesive, typical particle size ranging from 50 to 150 microns	1/3 -+ 1/2
Fine adhesive or sticky, flaky, easily fluidisable	1/2 -+ 2/3
Fibrous, flakes, light chips, long strands, shavings, sticky materials.	2/3 -+ 1

Cone Discharge Valve

Cone valves evolved from bin activators by combining the functions of discharge aid (bin activator) with shut off valve (discharge element). The cone acts as a discharge aid by lifting up and imparting vibrations into the bulk material (Figure 12). The rest position of the cone shuts off the flow to the outlet. These cones can be operated in series (one on top of the other) for bins/silos with high aspect ratio. While these devices provide some control over discharge rates, they can not always be used as feeders. In some applications, unsatisfactory sealing around the inverted cone can cause product leakage (esp. with fine powders). These valves have been successfully adapted to IBC applications.

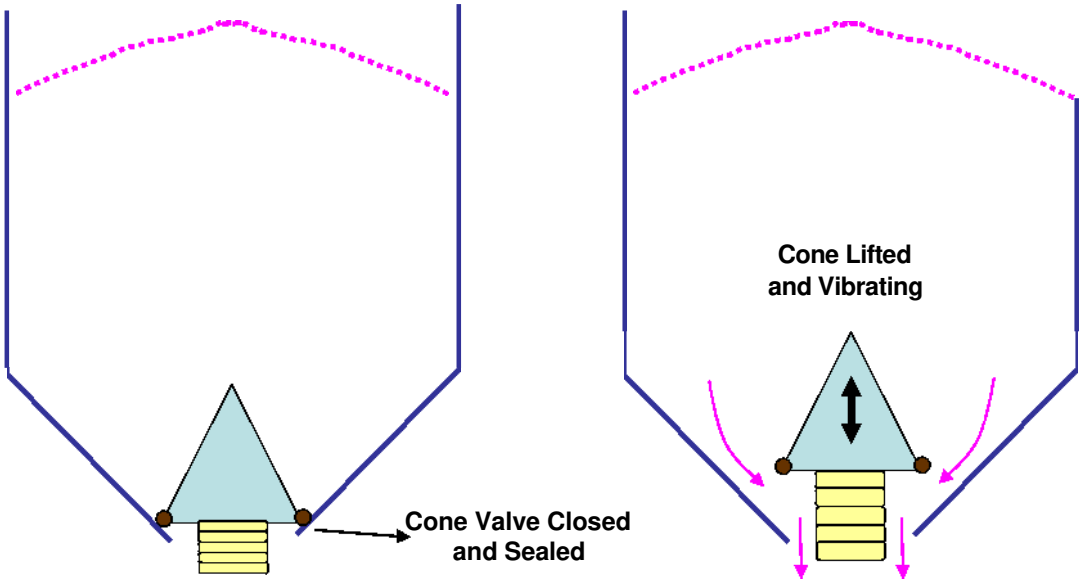


Figure 12. Cone valve operation

Slotted Bottom Dischargers

Vibrating Fixed Louvers

A vibrating drive and tray frame contain a removable feed tray in which is fitted a number of flat blades inclined at a certain angle (Figure 13). Each blade acts as a vibratory feeder. When the vibrations are stopped, the overlap between the blades prevents flow of product under the action of angle of repose. The blade dimension and angle are determined empirically by lab trials. The unit can be driven by electro-mechanical or electro-magnetic drives.
This discharge aid does not transmit vibrations further into the bin/silo, therefore, it will not initiate flow above its location. The material must flow into it under the action of gravity. The unit must be sized such that its size is greater than the arching or rathole diameters.

These devices can also be used as feeders since the discharge rate can be controlled by changing the amplitude of vibrations. Given that there is no means for positive shut off, some sort of valve must be installed downstream.

Vibrating Pivotable Louvers

This concept adds to the above design by pivoting the louvers (Figure 14). As a result, it achieves three functions: -:

1. **Promotes and maintains reliable flow**
2. **Acts as a flow regulating device (feeder) for downstream equipment**
3. **Serves as a valve to shut-off flow when not in operation (similar to slide gate)**

This design is more adaptable to variations in material properties since the angle and discharge opening can be dynamically changed. Additional mechanical complexity, however, increases maintenance in harsh conditions.

Vibrating dischargers tend not to perform well with products that absorb vibrations or mechanically interlock (e.g. wood shaving, ground plastic films, cellulose fibers etc.).

