A SunCam online continuing education course

Bulk Silos for Biomass Facilities

by

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1.0 PURPOSE

Bulk silos are an essential part of most biomass and some forest products facilities. They are used for intermediate storage of partially processed raw material and storage of final product. For example, at a wood pellet plant, there is typically a silo after the dryer, one after the dry hammermills and one or more after the pelleting process. These are often referred to as the Dry Chip Silo, Dry Fiber Silo and the Pellet Silo. In addition, a silo may be used for storage of hogged bark for dryer fuel. The purpose of this course is to provide an over-view of considerations in specifying a silo for a biomass processing facility.

2.0 ABSTRACT

2.1 Some of the considerations involved in designing a silo system are:

2.1.1 Capacity requirements.

2.1.2 Wall materials and construction.

2.1.3 Accessories

2.1.4 Discharge system.

2.1.5 Layout Issues.

2.2 These issues will be considered in detail below.

3.0 DESIGN

3.1 Capacity Requirements

3.1.1 Purpose of Silo: In determining the capacity requirements, there are often two purposes to consider. First, the silo acts as surge capacity, enabling equipment on either side of the silo to continue producing during short downtime or reduced flow events. Second, the silo provides an opportunity for equalization of moisture content that may improve processing downstream. In the case of the Pellet Silo, the silo may be sized to allow the plant to operate through the week-end and enable shipments of product only on week days. The client will usually provide input as to his requirements. In the case of pellet plants, the supplier of the pelleting equipment may provide input regarding equalization time needs.

Figure 1: Silos under construction at a pellet plant. Note explosion panels in top walls. The columns extending part way down from the top are to support loads from a feed conveyor that has not yet been installed.

3.1.2 Volume: The client will usually provide a capacity in terms of hours of production. For example, the Dry Chip Silo must be designed for 8.0 hours of dryer production. If the flow through the dryer is 25 tons per hour, than the silo must hold 25 x 8 = 200 tons of material. If the material density is 11.0 pounds per cubic foot, than the "working" volume is 200 x 2000 / 11.0 = 36,400 cubic feet. The engineer should have the client specify whether he means "full-to-empty", or between two designated operating volumes. Typically, an Intermediate Storage Silo will be operated about two-thirds full, to provide a place for upstream equipment to continue discharging material to if downstream equipment goes down. He may also have in mind a minimum operating volume at which point he intends to shut down to avoid sending completely "un-equalized" material to the process.

3.1.3 Weight: The silo structure must be designed for the weight of the material stored. Typically, biomass material will compact in the silo. Wood chips will compact about 10 percent if the silo is full, adding weight. If the silo is equipped with sprinklers for fire suppression, than the weight of the water must be considered. Commonly, the density is specified at 50 percent moisture content for weight design purposes to allow for a sprinkler event.

3.2 Wall Material and Construction.

3.2.1 General: Silos may have walls of steel or concrete. Steel walled silos may be bolted or welded. They can also be field or shop fabricated.

3.2.2 Condensation: A major consideration in selecting wall material is condensation. The material entering the silo may be very dry (8-10 percent moisture content), so one might assume that there will be no problem with moisture condensing along the inside walls of the silo. Wood exposed to the atmosphere tends to reach an equilibrium moisture content that is dependent on relative humidity. Furthermore, as temperature of the wood increases, the equilibrium moisture content at a given relative humidity decreases. For bulk wood in an enclosed container such as a silo, a reverse relationship exists, in which the wood controls the relative humidity and temperature of the spaces between the chips. For example, wood at 10 percent moisture content is in equilibrium with air at 77F and 56% RH and air at 212F and 80% RH. Wood exiting a dryer at 212F will condition the air in the silo to 212F with a vapor pressure of

11.76 psia and a dew point of 201F. Thus, moisture contained in the air near the cool walls of the silo will condense on the walls. Tannins and other acids leaching out of the wood will result in a highly corrosive situation.

