CHAPTER 5.1

Solids Storage

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In processing of minerals and other bulk materials, such as grains, salts, wood chips, cornmeal, rice, and so forth, material storage is generally needed at points along the flow stream or at the flow stream's termination. A large storage capacity may be required where feed delivery or product shipment is difficult to schedule; or, depending on the plant's production, the design flow rate is hampered because of unexpected equipment failure(s); or either scheduled or required maintenance must be performed on an as-needed basis. Sufficient storage capacity is generally required to meet the processing plant's requirements for sales, contracts, shipments, whether it is a new processing plant and/or an upgrade to an existing processing plant.

Large-tonnage shipments for overseas export, trade, or with unit trains require both adequate storage and properly sized materials handling equipment for loading and reclaiming material, and appropriate storage facilities to suit the materials being stockpiled or stored.

Within a process plant, storage capacity is required to accommodate differences in production capacity or reliability of the process units and when the various production units need to be taken off-line. The processing plant's designed requirements generally determine the plant's storage surge capacity to sufficiently provide for shutdowns required by emergency or scheduled maintenance. Where plant sections operate on different time schedules, storage capacity adequate for material differential is required. When required storage capacity is extremely large, ground storage stockpiles or multiple storage silos and/or storage domes or barns have proved to be an economic advantage.

The purpose of storage is to provide efficient storage capacity for (l) an adequate reserve of raw materials for the process plant; (2) an adequate raw materials reserve to enable a production rate different from the supply rate; (3) adequate supply reserves where these can be interrupted by shipping delays, weather, strikes, and so on; (4) blending of various grades, sizes, or types of materials; (5) reducing material surges at different process points; (6) collecting and distributing materials at different process points; (7) storing materials ahead of equipment shutdowns for temporary maintenance; (8) adequate buffering between batch and continuous process units; and (9) storing finished processed products/materials to satisfy market demands promptly and economically.

TYPES OF STORAGE

Storage types used in mineral and other bulk materials processing can be divided into open or covered stockpiles, silos, barns, hoppers, railroad cars, fabric tented structures, bins, bunkers, and underground caverns. Bulk materials are stored in ground-level stockpiles that may be exposed, covered, or indoors. They provide economical storage when requirements are large. Stockpiles vary in size and shape, such as conical, elongated, windrow, rectangular, triangular, and trapezoidal, with material placed and reclaimed by various methods and reclaiming equipment suitable for the material's stockpiled and stored characteristics. Bins vary in size from large, for run-of-mine (ROM) ore, to smaller vessels for process additives.

Depending upon process equipment, bins or hoppers vary in design, shape, and size, and are constructed of either masonry, concrete, wood, steel, abrasion-resistant (AR) steel, or synthetic materials. Hoppers are often located under stockpiles and bins to facilitate reclaiming.

The first step in storage facility design is to define storage purpose, capacity required (including surge capacity), and flow rates for stockpiling or storage and for reclaiming materials handling equipment appropriate for the materials to be reclaimed, stockpiled, or stored.

Bulk Materials Characteristics

The physical and chemical properties of the bulk material must be properly classified and described. Attention must be given

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Table 1 Data required for storage design

General Considerations Influencing Choice of Stockpiling and Storage:

1. Bulk material Conveyor Equipment Manufacturers Association (CEMA) Material Classification Code, pursuant to ANSI/CEMA Standard 550-R2009, *Classification and Definitions of Bulk Materials*, according to their individual characteristics (latest edition), and *Belt Conveyors for Bulk Materials* (CEMA 2014)
2. Chemical formulae (if any)
3. Purpose of stockpile or storage
4. Live storage required
5. Permissible dead storage
6. Inflow rate including design flow rate
7. Outflow/reclaim flow rate including design flow rate
8. Location and placement of storage
9. Space requirements
10. History of meteorological conditions/data
11. History of seismic activity
12. Soils report(s)
13. Topography
14. Material inflow velocity/trajectory

Bulk Material Characteristics Influencing Choice of Exposed or Protected Stockpiles and Storage:

1. Bulk density
2. Specific gravity
3. Porosity of particles
4. Surface and inherent moisture content (percentage)
5. Solubility in water
6. Consolidation/compacting tendency
7. Material contamination
8. Environmental contamination

Bulk Material Characteristics Influencing Choice of Equipment for Stockpiling and Storage of Reclaiming Materials:

1. Mohs hardness
2. Particle size distribution (pursuant to screen analysis test-work data)
3. Particle strength
4. Angle of repose
5. Ange of surcharge
6. Angle of drawdown and internal shear angle
7. Abrasiveness and roughness or smoothness
8. Particle shape
9. Percentage of particle fines and lumps
10. Tendency to pack (length of storage)
11. Material temperature
12. Corrosiveness
13. Hygroscopicity
14. Combustibility
15. Toxic fumes and dust
16. Oils or chemicals present? These may affect rubber; ultra-high molecular weight; high-density polyethylene, or HDPE, abrasion-resistant liners; and coating products
17. Floodability, flowability, and tendency to aerate
18. Tendency for interlock or matting
19. Very light and fluffy—material may be wind swept
20. Degradability affecting use or salability

to environmental factors if the materials are exposed. Table 1 presents data required for stockpiling and storage/reclaiming designs.

The CEMA Material Classification Code (CEMA 2014) for a given material provides a simple, standard manner to understand the handling characteristics of that material. Chapter 5.2, "Belt Conveyors," provides a detailed explanation and examples for the use of the CEMA Code. The Material Classification Code for a material is useful in the design of conveying, reclaiming, and materials handling equipment, as well as in the design of stockpiles, storage bins, silos, hoppers, chutes, and other storage vessels.

Characteristics Influencing Exposed or Protected Stockpiles and Storage

Light, fluffy materials that are low in bulk density are readily moved by wind, with resulting losses and nuisance to neighboring properties and plant operators, as well as incoming and outgoing delivery personnel. In such cases, protected storage is desirable. The material's bulking properties are affected by rain, snow, sleet, hail, wind, and climatic conditions. Specific gravity and particle size determine the extent to which wind transports the material. Wind erosion is a factor regardless of specific gravity with particles below 100 mesh such as power plant utility flue boiler dust, coal ash, carbon black, coke breeze (0.635 cm and under), diatomaceous earth, and grains (for ethanol fuel production).

Particles of high porosity pick up and retain moisture. In cold climates, particle freezing may result in degradation and material friability. Freezing of surface moisture binds particles together in a solid mass and makes reclaiming difficult, if not impossible, in cold climates. In such cases, protected storage is necessary. When control of moisture content is important, material should be protected from rain, snow, sleet, hail, and the drying effects of hot sun, ambient air temperature, and wind. In areas subject to blowing dust, protection should be provided to avoid the "drying" effect of dust fines to comply with all applicable environmental and occupational health regulations. Water-soluble materials must be protected. Where historical data show that rainfall occurrence is light, temporary covers may be adequate. The effect of humidity on such material should be considered. Cementing tendency due to long-term storage is closely related to the material's moisture absorption and solubility tendencies and requires similar protection, since it may affect reclaiming and/or discharging from silos, bins, or hoppers. Contamination or the degree to which a material may be diluted or spoiled by dust, with subsequent loss of market value, is a good economic measure for determining desirability of protected storage. Where contamination of the environment or neighboring products by dangerous or controlled material is at risk, protected storage is essential.

Characteristics Influencing Equipment for Stockpiling and Storage of Reclaiming Materials

Mohs particle hardness for a given bulk material provides an indication of the abrasive wear rate that will occur in bins, hoppers, silos, chutes, gates, and other materials handling equipment. Ranges of particle sizes provide an indication of the degree of segregation occurring in transport and drawdown storage. A wide range of particle sizes requires greater materials handling care. Particle strength is important in materials handling methods and materials handling equipment selections.

Material flowability influences stockpile design, storage type, and reclaim system design. The available live storage volume is a function of the material's angle of drawdown, which is generally different than the material's angle of repose. The flowability of materials, which is especially important in bin, silo, and hopper drawdown discharge design, is discussed later in the "Bins" section. Free-flowing materials, such as processed salts and dry sugars, may be reclaimed easily and economically through clamshell, horizontal slide, rolling blade, bifurcated, and adjustable proportional types of discharge gates.

Subsequent conveying systems usually require different types of feeders for flow regulation. For non-free-flowing materials, such as sticky and matting or interlocking materials, equipment that exerts a positive digging or displacing force—such as rotary table discharge plow feeders, hopper/bin air blasters, and adjustable, brute-force vibrators—must be used to dislodge and move material to the recovery point . When the angle of drawdown is steep, power shovels, bucket loaders, and scrapers are used. Stockpile height should be limited as a safety precaution against slides and ratholing. Material abrasiveness is a composite of several different material characteristics, including strength, Mohs hardness, and particle shape. Abrasive wear rate varies directly with the pressure and velocity of particle movement across an inclined surface.

Chutes, hoppers, bins, silos, and slopes, as well as their valley angles, should be designed as closely as possible to the material's angle of slide. Steeper slopes move more material but result in greater wear. AR steel, replaceable AR liners, alloy steels, or coatings may be desirable to reduce wear rates. Material dead beds at impact points reduce wear but may induce another problem in the case of wet, sticky, fibrous, or interlocking materials that show a tendency to build up into an immobile mass. Some loose materials have a tendency to pack and become denser, creating reclamation problems. Such materials usually require a feeder that has a strong positive action. In extreme cases, a digging action such as that provided by a power shovel or bucket wheel excavator may be required. Equipment should not roll or crawl on the materials being loaded.

Material temperature affects the choice of placing equipment. High-temperature materials, such as hot clinker, require special rubber or steel belts. Surface equipment for stockpiles should be chosen with care, and hazards to equipment and operators should be carefully considered. Corrosiveness can be controlled by use of protective coatings, but when abrasion is also present, the coating's effectiveness is reduced. Each passage of abrasive material over a surface exposes a new area of metal to corrosive elements. The combination of corrosion and abrasion requires investigation to keep maintenance costs of equipment and structures at a reasonable level.

Combustibility is a concern only for combustible materials, such as ammonium nitrate, barley, crushed calcium carbide, shelled corn, dry power plant utility flue ash and dust, dry pulverized salt cake, cracked soy cake, and dry beans, as indicated by the Conveyor Equipment Manufacturers Association (CEMA) class code. In addition, systems for sulfide concentrates and fuels should be considered combustible. With such materials, special methods of placing and protection are required, such as instrumentation controls, fire and combustion detection devices, blast gates, blast-relief panels, dust collection, methods of ventilation, and earth grounding.

Spontaneous combustion may occur in stockpiles of coal, sugar, and food powders if they are not properly layered and compacted. When toxic fumes and dust are emitted, remotely operated placing and reclaiming equipment should be used and operator exposure minimized. Flooding, the unstable fluid-like flow of dry solids, results from entrainment of air in material flowing in empty or partially empty hoppers or from collapse of the material arch in the hopper, bins, and silos. Floodable materials may not be suitable for stockpile storage and may require special attention in choice of materials handling equipment.

Material Flow

Successful operation of gravity storage is predicated on uniformity of materials when reclaiming. Flow patterns that occur in stockpiles, bins, silos, and hoppers are funnel, mass, and expanded flows. In funnel flow, material flows through a cylindrical channel extending upward from the discharge outlet, often colloquially called "ratholing." In mass flow, all material flows downward as material is reclaimed successfully. In expanded flow, the size of the flow channel expands upward from the discharge outlet, forming a cone. All three patterns occur in bins, silos, and hoppers, but generally only funnel and expanded flows occur in stockpiles with funnel flow the most commonly observed. Hoppers and bins are usually designed for material mass flow.

Gravity flow of solids occurs by the continuous formation and collapse of domes (arches) over the flow channel. Bulk materials have little or no strength in a loose state, but when under pressure, they consolidate and compact, especially in long-term storage, and gain strength by formation of bonds among particles. If the strength of these bonds is sufficient to support a stable dome or pipe (rathole), a flow obstruction develops. Flow analysis test work and historic flow-pattern data for the same type of material are useful in determining the minimum discharge outlet dimensions for those obstructions to be unstable. Those dimensions have a direct relation to the sizing and selection of bin, hopper, silo discharge gates, and reclaiming materials handling equipment.

Flow properties of bulk materials vary widely. The following characteristics affect flowability of materials from stockpiles, bins, hoppers, chutes, and silos: surface moisture content, atmospheric humidity, temperature, long-term storage, particle size distribution (percentage of fines to lumps), dustiness, stickiness, particle shape, forward velocity of the material as it is being loaded (as this acceleration causes turbulence and particle segregation in the material), and other CEMA class code particle characteristics (such as specific gravity, Mohs hardness abrasiveness, chemical corrosiveness, and hygroscopicity).

Flow analysis is based on mathematical theory and past historical data for the same type of material. This analysis is based on a characterization of the flowability of a solid called the flow function (FF) and the flowability of a solid of hoppers, bins, and silos called the flow factor (ff). These material characteristics can be obtained through laboratory tests and analysis of historical data, and various commercial and academic laboratories offer such services. It is important for the design engineer to supply to the laboratory samples of material that represent the worst cases of the product in question with regard to expected size distribution, screen analysis, particle characteristics, surface area, and inherent moisture content. The material samples should also conform as closely as possible to the anticipated CEMA Material Classification Code designation.

Environmental Factors Affecting Materials Storage

In selecting the type of storage, there must be a matching of storage purpose, overall required storage capacity, live and dead load capacity requirements, and physical and chemical properties of the material with various environmental factors. Table 2 provides recommendations regarding exposed and protected storage.