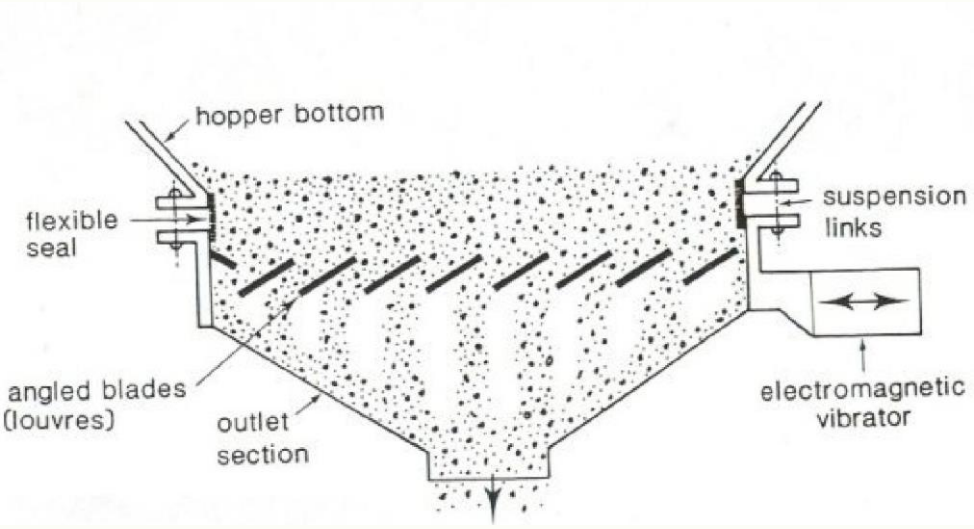


Figure 13. Slotted vibratory bottom feeder

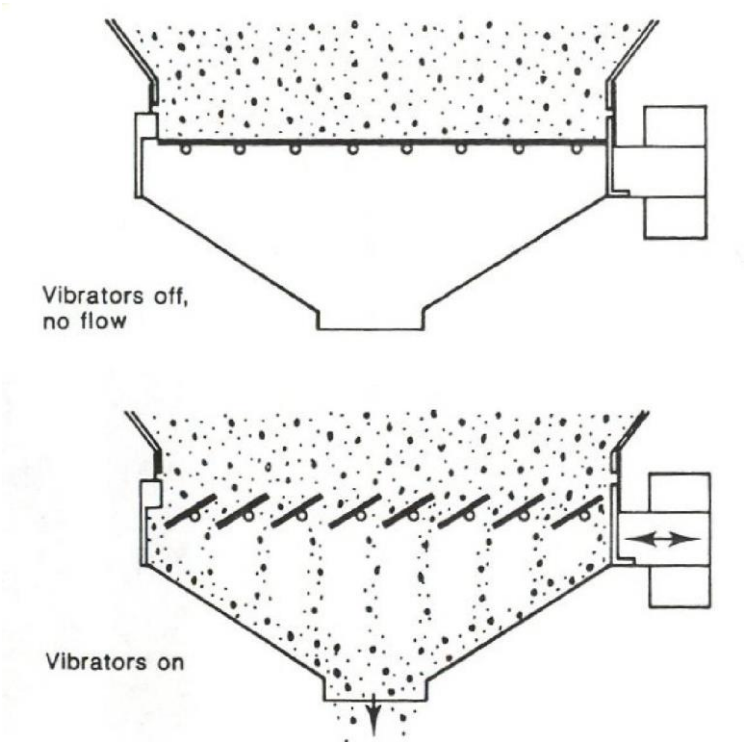


Figure 14. Slotted and movable vibratory bottom feeder

Sonic Horns

Horns are used to dislodge sticky or adhesive powders and fluidise fine powders using sound waves. High frequency air waves are produced that can disturb the structure of a bulk material. Their use must be considered on a case-by-case basis and noise considerations taking into account.

Movable or Vibrating Screen

Flow is initiated by vibrating an expanded metal screen which is mounted inside of and parallel to the hopper wall (Figure 15). The metal screen is fixed to a shaker assembly. A support bar welded to the hopper supports the shaker reaction spring and shaker assembly. The shaker which is air operated imparts a thrusting action to the screen with an amplitude (typically ±1/8") promoting the solids discharge.

