Extension Hoppers for Gravimetric Feeders

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Gravimetric or loss-in-weight feeders are frequently used in continuous processes that handle bulk solids. The gravimetric feeder and its extension hopper are configured with load cells which measure the loss in weight of the equipment over short time intervals, allowing the discharge rate to be calculated. Figure 1 is a schematic of a gravimetric feeder system.

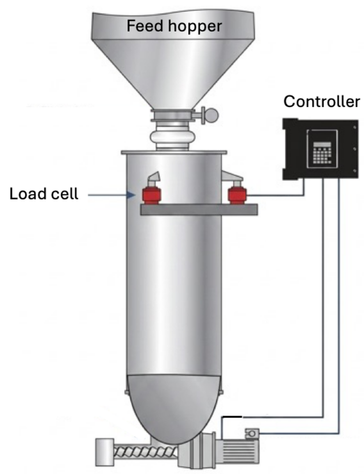


Figure 1. Gravimetric feeder system schematic.

The feed factor of a gravimetric feeder is defined as the mass of powder discharged per revolution of the screw. If the powder is compressible, its bulk density at the hopper outlet and feeder inlet will depend on the level of powder inside the extension hopper. Because the solids stress increases with depth, the bulk density of the powder will decrease as the hopper is emptied, and the feed rate will therefore become reduced as the hopper empties. Figure 2 illustrates how the feed factor varies with fill level when a silica powder is fed from a cylindrical hopper [1].

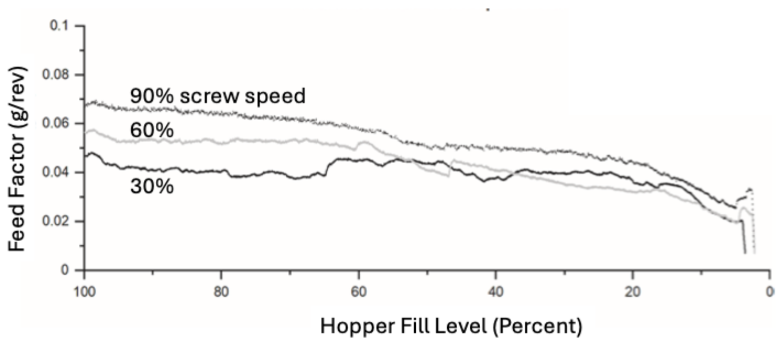


Figure 2. Feed factor *vs.* hopper fill level.

The solids stress profile in a cylinder can be modelled using the Janssen equation [2]:

$$\frac{d\sigma_v}{dz} + \tan\phi' \frac{k\sigma_v}{R_H} = \rho_b g \tag{1}$$

where σ_v and σ_w are the vertical and horizontal solids stresses, respectively, z is the vertical coordinate, k is the stress ratio (typically ranges between 0.4 and 0.6), R_H the hydraulic radius, *i.e.,* the cross-sectional area divided by the perimeter, ρ_b is the bulk density, and g equals acceleration due to gravity. The boundary condition is

$$\sigma_v(0) = \sigma_{v0} \tag{2}$$

where σ_{v0} is the solids stress at the top surface and equal to zero for a free surface.

Suppose a 1000-mm tall, 500-mm diameter cylinder were filled with powder with the bulk density-solids stress relationship given in Figure 2. If the wall friction angle is equal to 20°, integration of the Johanson equation gives the profile shown in Figure 3. Figures 4, 5, and 6 illustrate the solids profile when the cylinder is emptied and is 75, 50, and 25 percent full, respectively.

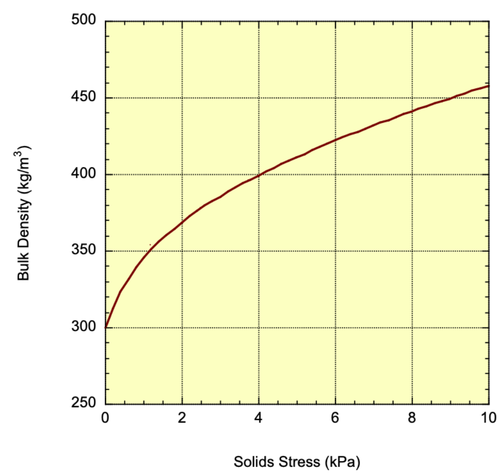


Figure 2. Bulk density-solids stress (compressibility).