STOCKPILES

Bulk material stockpiling is defined as storage of bulk material in variously shaped piles on the ground. They may be exposed or protected, with protection ranging from simple

Table 2 Recommendations for exposed (outdoor) and protected (indoor) storage related to material characteristics and environmental factors

Material Property		Environmental Factors														
		Rain and Snow			Humidity			Wind			Dust			Temperature		
Property	Degree	Heavy	Moderate	Little, none	High	Moderate	Low	Frequent and high velocity	Moderate	Infrequent and low velocity	High-dust area	Moderate-dust area	Low-dust area	Dry, arid area and high temperature	Moderate	Extremely low temperature
Bulk density	Light, fluffy	In	In	Out	—	—	—	In	In	In	—		—	—	—	—
	Intermediate	Out	Out	Out	—	—	—	In	Out	Out	—		—	—	—	—
	Heavy, dense	Out	Out	Out	—	—	—	In	Out	Out	—		—	—	—	—
Specific gravity	Low	—	—	—	—	—	—	In	In	Out	—	—	—	—	—	—
	Intermediate	—	—	—	—	—	—	In	In	Out	—	—	—	—	—	—
	High	—	—	—	—	—	—	Out	Out	Out	—	—	—	—	—	—
Porosity	High	In	In	Out	—	—	—	—	—	—	—	—	—	—	—	—
	Medium	In	In	Out	—	—	—	—	—	—	—	—	—	—	—	—
	Low, or none	Out	Out	Out	—	—	—	—	—	—	—	—	—	—	—	—
Moisture content	Control required	In	In	In	In	In	In	In	In	Out	In	In	Out	In	In	In
	Little control	In	In	Out	In	In	Out	In	Out	Out	In	Out	Out	In	Out	In
	None	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out
Soluble in water	Highly	In	In	In	In	In	Out	—	—	—	—	—	—	—	—	—
	Moderately	In	In	In	In	Out	Out	—	—	—	—	—	—	—	—	—
	None	Out	Out	Out	Out	Out	Out	—	—	—	—	—	—	—	—	—
Hygroscopity	High	In	In	In	In	In	In	—	—	—	—	—	—	—	—	—
	Moderate	In	In	Out	In	In	Out	—	—	—	—	—	—	—	—	—
	None	In	Out	Out	In	Out	Out	—	—	—	—	—	—	—	—	—
Cementing tendency	High	In	In	In	In	In	In	—	—	—	—	—	—	—	—	—
	Moderate	In	In	Out	In	In	Out	—	—	—	—	—	—	—	—	—
	None	Out	Out	Out	Out	Out	Out	—	—	—	—	—	—	—	—	—
Contaminable	Highly	—	—	—	—	—	—	—	—	—	In	In	In	—	—	—
	Moderately	—	—	—	—	—	—	—	—	—	In	In	Out	—	—	—
	None or little	—	—	—	—	—	—	—	—	—	Out	Out	Out	—	—	—

covers to enclosed buildings such as domes, A-frame barns, sprung fabric buildings, and prefabricated lightweight sheeted buildings. Stockpile size and location depend upon purpose, process requirements, and climatic conditions. Shape depends on purpose, capacity requirements, material characteristics, available space, methods of materials handling stacking, and reclaiming equipment. All of these factors interact on stockpile system design.

Stockpile Site

The surface selected for a stockpile should be firm, solid, and well drained. A review of the plant site's soils report should be made. The site should be raised, not subject to flooding, and have a good slope for adequate drainage away from the stockpile area. If the site is not well drained, ditches should be provided along the stockpile toe for the full length or circumference of the storage site. If tunnels or culverts are used for reclaim under the stockpile, they should be "daylighted" on both ends with an escape tunnel at one end, and sloped to drain to an open surface or provided with a sump and drainage pump. Before the stockpile is laid down, the area should be compacted to the proper density pursuant to the soils report, and cleared of all debris and organic materials.

The stockpile toe should be accessible for mobile equipment for maintenance purposes and for removing the dead storage and turnover of the larger lumps that normally roll to the toe of the stockpile. Other plant processing or administration buildings, such as the truck shop, warehouse, and operators' change room, should be located a safe distance from the stockpile toe. This distance is determined by the minimum material angle-of-repose boundary; otherwise, an adequate retaining wall(s) should be used to prevent engulfment of various infrastructure.

Stockpile Size

Stockpile volume is based on desired flow rate through the plant, period of retention, and period of plant operation, as determined by the process mass flow and process dynamic modeling. Stockpile size is based on the required storage volume, type of stockpile being used, and the method of stacking and method of reclaiming being used. Plant production rate and market demand should be determined as accurately as possible and a reasonable design safety factor added.

Blending piles are a special case. Their volume must be based on a balance between sources of supply and anticipated rate of demand. Blending normally requires twin stockpiles, so that one stockpile can be blended during stacking while the other stockpile is being reclaimed. In some cases, when the right equipment is available, blending can be done from one stockpile. Reclaim equipment must be designed to minimize segregation, material ratholing, degradation, and production of material fines. In some cases, land area may be adequate but height limitations may restrict stockpile capacity. Maximum height may be limited by the placing and reclaiming equipment; soil conditions; proximity to the loading point (railroad, dock, or stream); height of stacking tubes, if employed; characteristics of the material; and need to ensure a safe operation. Required stockpile height can be decreased by providing additional takeoff points or the choice of materials handling equipment, such as belt conveyor stackers equipped with stacking "slingers," slewing and luffing stackers, windrow stackers, traveling trippers consistent with cross conveyors, belt conveyor traveling belt plows or multiple stationary plows, a series of inclined piggy-back belt conveyors equipped with bifurcated discharge gates, reversible traveling shuttle belt conveyor(s), conveyor head discharge pulleys equipped with a rotating or fixed stinger, and belt conveyor stackers equipped with variable-frequency-drive, wound-rotor motors to adjust the material's velocity and stacking trajectories, each of which will increase available live tonnage. In addition, the delivery system can be altered to permit building additional stockpiles, the overall shape of the stockpile can be changed, or the single pile can be spread over a larger area. In some cases, it may be necessary to consider using mobile equipment to totally reclaim dead storage from the stockpile.

Stockpile Shape

Common stockpile types, based on geometry, are conical, lateral or windrow-parallel, windrow-radial and kidney shaped, ramped, terraced, bunkered, rectangular, triangular, trapezoidal, and elongated.

Conical stockpiles are common for ROM and primary crushed ore storage. *Conical stockpiles* can be defined as a mostly unrestrained stockpile fed at one or more stationary points. A common method of reclaiming a conical stockpile is by gravity from one or more extraction points underneath the stockpile with materials handling equipment.

Live storage represents the capacity available for reclaim by gravity without assistance from auxiliary materials handling reclaim equipment. The reclaiming of the live volume is calculated knowing the drawdown angle. In most cases, the drawdown angle is equal to the angle of internal friction of the specific material, as determined by material sample flow testing and the material's CEMA classification code. For most materials, the angle of drawdown is greater than the material's angle of repose.

For a simple conical stockpile with a single feed and single center extraction point, assuming no ratholing (Figure 1), the total volume can be calculated from the following equation:

$$\text{total volume} = \frac{1}{3}\pi r^3 h \text{ and } \frac{h}{r} = \tan(A)$$

where

r = base radius
h = stockpile height
A = material's angle of repose

The live volume can be calculated from

$$\text{live volume} = \frac{\tan^2(A)}{(\tan(A) + \tan(B))^2}$$

For more complex conical stockpile arrangements where multiple feed points or multiple drawdown reclaim points are present, it is often easier to use a computer model (Figure 2) to determine the total live and dead volumes.

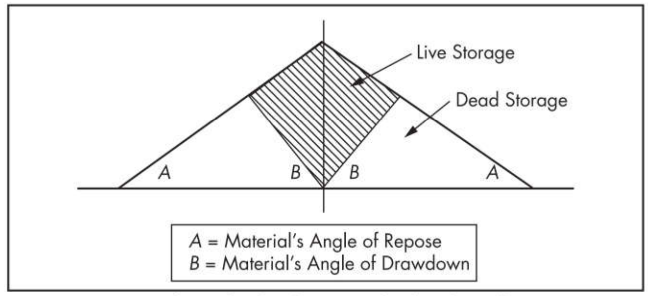
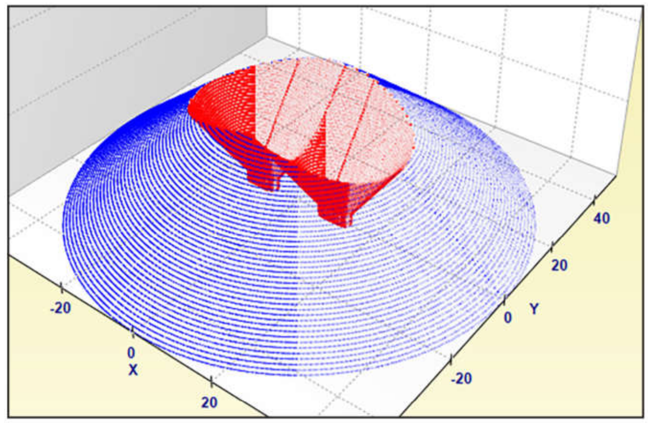


Figure 1 Conical stockpile "live" and "dead" volume



Courtesy of Martin Du Plessis

Figure 2 Computer model of a conical stockpile with two extraction points experiencing ratholing

Windrow stockpiles can be either linear elongated or radial. *Windrow stockpiles* can be defined as a stockpile with one or multiple feed points that either move linearly or radially. Reclaim methods can vary from gravity reclaim from under the stockpile using types of equipment based on the shape and length of the stockpile. Linear elongated stockpiles more than 1.6 km long are not uncommon in port-of-entry and port-of-export facilities.

The volume of a simple linear stockpile can be estimated by

$$\text{volume} = \frac{1}{2}BhL + \frac{1}{12}\pi B^2 h \text{ and } \frac{h}{B} = \frac{1}{2}\tan(A)$$

where

B = base width (see Figure 3)
h = stockpile height
L = stockpile length
A = angle of repose

The cross-sectional profile of elongated windrow stockpiles are seldom simple, which makes calculating total capacity as well as live and dead load capacities nontrivial. These stockpile types may include chamfered toes, multiple peaks, flat-surfaced peaks, compound material angle of repose, or material that maybe slightly compacted and embedded. The exact total capacity volume of these types of stockpiles should be estimated from their respective specific profiles or calculated by direct measurement using photogrammetry or laser scanning.

The volumes of other stockpile shapes depend on their exact geometries. Ramp lengths, step heights, retaining walls, and bunker walls add to the complexity of volume capacity calculations. When material is reclaimed under these type of stockpiles, the determination of live and dead storage is complex for multiple drawdown outlets. Additional design live load factors for reclaim capacity should be considered.

Methods of Placing Material in Stockpiles

Equipment for placing material in stockpiles includes conveyors, buckets, and surface equipment. Conveyors include belt conveyors, screw conveyors, and various types of stackers operating above and discharging material onto the stockpile. Buckets include drag scrapers, draglines, clamshells, bridge cranes, and drag conveyors operating above and depositing or moving material over the stockpile's top surface. The conveyor and bucket-type equipment usually reaches over and is not supported on stockpiled material. Exceptions are mobile and semimobile conveyor and bucket plant systems that can be supported on previously stockpiled material. Surface equipment includes loaders, dozers, and wheeled scrapers (carryalls) operating on and depositing or moving material over the stockpile's top surfaces. Mobile equipment must be supported on stockpiled material. It is often necessary or desirable to employ several different combinations with the more common groupings presented in the following discussion.

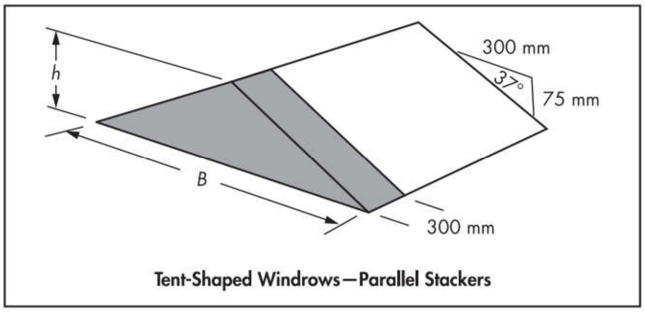


Figure 3 Linear windrow stockpile volume

Conveyors Above Stockpiles

Belt conveyors are the most common method of placing material in stockpiles. Commonly used arrangements of conveyors and auxiliary units are shown in Figure 4. The single stationary conveyor is a satisfactory and simple method for delivering material to a stockpile of moderate size but is often height restricted when supporting the cantilevered section of the feed

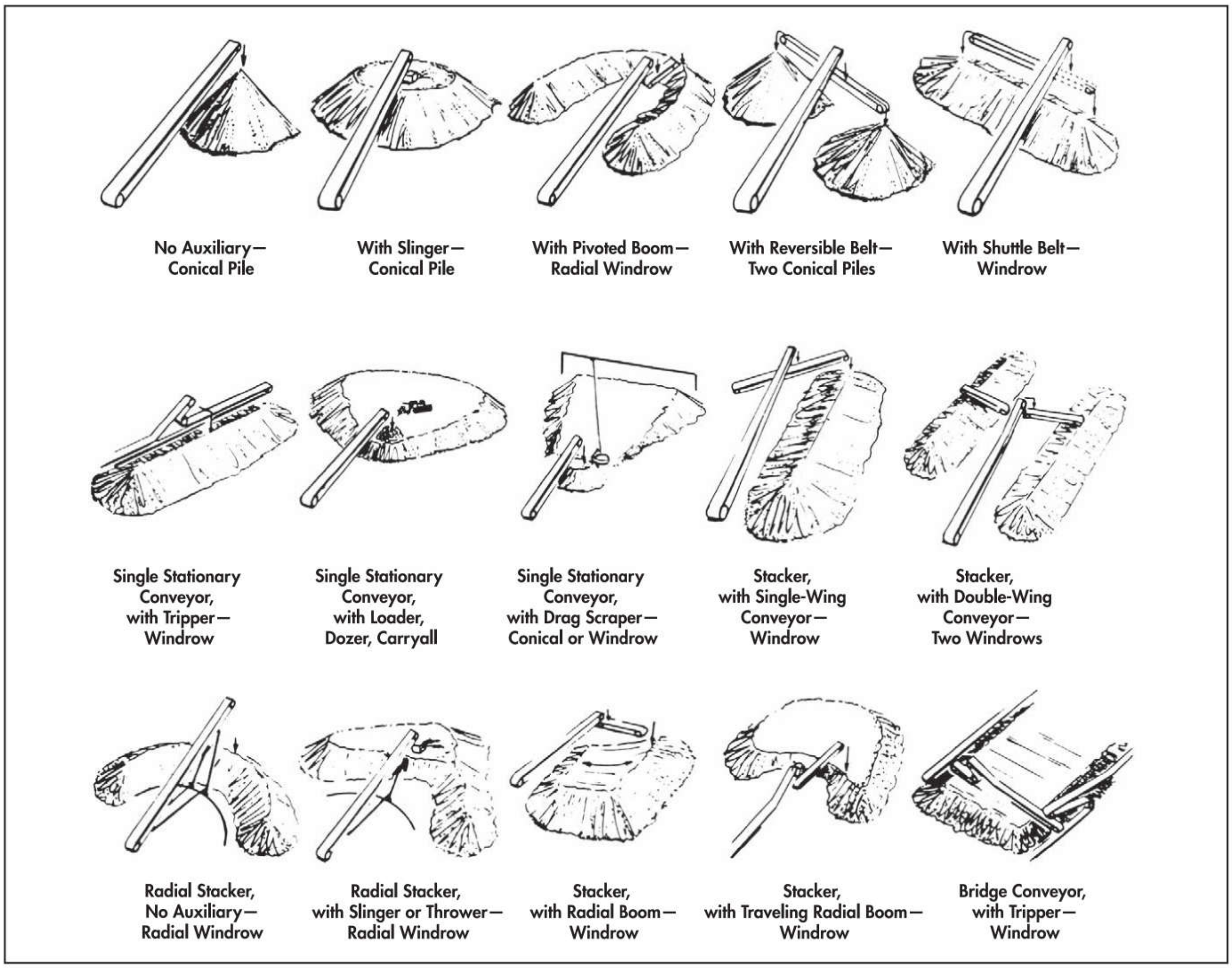


Figure 4 Methods of placing material in stockpiles using conveyors

conveyor. Conical stockpiles up to a height of 50 m have been built. Material segregation may occur with this arrangement.