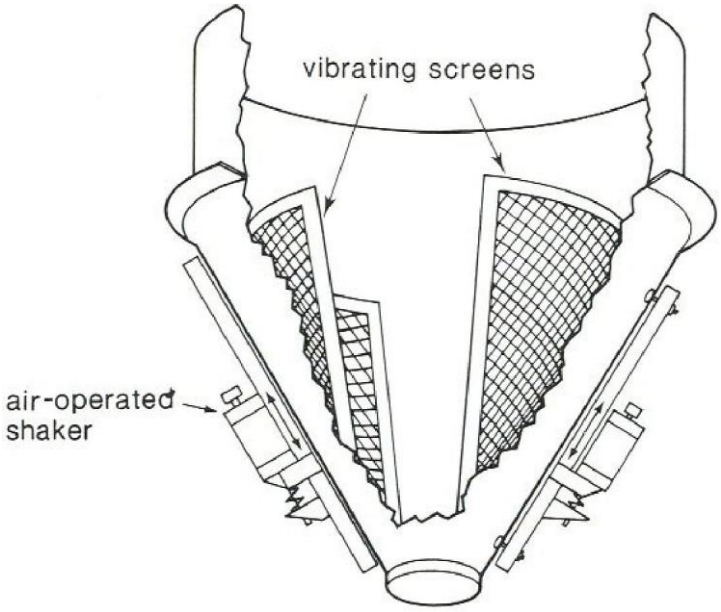


Figure 15. Movable screen discharger

Mechanical Discharge Aids

Mechanical devices of various proprietary designs are being employed to move the bulk solids out of silos, stockpiles and other storage facilities. Broadly speaking, these mechanical devices either rely on extracting stored bulk material towards the outlet or agitated/condition the material for reliable flow under gravity (Figure 16).

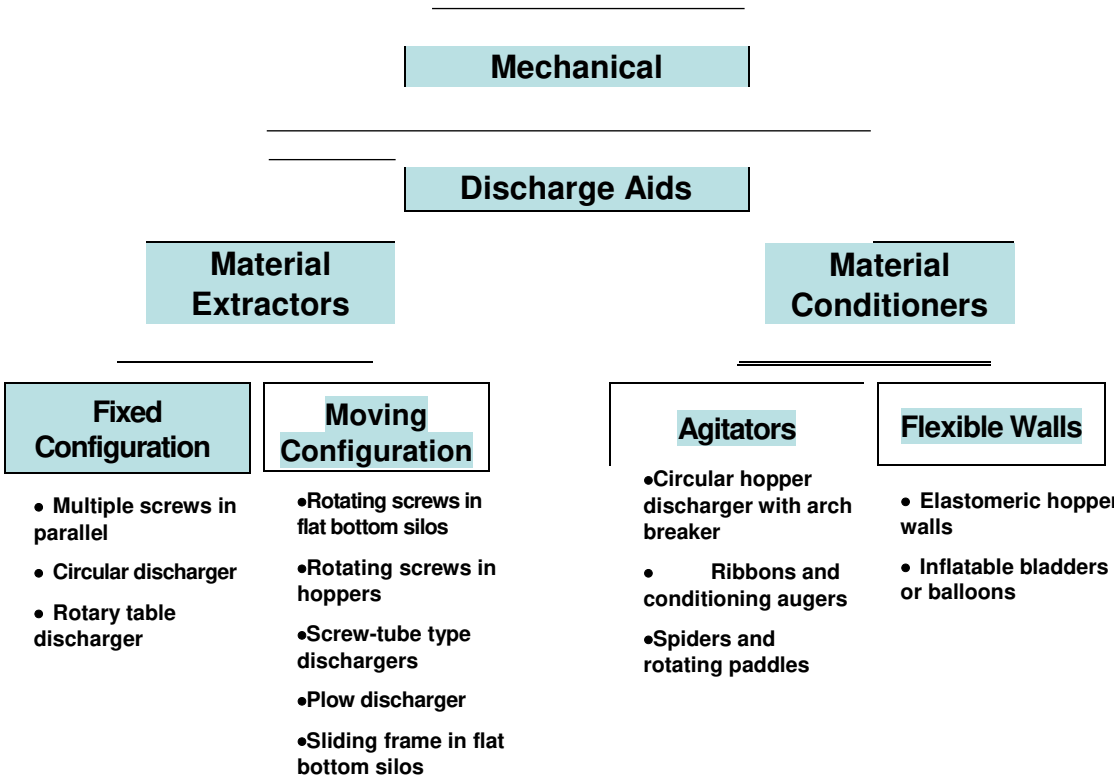


Figure 16. Classification of mechanical discharge aids

Material extractors

Material extractors are designed to suit the existing hopper or silo designs. Consideration is given to the flow property of bulk solids and the extent of consolidation with respect to time. These devices are expensive, and can only be viable if storing a large quantity of solids.

Fixed Configuration

Following are some of the types:

Single or Multiple Screws in Parallel

These are normally considered as part of an integrated design with the bin shape. In the case illustrated in Figure 17, a set of screw dischargers are used to discharge solids. These particular units cover almost the entire cross section of the silo, rotating slowly up to 5 rpm. The conveying part of the design is shrouded to prevent the uncontrolled 'carry-over' of solids.