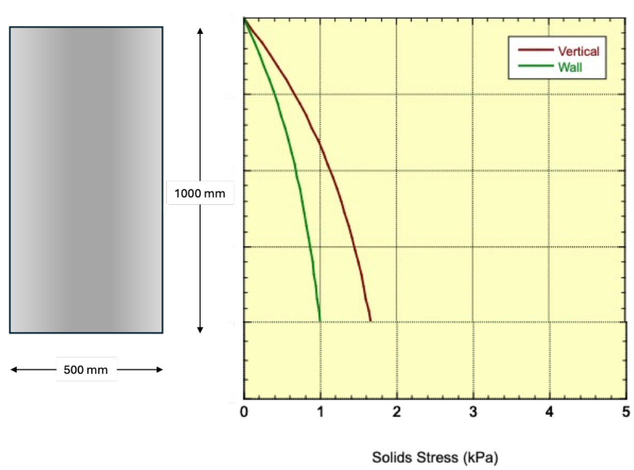


Figure 3. Solids stress profile in filled cylinder.

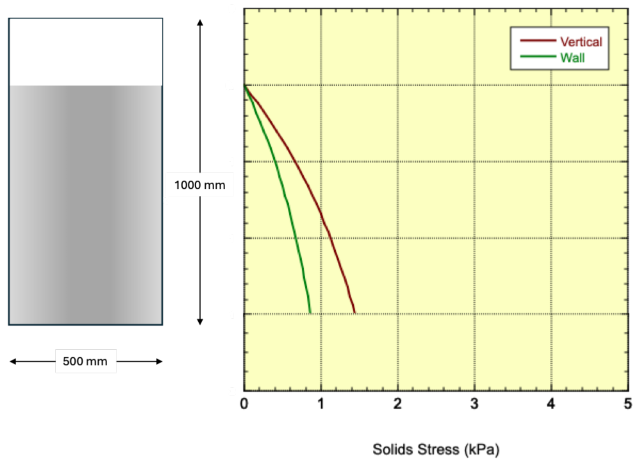


Figure 4. Solids stress profile in 75% filled cylinder.

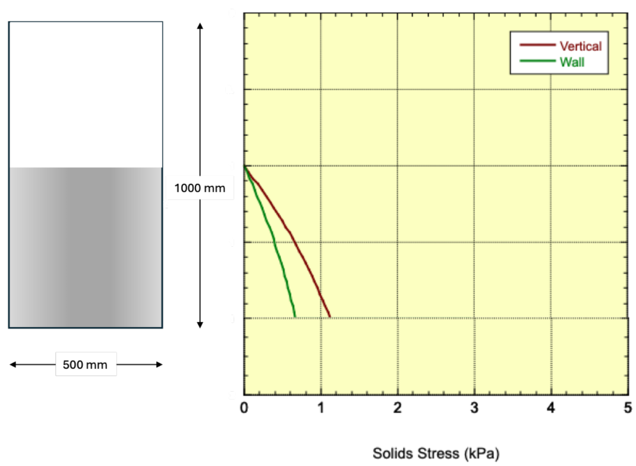


Figure 5. Solids stress profile in 50% filled cylinder.

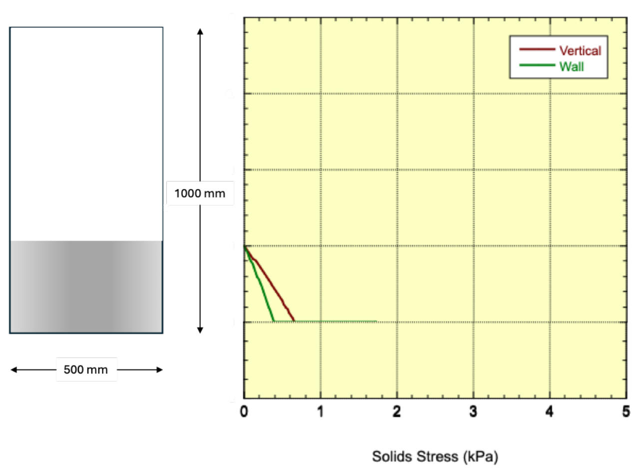


Figure 6. Solids stress profile in 25% filled cylinder.