A gain in storage volume can be obtained by attaching a slinger or thrower to the discharge chute of the stationary conveyor. A slinger is essentially a short, high-speed belt that can increase storage volume significantly. The slinger is not effective when segregation of sizes and densities is a problem, in windy areas, or when fines content is high and material is dry.

A single stationary conveyor with a pivoted boom increases storage volume by adding to the stationary conveyor a horizontal belt supported on a boom truss and arranged to pivot on the centerline of the conveyor discharge. The boom conveyor can discharge material along an arc of about 270°, building a large radial stockpile. The structure required to support a long boom can become elaborate and impose limitations. A single stationary conveyor with reversible belt can be used only if one type of material is being stockpiled. With this arrangement, a short, reversible belt is added under the discharge of the stationary conveyor, doubling storage volume. If more than one type of material is being stockpiled, the reversing cross-belt length should permit formation of two free-standing, nonoverlapping cones.

With a single stationary conveyor that has a shuttle belt arrangement, a reversing shuttle belt is placed on a wheeled frame under the stationary conveyor. The shuttle belt moves back and forth on an elevated track to expand the two cones into a long windrow. The shuttle can also be part of the conveyor, eliminating the transfer point. Volume gained is directly proportional to the length of the shuttle belt. Shuttle belts are often used to handle lumpy, sticky, or abrasive materials that would be troublesome in tripper chutes. They require less headroom than trippers, and their weight is more uniformly distributed along the supporting structure; shuttle belts up to 150 m long have been constructed. A traveling tripper can be installed to the stationary conveyor.

A tripper can be arranged to traverse almost the entire length of the elevated belt and discharge material into a long tent-shaped windrow. If desired, short-wing conveyors can be mounted under the tripper discharge to make a wider windrow. In windy areas, belting should be sheltered from the wind. Trippers may be driven by the conveying belt, powered by electric motors, or moved by a cable system. When using a single stationary conveyor with loader, dozer, or carryall, the conveyor serves as an auxiliary unit placing material within reach of the mobile equipment traveling on stockpiled material. The size and shape of the stockpile depends on the range and maneuverability of the surface units. If degradation of material is undesirable or the weight of equipment causes packing, this arrangement is not satisfactory. A single stationary conveyor with a drag scraper can be used when material properties prevent use of equipment operating on the surface of the stockpile. A conveyor is usually used to place material in a small "cushion" pile in front of the head post of the scraper. The cable-operated scraper moves the material over stored material and places it in piles or windrows.

A stacker usually consists of a cantilevered boom mounted on a wheeled or crawler-tread carriage that travels along a straight path or an arc of up to 270°. A stacker generally receives material from a conveyor–tripper unit. A single-wing stacker has a boom located on one side of its tower structure, usually fixed at right angles to the stacker's line of travel. The boom may be hinged for adjustment of the discharge height, minimizing material fall and reducing degradation, dusting, and wind segregation. A double-wing stacker can discharge to either side of its line of travel. This is accomplished by a single reversible belt conveyor or two separate conveyors. A radial stacker is a single, inclined conveyor pivoted at the tail end, on the loading-point centerline. The conveyor structure is supported near the midpoint by a tower. This support may describe an arc up to 270° in central angle. Units are available with rubber tires, flanged wheels, or crawler tracks. The carriage is usually self-propelled. When additional storage is required, a radial stacker with wing slinger provides an economical solution, sufficing when segregation, degradation, and dusting are not problems. For a stacker with radial-boom side conveyor, the boom is arranged to pivot about a vertical axis for approximately 90° of arc while the stacker moves along its main lines of travel. A hat-topped windrow of greater storage volume can be built. When using a stacker with a traveling radial boom where the boom can pivot through 180° of arc (90° on either side of the line of travel), a stockpile of enormous volume can be produced economically. Maximum movement is provided when the unit is mounted on crawler treads. With wheel-mounted units, the track is usually removed as stacking progresses.

A bridge conveyor is used when material must be placed in a stockpile in shallow, uniform layers to accommodate processing or blending requirements. Feed is delivered by a belt conveyor parallel to the stockpile's length. A moving tripper on the feed conveyor loads material onto the bridge conveyor, supported above the stockpile by a traveling bridge structure. The tripper on the bridge conveyor distributes material across the stockpile width, and the bridge movement distributes material along the stockpile length. The bridge can be equipped with a gantry crane mounted on top of the trusses and equipped with a clamshell to reclaim stockpile material by loading a hopper above the bridge conveyor. By reversing belt direction, material can be removed by the same units that delivered it to storage.

Buckets over Stockpiles

When properties of the material do not permit equipment traveling on the stockpile or when rate of material flow is relatively low, consideration should be given to reaching over the stockpile with drag scrapers, draglines, clamshells, bridge cranes, and drag conveyors (Figure 5).

Drag scrapers are suitable for moving relatively small volumes of material over large areas. The drag scraper consists of a cableoperated bottomless scraper bucket, controlled by a drum hoist, powered by electricity or an internal-combustion engine, and riding on a flow of moving material. When pulled forward, the bucket loads; when pulled backward, it empties. Drag scrapers give good service where material is wet, damp, abrasive, or of high temperature.

Wheel- or crawler-mounted draglines are used to excavate material at or below ground level. The stockpiles built by draglines are usually for short-term storage or surge piles. Pile height is limited to approximately 50% of boom length. This limitation results from the material's angle of repose, allowing for necessary dragline clearance. Clamshells are effective in placing materials into stockpiles because of their reach, dumping height, and dumping accuracy. They can pick up material above or below their level and place it at a higher level than is possible with a dragline or shovel.

Bridge cranes with clamshell buckets are used on bunker-type stockpiles within buildings or partially enclosed

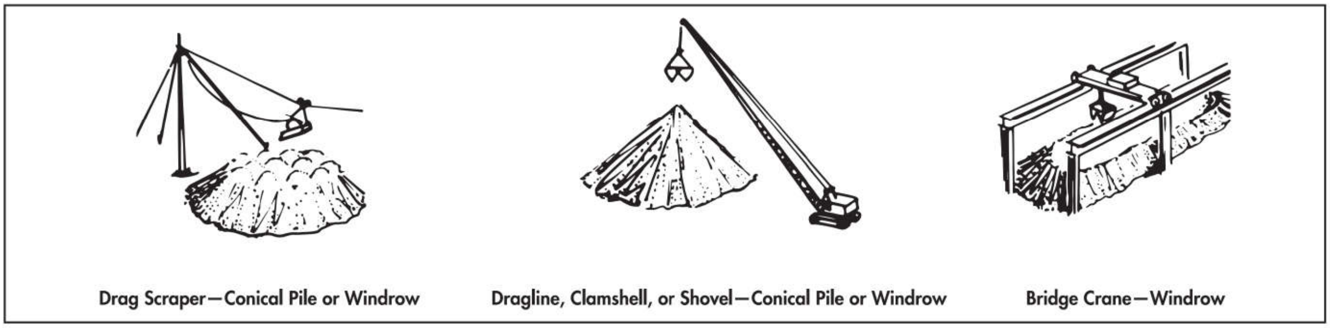


Figure 5 Methods of placing material in stockpiles using buckets over stockpiles

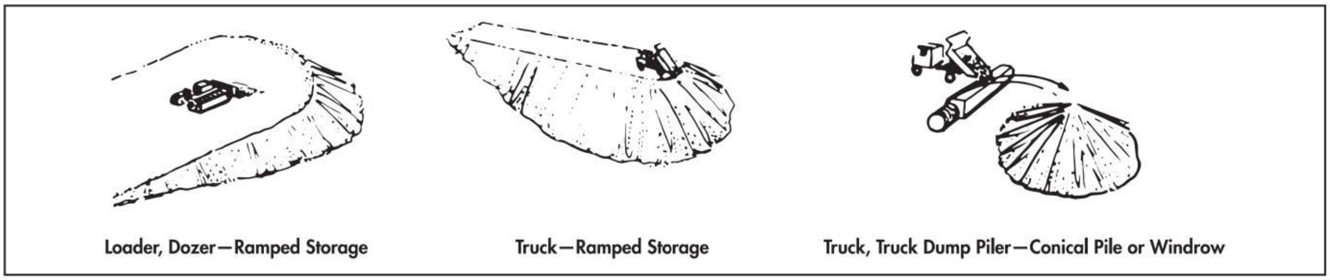


Figure 6 Methods of placing material in stockpiles using surface equipment on stockpiles

structures. The crane runway structure can be readily incorporated into the building's structural frame, making the bridge crane a reasonable choice for indoor bulk materials handling. Drag conveyors are of the bottomless variety in which the stockpile surface provides the bed on which incoming material is moved. Drag conveyors with bottom plates are suitable for many applications described for belt conveyors when handling damp, sticky, wet, or hot materials. Shovels are designed for digging, not stockpiling. Their limited boom and dipper stick length do not allow for development of large stockpiles.

Surface Equipment on Stockpiles

When material characteristics permit use of equipment traveling on the stockpile, loaders, dozers, wheeled scrapers, and trucks can be used (Figure 6 and Table 3). When trucks cannot operate on the stockpile, a portable dump piler can be used. Loaders and dozers are usually restricted to building ramped stockpiles in which material is spread over the ground. Succeeding loads are placed on top of previously placed materials. A ramp is developed gradually from which the loaders and dozers can dump material on existing slopes. The ramp should be kept at a reasonable grade (20%) so that the unit speed is not reduced too much. Rubber-tired units produce a more compact stockpile than crawler units because their wheels exert greater unit pressure. For large stockpiles occupying big areas, a wheeled scraper should be considered. It operates over a large radius and provides required compaction for materials such as coal. In addition, the unit may serve for reclamation.

Trucks are often used for placing materials directly onto small stockpiles, where material quantities are delivered from several sources. Reclamation is usually accomplished by surface equipment such as loaders and dozers. Where trucks cannot be operated on stockpiled material or where increased storage volumes are desired, a portable dump piler can be utilized (Sinden 1967). It can fill storage areas by throwing a steady, compact stream of bulk granular material up to 20 m and piling material up to 12 m high. Unit discharge angle can range from horizontal to vertical. The machine's unique centrifugal thrower action does not require material fall but operates with material fed through a side inlet from a hopper. The standard unit will unload a 5-t truck of 1,200 kg/m^3 material in one minute. Smaller units will discharge 90 t/h into 6-m-high stockpiles. Use of this unit is limited to materials that are not harmed by segregation and degradation and where dusting is not a problem.

Problems Encountered in Placing Material in Stockpiles

Segregation by size and density is a problem when materials have a wide particle size range or a difference in specific gravity. Segregation results from wind, water, and gravity action during use. Wind blowing across a stream of falling material will produce a segregation of fine from coarse particles or light from heavy particles. Fine (or light) particles of small mass will be carried horizontally for some distance while coarse (or heavy) particles of larger mass will fall downward. Depending on particle mass (size and specific gravity), windblown material may have considerable horizontal displacement. Rock ladders, telescoping chutes, or lowering wells are effective in countering wind action. Perforated pipe can be used effectively with finer material sizes. Hinged-boom conveyors that lower the discharge pulley to near the top of the pile minimize material freefall distance and reduce dusting. Segregation caused by gravity is the most common and greatest source of difficulty to stockpiling (Table 4).

Figure 7 illustrates theoretically how gravity segregation separates material sizes. Coarse material falling on the cone tip tends to roll down the sloping surface while finer particles tend to stop almost in the position of first impact.

