Chapter 28

SELECTION AND SIZING OF FEEDERS, BINS AND STOCKPILES

Andrew W. Jenike

Consultant, Jenike and Johanson, Inc.
No. Billerica, MA 01862, USA

STORAGE AND FLOW

Introduction

The layout and design of a bin or stockpile for bulk solids should assure reliable feed at the required time and rate without spillage and, when required, without segregation and degradation.

The typical procedure in the design for gravity flow follows these steps:

1. The bulk solids to be stored are identified and the range of moisture content, temperature, feed rate and time of storage at rest, as well as the storage capacity, are specified. The materials of construction of the hopper, that is of the converging part of the bin, are decided upon. Hopper liners and coatings to reduce wall friction are considered.

2. The flow properties of the bulk solids and the friction angles against the wall materials are measured for the expected range of conditions.

3. The width of a slot outlet needed for reliable flow of each solid under the full range of conditions is determined from the tests. This dimension is an explicit measure of flowability of a solid. The widest slot determines the critical solid and the critical conditions.

4. A suitable feeder of size sufficient for the widest slot outlet is selected.

5. On the basis of the measured wall friction angles, a suitable wall material is selected and a mass flow hopper is designed to ensure reliable and uniform flow of solid into the feeder and to minimize the load on the feeder. The mass flow hopper may extend upward to the intersection with the cylinder thus producing a mass flow bin. Alternatively, the hopper may terminate at a height equal to a few widths of the outlet and then expand at a less steep slope in its upper part in order to save headroom, or it may terminate in the flat bottom of a bin or stockpile. The choice depends on the flow properties of the solids and the size of the bin or stockpile.

6. The design of the bin is completed for the specified storage capacity. Multiple hoppers and

feeders are used for large bins.

7. For powders, gravity flow rate limitations are computed and air permeation is provided if needed to increase the flow rate.

While the above procedure sounds simple, in fact, the process is complicated by the wide range of solids flow properties and conditions of operation. Some solids may gain so much strength when stored at rest that they will not flow out of any bin. They need to be circulated periodically around the bin to destroy their strength, as it rises. This requires mass flow so that all solid is subjected to the shearing deformation of flow.

Some powders discharge at very low rates unless they are aerated. When they are fed from a bin into a pneumatic conveying line they can be fluidized in the hopper. However, when fluidization for conveying or process is not required, permeation of smaller quantities of air (gas) can assure the required flow rate without fluidization thus saving compressed air and subsequent air filtration and evacuation.

The same powders which at times flow at an insufficient rate may flush out uncontrollably at other times. This may be caused either by the lack of mass flow or by an excess of air entrained during the charging of the powder into the bin. The latter occurs when the powder is deposited in the bin rapidly in a concentrated, fluidized stream. Spreading the stream over the top surface radically reduces the amount of entrained air and increases the bulk density of the solid.

The temperature of a stored solid and, especially, temperature changes during storage at rest drastically affect the flow properties of some solids. The surface of particles may undergo changes due to the change of temperature alone or in combination with moisture migration. Such changes may lead to the development of bonds between adjacent particles and an increased tendency to obstruct flow.

Vibration used as promotion of flow is useful to start flow after extended storage at rest and may effectively reduce friction between a solid and the hopper walls thus promoting flow. However, applied indiscriminately to solids which gain strength rapidly with pressure (moist filter cake), vibration aggravates obstructions and hinders flow. When applied to nonmass-flow bins, vibration tends to increase the strength of the solid in the stagnant regions of the bins and may lead to a severe reduction in live capacity.

At this time it may be appropriate to list the problems that arise in the flow of bulk solids from bins, silos and stockpiles, to define the terms and concepts and to outline the principles of design of the hopper-feeder unit which - when not followed - cause most solids to be difficult.

Problems

1. No flow: solid arches over the outlet or ratholes, i.e. forms a stable empty pipe above the outlet.

2. Erratic flow: an arch or a rathole forms, collapses, then reforms.

3. Rathole flushing: a solid, charged into a stable empty rathole, falls right through the bin overflowing the feeder. When the solid is a powder, it fluidizes and flushes out.

4. The specified flow rate is not maintained. Up to a certain rate,

flow is well controlled. When the feeder is speeded further toward the specified rate, the flow rate does not increase proportionately but becomes erratic. Stoppages of flow followed by flushing occur in the case of powders.

5. Segregation: a solid containing a range of particle sizes segregates as it forms a pile during charging into a bin or onto a stockpile. The fines collect along the trajectory, the coarse particles roll toward the perimeter (Jenike 1961,1964, Johanson 1978).

6. Degradation: in nonmass-flow bins, solids may remain at rest for long periods of time leading to degradation or fires, in the case of coal.

Terms and Concepts

Hopper refers to the converging part of a bin.

Fully-effective outlet of a hopper obtains when there are no ledges in the lower part of the hopper and the flow control device - be it a gate, a valve, a feeder or a discharger - permits simultaneous solid flow through the whole area of the outlet.

Mass flow describes a type of flow in which all the solid in a bin flows whenever any of it is withdrawn. For mass flow to occur, the hopper must be sufficiently steep and smooth and the outlet must be fully effective. Typical mass-flow bins are shown in Fig. 1.

Mass-flow bins have certain advantages. Flow is uniform and the feed density is practically independent of the head of solid in the bin (Jenike & Carson 1975). This frequently permits the use of volumetric feeders for feed control. Low level indicators work reliably. In addition, segregation is minimized because, while a solid may segregate at the point of charge into the bin, the first-in-first-out flow sequence enforces the same particle distribution to exit the hopper as was charged into the bin. The flow sequence also ensures uniform residence and deaeration of a fine powder. Hence, air locks, often used with powders, can be dispensed with provided critical inflow and outflow rates are not exceeded.

Inflowing valleys, like those in the pyramidal hopper in Fig. 3, are not permitted, neither are ledges nor protrusions into the hopper, such as ladders or level indicators.

Mass-flow bins are recommended for cohesive solids, for solids which degrade with time, for powders and when segregation needs to be minimized. Mass-flow bins of special design are used for in-bin blending by circulation of the stored solid (Johanson 1970).

Johanson recently obtained a patent (U.S. 4286883) on a blending bin, Fig. 2, in which an insert is placed inside the hopper to provide mass flow through the central channel and through the annular space between the insert and the outside hopper wall. The concept has found its greatest use in eliminating segregation and ratholing problems in funnel flow bins, saving headroom for new designs, and creating mass flow in bins that were initially not mass flow.