From the bulk density-stress relationship given in Figure 2, the bulk density of the powder discharged from the cylinder as the hopper is emptied can be calculated (see Figure 7):

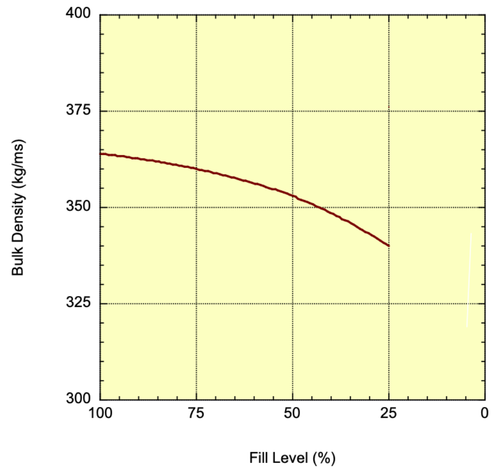


Figure 7. Bulk density *vs.* fill level.

Suppose additional powder is now added to the cylinder, *i.e.,* the hopper is about to be refilled. When the material contacts the surface, an impact stress on the order of *ca.* can be expected. Integrating the Johanson equation using σ_{v0} = 2.5 kPa as the boundary condition gives the solids profile plotted in Figure 8. The resulting increase in bulk density is illustrated in Figure 9.

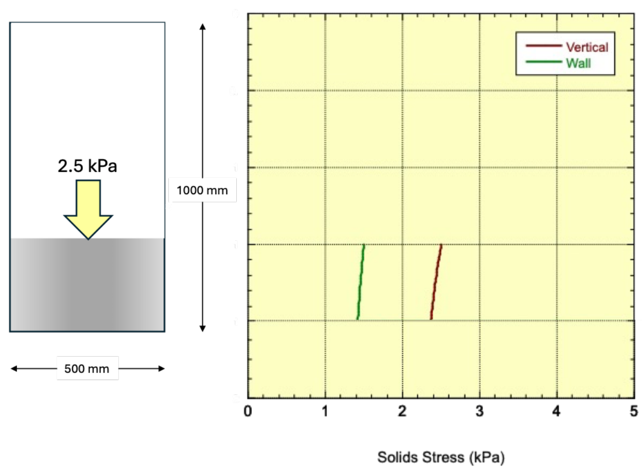


Figure 8. Stress profile of 25% full cylinder with 2.5-kPa impact pressure.

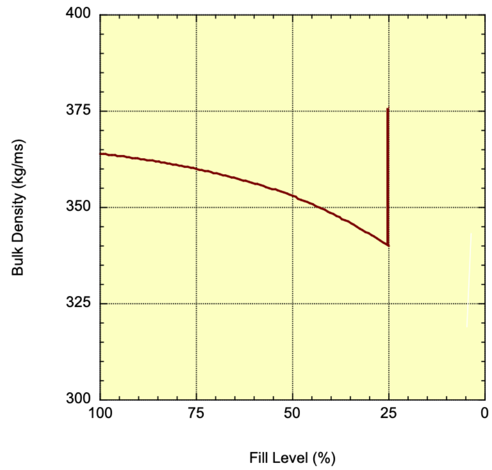


Figure 9. Increase in bulk density after refill.

As the hopper is refilled, the loss in weight cannot be measured, and the feeder is instead operated in a volumetric mode, usually operating at a constant speed equal to that just before the refill step started. Since the powder had been compacted, the discharge rate will now greater than the setpoint. This is shown in Figure 10 where an extension hopper was periodically refilled with a coarse powder [3].

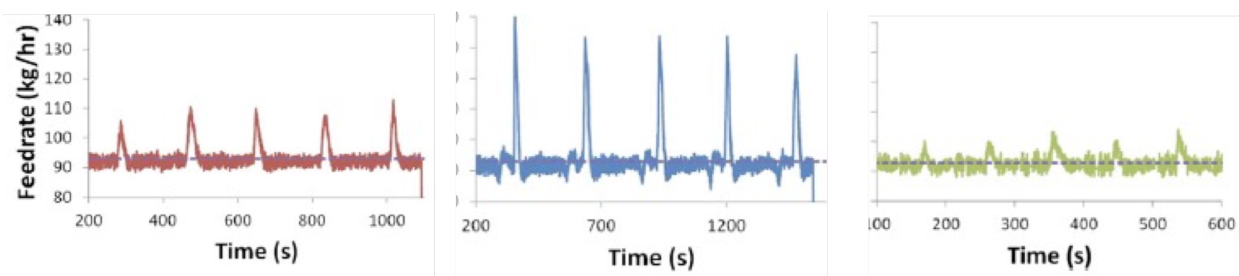


Figure 10. Feed rate disturbances due to refill.