Table 3 Equipment recommendations related to characteristics of stockpiled materials

Properties of Material to Be Stockpiled		Placing			Reclaiming			
Property	Degree	Conveyors over Stockpile	Buckets over Stockpile	Surface Equipment on Stockpile	Conveyors Under Stockpile	Buckets over Stockpile	Surface Equipment on Stockpile	Notes
Hardness	Very hard	OK	OK*	OK*	OK*	OK	OK*	*Check wear rate
	Moderate	OK	OK	OK	OK	OK	OK	
	Soft	OK	OK	NR†	OK	OK	NR†	†Not recommended
Range of sizes	Very coarse	OK	OK	OK	OK	OK	OK*	*Check maximum size
	Wide range	OK†	OK	OK	OK†	OK	OK†	†Check segregation
	Very fine	OK	OK	OK‡	OK	OK	OK‡	‡Check tire size
Particle strength	Strong	OK	OK	OK	OK	OK	OK	
	Medium	OK	OK	OK	OK	OK	OK	
	Weak–Friable	OK	OK	NR*	OK	OK	NR*	*Not recommended
Degradation of material	Undesirable	OK	OK	NR*	OK	OK	NR*	*Not recommended
	Not a factor	OK	OK	OK	OK	OK	OK	
	Desirable?	OK	OK	OK	OK	OK	OK	
Flowability	High	OK	OK	NR*	OK	OK	NR*	*Check tire size—flotation track
	Moderate	OK	OK	OK	OK	OK	OK	Consider special method
	None, or low	NR†	OK	OK	NR†	OK	OK	†Not recommended
Abrasiveness	High	OK	OK*	OK*	OK*	OK*	OK*	*Check wear rate
	Moderate	OK	OK	OK	OK	OK	OK	Consider abrasion-resistant plate
	None, or low	OK	OK	OK	OK	OK	OK	
Tendency to pack	High	OK	OK	NR*	OK*	OK	NR*	*Rip, scarify
	Moderate	OK	OK	OK	OK	OK	OK	
	None, or low	OK	OK	OK	OK	OK	OK	
Material temperature	Hot: >200°F	OK*	OK	OK*	OK*	OK	OK*	*Use high-temperature rubber, and check expansion
	Moderate: 200° to 70°F	OK	OK	OK	OK	OK	OK	
	Cool: <70°F	OK	OK	OK	OK	OK	OK	
Contaminable	Highly	OK	OK	NR*	OK	OK	NR*	*Not recommended
	Moderately	OK	OK	NR†	OK	OK	NR†	†Not recommended; check limits
	None, or little	OK	OK	OK	OK	OK	OK	
Corrosiveness	High	OK*	OK*	OK*	OK*	OK*	OK*	*Check coatings, etc.
	Moderate	OK	OK	OK	OK*	OK*	OK	
	None, or low	OK	OK	OK	OK	OK	OK	
Combustible	Highly	N/A	N/A	N/A	N/A	N/A	N/A	N/A = No data available
	Moderately	OK	OK	OK†	OK	OK	OK	†Provides compaction
	None, or little	OK	OK	OK	OK	OK	OK	
Toxic fumes and dust	Harmful amounts	OK	OK	NR*	OK	OK	NR*	*Not recommended; check safety requirements
	Moderate	OK	OK	OK	OK	OK	OK	
	None	OK	OK	OK	OK	OK	OK	
Floodability	Highly fluid	N/A	N/A	N/A	N/A	N/A	N/A	N/A = No data available
	Moderately	OK	OK	OK	OK	OK	OK	
	None, or low	OK	OK	OK	OK	OK	OK	

When material is drawn from the pile, it will have a widely varying size distribution; reblending to meet specification grades can be troublesome and costly. Segregation can be avoided by building the pile in shallow layers. For example, when working with a clamshell, the large pile is built up by accumulating many small heaps of material. Since it is not always feasible to prevent segregation, corrective measures are often necessary. Figure 8 is a theoretical model of a conical pile with a single center drawpoint showing probable particle size distribution in the cone's live storage portion. If this pile were drawn down, a sequential tapping of various particle sizes would occur. The first material discharged is primarily fines, followed by medium-sized and then coarse particles. This phenomenon and two corrective procedures have been verified by model tests.

The first procedure (Figure 9) uses four conical piles, each having a single, centrally located drawpoint. By filling these cones and drawing off in a definite sequence, the various particle size zones are reclaimed in approximately the desired proportions. The individual piles are never reclaimed until completely filled, and never filled until completely drawn off. Corrective reblending will not be attained unless this procedure is followed.

The second procedure (Figure 10) uses multiple drawpoints in a single-point loading cone. Illustrated is the theoretical particle size distribution in the cone and the way in which various size fractions can be reclaimed and blended. By regulating discharge rate from the various drawpoints, reblending of particle sizes is accomplished. It is also desirable to have

Table 4 Problems encountered in placing materials in stockpiles

Problem	Preventive Procedure	Corrective Procedure
Segregation, wind	Telescoping chutes Lowering wells, limber pipes Rock ladders Hinged booms, limit freefall of material	Blending operation
Segregation, gravity	Rock ladders Hinged booms Limit height of piles Place material in horizontal layers dropped from low belt; place material in small piles, avoid long slopes on which material can run If segregation must be avoided, do not place material having size ratio over 2:1	Blending operation Multiples drawpoints Sequential loading and reclaiming from several piles
Degradation	Rock ladders, reduce impact Hinged booms, reduce abrading and crushing of particles due to impact Avoid heavy equipment operating on stockpile or use crawler treads Raise scraper buckets above surface of material	
Dusting	Hinged boom, lessen free fall of material and exposure to wind Telescoping chute lowering wells	Use chemical sprays and binders
Windage loss	Place stockpile in building	Use dust-suppressing chemical sprays
Contamination	Cover material Building for the long term Covers or sprays for the short term	
Erosion	Cover material; temporary covers or sprays for the short term	
Abrasion and corrosion	See Table 6.	

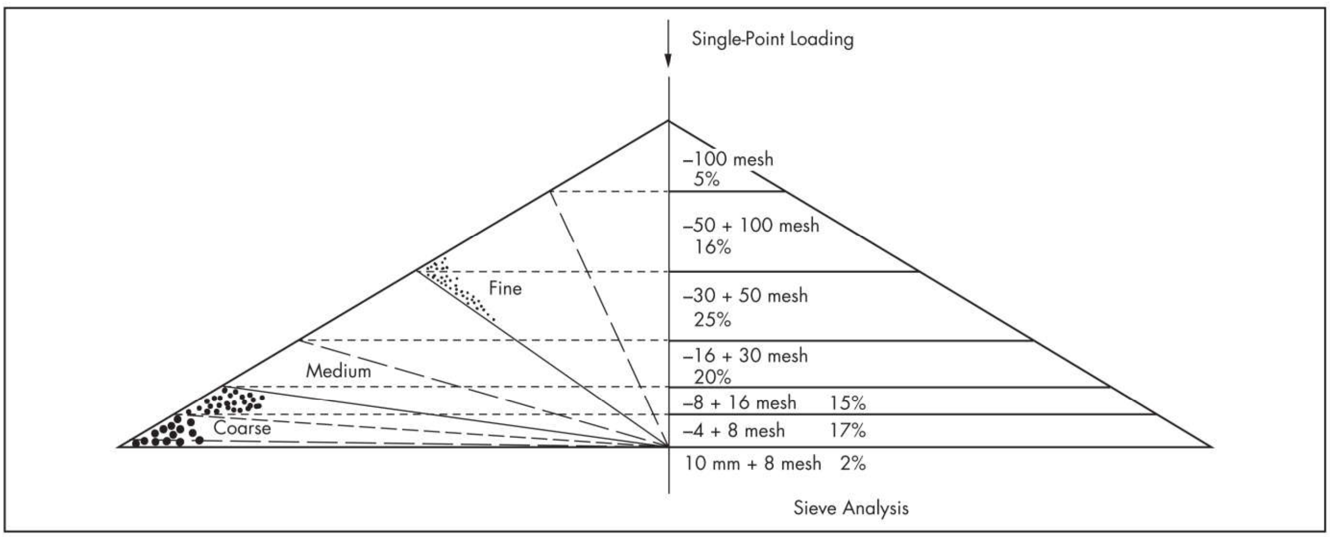


Figure 7 Particle segregation in stockpiles (cross section of initial loading, 31° cone)

the feed conveyor and the reclaim conveyor parallel to each other to improve blending.

Particle size degradation of material occurs wherever there is falling, sliding, or abrading of particles. An increase of fines may be detrimental. Production of excessive fines can make material more susceptible to "dusting" and result in economic losses. However, the greatest problem is the creation of a health hazard or community nuisance. Degradation can be reduced by using "rock ladders" that break the total freefall distance into a series of relatively short drops. Material falls on a dead bed of its own material, slides on the sloping surface, drops over the edge of the ladder "rung," and lands on the next lower ledge. Each time, direction of travel is reversed so that the material starts each subsequent fall with little or no momentum from the preceding drop. Both velocity and individual vertical fall distance are minimized. Degradation resulting from equipment weight can be lessened by proper choice of equipment, such as cushioned crawler treads or flotation tires. If no degradation is permissible, use of equipment moving on the stockpile surface should be avoided and preference given to units suspended above the material.

Dusting and wind losses can be reduced by minimizing the distance through which material must fall. Exposure time to wind action is lessened and material impact is reduced by means of hinged-boom conveyors and "rock ladders." Another device is the telescoping chute, which in extended position reaches from conveyor discharge point to stockpile bed. As stockpile height increases, the chute is gradually retracted, completely sheltering material from all normal wind action. "Lowering wells" can provide wind protection. These wells are constructed of circular pipe sections arranged on a vertical centerline coinciding with that of the discharge chute. At intervals

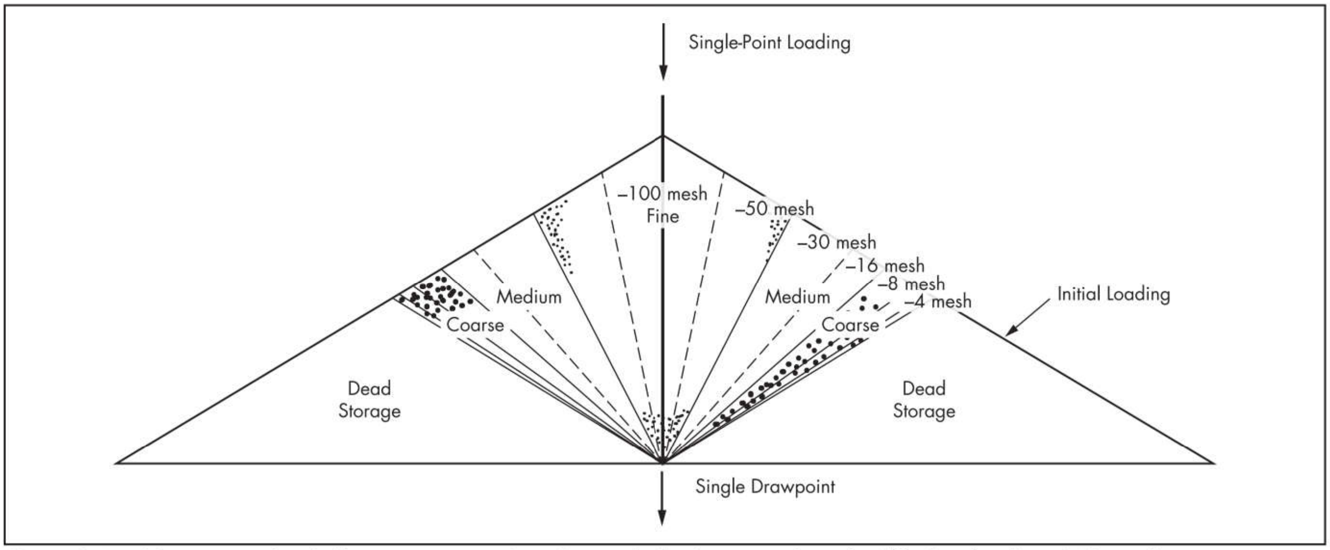
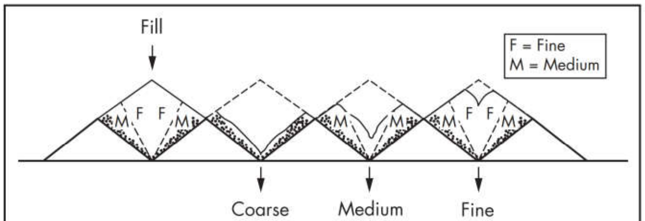


Figure 8 Particle segregation in live storage portion of a stockpile (cross section of refill after loading, 31° cone)



Note: Piles are to be drawn down in sequence so that a different size fraction is being tapped in each pile. Filling is begun when the live portion is emptied.

Figure 9 Multi-cone arrangement for stockpiling

along this vertical pipe column, openings are provided through which material can flow when the pipe is filled to the level of that particular opening. Water sprays in the discharge chute of the feed conveyor and over the stockpile surface can significantly reduce dusting during stockpiling. Fine water sprays for settling dust are often made more effective by addition of wetting agents, which reduce water surface tension. Dust suppression only provides temporary relief unless moisture content is maintained by spraying water on the surface. Material in a stockpile can be sprayed with chemicals that bind fine particles together, forming a porous surface crust that is resistant to wind action. Protective covers or buildings do not prevent dust production during materials handling, but they do reduce the wind effect on material already deposited. A permanent weathertight enclosure is the most effective protection from environmental dust, windblown debris, and rain. Where this is not possible, a temporary cover can be considered.

Summary

Equipment selection for placing material in a stockpile is dependent on material characteristics, stockpiling feed capacity, and type of stockpiles. The stockpiling rate provides approximate limits for standard equipment units. While not exact, these values provide a rough basis for eliminating a method on the basis of capacity requirement. Stockpile types and usual protection and materials handling methods are given in Table 5. Common problems experienced with placing material on stockpiles include segregation by size, density, and dust and wind losses. Methods can be applied to limit the impact of these problems.

Reclamation from Stockpiles

Conveyor equipment includes gates, feeders, and conveyors operating under the stockpile and withdrawing material from below the pile. Buckets include drag scrapers, draglines, clamshells, shovels, cranes, rotary reclaimers, bucket-wheel excavators, and drag conveyors operating over the stockpile with material taken from the top of the pile. Conveyor and bucket equipment are not supported by the stockpile. Surface equipment includes loaders, shovels, dozers, and wheeled carryalls, operating on the stockpile with material taken from the top surface of the pile. Surface equipment is supported by the stockpile.

Conveyors Under Stockpiles

Compact, efficient, and economical prefabricated tunnel sections and feeders have encouraged conveyor use under stockpiles. Tunnels generally run below grade for the stockpile length and slope upward to a discharge point above ground level. At intervals along the tunnel, openings in the tunnel roof permit flow of stockpile material into the tunnel and onto the belt conveyor. Material is usually funneled through a hopper. Flow rate is controlled by gates, chutes, or feeders. Tunneling arrangement and related equipment is determined largely by stockpile type and size. For free-flowing materials, a feeder may not be required.