By adjusting the relationship of the cones with respect to each other and the bottom outlet configuration the bin insert can be used to create either a perfectly uniform flow pattern or rapid velocity gradient across the bin. The latter is useful in blending the solid as it discharges from the hopper or as it is recirculated through the hopper. The advantage of this form of blending over the more typical tube-type

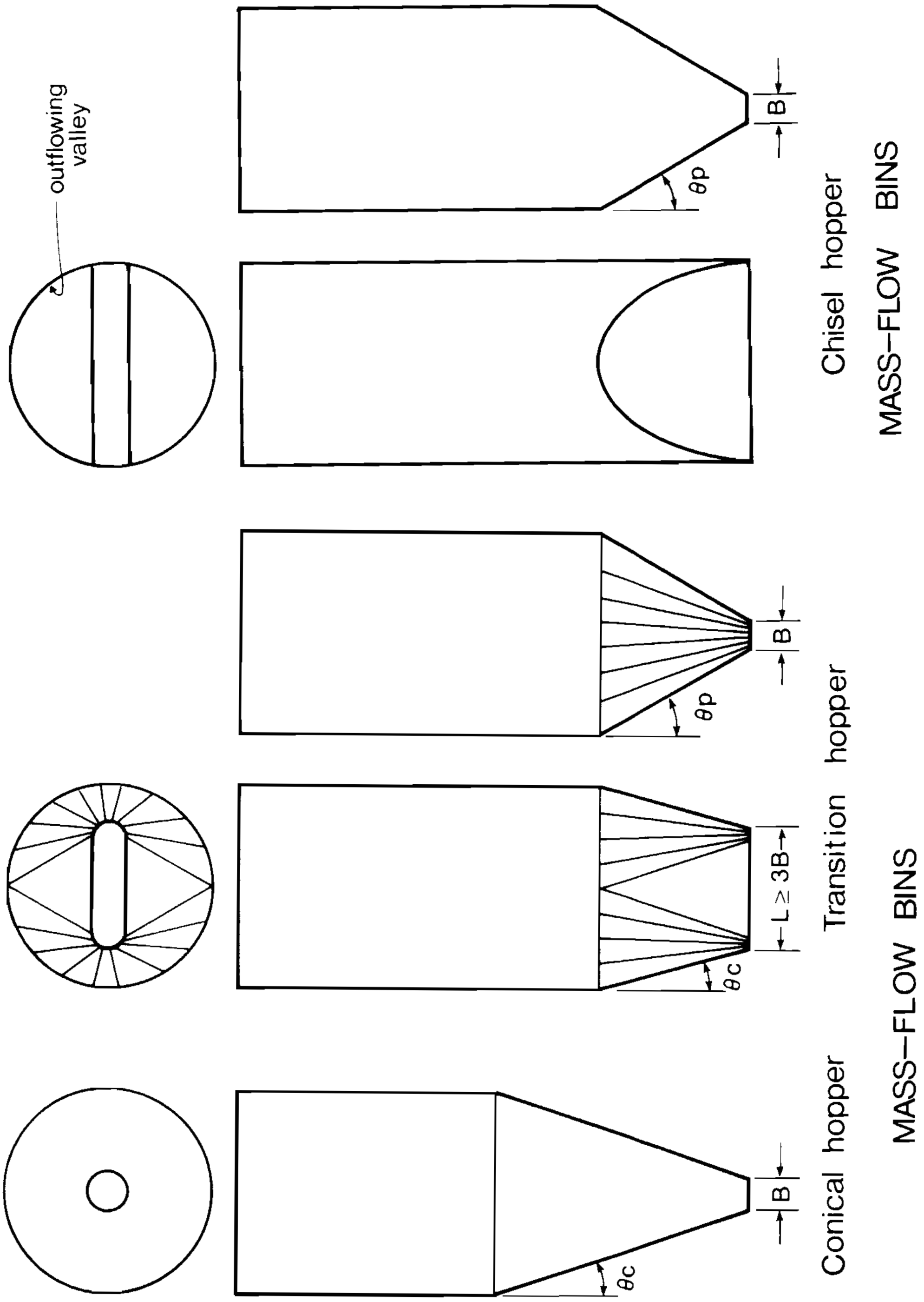

Conical hopper
θc
B
MASS–FLOW BINS
Transition hopper
θc
L ≥ 3B
θp
B
Chisel hopper
outflowing valley
θp
B
MASS–FLOW BINS