Suppose a mass-flow hopper were instead used as the gravimetric feeder's extension hopper. In a mass-flow hopper, a radial stress profile develops, and at and near the hopper outlet, the solids stress will only depend on the diameter or width of the hopper. The stress profile can be calculated by integrating Equation 3 [4].

$$\frac{d\sigma_v}{dz} - n\frac{\sigma_v}{z} = -g\rho_b \tag{3}$$

where n is given by

$$n = (m+1)\left[k\left(1 + \frac{\tan\phi'}{\tan\theta'}\right) - 1\right] \tag{4}$$

and m is equal to 0 or 1 for a slotted or round outlet, respectively. The stress ratio k for the hopper section can be determined using relations given in the Eurocode [5].

At the hopper-cylinder junction, the boundary condition is

$$\sigma_v(h) = \sigma_{vht} \tag{5}$$

Equation 3 can be integrated to give the solids stress profile in a hopper. Because a radial stress profile develops, the solids stress at the hopper outlet and feeder inlet will be nearly constant, as will the bulk density of the powder. This is illustrated in Figures 11 through 15 which plot the stress profiles over the range of fill levels and after 2.5 kPa pressure is applied when the level reaches 25 percent. Bulk density of the powder in the feeder *vs.* fill level is plotted in Figure 16.

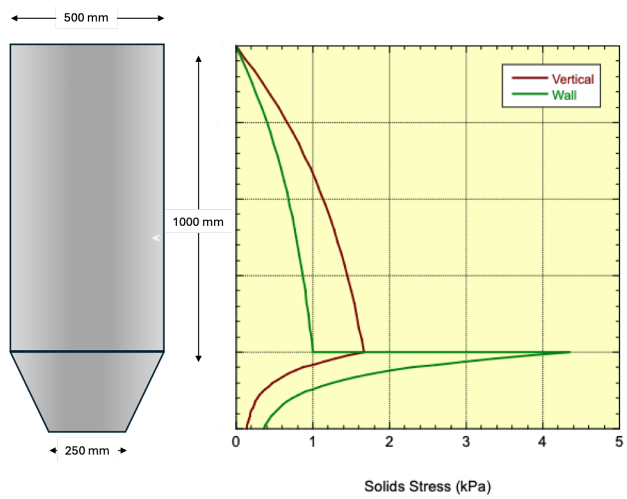


Figure 11. Stress profile in filled mass-flow hopper.

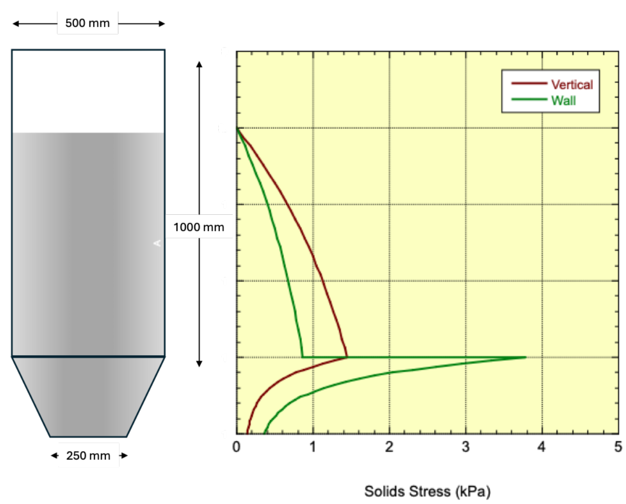


Figure 12. Stress profile in 75% full hopper.

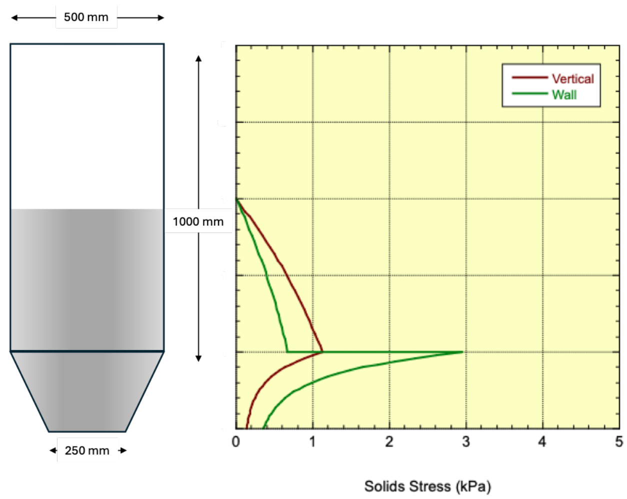


Figure 13. Stress profile in 50% full hopper.