The design of the flights depends on the solids flow properties and there are several flight designs and pitch to diameter ratios that govern the extraction pattern of solids. For progressive discharge, these discharges require gradually increasing pitch to draw the solids evenly. Ribbon screw flights are used for fine and cohesive solids such as micro talc.

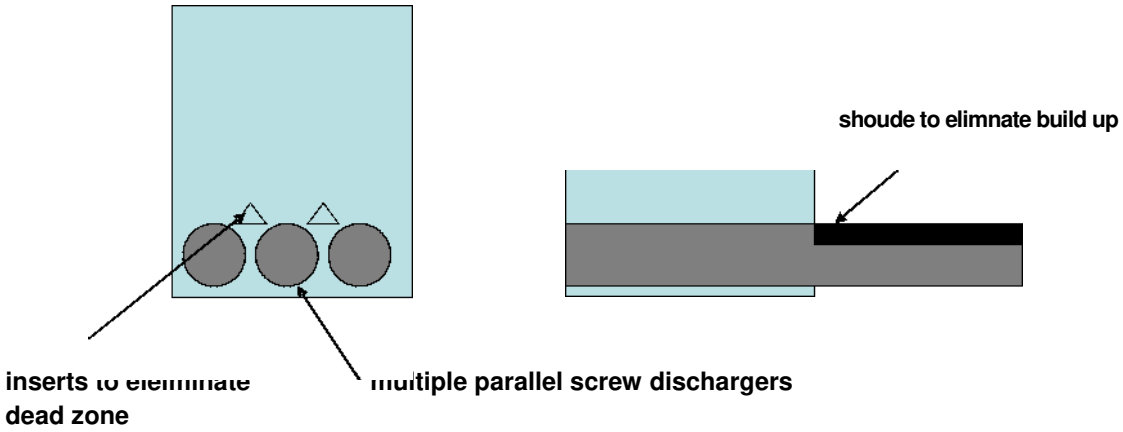
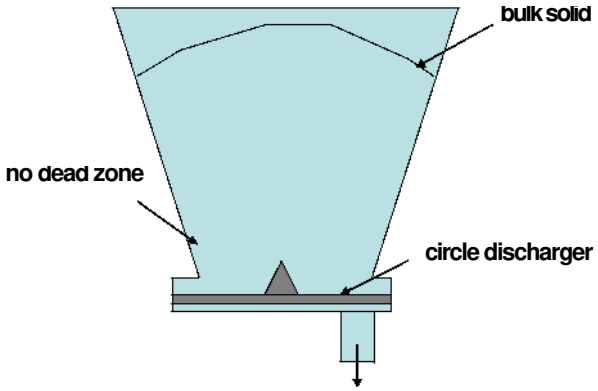


Figure 17. Multiple screws in parallel

Circular Discharger

These dischargers consist of a stationary table and a set of blades mounted on it (Figure 18). There is close degree of tolerance in clearance between the table and the blades to minimise a permanent coating of the solids stored. During operation, these feeders rotate slowly and pushing the solids to an outlet placed just underneath. The circle feeders are slightly larger in diameter as compared to the outlet, thereby eliminating the formation of dead zones at the silos wall. Since the discharge takes place through an opening, designing several such opening



will enable a more uniform discharge of solids without creating preferential flow.

Figure 18. An illustration of a circular

discharger *Rotary Table discharger*

Rotary table, shown in Figure 19, as the name suggests consists of a circular table that can rotate underneath a large opening at a speed of up to 10 rpm. Material flowing from the silo is discharged by a fixed blade/plow.
One critical point to remember is the skirt design around the table and the outlet should be gradually increasing from the discharge point to draw the solids evenly. This skirt is raised above the table in a helical pattern to provide increased capacity in the direction of rotation.

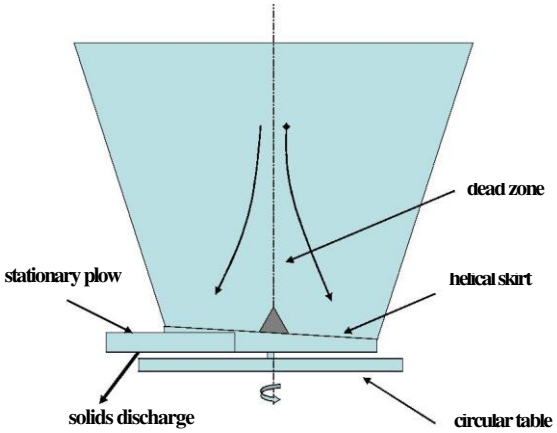


Figure 19. Rotary table discharger

Such dischargers are suitable for very fine or sticky solids and provide a low flow rate from very large openings. Drawbacks are the high installation costs and usually a dead mass at the center of the unit, often occupying up to 40 -50% of the area.