FIGURE 1

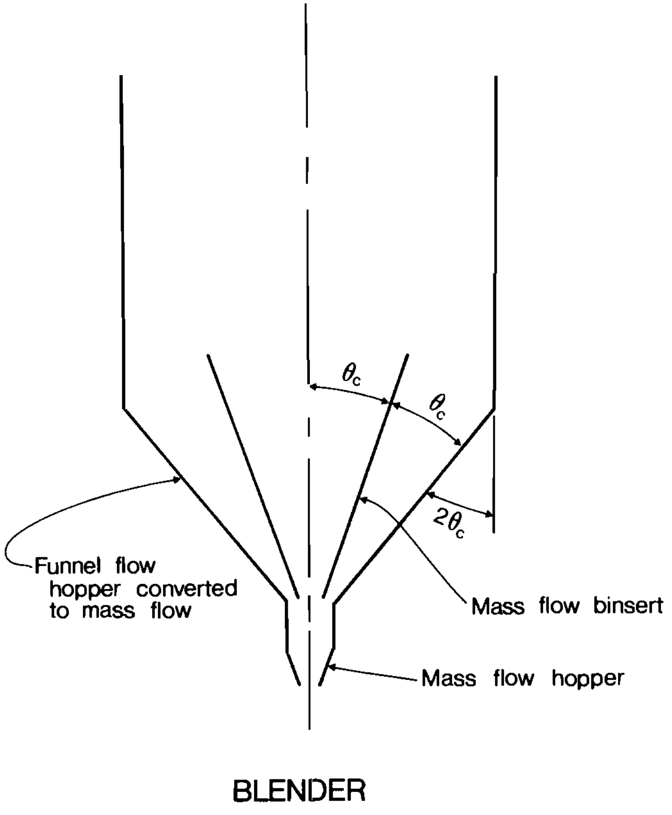


FIGURE 2

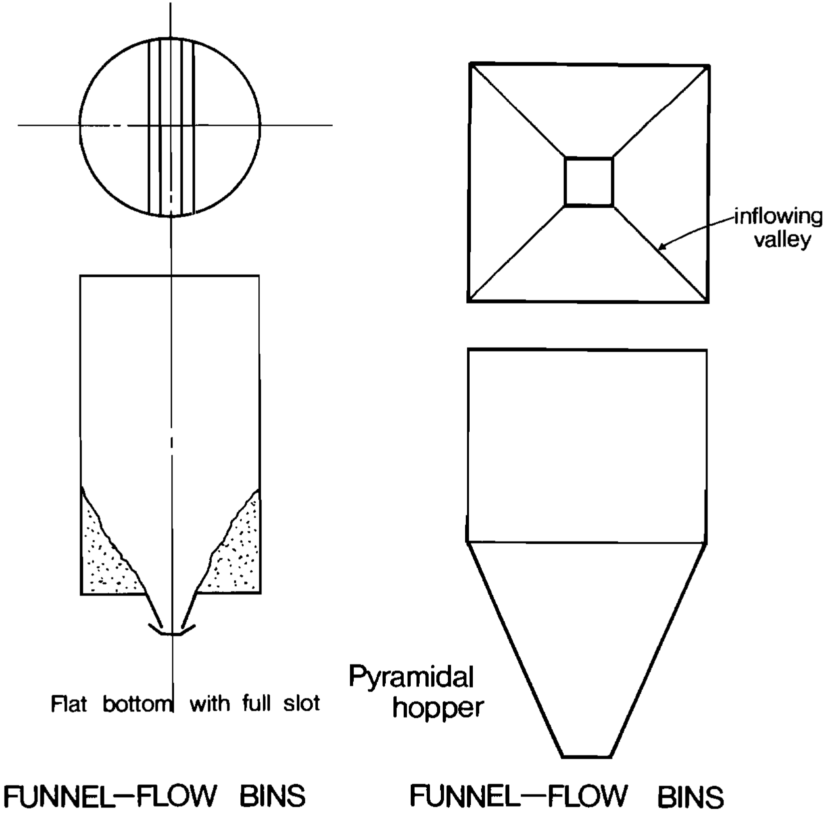


FIGURE 3

blenders for large batches of solid is that the bin insert can be designed to handle sticky as well as free-flowing solids.

Funnel flow occurs when the hopper walls are not sufficiently steep and smooth to force solid to slide along the walls or when the outlet of a mass-flow hopper is not fully effective. Examples of funnel-flow bins are shown in Fig. 3. In a funnel-flow bin, the solid flows toward the outlet through a channel that forms within stagnant solid. With a non-freeflowing solid, the channel expands upward from the outlet to a diameter that approximates the largest dimension of the effective outlet. When the outlet is fully effective, this dimension is the diameter of the outlet, if it is circular, or the diagonal, if the outlet is square or rectangular.

When the bin discharge rate is greater than the charge rate, the level of solid within the channel drops causing layers to slough off the top of the stagnant mass and fall into the channel. This spasmodic behavior is detrimental with cohesive solids because the falling solid packs on impact thereby increasing the chance of arching. With sufficient cohesion, sloughing may cease completely, producing an empty rathole. Solid charged into a rathole may overflow the feeder.

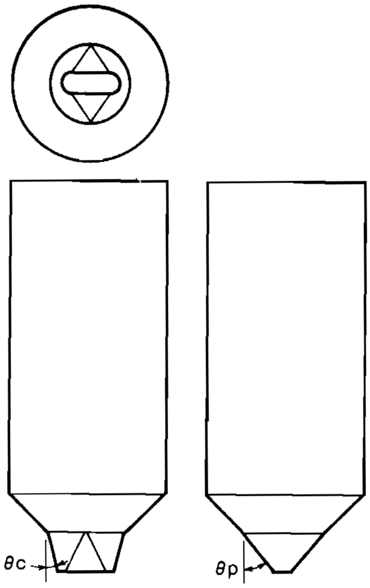
Funnel-flow bins are suitable for coarse, freeflowing or slightly cohesive, nondegrading solids when segregation is unimportant.

Expanded flow refers to a bin in which only the bottom part operates in mass flow, Fig. 4. The mass-flow hopper should expand the flow channel to a diameter or diagonal sufficient to prevent the development of stable ratholes. These designs are used for large bins and for stockpiles. The design is also useful as a modification of existing funnel-flow bins to correct erratic flow caused by arching, ratholing or flushing.

Flow criterion. Problems 1, 2 and 3 are evidently caused by an excessive strength of the solid. For these problems not to occur, the flow criterion, "a solid will flow provided the strength generated in the solid during storage is - at all levels of the bin - less than the stress in a potential obstruction to flow" (Jenike 1961, Jenike & Leser 1963, Johanson 1964, Jenike 1964), must be satisfied.

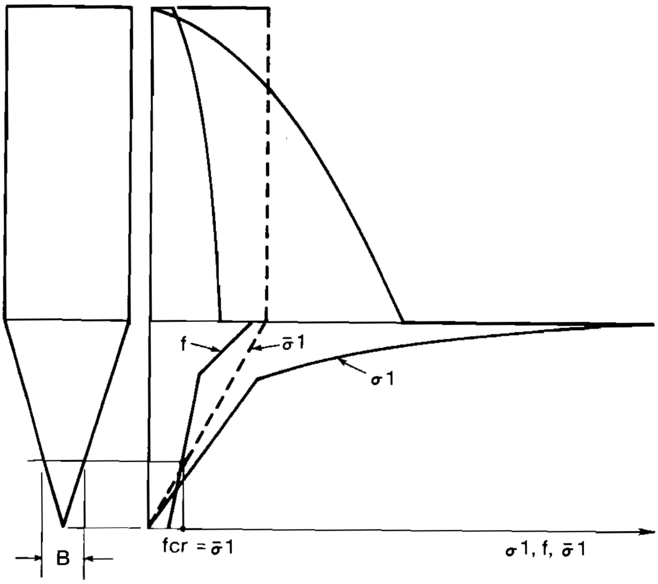
The application of the flow critrion leads to the determination of the minimum hopper outlet dimension required to assure flow. The procedure is illustrated in Fig. 5. The strength of a solid is generated by solids contact pressure, σ_1, which acts within the solid while it is flowing or resting in a bin. A likely distribution of this pressure is shown in the figure. σ_1 increases down from the top, reaches a maximum just below the transition from cylinder to hopper and decreases in the hopper toward zero at the vertex. In the lower part of the hopper, this pressure can be assumed decreasing along a straight line of slope independent of the head of solid in the bin (Jenike 1954, Johanson 1964, Hadley & Perry 1967/1968) Under the action of the consolidating pressure the solid gains strength, measured by the unconfined compressive strength, f.

The stress $\bar{\sigma}_1$ which is needed to support an obstruction to flow, such as an arch across a hopper (Jenike & Leser 1963), is also shown in Fig. 5 with a dashed line. For a given hopper, $\bar{\sigma}_1$ increases with the span of the arch from zero at the vertex. The flow criterion leads to the conclusion that flow will occur provided the outlet dimension is greater than B, defined by the intersection $f = f_{cr} = \bar{\sigma}_1$. For larger outlets, $f < \bar{\sigma}_1$, the criterion is satisfied.



EXPANDED FLOW BIN

FIGURE 4



FLOW CRITERION

FIGURE 5

Flowfunction of a solid. The relation $f(\sigma_1)$ is obtained from bench tests run on a sample of the solid (Jenike et all 1960, Jenike 1964, Johanson 1978). This relation is called the flowfunction of a solid, FF, and is indicated in Fig. 6 with a continuous line. Evidently, the higher this line lies, the stronger and less flowable is the solid.