3.2.3 Steel Silos:

3.2.3.1 Steel silos may be bolted or welded. Welded silos are usually shop-fabricated and are limited to a diameter of 14 feet for road transportation. For these smaller diameter silos, economics will usually favor the shop-welded silo, unless transportation distances are great. For larger, field-erected silos, bolted silos are more economical and erection is faster. The inside of the silo should be coated for corrosion resistance, as should the outside. Fasteners should be stainless steel or galvanized. Here, galvanized fasteners are considerably more economical, and have reportedly acceptable performance.

3.2.3.2 Concrete silos are rarely used in wood products or biomass applications. They have some advantages over steel, mainly strength and corrosion resistance. However, wood products and biomass investors have not been willing to pay for increased longevity, possibly because the projects are not expected to have long economic lives, giving preference to lower first cost. Concrete is more economically favorable for larger silos, say greater than 50 feet diameter, but this is larger usually required in these industries.

3.3 Accessories. A number of accessories should be considered for a bulk silo:

3.3.1 Manway: A manway in the roof is required for inspections.

3.3.2 Product Inlet: Provide a flanged opening for product inlet. The flange will be used for attaching a chute from the delivery conveyor discharge. Opening size should match the conveyor discharge size if reasonable.

3.3.3 Pressure/Vacuum Relief: Steel silos are typically rated at 1 ½ oz/sq. in. over pressure and ½ oz/sq. in vacuum. The relief is often built into the manway cover, but may be separate.

3.3.4 Fire Protection: NFPA does not explicitly require sprinkler protection for silos, leaving it largely up to the judgement of the Engineer and Authority Having Jurisdiction (AHJ). According to NFPA 664-8.10.3.1 for Silos and Storage Bins:

> *Where automatic sprinkler protection is provided in bins, hopper and silos, the system shall be hydraulically designed to provide a minimum density of 0.2 gpm/sf over the horizontal projected area of the piece of equipment.*
>
> And A8.10.3.1:
>
> *Adequate drainage should be provided to prevent structural collapse. In addition, a means should be available to remove the contents other than through the facility process to permit removal of burning material without threatening the rest of the facility. Storage bins and silos should be located outside the building on independent support structures and should be accessible for fire-fighting. It is not advisable to locate bins or silos on the roofs of buildings.*

Steel silos are not designed for hydrostatic pressure. They are designed with the assumption that much of the weight of the stored material is absorbed by wall friction. If enough water is introduced that the interstices between particles becomes filled with water, then the load will become hydrostatic and the silo will fail. The discharge opening may provide the drainage required by NFPA 664 A8.10.3.1. If there is a screw reclaimer, then the reclaimer would need to run to provide drainage. Any means for diverting the contents would be provided in the discharge conveyor design and would not be provided by the silo manufacturer.

The deluge system can be incorporated into a plant-wide "Spark Detection and Extinguishment" system as would be provided by companies like Grecon or Flamex. In this case, a spark detector in the inlet chute would activate the spray deluge for a programmed time period such as 5 seconds. Temperature detectors in the silo roof would look for temperature rate of rise and automatically activate the deluge. In this case, an operator is responsible for de-activating the deluge.

If portions of the silo become stagnant, conditions become conducive to spontaneous combustion in the stagnant portion. This is one reason that it is important that the silo be designed for mass flow, that is, all points of the surface of the stored pile move downward at the same rate.

3.3.5 Bin Vent Filter: A bin vent filter is required to filter the displaced air as the silo is filled. It should be rated for the volume of air equal to or greater than the bulk volume rate of material entering the silo, with the assumption that no material is being withdrawn. Based on this volume rate, a maximum air-to-cloth ratio of 5.0 (CFM air / SF of filter surface) should be specified. The filter should be pulse jet cleaned. It should be specified to have a maximum particulate discharge of 0.01 grains/cubic foot (See EPA Air Pollution Control Technology Fact Sheet EPA-452/F-03-025). The filter will bolt to a flange on the roof of the silo, so that displaced air moves through the underside of the filter media and discharges from the top of the filter. Unfortunately, silo suppliers will usually not supply the filter, so it will have to be purchased separately. If the supplier of the filter can be settled on early, then the flange can be specified in the bid documents for the silo. Otherwise, the flange requirements will be approximated and updated when the silo approval drawings are received. There will be a need to pipe compressed air to pulse jet.