A gate of a radial, clamshell, or slide type in the chute between the drawpoint hopper and transporting conveyor is necessary to shut off material flow. These gates provide a fairly positive shutoff and can be used safely with materials of highly fluid characteristics. With free-flowing material that does not "flood," an adjustable chute can be used. The chute is raised or lowered to vary the slope and thus regulate the flow. Flow is shut off by raising the chute so that the toe of material falls within the chute length.

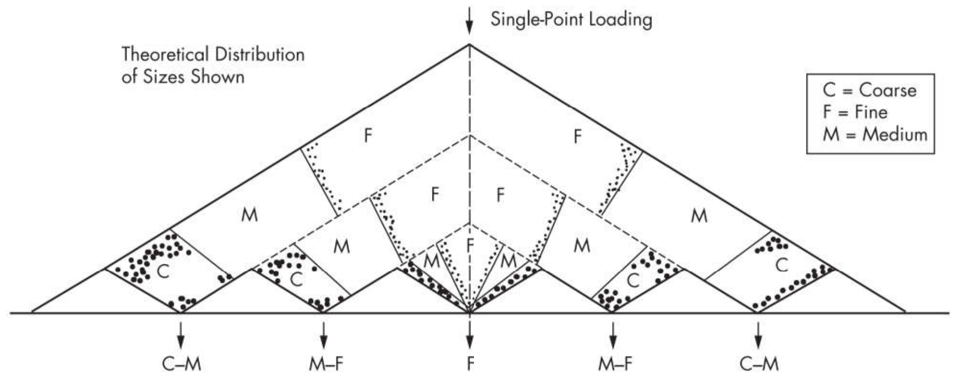


Figure 10 Multiple drawpoints for a stockpile

Table 5 Stockpile types and usual protection and materials handling methods

Type of Stockpile	Methods of Protection	Methods of Placing Material in Stockpile	Methods of Reclaiming Material from Stockpile
Conical piles	Buildings Plastic covers Chemical binders	Conveyors Clamshells Draglines	Conveyors Loaders and dozers Clamshells and draglines Shovels Drag scrapers
Windrows—parallel	Buildings Plastic covers Chemical binders	Conveyors Drag scraper Clamshells Draglines	Conveyors Loaders and dozers Clamshells and draglines Shovels, bucket wheels Drag scrapers, rotary reclaimers
Ramped stockpiles	Compaction Chemical binders Seeding	Trucks Scrapers, tractor-drawn Dozers	Loaders and dozers Clamshells and draglines Shovels Drag scrapers
Cribbed piles	Buildings	Conveyors Trucks Loaders and dozers	Conveyors Loaders and dozers Clamshells and draglines Shovels
Bins—on ground	Buildings Self-enclosed	Conveyors	Conveyors Cranes, with clamshells
Bins, mobile, railway, cars, barges	Self-enclosed	Conveyors Clamshells Loaders	Conveyors (track hoppers) Unloaders, bucket Clamshells Pneumatic conveyors

When control of flow is desired or materials are not free flowing, a feeder is necessary. Vibrating pan feeders, apron feeders, and belt feeders are used depending on the application. Vibrating pan feeders are a cost-effective solution for lower-capacity stockpile withdrawals of small to medium particle size. Higher-capacity stockpile withdrawals are possible for larger-particle-sized material like primary crushed ore using belt and apron feeder equipment. When the material shape and hardness pose a risk of damage to belting when being drawn, apron feeders are preferred. A shutoff mechanism is required to provide safe access to the feeders for maintenance. Sliding gates and spile-bar systems are often used.

Spile bars are large steel rods that can be inserted across the drawpoint hopper to restrict flow through the length of the hopper. Inserting all the spile bars effectively shuts off the flow of larger-particle materials. Partially inserted spile bars are often used to further control drawdown of a stockpile. Insertion and extraction of spile bars can be manual or with hydraulic spile-bar insertion equipment.

Equipment Operating over Stockpiles

Drag scrapers for placing material have been previously described. To adapt a drag scraper to reclaim operations, a sloped loading ramp is added to elevate material. Draglines may be used for reclaiming materials from stockpiles by providing a loading hopper into which the bucket can be emptied. Trucks or cars can be loaded by opening the flow-control gate under the hopper. Small draglines can empty their buckets directly into transport equipment, but this procedure usually results in considerable spillage.

Clamshells are especially suited to stockpile reclamation since they operate in a vertical digging range. Their dumping accuracy is well suited to direct loading into trucks, railroad cars, or elevated hoppers. Power shovels can reclaim material from stockpiles, especially where a strong digging action is required. Material can be placed readily in hoppers, trucks, or railroad cars.

The rotary reclaimer is used successfully to reclaim from both linear and radial windrows. Bucket-wheel boom reclaimers run on tracks parallel to the windrow stockpile over a stationary conveyor onto where the reclaimed material is discharged. The system allows the boom to move in a sweeping and up-and-down movement. By a unique harrow arrangement, this unit minimizes segregation that often accompanies reclaiming operations. Pickup is by rotating buckets which discharge onto a belt conveyor on the boom that discharge onto the stationary conveyor. On linear windrow stockpiles, the bucket-wheel boom reclaimer can be rotated 180° to reclaim a second stockpile that is running parallel with the first. The bucket-wheel boom reclaimer can be combined with a boom stacking conveyor into one unit that can alternate between stacking and reclaiming. Bucket-wheel boom conveyors can also be mounted on a tracked crawler, allowing the reclaiming of irregular-shaped stockpiles. The bucket-wheel stacker/reclaimer, both rail and crawler mounted, was developed extensively in Europe prior to 1960 and has been extensively used in North America since that time. Most American installations are used for coal storage and reclaiming in and around thermal storage plants, although some are located at steel plants for raw materials handling there.

Bucket-wheels are also used in bridge-type reclaiming arrangements. A bridge structure spans across the width of a linear or radial windrow stockpile. One or two bucket-wheels transverse the bridge structure, discharging onto a conveyor running across the bridge. The bridge can move along the stockpile length on tracks while discharging the material onto a stationary conveyor along the stockpile or, in the case of a radial stockpile, into a center chute. Segregation reclaim variations are experienced with single bucket-wheel bridge reclaimers but with a double bucket-wheel bridge reclaimer, the two wheels are arranged in such a manner to smooth out the variation in material due to segregation.

In the Messiter system, a harrow rakes material from the pile face and a drag conveyor moves it laterally from the toe and delivers it to a belt conveyor parallel to the stockpile centerline. In the Dodge system, drag conveyors with adjustable bottoms are used to place stockpile material. In reclaiming, drags without bottom plates are used to rake material from the pile toe into a hopper that loads a belt conveyor. Another system uses the drag to rake material down the windrow slope and into a hopper that loads a belt conveyor running parallel to the pile. The bucket unloader is similar to a bucket elevator without a casing. Such a unit is used principally for unloading from barges, rectangular bins, or other containers. It is well suited for work in close quarters.

Surface Equipment on Stockpiles

The modern front-end loader's operating flexibility and speed provide an efficient unit for reclaiming and cleanup work around stockpile areas. These loaders have bucket capacities up to 40 m^3. The loader can load trucks or railroad cars directly or place material in a discharge hopper. It is sometimes unnecessary to pick up and carry material. The dozer can push material into a "trap" (depressed hopper) that feeds an inclined conveyor for loading transport units. Wheeled scrapers are limited to large stockpiles since the average-sized plant cannot justify their cost. They are used where large tonnages must be handled quickly and inexpensively.

Problems Experienced with Reclaiming

Material characteristics should be checked before deciding on a reclaim method. Some materials pack more under vibration and others fluidize with aeration. Material may often exhibit a tendency toward funnel flow or ratholing over drawpoint openings by flowing only through a cylindrical channel just above the drawpoint. In extreme cases, this could not only reduce the live volume but also make reclaiming inefficient. The drawdown opening size could be maximized and a larger number of closely spaced openings under the stockpile could improve flow. Flow promoters can be used. The friction angle of material to the chute liners is often lower than the internal friction angle of the material. The material will flow more readily against a liner than shear against itself. Internal surfaces can be provided in drawdown hoppers to improve flow.

Some material may be difficult to flow even when great care is taken in engineering the drawdown openings, hoppers, and chutes. For fine nonabrasive materials, liner products like glass and ultra-high-molecular-weight polyethylene show improved friction values for sticky materials. Poke holes provide some relief but are usually inadequate. Air cannons can be installed to shear the material during drawdown in finer materials. Vibrating bin bottoms and vibrating motors mounted on the side of hoppers can improve flow in some cases. When these methods are not a viable option, serious consideration should be given to a different system of reclaiming, preferably the use of buckets or surface equipment.

Packing can be the result of many factors such as adverse moisture content, freezing, cementing action, or pressure from vehicles or overlying material. When material exhibits a tendency to pack, overhead equipment for material placement and equipment with a strong digging action for reclaiming should be used. Drag scrapers, loaders, or shovels working at the pile edges may be satisfactory. When reclaiming with loaders or shovels, the operator must be alert for the formation of "cliffs" that may collapse suddenly, endangering personnel and equipment. In extreme cases, it may be necessary to blast or rip material and to crush the material to regain the required particle size. Plugging of drawpoint openings as a result of interlocking of coarse particles can be corrected by proper sizing of opening dimensions (Figure 11).

Care must be exercised in designing gates for the regulation and flow control of floodable materials. Feeder selections should only be made after consultation with the equipment manufacturer. Abrasive and corrosive properties have little effect on flow characteristics, but they are important in selecting construction materials. Hoppers and chutes for reclaiming or transferring stockpiled materials are usually fabricated from steel plate. Ordinary mild steel is satisfactory when the hardness of the bulk material is 4 or less on the Mohs hardness scale. Mild abrasion occurs when the Mohs hardness is between 5 and 7; severe abrasion is likely for hardnesses between 8 and 10. However, hardness alone is not a valid guide to abrasive wear. Particle shape, weight, and angularity;

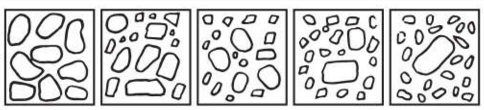
sharpness of edges; flow rate; and amount of impact influence the abrasive wear rate.

If severe abrasion is encountered, AR liners can be installed at wear points. Some operators try to anticipate these before starting operation while others install unlined hoppers and chutes, run them for a brief period, and shut down to install liners at points that exhibit the greatest wear. In either case, further abrasion occurs on an expendable liner and the costlier conveying structure is given extended operating life. Table 6 provides a summary of common problems encountered in reclaiming material from stockpiles, including preventive and corrective procedures.

Unprotected Stockpiles

Protection of stockpiles is often omitted when the type of stacking and reclaim equipment and the scale of the stockpile make protection uneconomic. Stockyards where boom stacking conveyors are used for stacking multiple linear-windrow stockpiles and bucket-wheel reclaimers are used to reclaim the material are too large for covering by buildings. Large conical stockpiles are often more than 50 m high, which often makes protecting the stockpile from the elements uneconomical. Water sprays may be used for dust suppression of fine material, with chemicals added to form a crust that is resistant to wind blowing up dust.

Ore Type →



Throat Opening Factor:	3½	3	2½	2	1½
Percent Larger-Size Pieces:	95–100	60–80	40–60	20–30	5–10
Other Conditions:	Screened	Mine Run	Mine Run	—	—

Throat opening selection. To determine the throat opening, (1) select the picture that matches the type of material to be handled, and (2) select the corresponding throat opening factor. Multiply the factor by the largest dimension of the biggest piece of material. This will provide the minimum throat opening to prevent bridging.

Figure 11 Throat opening size

Protection of Stockpiles

Indoor Storage

Building configuration generally is determined by stockpile type and placement, and by the reclaiming equipment used. Buildings are of three general shapes: (1) conical, including domes and semi-domes; (2) tent-shaped, including arches; and (3) box-shaped, rectangular, and flat-roofed.

Conical and radial windrow stockpiles are often stored in dome, semi-dome, or conical buildings where freezing during winter months or high seasonal rainfall may reduce the free flowing of material. Conical stockpiles could also be protected when the stored material poses an environmental or health risk (e.g., because of asbestos in the ore) or where product loss is unacceptable (e.g., with high-grade gold ore fines). Short windrow stockpiles can be protected by tent-shaped or box-shaped buildings.

Table 7 provides information on building type, construction materials, stockpile type, and placing and reclaiming equipment for the various building types. Figures 12 and 13 are examples of indoor storage. Common construction materials are steel, wood, aluminum, and concrete; the choice is usually determined by the corrosive characteristics of stockpiled material. However, protective coatings permit the use of non-corrosion-resistant materials having adequate stiffness and strength. When in doubt, the effect of raw material on structural components should be tested.

Temporary Covers

Plastic, canvas, or other film coverings are often adequate for temporary protection. Nylon-reinforced plastic covers are

Table 6 Problems encountered in reclaiming materials from stockpiles

Problem	Preventive Measures	Corrective Measures
Bridging or arching over drawpoint	Design hopper slopes to be steeper than minimum angle of slide. Make hopper opening as wide as possible. Use multiple openings close to each other.	Use flow-promoting methods. Provide poke holes. Agitate material with vibration, aeration, and pulses.
Ratholing	See bridging above.	See bridging above. Use equipment such as drag scrapers, drag conveyors, or screw conveyors to move the material along the top of pile to the hole.
Packing	Avoid placing weight on the material and compacting it. If excessive moisture is part of the problem, dry the material before stockpiling.	Rip, scarify, or blast material to dislodge it from the pile. In extreme cases, it may be necessary to crush material to regain desired range of sizes.
Plugging of openings	Design the openings to be large enough to handle the largest dimension of maximum particle size. Steepen slopes of chutes and hoppers; use low-friction liners; use coatings to reduce resting and roughening of surface.	Rodding is probably the only effective method.
Flooding	Select gates and feeders that provide positive shutoff of flow.	Install replacement gates and feeders that provide positive shutoff of flow.
Abrasions	Use abrasion-resistant liners, alloy plates, epoxy coatings, fiberglass coatings, or rubber linings. Use dead beds at impact points.	Use abrasion-resistant liners, epoxy or fiberglass coatings, or rubber linings.
Corrosion	Select corrosion-resistant materials. Use protective coatings; avoid the use of dissimilar metals or employ insulators.	Remove products of corrosion by sanding; apply protective coatings to the cleaned surfaces.
Caving materials	Keep shovels and loaders away from toe of wall to avoid damage from fall of material.	Break down "cliffs" with boom or cable before it becomes too high and too steep.