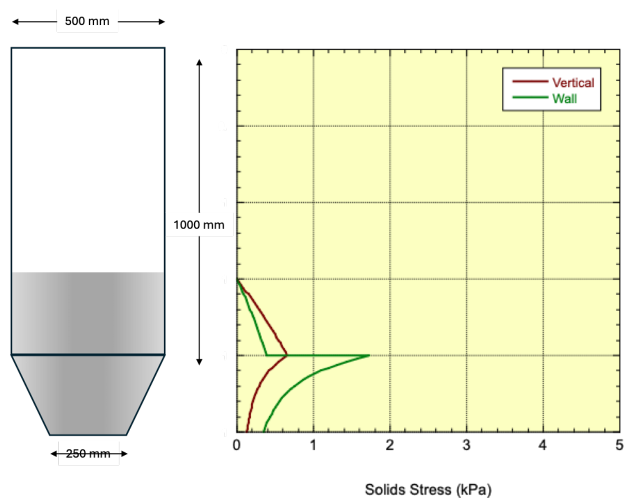


Figure 14. Stress profile in 25% full hopper.

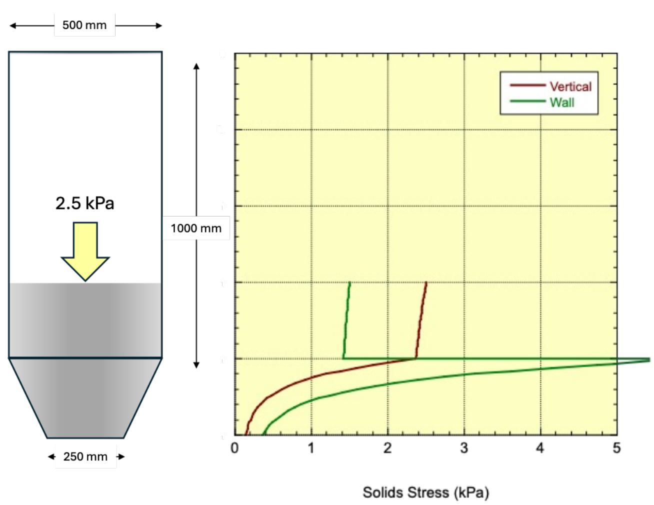


Figure 15. Stress profile in 25% full hopper after 2.5-kPa impact pressure.

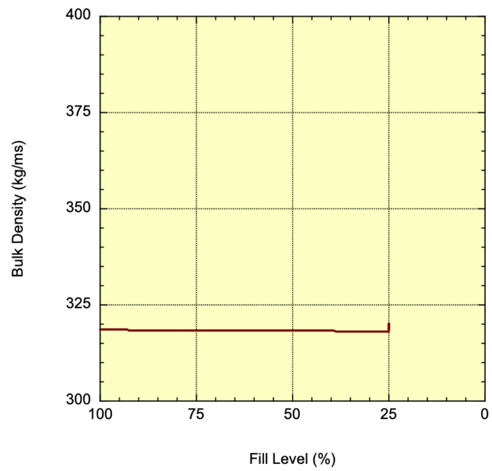


Figure 16. Bulk density *vs.* hopper fill level.

In general, gravimetric feeders have round inlets, and the walls of a conical extension hopper usually must be very steep to allow mass flow. For this reason, many commercially available gravimetric feeders have extension hoppers that are asymmetric cones. Unfortunately, the primary solids stresses point downward, and the powder is compacted during the refill step.

A Diamondback hopper [6], which has converging side walls and slightly diverging walls can be relatively shall and provide a radial stress profile. Figure 17 is a drawing of a gravimetric feeder equipped with a Diamondback extension hopper.