3.3.6 Stairs and Catwalks: A stair or ladder should be provided to the top of the silo and a catwalk for access to the bin vent filter and fire suppression elements. Typically a ladder is deemed adequate. The top of the silo should be surrounded by a rail. All of these components should be OSHA-approved.

3.3.7 Level Detection: There is usually a need for level detection. This can be in the form of discreet or continuous level devices. Continuous level detection is often preferred so that the level can be monitored continuously and operators are not faced with sudden surprises such as a full or empty silo. This will normally be provided separately, but the silo supplier will have to provide nozzles for mounting.

Possible continuous level detection types include laser, radar and sonic detectors. In selecting a level detector, consideration must be given to interference caused by dust in the atmosphere.

3.3.8 Explosion Protection: NFPA 664 8.10.2 states:

Silos and storage bins with a deflagration hazard shall be equipped with either of the following:

(1) Deflagration relief venting designed to relieve the deflagration to a safe area and maintain the pressure below the yield strength of the vessel.
(2) Explosion suppression systems designed, installed and maintained in accordance with NFPA 69, Standard on Explosion Prevention Systems.

The usual solution to this problem is to provide explosion panels, and the silo supplier will provide them if they are included in specifications. Ideally, the supplier will be provided with "K_{st}" and "P_{max}" of the material to be stored. These values relate to the rate of pressure rise and the maximum obtained pressure in tests performed in accordance with ASTM E 1226.

Without specific information, the silo supplier will revert to published information for similar materials, with a tendency to err on the conservative side. NFPA 68, Figure F.1(a) lists the following values for wood flour with a median particle diameter of 29 microns:

P_{max} = 10.5 bar
K_{st} = 205 bar-m/sec

Silos should not be located so that an explosion pressure wave impinges directly on another structure or silo. The supplier should be consulted in this regard.

3.4 Reclaim Systems

3.4.1 General: The discharge of a silo should be designed to promote mass flow of the material. This means that every point on the top surface of the stored material moves downward at the same rate. Alternatively, funnel flow or rat-holing may develop, in which a passageway develops from the top surface, directly to the discharge point, leaving large masses of material stagnant. Not only does this reduce the effective volume of the silo, but it may result in a fire hazard as spontaneous combustion may result. Another possible flow hindrance is bridging, in which the material forms a stable arch over the discharge point and flow stops completely. The discharge system must be designed to prevent this.

3.4.2 Flow Characteristics: Wood chips and ground dust are not particularly free-flowing and are prone to bridging and funnel-flow. This results from the shape of the particles which causes a certain amount of interlocking. Smaller particles tend to flow more freely than larger ones, at least in part because they tend more to an ideal spherical, or non-interlocking shape.

3.4.3 Aspect Ratio: One of the means for improving flow is through aspect ratio of the silo. The shape of the pile inside a flat bottom silo is of a cylinder with inverted cone on top and sometimes on the bottom. The aspect ratio is defined as the height of the cylindrical portion of the pile divided by the diameter. It is generally less expensive to add volume by adding height than by adding diameter. Therefore, in the interest of economics it is desired to keep the aspect ratio high. However, a lower aspect ratio promotes better flow characteristics. For chips, an aspect ratio of about 1.5 is often required, while for bark, the aspect ratio may be as low as 1.0. For pellets, the aspect ratio may be 2.0-2.5. It is normally best to let the supplier determine the aspect ratio, however, it can become an issue in bid comparisons.

3.4.4 Screw Reclaimer: For chips and bark, a screw reclaimer is necessary. This takes the form of a screw feeder in the bottom of the silo that rotates to move material to the center discharge opening, and revolves about the bottom of the silo to sweep the entire bottom surface. The flights of the screw must be designed to entrain material from the entire radius of the silo. This may be achieved by gradually increasing the pitch (distance between flights) of the screw toward the discharge point. The silo may be flat-bottom or conical bottom. The conical bottom system has a maintenance advantage in that all drive components can be outside of the silo, rendering them more accessible for maintenance. For smaller sizes, the conical bottom may have a price advantage, as less structural support is required, then of a flat bottom. However, the conical shape may detract from the mass flow characteristics of the silo as material may bypass the screw and flow directly to the discharge opening. Conical bottom systems tend to work best on smaller silos handling smaller chips that have better flow characteristics.