Table 7 Types of buildings used to protect stockpiles from weather

Types of Buildings	Materials of Construction	Types of Stockpiles	Placing Equipment Commonly Used	Reclaiming Equipment Commonly Used
Cones or domes	Frame • Steel • Wood • Aluminum • Plastic Cover • Steel • Wood • Aluminum • Plastic • Protected metal	Conical piles Radial windrows	Conveyors • Belt • Screw • Shuttle • Trippers • Slingers • Pneumatic	Feeders Conveyors Rotary reclaimers Loaders
A-frames or arches	Frame • Steel • Wood Cover • Steel • Wood • Aluminum • Plastic • Protected metal	Windrow (parallel)	Conveyors • Belt • Screw • Shuttle • Trippers • Slingers Drag scrapers	Feeders Conveyors • Belt • Screw • Drag Drag scrapers Loaders Rotary reclaimers
Box or rectangular frames	Frame • Steel • Concrete Cover • Steel • Wood • Aluminum • Plastic • Protected metal • Concrete	Windrows (parallel) Bins on ground, craneways	Conveyors • Belts • Screws • Shuttles • Trippers • Slingers Drag scrapers Cranes, bridge with clamshell bucket	Feeders Conveyors • Belt • Screw • Drag Drag scrapers Loaders Rotary reclaimers Crane, bridge with clamshell bucket

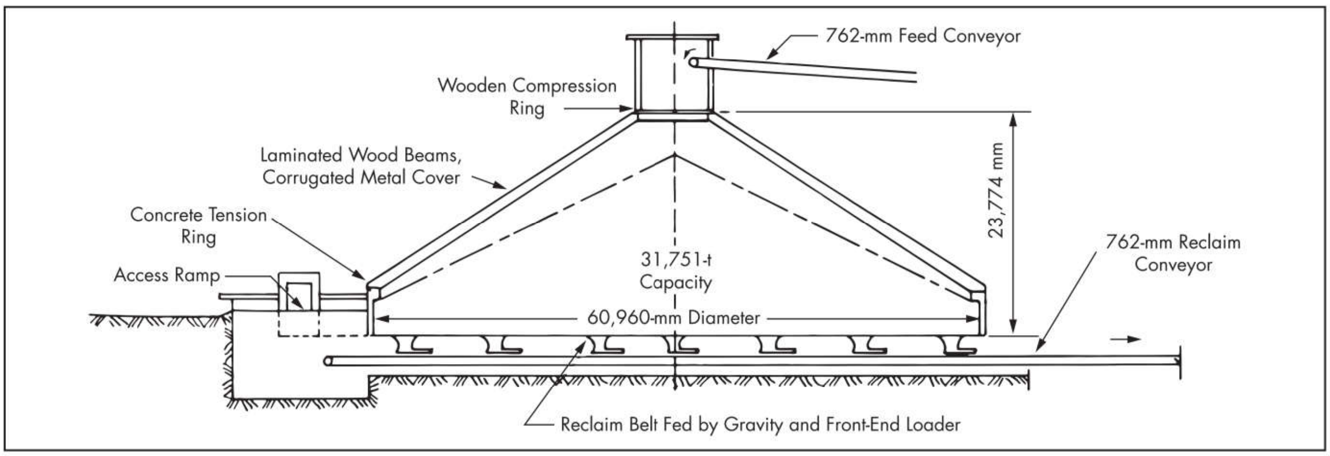


Figure 12 Conveyor reclaim system in a semi-dome, indoor stockpile system

available in different sizes up to 60 × 60 m. Generally, the sheet size is limited by the purchaser's handling capabilities. For cover hold-down, the sheet should be tied at the pile bottom (fastened to a plank border) to prevent stress concentrations. Weights should be placed along the pile top and sides so that wind action does not damage the cover. Sacks filled with stockpiled material can be used as weights to avoid contamination through breaking and spillage of the sacks. Various weights and grades of plastic covers are available. For large stockpiles, three- or four-ply material is recommended.

BINS

The top, vertical portion of a bin is called the *cylinder* and the bottom converging portion, the *hopper*. Purpose and process requirements determine bin capacity and discharge flow rate. Bin type and flow control device depend on storage requirements, material characteristics, discharge rate, anti-segregation and blending requirements, temperature, operating controls, and number of drawpoints. Possible constraints are plant layout, headroom, and foundation restrictions.

Bin Flow Patterns

The three flow patterns in bins are mass, funnel, and expanded (Figure 14). In mass flow bins, all the material is in motion within the bin when the material is drawn from the outlet. The bin hopper must be sufficiently steep, the surface-to-material friction low, and the feeder under the hopper outlet must draw material across the full outlet area. There is material flowing along the wall of the cylinder section and the hopper section of the bin. Since mass flow bins do not channel, they have a first-in, first-out flow sequence with a relatively uniform residence time for all particles and depend only to a small degree on initial position of the particles in the bin. Fine particles or powders flow uniformly and without flooding or flushing from mass flow bins, providing the bin level is maintained, allowing for deaeration, and a shutoff gate is available for initial filling. With mass flow bins, complete discharge of the bin contents is guaranteed.

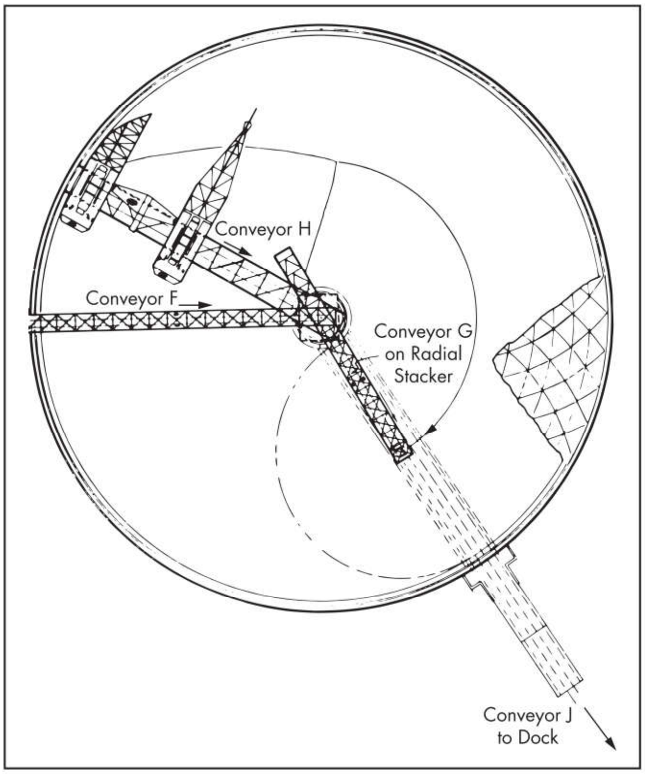


Figure 13 Indoor dome storage with a radial stacker and reclaimer

Materials that degrade and cake have a minimum residence time in mass flow bins. Caking can be prevented and blending achieved by recirculating material through a mass flow bin. Suitably designed mass flow bins also can provide nonsegregating storage. Even though material segregates during placement into a bin, the various fractions remix in the hopper and are withdrawn in the same proportion as charged. Level indicators work reliably in mass flow bins.

In funnel flow bins, material flows toward the outlet through a channel extending upward from the discharge point. The drawdown opening governs the size of a flow channel that develops above the opening. The walls of the flow channel extend slightly, diverge from the opening, and are surrounded by stagnant material. In some extreme cases, the flow channel walls may be vertical. As material discharges, the channel level drops and layers of stagnant material slough from the top of the surrounding mass into the channel. Funnel flow is the result when the bin hopper wall is not steep enough and the surface-to-material friction is too high to achieve mass flow. This pattern leads to a first-in, last-out flow sequence because most of the material that was first deposited at the bin bottom around the channel does not discharge until the bin is emptied.

In all bins, segregation occurs at the impact point of the falling material. In funnel flow bins, there is no remixing of segregated material in the hopper. Funnel flow bins may lead to piping (ratholing) when stagnant material consolidates and they remain stable after the channel empties. Flooding or flushing may result when layers slough from the top of the stagnant mass and hit the channel bottom or as loose material is loaded into a bin and rushes to the outlet. Conventional level indication does not provide a reliable indication of the bin's content or condition.

Funnel flow bins are acceptable only for chemically stable and nonsegregating materials. Coarse, free-flowing material often contains a fine, non-free-flowing fraction. This fine

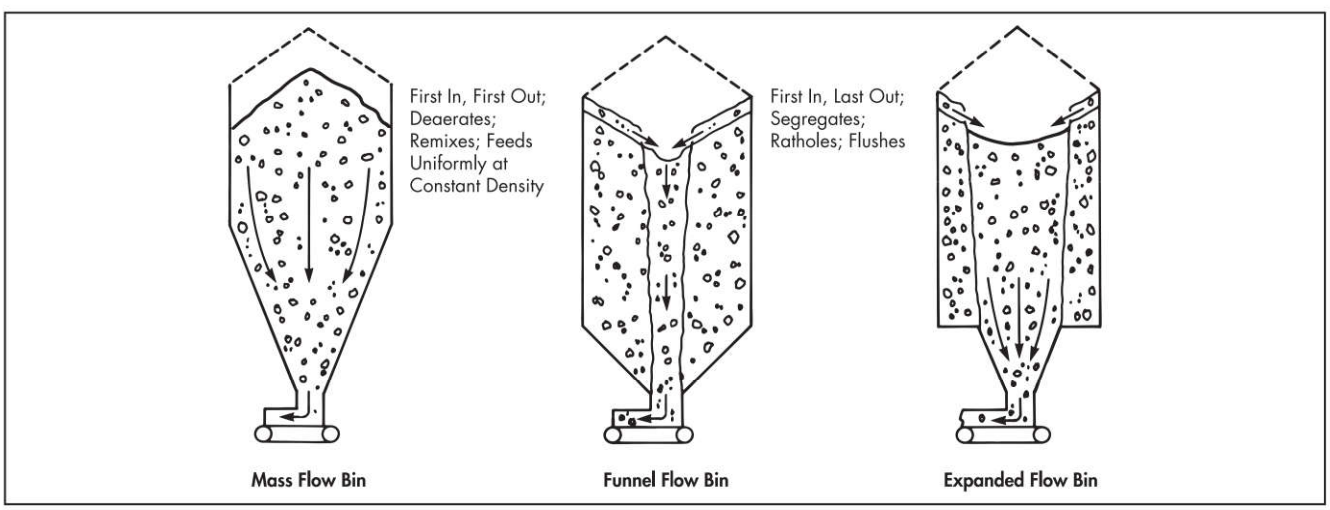
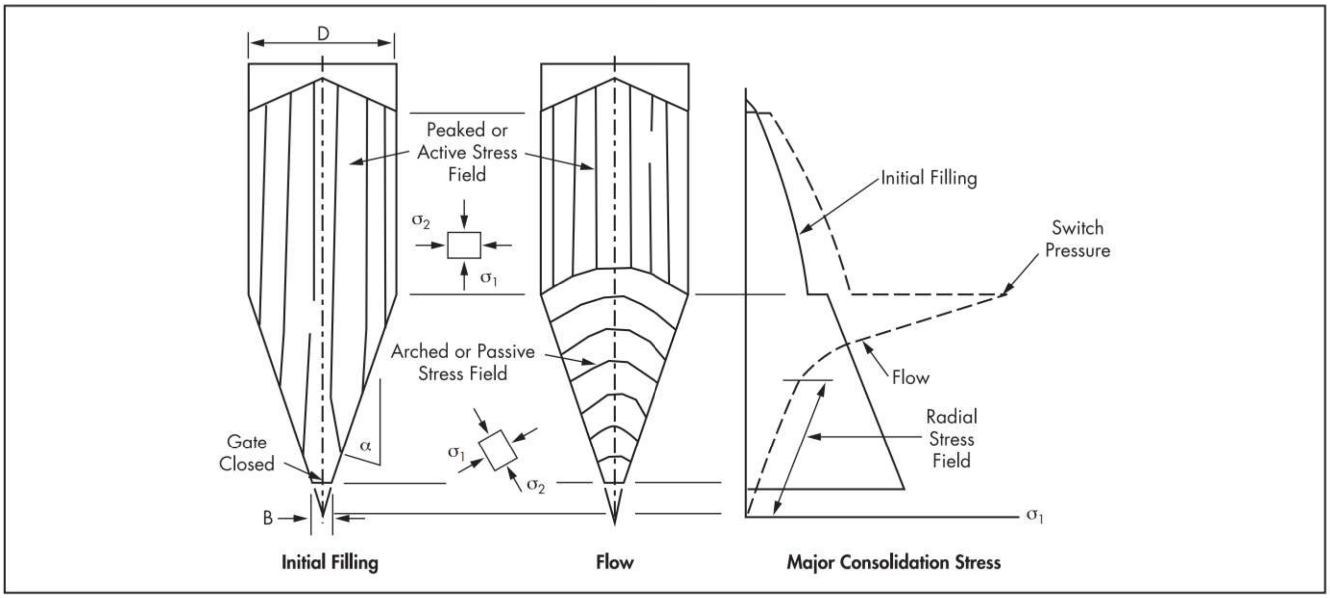


Figure 14 Types of bins



Source: Roberts 2005

Figure 15 Stress fields for initial filling and flow in mass flow bins

fraction may be uniformly distributed throughout the material when placed in the bin, but fines tend to segregate in the bin and percolate into stagnant regions. To prevent loss of live capacity, funnel flow bins for coarse materials should be emptied completely at regular intervals.