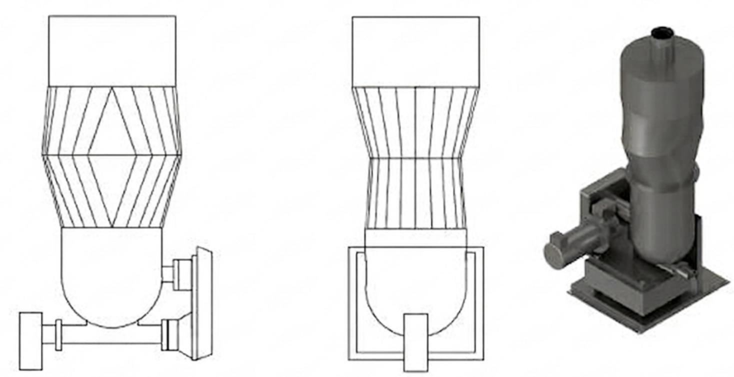


Figure 17. Gravimetric feeder with Diamondback extension hopper.

Discharge rates and fill levels are plotted in Figure 18. Note that in most cases, deviations from the setpoint during the refill steps is minimal. The bulk density of the powder at the hopper outlet and the feeder inlet is nearly constant because of the radial stress profile that develops inside the hopper.

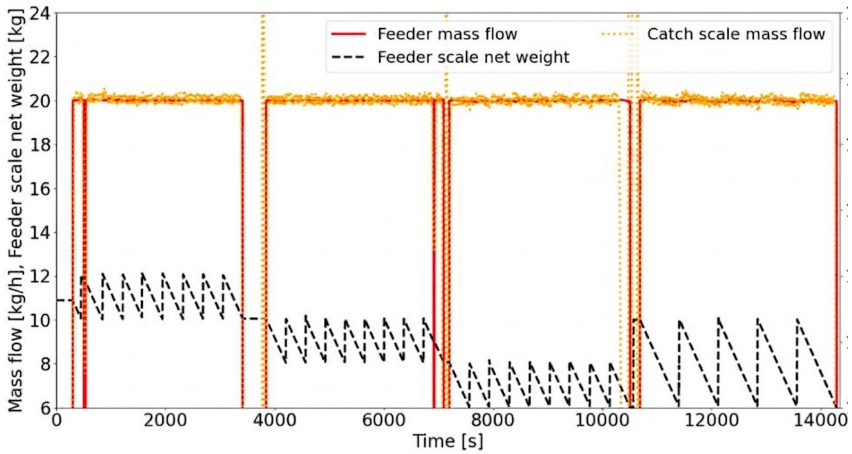
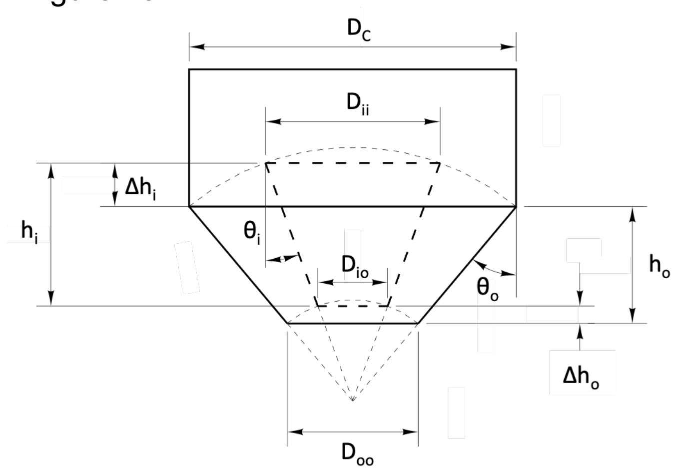


Figure 18. Discharge rate of powder from feeder and Diamondback hopper.

Similar results can be expected with feeders that incorporate conventional conical mass flow hoppers provided that their walls are steep enough for mass flow. A conical hopper with a cone-in-cone insert can have relatively shallow walls, provided that the walls of the inner hopper are steep enough for mass flow. The angle of the outer cone, relative to vertical, should be twice that of the inner cone. The design of a conical hopper with an insert is illustrated in Figure 19.



Δh_i	Distance between inner and outer cone inlets
Δh_o	Distance between inner and outer cone outlets
h_i	Height of inner cone
h_o	Height of inner cone

Figure 19. Insert geometry.

To summarize, the performance of gravimetric or loss-in-weight feeders can be improved by using an extension hopper that is designed for mass flow. A radial stress profile gives a nearly constant solids stress level at the hopper outlet, which allows the bulk density of the powder discharged from the feeder to remain steady. The discharge rate of powder during refill can be expected to remain near its setpoint.

References

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