Flat-bottom reclaimers can be cantilevered, with center-driven screw, or perimeter-assisted. Perimeter-assisted designs are used for larger diameters and for materials with poor feed characteristics such as hogged bark. A sprocket or gear engages a rack around the perimeter, reducing the mechanical stress in the screw. Teeth or cups may be added to the outside edge of the screw flights to help break up clumps of material, aiding entrainment into the screw flights.

In order to properly size the reclaimer, the supplier will need to know the maximum reclaim rate.

Typically, the reclaim screw feeds to a hopper below the floor of the silo. The hopper in turn discharges to a feeder screw. The feeder screw runs full and can be used as a variable speed metering device. Alternatively, the hopper may discharge to an Owner-supplied drag chain or other conveyor type. In this case, metered feed is not practical.

Figure 2. Screw Reclaimer. Note that flights are closer together near the wall and open up toward the center. This ensures that material is drawn from the entire radius of the silo. Also note the metering screw below the silo floor is inclined upward, providing clearance for a receiving conveyor. This is a flat-bottom silo with perimeter-driven screw.

3.4.5 Passive Reclaim: Passive reclaim relies solely on gravity to maintain flow from silo. This works well only for free-flowing material such as wood pellets or corn. The bottom of the hopper tapers conically to a small opening at the bottom. Typically a slope of 60 degrees to horizontal is required to maintain flow. Some special hopper outlet designs are available to improve flow characteristics.

Test laboratories such as Jeneke-Johansen are available that can recommend hopper designs based on tests of sample material. The engineer will supply expected operating parameters such as required working volume and reclaim rate. Recommendations will include minimum opening size, hopper slope, silo diameter and vertical wall height. This type of testing is highly recommended and should be budgeted as part of the engineering effort.

Flow can be metered somewhat through the use of a variable-opening gate in the hopper outlet. The problem is that, when the gate is fully open, flow may be far too high. When the gate is closed far enough to produce the desired flow rate, the material may bridge across the opening.

The preferred method for metering flow from a passive-reclaim hopper is through the use of a feed conveyor. This may be a belt or vibrating feeder. The opening of the hopper discharges directly, to the feeder conveyor through a chute that terminates a few inches above the conveyor surface. Free discharge is limited by the angle of repose of the material resting on the conveyor. The feeder conveyor operates at variable speed, dragging material out from under the hopper discharge chute.

A lower cost alternate may be to provide a rotary feeder at the silo discharge. For friable products such as wood pellets however, there will be a crushing action on a small percentage of material that may be unacceptable.

A maintenance gate below the silo discharge opening should be provided to allow maintenance of the feeder conveyor or rotary feeder. This is a manual slide gate that will always be either fully open or fully closed.

The feeder conveyor will typically not be supplied with the silo. The feeder conveyor supplier should be consulted in the design of the discharge chute.

3.5 Layout Issues

3.5.1 If the floor height is not mentioned in the bid documents, it will typically be quoted at 10 feet above grade. This may not be high enough. The hopper may extend as low as 5 feet below the floor level and the metering screw will be below this. The metering screw will discharge to another conveyor. The floor height may substantially affect the price, so a reasonable estimate of floor height should be made and included in the bid documents. This will require a layout of equipment discharging from the silo. The final floor height may not be known until discharge equipment has been selected. Typically, the engineer will specify the discharge height requirement of the feeder screw or hopper. It is up to the silo supplier to determine the floor height.

3.5.2 Loads: The silo roof must be designed to support equipment located on the roof. Substantial loads may be imparted by the feed conveyor(s). These loads are transferred to the walls by columns extending part way down from the top. An example can be seen in the photo in Figure 1. An estimate of the loads will be required for bid documents.