Dischargers with Moving Configuration

These types consist of moving dischargers in addition to rotating on their axis, sweeps or traverses across the cross section of the storage units.

Rotating Screws in Flat Bottom Silos

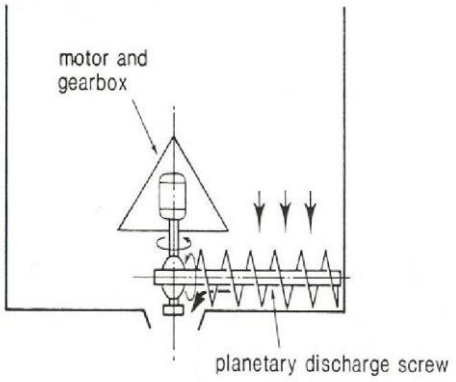


Figure 20. Rotating screws in flat bottom silos

These types are commonly used for large volume particularly with volume efficient flat bottom silos. The screws slowly sweep the silo bottom and at the same time rotate to move the solids toward the outlet at the center of the silo (Figure 20). These units handle cohesive, sticky and difficult to discharge type of solids. In certain designs, two dischargers sweeping the silo bottom continuously.

The drives for screw re-claimers usually have hydraulic motors for better control and start up torque. The drives can be either housed inside the storage facility, in which case accessibility is through the outlet. The drives can also be located outside for some of the above types in which case the outlet design has to accommodate the drives. In case of longitudinal or rectangular storage facility, drives are placed at one end of the facility while the cables move back and forth with the discharger

A major drawback of all the units described above is securing access for maintenance and repair if the discharger breaks down in a pile of bulk solid As this has happened, it is sensible to pay attention to the design of the latter by calculating the stresses and torques due to solids, particularly while starting the unit. Additionally, providing blinded ports along the periphery of silosl enables the discharger to be pulled out for maintenance or any other reason. Good engineering design is necessary for these designs to be robust and reliable.

Screw-tube Discharger

A recent version of these designs as shown in Figure 21 has a tube and a screw re-claimer is housed inside of it. The tube rotates independently of the screw and uniformly reclaims the bulk solids through slots along the length of the tube. The inner screw transports the material to the end of the tube where it is discharged to a take-away conveyor.

These types consume significantly lower power compared to normal screw dischargers. This is due to less friction of solids on the tube than the work content of the screw action. Attrition is also lower in screw-tube types and hence better product integrity is maintained.

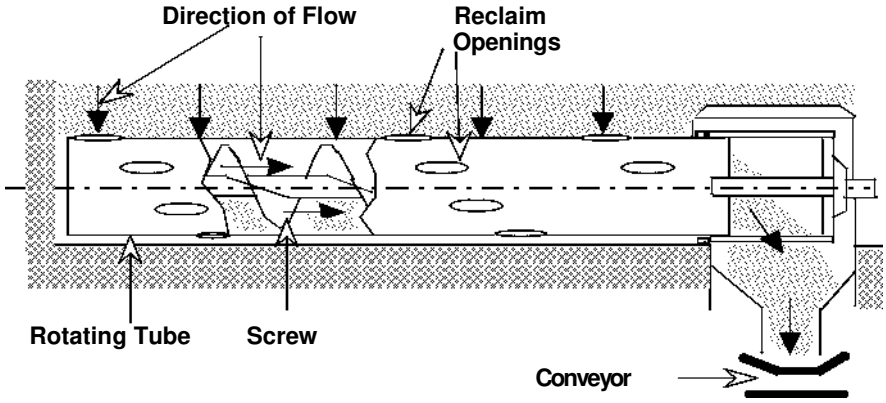


Figure 21. An illustration of a screw-tube type discharger

Plow Discharger

The plow dischargers are simple and are easy to maintain. Normally are located under a conical silo or traveling under a long stockpile. As the plow rotates, it pushes the solids, and loosens the solid above it and the discharge occurs. In some cases, two plows are used.

One of the disadvantages of the plow feeder is the dead zone that can extend along the wall since the penetration of the plow falls short of the silo wall. In order to circumvent this [2], the hopper design at the interface of the plow must include either a straight part or the plow length has to be longer than the hopper part. In order to overcome the dead zone at the central part, a cone insert has to be designed properly as shown in Figure 22.

Sliding Frame in Flat Bottom Silos

The sliding frame in a flat bottom silo consists of a frame sliding to and fro on top of it and promoting solids to fall into a slot across the middle of the floor, on to a screw (Figure 23). This type of discharger was mainly developed to deal with bulk solids of the most severe flow characteristics, such as high water content, compressible, highly cohesive materials (e.g. partially dewatered sewage sludge, paper pulp waste etc.) that cannot be easily be handled by other means.