Expanded flow combines the wall protection that funnel flow offers with the reliable drawdown of mass flow. The hopper section of the bin is designed for mass flow while the cylinder section for funnel flow. The size of the hopper section opening at the transition should be at least equal to the critical rathole dimension at that height. The mass flow hopper eliminates the possibility of piping (ratholing), ensures deaeration and smooth flow, and reduces segregation. Expanded flow bins are used when storage of large volumes of material is required at acceptable bin heights. This design is also useful in storing large quantities of non-degrading materials. A low-level indicator can be placed within the mass flow hopper. Several mass flow hoppers can be placed under a storage pile or expanded flow bin to reduce dead storage.

Bin Geometry

Bin geometry is determined by volume and flow requirements, taking into consideration maximum pressure limitations. Design for strength of the bin structure needs to take into account the initial and flow stress-field conditions. Resulting stress-field patterns are determined by the bin geometry. When the bin is filled from the empty condition, a peaked or active stress field develops with the major principal stress almost vertically acting on the bottom of the bin and drawdown gate. Once the bin is being drawn down and material flow starts inside the bin, the vertical reaction provided by the gate is removed and the load is transmitted to the hopper walls. The stress field in the hopper changes from a peaked stress field to an arched stress field up to the transition from hopper section to cylinder section. Once a stable stress field is obtained, it is retained even after drawdown is stopped. This means that the load on the gate once the flow has stopped is significantly lower than during initial fill from empty. A major part of the material load in the cylinder section is carried by the upper region of the hopper due to the arched stress field in the hopper. The stresses at the discharge are relatively quite low. Figure 15 presents a graphical representation.

Methods of Placing Material in Bins

Conveyors and buckets are used to place material in bins, as previously described. Material segregation and degradation are minimized during placement in the bin by the same methods used in stockpiling.

Bin Selection

A bin, silo, or bunker generally consists of a vertical cylinder and a sloping converging hopper. Based on the flow pattern that develops, there are three types of bins: mass flow, funnel flow, and expanded flow. The type of bin selected should have the desired capacity, be capable of discharging its contents reliably on demand, and be safely constructed.

Jenike (1964) developed the continuum mechanics approach to hopper design. He defined "mass flow" and showed how the flow properties of bulk solids could be measured as well as how these measurements could be used to design hoppers. Jenike is most strongly associated with the Jenike shear tester. Jenike developed the "rational design method" for bins and hoppers, based on continuum mechanics. As described by Bradley et al. (2011), this method is based on a model of stress distribution in the hopper, calculated using measurements of the flow properties of the material being handled. It predicts the flow pattern that will occur and whether or not flow will be reliable. Bradley et al. note that "… provided the material tested is representative of that loaded into the plant, and any issues of change in moisture content, time in static residence, caking effects etc. are taken into account, it delivers a hopper design that can be guaranteed to work."

Unfortunately, the cost of the testing required for the use of the rational design method can be quite high. Tests using Jenike's shear tester can easily take two days' work by a highly skilled technician to determine the properties of one

Table 8 Important flow properties

Parameter	Measured by	Useful for Calculations of
Cohesive strength	Shear tester	Outlet sizes to prevent arching and ratholing
Frictional properties	Shear tester	Hopper angles for mass flow, internal friction
Sliding at impact points	Chute tester	Minimum angle of chute at impact points
Compressibility	Compressibility tester	Pressure calculations, bind loads, feeder design
Permeability	Permeability tester	Discharge rate calculations, settlement time
Segregation tendency	Segregation tester	Predicting whether segregation will occur
Abrasiveness	Abrasive wear tester	Predicting the life of a liner
Friability	Annular shear tester	Maximum bin size, effect of flow pattern on particle breakage

Source: Carson and Holmes 2002

material. Subsequent designs improved on Jenike's original, and it is now reasonable to test materials in a short time and at a reasonable cost. Several companies offer this service.

A procedure for designing and sizing a storage bin should include the following steps.

Step 1. Define the Storage Requirements

Identify the operating requirements and conditions. Some of the more important ones include the following:

- **Capacity.** This will vary with the plant's operating philosophy and where the bin is to be located (e.g., start of your process, at an intermediate process step, or at the end).
- **Discharge rate.** Consider average and instantaneous rates, minimum and maximum rates, and whether the rate is based on volume or mass.
- **Discharge frequency.** How long will your material remain in the bin without movement?
- **Mixture and material uniformity.** Is particle segregation a concern in terms of its effects on material discharge or, more importantly, downstream processes?
- **Pressure and temperature.** Consider differences between the bin and upstream and downstream equipment.
- **Environmental.** Are there explosion risks, human exposure concerns, and so forth?
- **Construction materials.** Abrasion and corrosion concerns may limit the types of materials you can use to construct your bin.

Step 2. Calculate the Approximate Size of the Bin

Initially, ignore the hopper section. Use the following formula to estimate the approximate height of the cylinder section that is required to store the desired capacity:

$$H = \frac{C}{\gamma_{avg} A}$$

where

H = cylinder height, m
C = bin capacity, m^3
γ_{avg} = material's average bulk density, kg/m^3
A = cross-sectional area of cylinder section, m^2

The actual cylinder height will have to be adjusted to account for volume lost at the top due to the material's angle of repose as well as for the volume of material in the hopper section. In general, the height of a circular or square cylinder should be between about 1.5 and 4 times the cylinder's diameter or width. Values outside this range often result in designs that are uneconomical or have undesirable flow characteristics. It is important to recognize that a bin's storage volume and its active (live, useable) volume are not necessarily the same. With a funnel flow or expanded flow pattern (described later), significant dead (stagnant) volume may need to be taken into account.

Step 3. Determine Your Material's Flow Properties

The flow characteristics of a bulk solid must be known to predict or control how it will behave in a bin or hopper. These characteristics can be measured in a solids flow testing laboratory under conditions that accurately simulate how the solid is handled in the plant. Tests should be conducted on-site if the solid's properties change rapidly with time or if special precautions must be taken.

The most important bulk solids handling properties that are relevant to predicting flow behavior in bins and hoppers are listed in Table 8. Each of these parameters can vary with changes in the following:

- Moisture
- Particle size, shape, hardness, and elasticity
- Temperature
- Time of storage at rest
- Chemical additives
- Pressure
- Wall surface

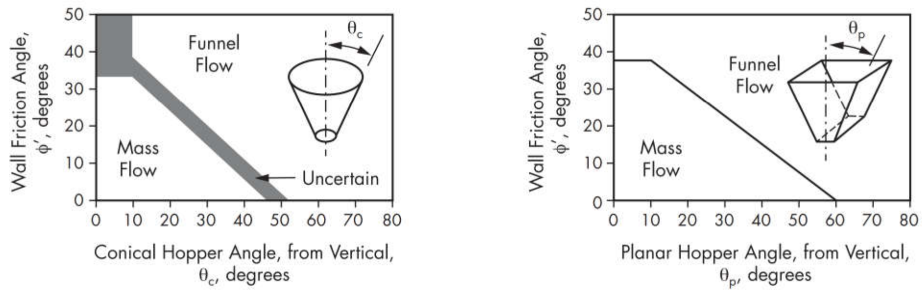
The appropriateness of these bin design parameters has been proven over many years in thousands of installations handling materials as diverse as fine chemical powders, cereal flakes, plastic granules, and mined ores.

Step 4. Understand the Importance of Flow Patterns

Although it is natural to assume that a bulk solid will flow through storage or conditioning vessels in a first-in/first-out sequence, this is not necessarily the case. Most bins, hoppers, silos, and conditioning vessels move solids in a funnel flow pattern.

With funnel flow, some of the material moves while the rest remain stationary. This first in/last-out sequence is acceptable if the bulk solid is relatively coarse, free flowing, nondegradable, and if segregation is not important. If the bulk material and application meet all four of these criteria, a funnel flow bin is the most economical storage device.

Unfortunately, funnel flow can create serious problems with product quality or process reliability. Arches and ratholes may form, and flow may be erratic. Fluidized powders often have no chance to deaerate. Therefore, they remain fluidized in the flow channel and flood when exiting the bin. Some materials cake, segregate, or spoil. In extreme cases,



Source: Carson and Holmes 2002

Figure 16 Typical charts for determining mass flow wall angles

unexpected structural loading can result in equipment failure. These problems can be prevented with storage and conditioning vessels specifically designed to move materials in a mass flow pattern. With mass flow, all material moves whenever any is withdrawn. Flow is uniform and reliable; feed density is independent of head solids in the bin; there are no stagnant regions, so material will not cake or spoil and low-level indicators work reliably; sifting segregation of the discharge stream is minimized by a first-in/first-out flow sequence; and residence time is uniform, so fine powders are able to deaerate. Mass flow bins are suitable for cohesive materials, powders, materials that degrade with time, and whenever sifting segregation must be minimized.

A third type of flow pattern is called expanded flow. In this pattern, the lower part of a bin operates with flow along the hopper walls as in mass flow, while the upper part operates in funnel flow. An expanded flow bin combines the best aspects of mass and funnel flow. For example, a mass flow outlet usually requires a smaller feeder than would be the case for funnel flow. This flow pattern is suitable for storage of large quantities of nondegrading solids. It can also be used with multiple outlets to cause a combined flow channel larger than the critical rathole diameter.

Step 5. Follow These Detailed Design Procedures

Step 5A, mass flow. To achieve a mass flow pattern, it is essential that the converging hopper section be sufficiently steep and have low enough friction to cause flow of all the solids without stagnant regions whenever any solids are withdrawn. In addition, the outlet must be large enough to prevent arching and to achieve the required discharge rate.

Typical design charts showing the limits of mass flow for conical- and wedge-shaped hoppers are given in Figure 16. Hopper angle (measured from vertical) is on the abscissa, and wall friction angle is on the ordinate. For example, mass flow will occur in a conical hopper that has an angle of 20° and is constructed from or lined with a wall material that provides a wall friction angle of 23° or less with the stored bulk solid. Making the hopper walls less steep by 4° or more could result in funnel flow. Alternatively, keeping the wall angle at 20° but increasing the wall friction angle to 28° or more would also result in funnel flow.

Step 5B, funnel flow. The key requirements for designing a funnel flow bin are to size the hopper outlet large enough to overcome arching and ratholing, and to make the hopper slope steep enough to be self-cleaning. Minimum dimensions to overcome arching and ratholing require knowledge of the material's cohesive strength and internal friction. The requirement for self-cleaning can usually be met by making the hopper slope 10° to 15° steeper than the wall friction angle.

Step 5C, expanded flow. Consideration must be given to both the mass flow and funnel flow sections. In the lower mass flow section, the procedure outlined above for a mass flow hopper should be followed. In addition, the flow channel must be expanded to a diagonal or diameter equal to or greater than the material's critical rathole diameter, which can be calculated using the procedure in Janike (1964). Here too, the hopper slope in the funnel flow portion should be steep enough for self-cleaning.

Step 6. Consider the Bin's Shape

At first glance, it might appear that a square or rectangular straight-sided section at the top of a bin is preferable to a circular cross section. Such bins are easier to fabricate and have greater cross-sectional area per unit of height. However, these advantages are usually overcome by structural and flow considerations.

A circular cylinder is able to resist internal pressure through hoop tension, whereas flat walls are subjected to bending. Thus, thinner walls and less external reinforcement are required with circular cross sections. In addition, there are no corners in which material can build up. This is particularly important when interfacing with a hopper at the bottom.

Following are several factors to consider when choosing hopper geometry:

- **Sharp versus rounded corners.** Pyramidal hoppers usually cause a funnel flow pattern to develop because of their inward-flowing valleys that are less steep than adjacent sidewalls. Conical, transition, and chisel shapes are more likely to provide mass flow because they have no corners.
- **Headroom.** Typically, a wedge-shaped hopper (e.g., transition or chisel) can be 10° to 12° less steep than a conical hopper and still promote mass flow. This can provide significant savings in hopper height and cost, which is particularly important when retrofitting existing equipment in an area of limited headroom. In addition, a wedge-shaped hopper design is more forgiving than a cone in terms of limiting hopper angles and wall friction.
- **Outlet sizes.** To overcome a cohesive or interlocking arch, a conical hopper must have an outlet diameter that is roughly twice the outlet width of a wedge-shaped hopper (provided the outlet length is at least three times its width). Thus, cones generally require larger feeders.

- **Discharge rates.** Because of the increased cross-sectional area of a slotted outlet, the maximum flow rate is much greater than that of a conical hopper.
- **Capital cost.** Each application must be looked at individually. Although a wedge-shaped hopper requires less headroom or a less expensive liner than a cone, the feeder and gate (if necessary) may be more expensive.
- **Discharge point.** In many applications, it is important to discharge material along the centerline of the bin to interface with downstream equipment. In addition, having a single inlet point and single outlet, both located on the bin's centerline, minimizes flow and structural problems. Generally, conical hoppers are better for these situations, particularly if only a gate is used to stop and start flow.
- **Mating with a standpipe**. If material is being fed into a pressurized environment, a circular standpipe is often preferred to take the pressure drop.