Flowfactor of a hopper. In the region of the outlet, σ_1 and $\bar{\sigma}_1$, both increase linearly with the width or diameter of the hopper. Therefore relation $\bar{\sigma}_1(\sigma_1)$ plots as the straight dashed line, ff, through the origin in Fig. 6, if $\bar{\sigma}_1$ is measured alongside axis f.

Line ff = $\sigma_1/\bar{\sigma}_1$ provides a measure of the flowability of a hopper and is referred to as the flowfactor of a hopper. The intersection of the hopper flowfactor, ff, with the solid flowfunction, FF, determines the critical value, fcr, from which the minimum outlet dimension of the hopper is computed, usually directly from Fig. 6, without reference to Fig. 5 which only serves here as an explanation of the procedure.

The higher the location of line, ff, the more flowable the bin. ff is not constant within a bin but varies with elevation. Since arches tend to form most readily in the region of the outlet, the flowfactor, ff, in that region assumes the greatest importance.

Values of that flowfactor have been published in reference (Jenike 1964). Examples of the published charts are given in Figures 7 and 8, for mass flow conical and transition (wedge, chisel) hoppers, respectively. These examples are for an effective angle of internal friction of a solid, δ = 50 deg. The flowfactors are a function of that angle, the shape of the horizontal cross section of the outlet, as well as of the hopper slope angle θ_c, or θ_p, Fig. 1, and the friction angle between the solid and the wall, ϕ'. For funnel flow the arching flowfactor is taken at 1.7.

In transition hoppers, Fig. 1, the slot end-slopes are taken from Fig. 7 and the slot side-slopes from Fig. 8. The recommended bounds on the slopes for mass flow are shown in Fig. 9 as a function of the wall friction angle ϕ' for δ = 50 deg.

The minimum outlet dimension, B, of a hopper is calculated from the following formulas:

$$B=[2.0+0.015\times\theta_c(\text{deg})]\times f_{cr}/\gamma \qquad (1)$$

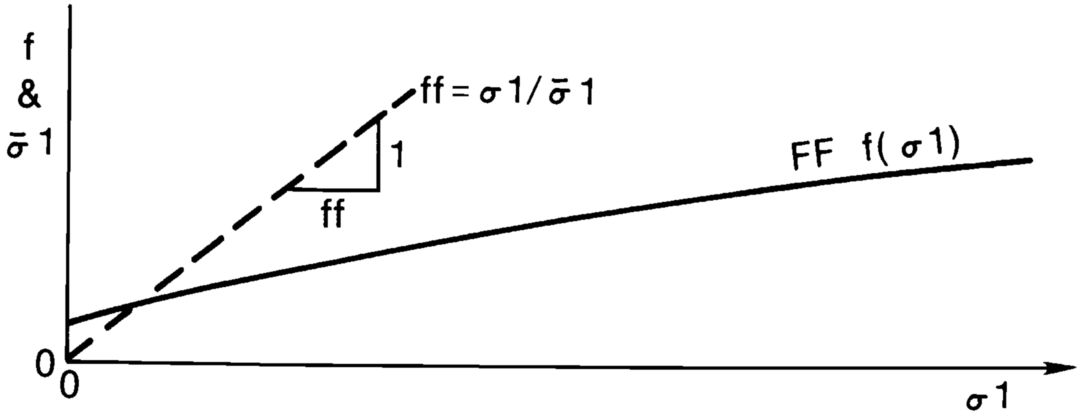
for conical hoppers, and

$$B=[1.0+0.005\times\theta_p(\text{deg})]\times f_{cr}/\gamma \qquad (2)$$

for transition, wedge and chisel hoppers. γ is the bulk unit weight of the solid.

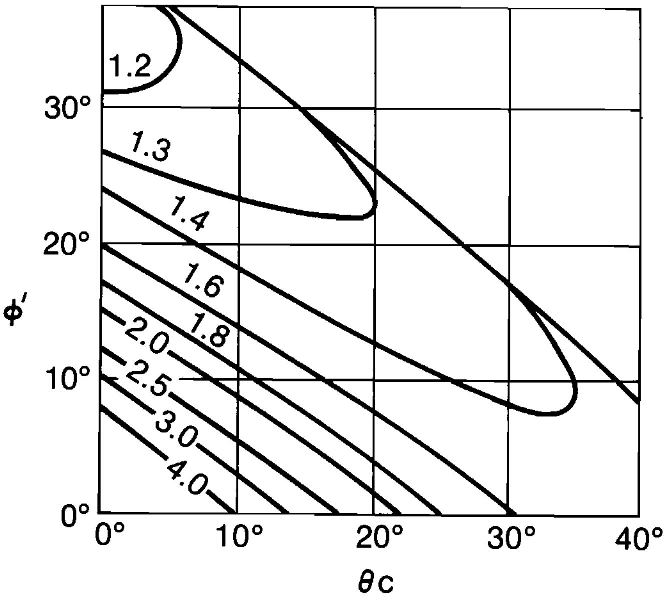
It will be observed that the outlet diameter of a conical hopper, eq. (1), is approximately twice as large as the width of a slot outlet, eq. (2). Square outlets and rectangular outlets of length to width ratio less than 2.5 should be used only for freeflowing solids. In those cases, the minimum outlet size is determined by the largest particle size and the outflow rate, and the above formulas do not apply. The critical rathole diameter in funnel flow is similarly determined by Jenike (1964) and by Johanson (1969). The largest dimension of a funnel-flow outlet must exceed this diameter.

Pore gas pressure gradients. Flow Problem 4 is of a different nature. It is caused by pore gas pressure gradients which arise in a flowing solid as it first densifies and then