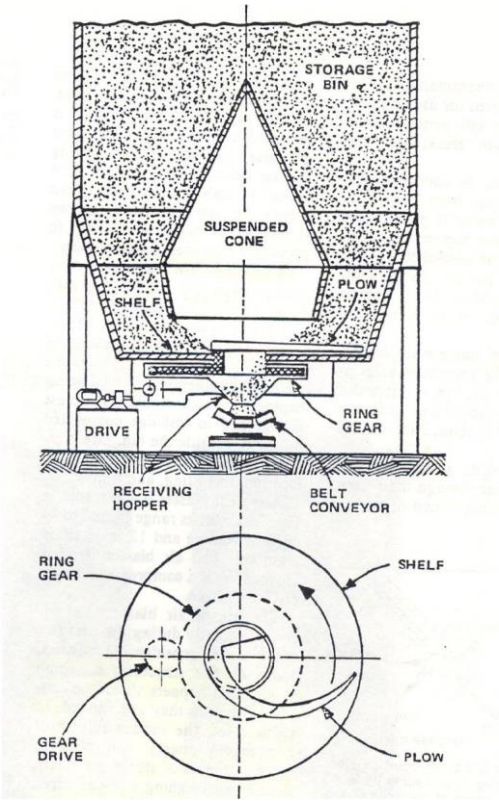


Figure 22. Illustration of a plow type discharger

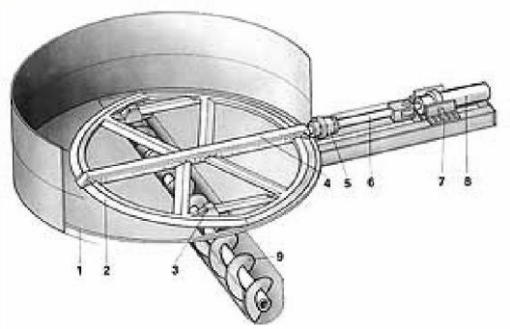


Figure 23. Illustration of a sliding frame

As opposed to a sliding frame, A variation in the design is the 'walking floor' type. This consists of a flat silo floor frame divided into several strips, which oscillate alternately to and fro alongside each other. At one end of the assembly there is a clearance down which solids fall on to a screw conveyor.

Agitators

Hopper Discharger with Arch Breaker

These devices are inside the cone of the silo driven from a universal joint at the outlet. The length of the arm is almost equal to the slope length of the hopper cone, and rotates slowly, being free to move and shear the bulk solid. These devices can be retrofitted to an existing silo without the need to cut the whole bottom off the vessel. Again they can discharge materials for which gravity-discharge hoppers would be. Impractical.

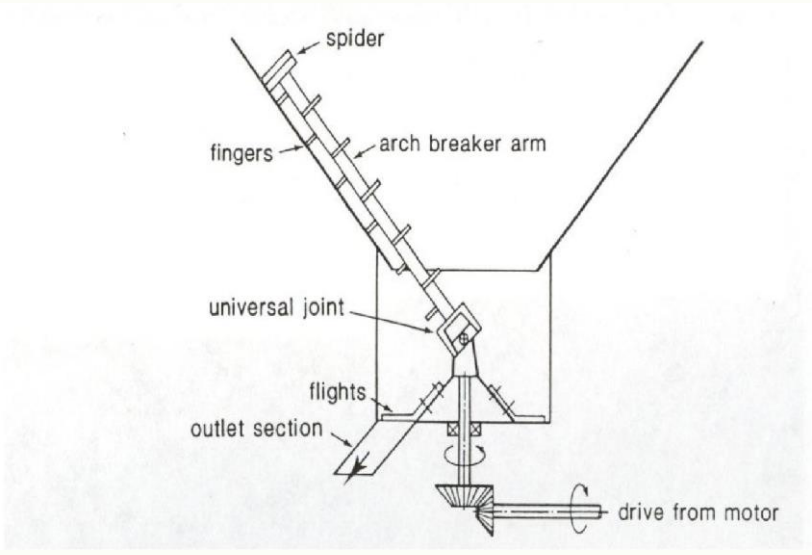


Figure 24. An illustration of a circular hopper discharger with arch

breaker *Ribbons and Conditioning Augers*

Metering or dosing solids that are cohesive, is often undertaken by an augur with a surrounding ribbon flight for disturbing the solid in the feed hopper

Similar 'conditioning', or agitating augurs can also be used in a vertical axis,to assist flow onto a screw feeder.