3.5.3 Dimensional Estimates: Early in the project, for example, during the cost estimating phase, it is necessary to provide an approximate equipment layout. Silo locations are critical and locations depend somewhat on height and diameter, due to practical limitations on the angle of the feed and discharge conveyors. As a rule of thumb, en-masse conveyors are limited to about 45 degrees as the volumetric capacity drops off at higher inclines. A quick dimensional estimate may be made as follows:

Referencing Figure 3:

V_1 = Volume of cone formed by free-falling material entering at center of silo roof.

V_2 = Volume of cylinder of material.

V_3 = Volume of cone formed by hopper discharge for a conical-bottom silo.

V_T = Total required volume

θ = Angle of repose for material (45 degrees for chips or bark, 30 degrees for pellets).

α = Hopper angle, estimated. For flat-bottom silos, $\alpha = 0$. For pellet silos, α = 50-60 degrees.

h_1, h_2, h_3 and h_4 are heights indicated.

D = Silo diameter.

H = Overall Height

At this point, the engineer will have estimated the total volume requirement, V_T and needs to estimate diameter, D, and height H.

From knowledge of the material, we estimate α and determine θ.

Also, from knowledge of the material, we estimate the aspect ratio, R_a.

The following relationships apply:

$h_1 = D(\tan\theta)/2$ (1)

V_1 = Volume of Cone = $(\pi/3)(D/2)^2h_1$ (2)

$h_2 = DR_a$ (3)

V_2 = Volume of Cylinder = $D^2h_2/4$ (4)

$h_3 = D(\tan\alpha)/2$ (5)

V_3 = Volume of Cone = $(\pi/3)(D/2)^2h_3$ (6)

$V_T = V_1 + V_2 + V_3$ (7)

$H = h_1 + h_2 + h_3 + h_4$ (8)

Combining equations (1), (2), (3), (4), (5), (6), and (7) and solving for D,

$$D = \left[\frac{V}{\pi[\ (\tan\theta)/24 + R_a/4 + (\tan\alpha)/24\ ]} \right]^{1/3} \quad (9)$$

Once "D" is known, solve for h_1, h_2 and h_3 using equations (1), (3) and (5), respectively. A value for h_4 must be estimated. Then calculate H using equation (8).

Example Calculation:

A silo is required to hold 8 hours production of dry Southern Pine chips (full-to-empty). The production rate is 24 tons per hour. The density is 11.0 pounds per cubic foot. The angle of repose is 45 degrees. The silo is to have a flat bottom.

Solution:
The height of the floor above grade is estimated to be 10 feet.
The aspect ratio is estimated to be 1.5.

For this common case, equation (9) simplifies to:

$$D = \{V/[\pi(1/24 + 1.5/4)]\}^{1/3} \qquad (10)$$

But V = 8 hr x 24 ton/hr x 2000 #/ton /11 #/CF = 34,900 CF

Inserting this value into Equation (10) we get D = 29.8 ft.
From Equation (1), h_1 = 29.8 Tan(45)/2 = 14.9 ft.

From Equation (3), h_2 = 29.8 x 1.5 = 44.7 ft.

Since the bottom is flat, h3 = 0

As stated earlier, h_4 is estimated at 10 ft.

From Equation (8), H = 14.9 + 44.7 + 10 = 69.6 ft.

The diameter of this silo is estimated at 29.8 feet and the height at 69.6 feet. These should be regarded as preliminary, working dimensions. Proposed dimensions from suppliers may vary. Most suppliers have standard diameters that they prefer to use. Also they may propose different aspect ratios for the application.