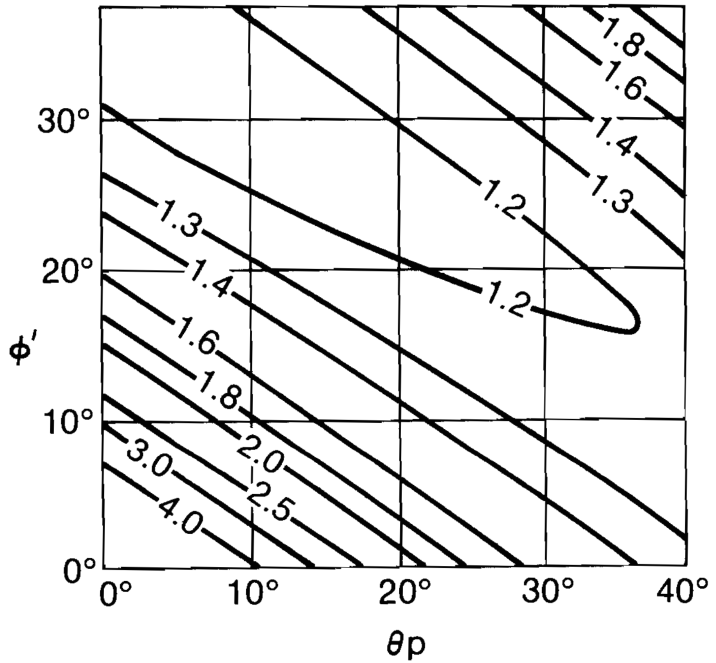
FLOW FACTOR ff and
FLOW FUNCTION FF

FIGURE 6



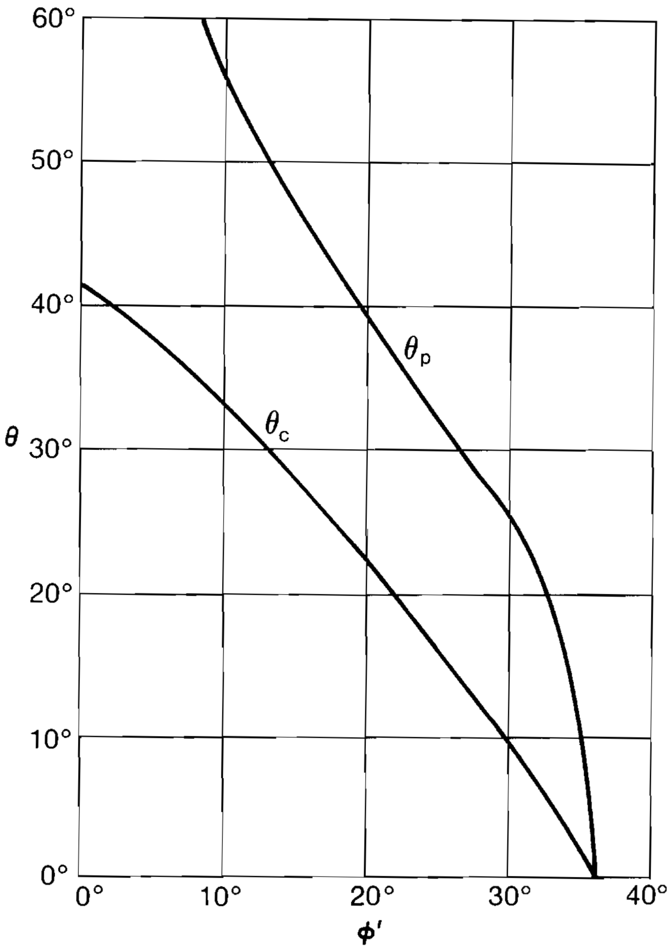
Flow factor for two-dimensional convergence

FIGURE 7



Flow factor for plane convergence

FIGURE 8



Bounds on angles θ_c and θ_p

FIGURE 9

dilates during flow (Bruff & Jenike 1967/1968, Reed & Johanson 1973, Johanson 1979).

TYPES OF SOLIDS

Easy Flowing Solids

Solids containing only large, hard, chemically stable particles are free flowing. Clean gravel is a perfect example. A funnel-flow bin with a pyramidal hopper with valleys just steep enough for the gravel to slide down is sufficient. There are not many solids like gravel. Most solids contain some fines. In a funnel-flow bin which is infrequently emptied out completely the fines tend to collect in the void spaces of the stagnant regions and may give solid in those regions enough strength to support a rathole. An average fines content of even a few percent may be sufficient to cause obstructions over a period of time. Small hoppers can be cleaned out with external vibrators. In large bins, serious obstructions may develop. With coal, this may lead to fires.

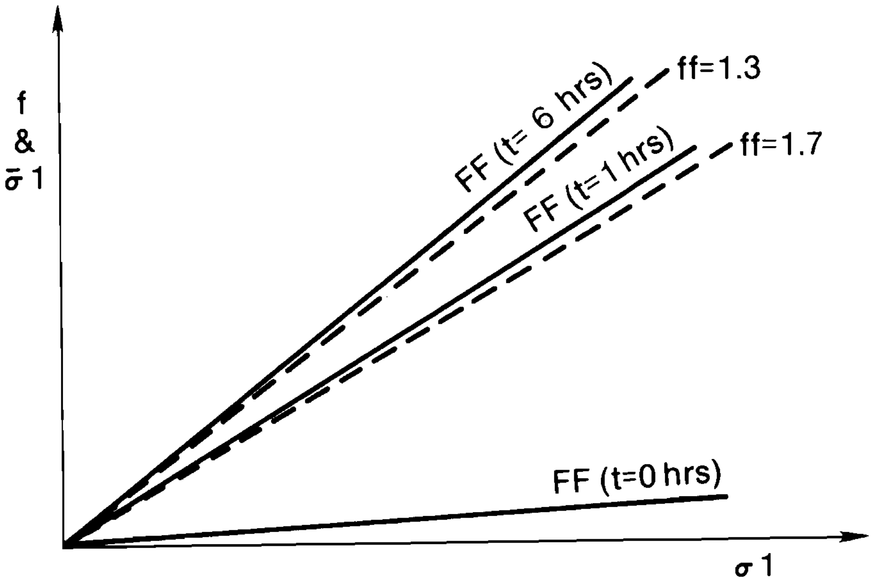
A prediction of the possible difficultes can be made on the basis of flowability tests of the fine fraction (-2 mm). The largest dimension of the outlet plays a decisive role. A long slot outlet, especially one extending the full width or diameter of the bin, assures a large live volume even in a flat bottom bin, Fig. 2. This is so because a stable rathole assumes a diameter equal to the largest dimension of the effective outlet. With a full slot, this amounts to the bin diameter; hence there is no ratholing. However, the feeder must draw along the full length of the slot.

Caking Solids.

These solids are usually freeflowing so long as they are not left to compact in storage at rest beyond a critical time period. That period may be minutes, hours or days. If left longer at rest under pressure, these solids cake into a firm mass. However, when the mass is broken up, they again become freeflowing.