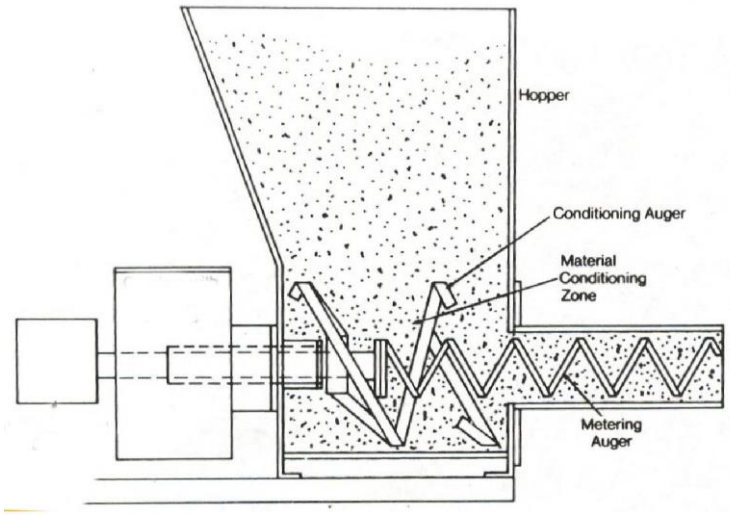


Figure 25. An example of conditioning auger

Spiders and Rotating Paddles

In certain cases, spiders and rotating paddle can be fitted in side a hopper. The motion loosens the solid and hence promotes in discharge.

Flexible walls

Agitation to solids contained in hopper is also imparted by using walls that are totally flexible or have elastomeric panels on the sides walls. The walls can be inflated or a slow massaging applied mechanically.to help the solids to flow.

Inflation of the bladders or balloons can be effected by air, forcing the solid to flow. The sequences of pulsing these inflations must be determined by trials and a procedure has to be worked out for a given solid or one may consolidate the solid. The operating temperature may also limit the usage of these types.

Passive Discharge Aids

Gravity flow can also be assisted by using passive devices that change the stresses and flow patterns within the converging section in a favorable way. BINSERTTM, inverted cone (Chinese Hat) or pyramid and DiamondbackTM hoppers are examples of such devices.

Whilst inserts can offer considerable operating and flow benefits, they are generally the domain of specialists as it is necessary to consider the following issues:

- **Ease of cleaning: passive devices limit access to regions where blocking is most likely to occur.**
- **Variability in flow properties: passive devices can be designed to operate within a limited range of wall friction and cohesive strength.**
- **Stresses: the loads acting on inserts and its supports can be quite large. Therefore structural design must be carefully evaluated.**
- **Impact forces: structural integrity to handle impact forces during filling.**
- **Fabrication tolerances: define tolerances required for operation.**
- **Pressure rating of vessel (esp. with flat surfaces such as on DiamondbackTM hoppers).**
- **Effect on secondary operations: Special gas distribution system needs to be designed to achieve uniform distribution in hopper and purge bins.**

Other approaches include use of smooth liners and addition of flow additives to improve product flowability and/or reduce caking tendency.

Operation of Dischargers – Intermittent vs. Continuous

Bins/hoppers/silo discharger systems can be operated in a number of ways.

1. **Operation of discharger required continuously because the critical arching dimension for instantaneous flow is larger than the outlet.**
2. **Bin outlet is sufficiently large to provide reliable flow once the flow is initiated. The outlet size is larger than arching dimension based on instantaneous flow conditions. Discharger is only required to initiate flow upon stoppage. In such situations, it is advisable not to overuse a bin discharger.**
3. **Bin outlet is sized for typical process operating conditions. The discharger is operated only in case of extended time storage during shut down or unexpected process upsets.**

Selection of Dischargers

STEPS:

a. Determine the maximum operating bounds of variability of the bulk material and secure the following measured properties: cohesion, time consolidation, flowability, particle size distribution, fluidisation characteristics, variability in material, abrasiveness, friability, stickiness, wall friction characteristics, moisture%, dust explosion potential.

b. Understand process requirements: installation (existing vs. new silos), height constraints, feed-out demand, acceptable attrition and abrasion, maintenance requirements, availability of utilities (compressed air vs. electricity).

c. Short list the class of dischargers that would be suitable for a given application based on initial set of questions. There might be cases where more than one method is suitable. See Table 4.

d. Drill down deep into each of the categories to identify suitable dischargers. At this point, one must consider retrofit situation and new bin/silo design separately. Retrofit situation imposes many constraints, such as –

1) **Ease of installation in existing space**
2) **Available utilities (electricity, compressed air, inert gas)**
3) **Access for maintenance**
4) **Ability to performance maintenance without emptying the product**
5) **Need for ancillary equipment**
6) **Effect on process safety and safety during maintenance**
7) **Need to install discharge aid without shutting down the process**
8) **Cost**

e. Conduct vendor trial, pilot scale test or verify in field.

f. Go back to step c if the concept does not perform satisfactorily during vendor trials.