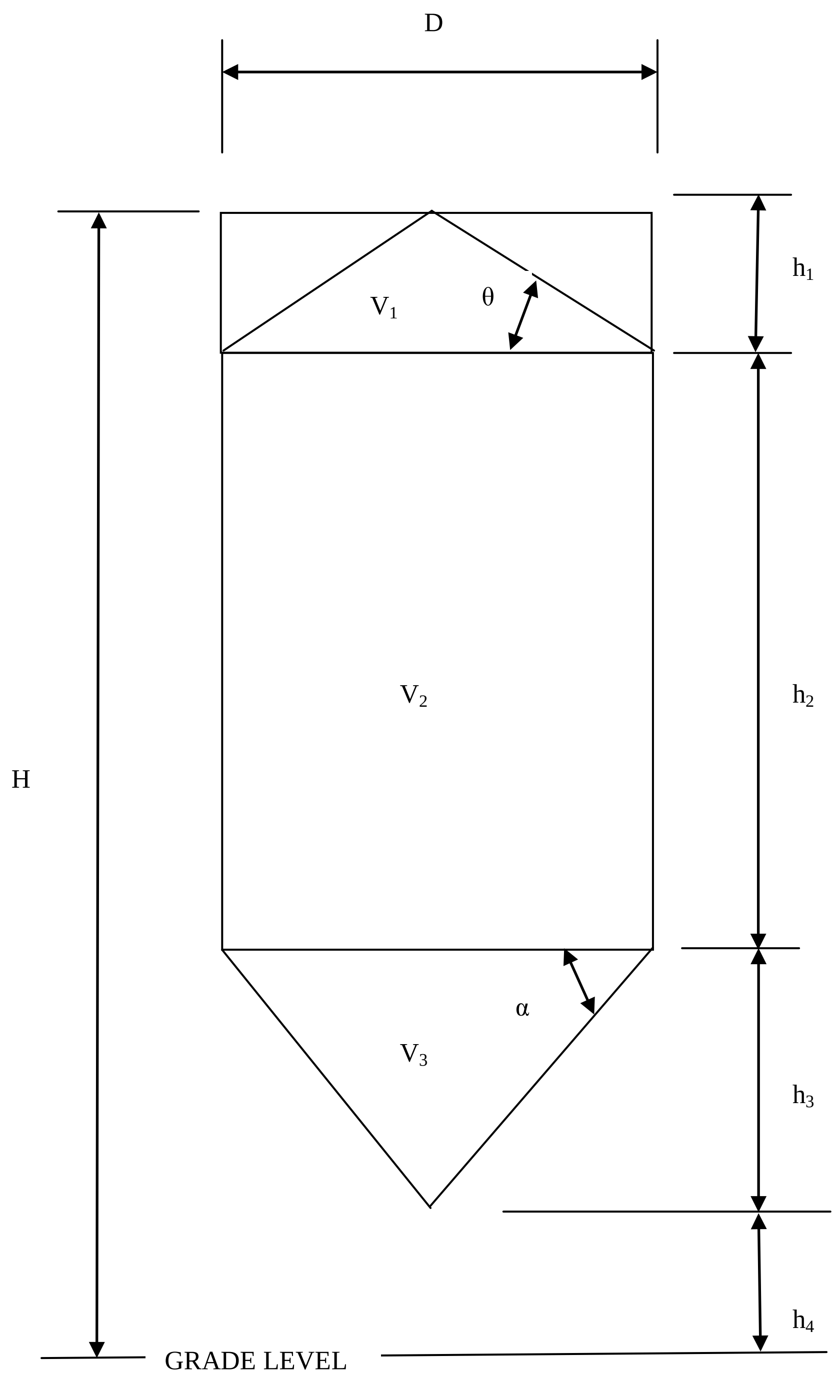

Figure 3. Silo sketch for dimensional estimate.

4.0 SUMMARY AND CONCLUSIONS

4.1 Bulk silos in biomass processing systems function to provide surge capacity and moisture equalization capability.

4.2 To specify the silo, the engineer must first determine its weight and volumetric capacity requirements.

4.3 The materials of construction must be specified. Corrosion resistance is a consideration.

4.4 Accessories must be specified or allowed for, including:

- 4.4.1 Manway
- 4.4.2 Product Inlet
- 4.4.3 Pressure/Vacuum Relief
- 4.4.4 Fire Protection
- 4.4.5 Bin Vent Filter
- 4.4.6 Stairs and Catwalks
- 4.4.7 Level Detection
- 4.4.8 Explosion Protection

4.5 Type of reclaim must be considered. This usually will be a screw reclaimer for material with poor flow properties and passive reclaim for materials with good flow properties. Choosing the optimum aspect ratio for the material is part of the process. The goal is to obtain mass flow from the silo.

4.6 Some layout issues, including discharge height, loads and preliminary dimensional estimating were presented.