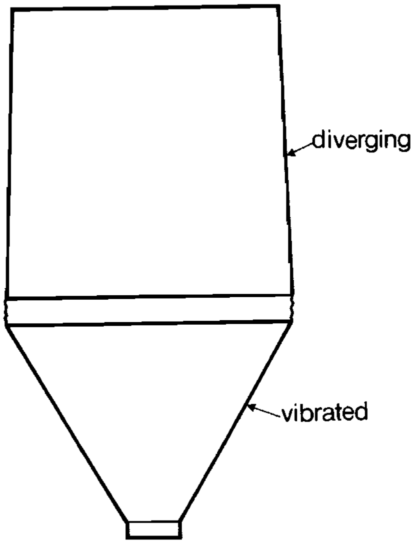
Kernite ore provides an extreme example. For the tested kernite ore $\delta = 50$ deg. The funnel-flow flowfactor is ff(f) = 1.7 and the mass-flow flowfactor, ff(m) = 1.3. The flowfunction of the ore at a temperature of 25 deg. varies with the time of storage at rest as shown in Fig. 10. The ore gains strength rapidly, as indicated by the flowfunctions which rise with the time of storage at rest. In a funnel-flow bin, arching would occur within a very short period of time. In a mass-flow bin, the ore arches after about 6 hours. This means that every 6 hours the ore has to be circulated around the silo to destroy the rising strength and ensure flowability. This is not very practical. A vibrated hopper is therefore used to break up the caked mass, Fig. 11. The fact that the time flowfunction increases linearly and lies well above the flowfactor, indicates a capability of the solid to arch across any cylinder diameter. The cylinder is therefore replaced by a slightly diverging, truncated cone. The truncated cone must have a smooth surface to which the solid will not adhere. (Adhesion tests should be run before specifying the material of construction of the truncated cone.) This causes the weight of the whole stored solid to rest on the vibrated hopper which must be capable of operating under these severe conditions. It therefore limits the height of the truncated cone and hence the capacity of the storage bin.

In a less severe case, a large mass-flow silo with periodic circulation can be used. An example



Flow—functions of kernite ore

FIGURE 10



Bin with vibrated hopper

FIGURE 11

is shown in Fig. 12 for a wall friction angle $\phi' = 20$ deg. The principle of design here is to avoid inflowing valleys. An inflowing valley occurs when two sloping surfaces meet at a sharp angle as in a pyramid, Fig. 2. An example of an outflowing valley - which is acceptable - is provided by the chisel hopper, Fig. 1. The hopper with a slot outlet which causes plane convergence is distinctly more economical in terms of height than a conical hopper with a circular outlet which requires axisymmetric convergence. In this case, the angle for a chisel hopper is $\theta p = 40$ deg., while for the cone the slope angle $\theta c = 21$ deg., Fig. 9. In a large silo, a multiple hopper is used to stay within a reasonable silo height and feeder length. A 12 meter diameter silo with two slot outlets is shown in the figure. A cone reduces the diameter to 10 meters, then a circular cylinder with four flat surfaces to a 7071 mm square. A wedge converges the square to a rectangle 7071 mm by 4000 mm diameter. This permits the use of 500 mm screws. Three hoppers feed screw feeders of the type shown in Fig. 16 through 4000 mm by 500 mm slots. All the hopper surfaces are flat - there are no inflowing valleys.

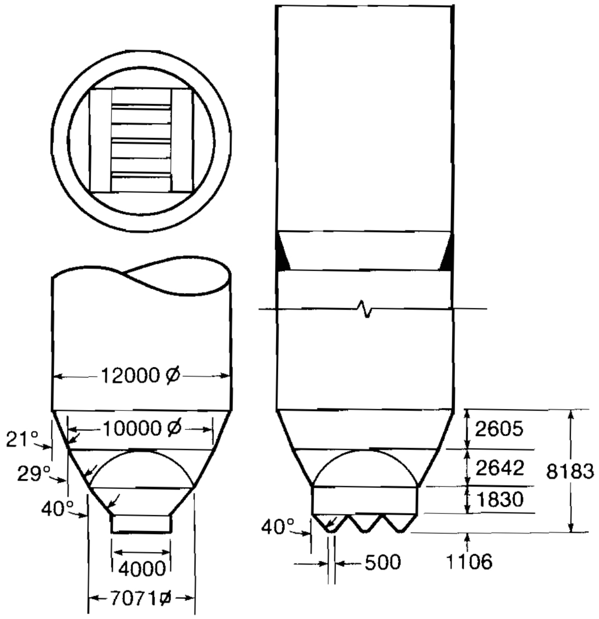
An alternative approach to this class of solids is to use air cannons. The rapid introduction of high pressure air has been used successfully to initiate and to restore the flow of coal and ore under freezing, winter conditions (Moavani & Carson 1980). However, there is a danger of structural failure if large voids are allowed to develop.

A note on silo loads. In a centrally charged, circular bin with a conical hopper and a small, fully effective, centrally located outlet, the loads on the walls are axisymmetric. In mass flow, the bin is subject to a primary overpressure just below the transition from the cylinder to the cone (Jenike 1980). This overpressure projects an overpressure wave upward into the cylinder and downward into the hopper. Only the first upward projection at a height of one half to one diameter is significant. In funnel flow the elevation of the effective transition at which the channel expanding upward from the outlet reaches the wall is uncertain and varies with the solid and with time.

If flow in the cylinder is uniform (plug flow), solid within the cylinder is not in a limiting (plastic) state of stress and overpressure causes only an increased hoop tension and some vertical bending moments. In this condition, the solid resists lateral deformation and stabilizes the walls.

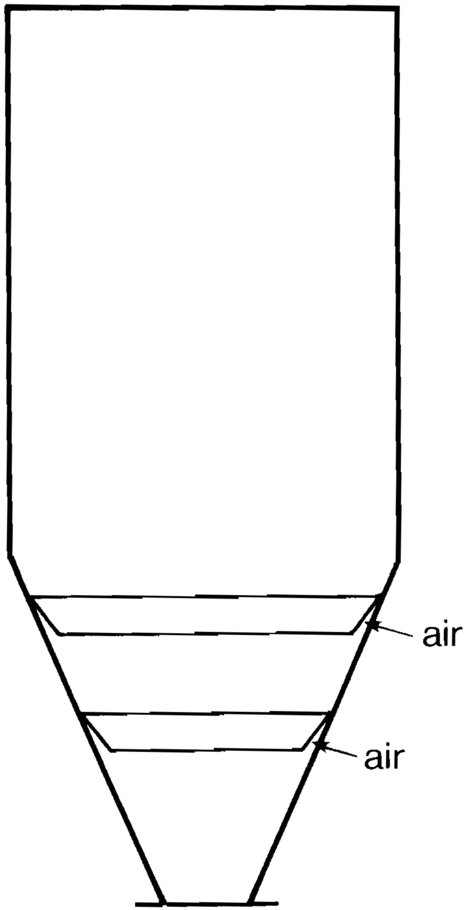
In circular bins of other hopper configurations and in bins with multiple outlets, asymmetric loads on the walls cannot be avoided. Design and operation can only aim at minimizing the asymmetry. If, due to nonuniform withdrawal, a faster flowing channel develops within a slowly moving or stagnant mass, the pressures within the channel are lower than the pressures within the slowly moving or stagnant solid. In addition, solid within the channel is invariably in a limiting state of stress. When the channel borders with the silo wall wall, an underpressure acts on the wall and horizontal bending moments arise within the wall. This causes inward bending of the part of the wall facing the channel. The solid in the channel, being in a limiting state of stress, conforms to the deforming shape of the wall with little resistance thus allowing large deformations of the wall. This is a frequent mechanism of silo failure.