Step 7. Consider Other Important Factors

Some additional considerations include the following:

- **Gate.** A slide gate at the outlet of a bin must generally be used only for maintenance purposes, not to control or modulate the flow rate. Therefore, it should only be operated in a full-open or full-closed position.
- **Feeder.** The feeder's design is as important as that of the bin above it. The feeder must uniformly draw material through the entire cross section of the bin's discharge outlet to be effective.
- **Mating flanges.** The inside dimensions of the lower of two mating flanges must be oversized to prevent any protrusions into the flowing solid. The amount of oversize depends on the accuracy of the construction and erection. Usually 2–3 cm overall is sufficient. If gaskets or seals are used, care must be taken to ensure that these do not protrude into the flow channel. All flanges should be attached to the outside of the hopper, with the hopper wall material being the surface in contact with the flowing solids. This ensures that the flange and gasket do not protrude into the flowing solids.
- **Interior surface finish.** Whenever possible, welding should be done on the outside of the hopper. If interior welding is necessary, all welds on sloping surfaces must be ground flush and power brushed to retain a smooth surface. After welding, all sloping surfaces must be clean and free of weld spatter. The surface finish is most critical in the region of the hopper outlet. Therefore, any blisters in this area from exterior welding must be brushed smooth. Horizontal or diagonal welded connections should preferably be lapped with the upper section on the inside so the resulting ledge does not impede flow. If horizontal butt welds are used, care must be taken to avoid any protrusion into the flowing solid.
- **Liner attachment.** Inside liners, such as stainless sheet or ultra-high-molecular-weight polyethylene, must be placed on sloping surfaces with horizontal or diagonal seams lapped with the upper liner on top in shingle fashion. Vertical seams may be either lapped or butted.
- **Abrasive wear considerations.** In mass flow, a bulk solid flows against the hopper and cylinder walls. Handling an abrasive bulk solid may result in significant abrasive wear of the wall material, including coatings and liners. Therefore, when designing a mass flow hopper, it is important to assess the potential for abrasive wear. Generally, a hopper surface becomes smoother with wear. However, a wall occasionally becomes rougher, which may upset mass flow. The life of a given wall material can be estimated by conducting wear tests.
- **Access doors and poke holes.** In general, poke holes are not recommended in mass flow bin designs because they have a tendency to prevent flow along the walls, thus creating a problem that mass flow bins are intended to solve. Access doors are also a frequent cause of problems. If they are essential, it is better to locate them in the cylinder rather than in the hopper section.
- **Structural design issues.** It is important that the bin be designed to resist the loads applied to it by both the bulk solid and external forces. This is particularly important when designing, or converting, an existing bin to mass flow because unusually high localized loads may develop at the transition between the vertical section and the mass flow hopper.
- **Bulk materials of inferior flowability** (e.g., more cohesive, with larger critical arching and ratholing dimensions than the material upon which the design was based, or more frictional, requiring steeper wall angles) should not be placed in the bin because flow obstructions are then likely to occur. Such obstructions may lead to the development of voids within the bin and impose dynamic loads when material collapses into the voids. Bin failures have occurred under such conditions.
- **Prefabrication drawing review.** Before fabrication of the bin and feeder, an engineer trained in solids flow technology should review all detailed design drawings. This review is necessary to ensure that the design follows the recommendations and that any design details or changes are consistent with reliable bulk solids flow.

Outlet Sizing

In most applications, a feeder is used to control discharge from a bin or hopper. For such applications, the maximum achievable flow rate through the hopper outlet must exceed the maximum expected operating rate of the feeder. This ensures that the feeder will not become starved. This is particularly important when handling fine powders, since their maximum rate of flow through an opening is significantly less than that of coarser particle bulk solids whenever a mass flow pattern is used. In addition, any gates must not interfere with material discharge.

The following step-by-step procedure will assist in properly sizing a hopper outlet.

Step 1. Calculate the Ratio of Outlet Width or Diameter-to-Particle Size

Flow stoppages due to particle interlocking are likely if the diameter of an outlet is less than about six times the particle size. With an elongated outlet, problems are likely if the ratio of outlet width to particle size is less than about 3:1.

Step 2. Determine Whether the Material Is Coarse, Easy Flowing, or Fine

For purposes of flow rate calculations, a bulk solid is often considered coarse if no more than 20% will pass through a 0.7-cm screen. Whether or not a material can be considered easy flowing depends on the cohesiveness of the bulk solid, the dimensions of the container in which it is stored, and whether or not any excess pressures are applied to the material (e.g., the container is vibrated after being filled). If the combination of these factors results in no flow stoppages at the vessel's outlet (due, for example, to arching or ratholing), the aterial can be considered easy flowing in that application.

A fine powder is a bulk solid whose flow behavior is affected by interstitial gas. Common household examples of fine powders include flour and confectioner's (icing) sugar.

Step 3. Determine Maximum Achievable Flow Rates

Step 3A. The bulk material is coarse but not easy flowing. Either the outlet size must be increased or the material's cohesive strength must be decreased to allow the material to flow.

Step 3B. The bulk material is coarse (>500 mesh) and easy flowing. If the ratio of outlet size to particle size is sufficiently large to prevent particle interlocking, then the maximum achievable rate through an orifice of a coarse, easy flowing bulk solid such as plastic pellets is given by the Johanson (1965) equation:

$$\dot{m} = \rho^{\circ} A \sqrt{\frac{Bg}{2(1+m)\tan\theta}}$$

where

θ = semi-included angle of the hopper
$\dot{m}$ = discharge rate, kg/s
ρ° = bulk density, kg/m^3
g = gravity acceleration, 9.807 m/s^2

Parameters B, A, and m depend on whether the discharge is conical or a symmetrical slot, as shown in Table 9. For a symmetrical slot opening, W (width) is the smaller dimension of the slot and L (length) is the larger.

With a mass flow hopper, the flow channel coincides with the hopper wall; hence, zero is the hopper angle. On the other hand, with a funnel flow hopper, the flow channel forms within stagnant material and, while it is steeper than in mass flow, it is variable. Thus, the maximum flow rate from a funnel flow hopper is generally higher but less predictable than the flow rate from a mass flow hopper having the same outlet size.

Table 9 Parameters in the Johanson equation

Parameter	Conical Hopper	Symmetrical Slot Hopper
B	D, diameter of outlet	W
A	$\frac{\pi}{4}D^2$	WL
m	1	0

Source: Chase 2015

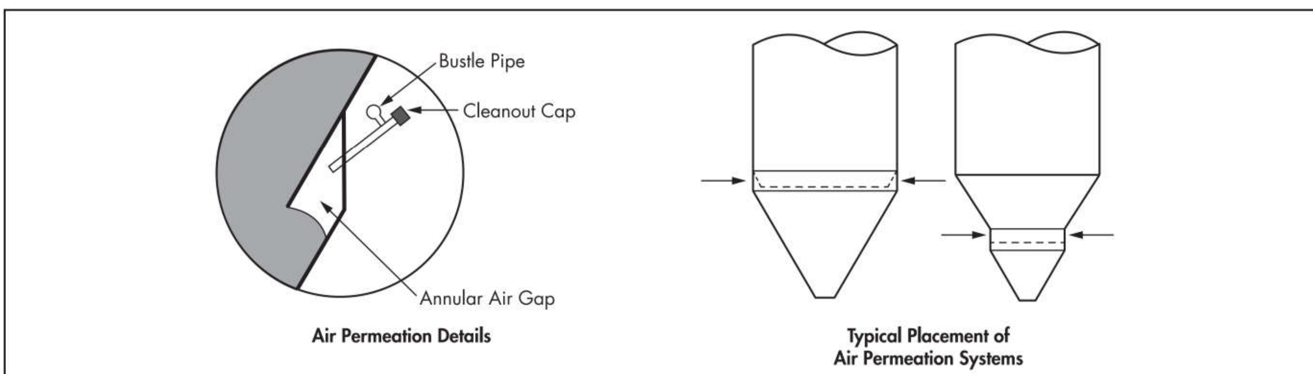
A theoretical expression for funnel flow discharge of fine powders is not available. An empirical equation was derived by Beverloo et al. (1961) based on testing a variety of seeds.

Step 3C. The bulk material is a fine powder. Fine powders are often mishandled in funnel flow bins. Fine powders have little or no chance to deaerate in such bins. Instead, they often remain fluidized in the flow channel and flood uncontrollably when exiting the bin. A funnel flow pattern should therefore be avoided when handling fine materials.

Mass flow bins, on the other hand, can provide predictable and controlled rates of discharge of fine powders as well as other bulk solids. Unfortunately, a fine powder's maximum rate of discharge through a mass flow hopper outlet is often several orders of magnitude lower than the limiting rate of a coarse particle material having the same bulk density. This severe flow rate limitation is the result of the upward flow of air through the hopper outlet caused by the slight vacuum condition, which naturally forms in the lower portion of a mass flow hopper as material flows through it.

The limiting rate of material flow through a mass flow hopper outlet can be calculated once the powder's permeability and compressibility have been measured. If the limiting discharge rate is too low, there are several ways to increase it:

- **Increase the outlet size.** Since the limiting rate is approximately proportional to the crosssectional area of the outlet, doubling the diameter of a circular outlet increases the maximum discharge rate by roughly a factor of 4.
- **Decrease the level of material in the bin.** Fine powders do not behave like fluids. Thus, lower heads result in higher discharge rates, although the effect is generally not very pronounced.
- **Provide an air permeation system, as shown in Figure 17.** This has the effect of partially satisfying the vacuum condition that naturally develops. As a result, there is less need for air to be pulled up through the outlet counter to the flow of particles. With such a system, the maximum flow rate can often be increased by a factor of between 2 and 5.



Source: Carson and Holmes 2002
Figure 17 Air permeation system for discharge of fine powders

If none of these will allow the desired discharge rate, fluidization, as discussed in the next step, can be considered.

Step 3D. The bulk material is a fine powder and the required discharge rate is high. Fine particles (<500 µm) tend to flow slower by a factor of 100 to 1,000 than that predicted by the Johanson equation. This is because the effect of air drag on the motion of the particles is much greater for fine particles.

Particle beds need to dilate (increase distance between particles) before the powder can flow. This means air must penetrate into the bed through the bottom surface of the hopper as the powder moves through the constriction formed by the conical walls. For fine particles, the pore diameters in the powder bed are small and there is a significant amount of air drag that resists the powder motion. Carleton (1972) gives an expression for predicting the velocity of fine particles in a moving bed.

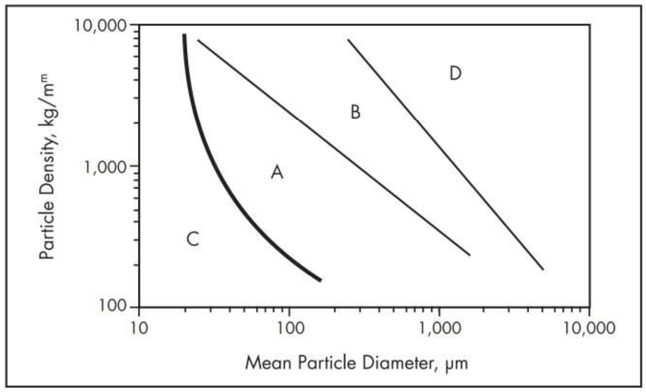
If the limiting flow rate from a mass flow hopper is still too low, consideration should be given to fluidizing the fine powder and handling it like a liquid. For this technique to be successful, it is generally necessary that the powder have low cohesion and low permeability. Low cohesion allows the material to fluidize uniformly, so the air does not channel around large lumps. With a low-permeability material, significant pressure gradients can be established and the material takes a long time to deaerate.

The Geldart chart, shown in Figure 18, provides a rough indication of whether a particular material is a good candidate for fluidization. Powders falling within classifications A and B are generally considered good candidates, while category C materials are difficult to fluidize. Category D materials are acceptable for fluidization, but the bed settles quickly and high gas rates are required.

If the bin is small, it may be practical to fluidize the entire contents. With larger bins, this is neither practical nor necessary. However, if only localized regions are fluidized, consideration must be given to the potential for arching and ratholing in non-fluidized regions. In some cases, it is necessary to only fluidize intermittently, while in other cases, continuous fluidization is required during discharge. Whether batch or continuous discharge is required will influence this, but there are other factors to consider as well.

When considering the fluidization option, several operational requirements must be evaluated:

- The bulk density of the discharging material will be lower than if the material were not fluidized. Therefore, a given mass will occupy more volume, which could result in downstream equipment (such as a bulk bag, hopper, or railcar) receiving less than the desired mass even though it is full.
- The material's bulk density will also vary with time, depending on the degree of fluidization of the discharging material. This can present process problems downstream.
- Some materials are hygroscopic, while others are explosive. In such cases, dry air or inert gas may be required for fluidization. Higher energy and gas consumption rates must be taken into account as an additional operating cost.
- The feeder controlling the discharge must be capable of metering fluid-like materials, but this should be avoided if particle segregation is a concern.



Source: Carson and Holmes 2002

Figure 18 Geldart's fluidization classification

Problems Encountered in Bins

The successful operation of gravity storage bins is predicated on reliable flow of material to the bin outlet. Many problems associated with discharging material from bins are similar to problems encountered in reclaiming material from stockpiles. However, the best solution to these problems is proper bin design.

Many bin problems are related to improper operation of bin and feeder. The principal flow problems are no flow, erratic flow, flooding or flushing, lack of specified storage capacity, degradation, and segregation. No flow occurs when stored material forms a stable dome above the outlet or higher within the bin. Severe vibration, poking, air-lancing, knocking, and even explosives are needed to maintain flow. Erratic flow occurs when momentary domes form within the flow channel and interrupt flow. When the dome collapses, flow resumes and flow rate control is difficult. Dome collapse may result in large impact loads on the bin bottom and causes structural failures. When dry fine materials (powders) flow erratically, they tend to aerate, fluidize, and flush. Material in dead regions is unavailable for processing without an interruption of operations. Furthermore, material may remain in storage for a long time and possibly deteriorate through chemical or physical change.

The flow pattern within the bin is important for minimizing segregation. Materials containing a particle size range will segregate during placement in bins unless special distributing chutes are used. The degree or remixing or the separate fractions as they flow toward the outlet depends on the flow pattern in the bin.

Silo quaking is a problem experienced in mass flow gravity-drawn bin and silos. It is a low-frequency cyclic or pulsating type of flow as a result of changes in density in the material during flow and by changes in the internal friction and boundary wall friction. The pulses are observed as shock waves in the material flowing upward, causing nuisance vibration to structural fatigue failures when the bin's natural frequency is excited by the pulses. Careful design of the bin can prevent or minimize the effect of silo quaking. Scale modeling and discrete element modeling are important tools in the design of bins that would indicate potential silo quaking problems.

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SME Mineral Processing Handbook. The second is from "The Selection and Sizing of Bins, Hopper Outlets, and Feeders" by J. Carson and T. Holmes in the 2002 volume of *Mineral Processing Plant Design, Practice, and Control*. The authors of this current chapter updated the data and information and revised selected material while retaining much of both chapters as originally written. All figures and tables are from (or adapted from) Matthews et al. (1985), unless otherwise indicated.

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