Table 4. Preliminary Selection of Discharger Type

Discharger Class	Suitable For	Unsuitable For
Pneumatic type	**Powders – cohesive and fluidisable,**	**Caked materials, moisture level is critical, large particles, floodable, potential dust explosion**
Vibrational type	**Cohesive, caking, brittle arching, sticky**	**powders that tend to consolidate with vibrations, spongy, soft,**
Mechanical type	**Very difficult to handle materials, moisture level is critical, materials with dust explosion potential**	**Silos with high aspect ratio; friable, springy, soft and abrasive materials**
Passive type	**Materials that are marginally unsuitable for typical hopper design, locations where utilities (air / electricity) are not available**	**Materials with high variability in flow properties, sticky and caking type.**

Pitfalls with Vendor Trials

As pointed out earlier, the process of selection of bin dischargers is still very empirical and dictated by experience of the plant and the vendor with similar material. After making a preliminary shortlist, the reader is advised to conduct trials at the facility of a reputable vendor. This is particularly true for proprietary designs. In our experience, a successful trial often times does not always translate into successful implementation. Here are a few reasons why -

- **The test material was not representative of the actual product being handled. There are certain limitations imposed by conducting an offline and offsite test.**
- **The process conditions (temperature, humidity, pressure) are significantly different that those in the test lab.**
- **Performance of the bin discharger is sensitive to operating conditions.**
- **The design does not scale up very well or scale up not well understood.**
- **The vendor may not be competent or have experience in product class which you are testing.**
- **It is difficult to anticipate process upset conditions.**
- **Mechanical robustness, maintenance and fouling issues are difficult to gauge with a short term test.**

Interfacing Dischargers with Feeders

Dischargers feeding into downstream processes use feeders to regulate the flow rate of product. It is important to interface the feeders at the outlet of the discharger properly such that material is uniformly withdrawn across the entire outlet. Preferential withdrawal of material from one region can lead to dead zones, unexpected stresses, segregation and potential caking of material. The illustrations in Figure 26 can be extended in principle to almost all other types of dischargers.

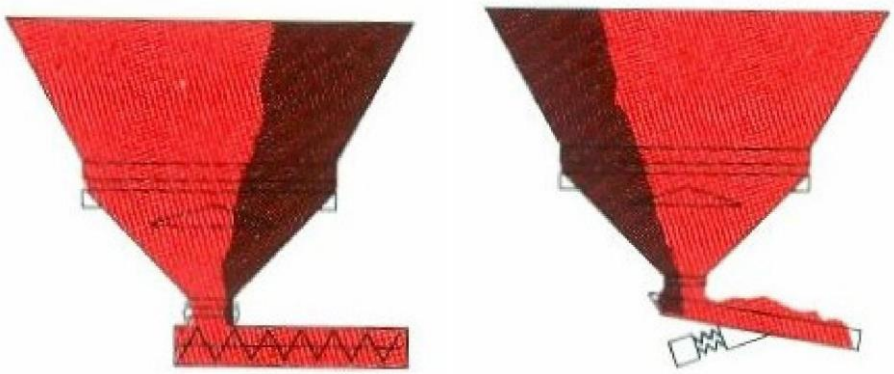


Figure 26. Examples of incorrect interfacing discharger with feeders

Specification of Dischargers

The following line items must be covered while specifying a discharger.

1. **Mode of operation: continuous, intermittent**
2. **Material of construction (parts in contact with product)**
3. **Discharge rate expectation**
4. **Process temperature and pressure conditions**
5. **Compatibility between bulk material and seals / parts: corrosion, wear**
6. **Maximum duration of storage between withdrawals**
7. **Provide design details of the silo where the discharger will be installed**
8. **Maintenance Issues: Can maintenance be done onsite and in-situ?**
9. **Cross contamination and cleaning requirements**
10. **Need for separate feeder or discharge valve**

Summary

Successful selection and specification of a bin discharge system requires understanding of the operating principles of various dischargers, process parameters and limitations, available space and constraints, bulk material properties and their sensitivity to process conditions, knowledge of solids handling theory, knowledge of mechanical details of various commercial designs and information on proper installation. Often it is difficult to get an objective opinion from a single source (vendor) because each vendor specialises in a limited range of dischargers. By having a clear understanding of various options, applying sound principles of powder mechanics and working closely with the vendor, it is possible to minimise the risk associated with installing bin/silo dischargers.

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