In order to minimize this effect, it is advisable to have an initial cylinder-cone transition, as shown in Fig. 12. In multiple outlet bins, it is recommended that all the feeders be always operated simultaneously with



Bin for caking solids

FIGURE 12



Bin with air permeation

FIGURE 13

the possible exception of a centrally located feeder which can be operated alone. However, the latter usually draws the fine fraction of the stored solid first thus contributing to size segregation.

Materials which, like kernite ore, are characterized by almost straight flowfunctions which keep rising with increasing consolidating pressure, pause the additional danger of stable arches in the upper part of the hopper and at the transition where the high pressures occur. The stability of these dangerous arches can be analyzed by one of the methods desribed in references (Jenike 1980, Enstad 1981). When necessary to reduce those pressures, it is recommended that the cylinder of the silo be built with ledges, as shown in Fig. 12. The ledges should be spaced at one diameter intervals and should be designed to support the full weight of the solid within the interval.

Sticky Solids

These are solids which readily compact into a snowball. They contain fines and their instantaneous strength is due primarily to surface liquid. The instantaneous flowfunction, FF, is often close to the critical flowfactor, ff. There is usually little gain of strength with time of storage at rest so long as there are no extraneous vibrations, and so long as liquid is not allowed to evaporate during storage. Vibratory dischargers should not be used with sticky solids because any pressure in excess of static will instantly cause further densification and an increase in the strength of the solid. If surface liquid evaporates, the particles may cement so strongly that they can be loosened only by mining methods.

Assuming the latter are not allowed to occur, $FF_t \simeq FF$. A mass-flow bin, with a well designed feeder, without any internal protrusions or ledges is imperative for a solid of this type.

Nonflowing Solids

Some solids will not flow by gravity and should not be stored in bins. These solids are characterized by an instantaneous flowfunction, FF, which lies above the corresponding flowfactor over the whole range of applicable pressures σ_1. Lateral confinement of such solids invariably leads to stable build-up against the walls and arching across the bin.

Powders

In addition to the above described considerations, bins for powders need also be designed for the required flow rate without flushing. Since no method of this type of design has been published, the usual approach is to aerate the stored solid as required to obtain the desired flow rate and to control flushing with a rotary valve.

At low feed rates of a freeflowing powder, little aeration is required and this solution is adequate. At higher rates, the rotary valve fails as a feeder; flow is irregular, the gas content of the solid varies widely as does its bulk density. Close feed rate control is not possible. With non-freeflowing, cohesive powders it is difficult to distribute injected air uniformly and flow is uncertain. Whether feeding into process or into a pneumatic conveyor, the erratic flow rate is a drawback, especially in dense phase conveying.

Powder outflow is affected by: the rate of charge into the bin - including intervals of no charge, the level of powder in the bin, the sequence of charge and withdrawal, and the amount of air and method of injection into the bin. All these factors may change from day to day. A bin which flushes uncontrollably on Monday, may feed well on Tuesday and erratically, at an insufficient rate, on Wednesday.

While no quantitative method of design is proposed here, the following suggestions are offered. A well designed screw or belt feeder is better than a rotary valve which tends to pump air upward into the hopper as it feeds solid out. However, these feeders do not provide a positive seal and, therefore, flushing must be prevented. Since some flushing may occur when powder is charged into an empty bin, it is advisable to have a shutoff gate. Such a gate can be readily located above or below a screw or vane feeder. Shutting off is less certain with a belt feeder which is therefore more suitable when a minimum level of powder can be maintained in the bin at all time.

The bin in Fig. 13 permits permeation of air into the flowing powder to increase its outflow rate. Air is introduced under the two conical ledges (Reed & Johanson, 1973, U.S. Patent 3797707), assuring distribution throughout the flowing solid. As a rule, quite small quantities of air are used, e.g. from a few to 100 liters per minute (Bruff & Jenike 1967). The specification of the number and location of the ledges, as well as of the pressure and air inflow rate under each ledge is important. An excessive air inflow leads to the development of voids above the ledges and results in flushing. Air permeation is usually maintained without interruption whether the solid flows or not.

At times, powder charged into a bin entrains too much air resulting in periodic, uncontrollable flushing. This occurs particularly when the powder is very fine, the charge rate into the bin is high and the charged powder is highly aerated. Such a powder behaves much like a fluid and, when charged in a narrow concentrated stream, the falling powder tends to bury itself under an essentially static, firm surface, Fig. 14. As a result, a large part of the inflowing air is entrained into the bin. This condition can be improved by spreading the falling stream over a larger area of the top surface, Fig. 15.

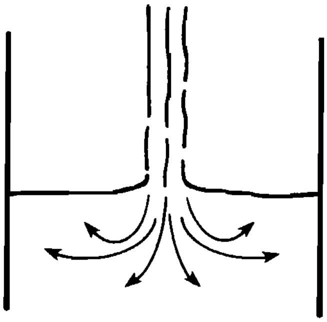
EQUIPMENT AND LAYOUT

Feeders

It is of utmost importance that the outlet of a hopper be fully live, i.e. that the feeder permit the solid to flow through the whole area of the outlet. This requires the feeder to have a uniformly increasing flow rate in the direction of flow within the feeder.

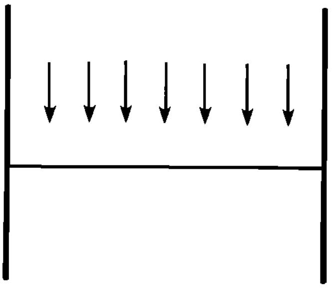
Screw, Fig. 16. The screw is made in three sections: L1 is of constant pitch equal to one half the screw diameter, built on a truncated cone. L2 is of a pitch continuously increasing from one-half to full screw diameter. This part ends one screw diameter beyond the hopper outlet. These two parts are of equal length. L3, the conveying part of the screw, is of constant pitch equal to the screw diameter. For satisfactory operation of such a screw, the ratio of length to diameter of the part of the screw within the hopper outlet should not exceed eight. No hanger bearings are allowed. The enclosure should be either a pipe or a trough with a shroud at the entry to the conveying section.

As an example, the 500 mm diameter screws for the bin shown in Fig. 12, would have L1 = L2 = 2250 mm. The vertical running load on a screw for a solid of 1.0 density is estimated at 400 kg. The load is small because the weight of the stored solid is taken up



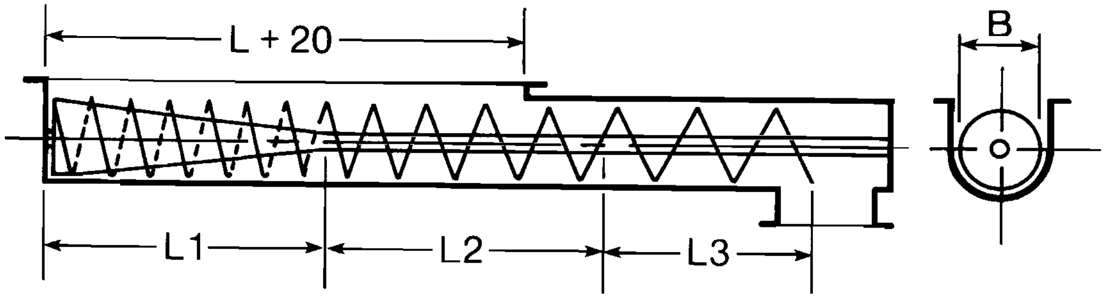
Concentrated stream

FIGURE 14



Distributed stream

FIGURE 15



Screw feeder

FIGURE 16

by the converging hopper walls. For a feed rate of 100 tons per hour per screw of this material, the horsepower per screw is calculated at 7.5, for a total of 22.5 HP for the silo. During normal operation, these screws will consume less than 50% of the specified horsepower.

Belt, Fig. 17. Uniform outflow along the slot outlet is obtained by the tapered gap, g, and the concurrent increase in slot width. The narrow end of the slot should be not less than the critical width B computed for flow. This produces a cross section of flowing bed on the belt increasing in the direction of flow thus assuring a live outlet. The function of the outer, sealing skirts is to contain the solid falling through an empty bin from splashing off the belt. The skirts should not restrict the outflowing solid. The belt can be inclined upward or downward if the layout requires it.

Long vane, Fig. 18. This vane feeder does not attempt to seal against a gas pressure differential, it just controls the rate of outflow. Therefore, close tollerances are not required. The feeder provides very uniform feed along the slot. The asymmetric inflow into the feeder compensates for the fact that the vanes tend to fill as they enter the slot, thus favoring one side of the slot. A parallel screw conveyor conveys away the outflowing solid. When uniform filling of the screw is required, the vane should have a spiral shape.

Rotary plough feeder. This feeder does not limit the length of the slot. When used in a bin and in order not to expose the bin walls to excessive off-center loads the plough should not be allowed to operate in a stationary position close to the extreme points of travel.

Dischargers

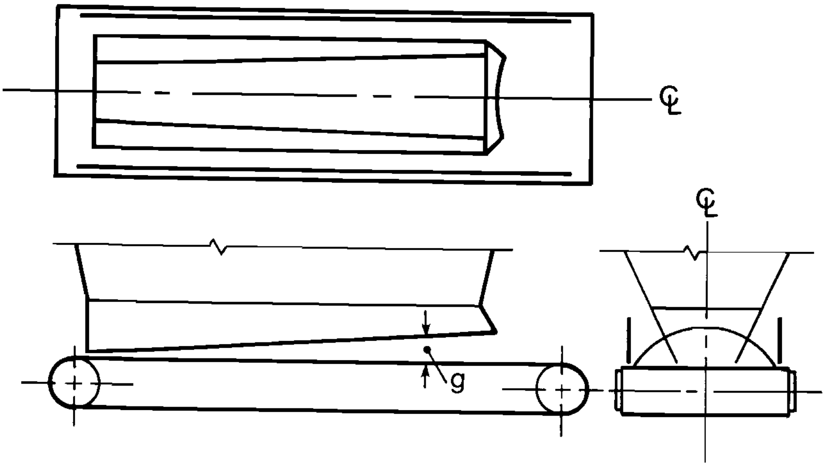
In contrast to feeders, dischargers are mechanisms which control outflow from hoppers without positively setting the flow rate. When flow rate control is required, a discharger is followed by a screw or belt feeder, at times with gravimetric flow rate measurement.

Rectangular vibrating pan. The principle of design described for the belt feeder applies to this vibrating pan discharger with the difference that the pan is generally inclined downward in the direction of flow of the solid to promote flow.

Circular vibrating pan. Ever since the introduction of the Bin Activator, this neat device has found wide application. Its main advantages are that it fully encloses the flowing solid and requires little headroom.

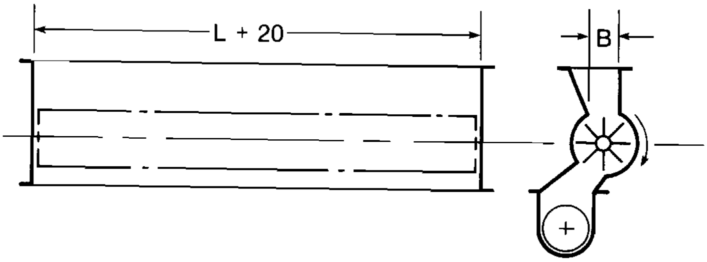
Stockpile layout.

While travelling rotary plough feeders can accommodate a stockpile of any length, they have the disadvantage of withdrawing the solid along lines parallel to the line of the charging conveyor. As a result, this layout has no inherent remixing mechanism and size segregation is significant. Such a mechanism exists when reclaiming from a stockpile by means of a series of belt feeders running across the pile to a collecting conveyor, Fig. 19. Each feeder collects a cut across the pile thus remixing the segregated solid.



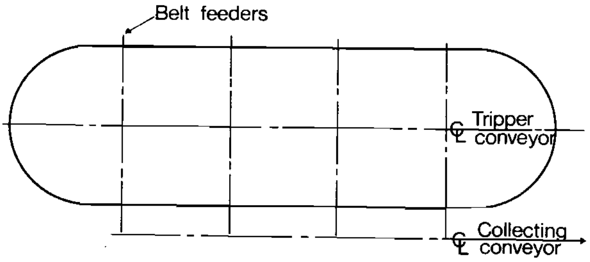
Belt feeder

FIGURE 17



Long vane feeder

FIGURE 18



STOCKPILE

FIGURE 19

SYMBOLS

B = width of slot outlet, diameter of circular outlet (m)

f = unconfined compressive strength of a solid (Pa)

fcr = critical value of unconfined compressive strength of a solid (Pa).

ff = flowfactor of a hopper

FF = instantaneous flowfunction of a solid

FFt = time flowfunction of a solid

g = gap between the skirts and belt of a belt feeder (m)

L = length of a slot outlet (m)

γ = bulk unit weight of solid (N/m^3)

δ = effective internal angle of friction of a solid (deg)

θc = slope angle of a conical hopper and end slope angle of a transition hopper, measured from the vertical (deg)

θp = side slope angle of a transition, wedge or chisel hopper, measured from the vertical (deg)

$\sigma 1$ = major solid contact pressure during flow in a bin (Pa)

$\bar{\sigma} 1$ = major solid contact pressure in a potential obstruction to flow (Pa)

ϕ' = angle of friction between solid and wall (deg)

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