As appeared in June 2020 *PBE* Copyright CSC Publishing powderbulk.com

PBE

AGGLOMERATION ADVISOR

Greg Mehos, president
Greg Mehos & Associates

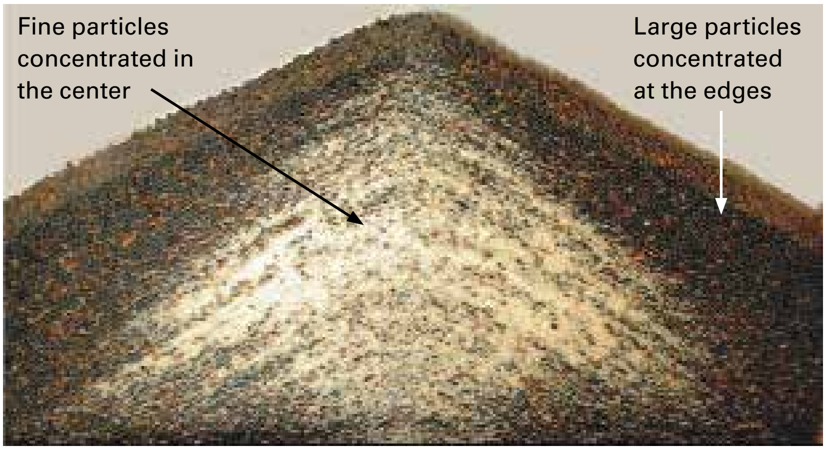
Mitigating agglomerate segregation

Agglomeration processes often yield a material with an array of particle sizes. When handled, agglomerated materials, such as cat litter and fertilizer, can separate by particle size. An example of this is when a bin is filled from a single inlet. Once a pile is formed in the bin, the larger particles, which are relatively free-flowing, will roll down the pile's surface toward the bin's periphery while smaller particles percolate through the material bed and concentrate in the pile's center. The pile will inevitably avalanche, and when it does, the larger particles' momentum will cause them to travel farther than the finer particles. This phenomenon is referred to as *sifting segregation* or *Christmas tree segregation*[1], as shown in Figure 1. In the pile shown, the lighter-colored particles are smaller and the darker-colored particles are larger. The particles' tendency to travel as they do is called Christmas tree segregation because the resulting pile — when bisected down the middle — looks like a Christmas tree.

If the material is handled in a funnel-flow bin, its average particle size may vary during discharge. In funnel flow, material will flow in a flow channel above the outlet. As the flow channel empties, material along the walls, which will have a larger average-particle size, will fall into the channel. As a result, the material's average particle size upon leaving a funnel-flow bin will cycle from small to large and back to small again.

FIGURE 1

Christmas tree or sifting segregation



To mitigate sifting segregation, agglomerates with a wide particle size distribution should be handled in a mass-flow bin in which the hopper walls are steep enough and fabricated from materials low enough in friction to allow the material to flow along the walls. For agglomerates that have very high wall friction, mass flow can be nearly impossible to achieve in a conical hopper and would result in funnel flow. Mass flow can usually be achieved in a wedge-shaped hopper with flat walls, but a specialized feeder is required.

A *dispersion cone* is an alternative device for mitigating sifting segregation. The device is comprised of an inverted cone above a ring that has equally spaced extensions or "teeth" that redirect approximately half of the particles when they travel past the cone, as shown in Figure 2. The particle redirection results in the particles mixing as they fall inside the bin, forming multiple piles of mixed particle sizes instead of a single pile of particles in which fines have accumulated in the center. You can imagine the particles hitting the cone's tip and surrounding area in looking at the dispersion cone's aerial view in Figure 2. Notice how the ring's diameter is larger than

FIGURE 2

Dispersion cone schematic

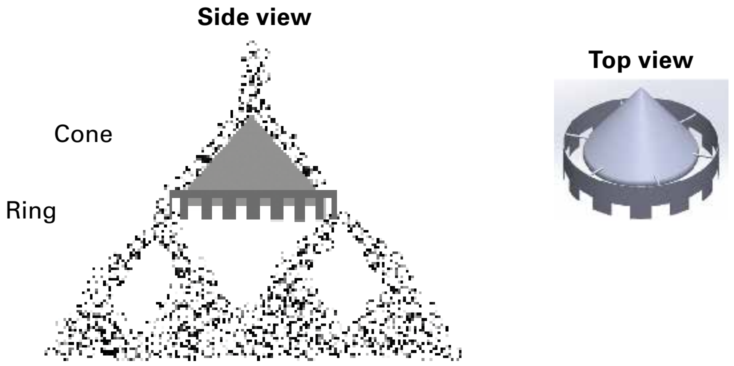


FIGURE 3

Dispersion cone and ring dimensions

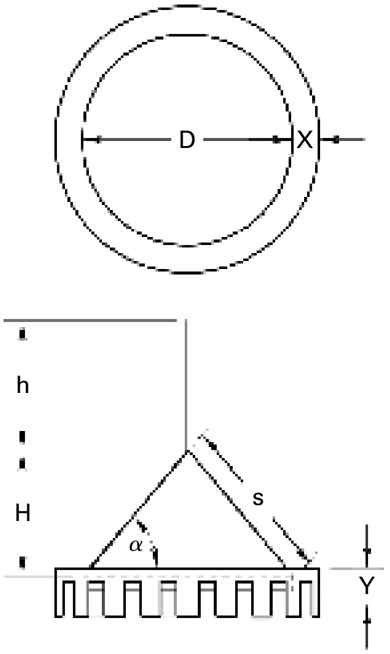
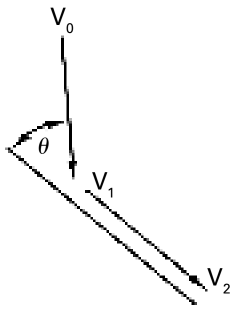


FIGURE 4

Particles' different velocity point changes



the cone's and how the cone sits just within the ring's top. This helps to facilitate the dispersion dynamics.

A dispersion cone and ring can be designed using simple physics. If the particles fall freely when they're dropped onto the cone, their velocity before impact, V_0, on average is their free-fall velocity

$$V_0 = \sqrt{2gh}$$

where g is the acceleration due to gravity and h is the drop height, as shown in Figure 3. Other measurements pertaining to dispersion cone schematics are also shown in Figure 3 and will be covered later.

Upon hitting the cone, the particles will start to descend down the cone. From a momentum balance, V_1, which is the particles' velocity after impact, as shown in Figure 4, is determined by

$$V_1 = V_0(\cos\theta - \sin\theta \tan\phi')$$

where θ is the impact angle and ϕ' is the angle of wall friction. The angle of wall friction is the inverse tangent of the friction coefficient and can be determined from shear cell testing.

While sliding on a straight surface, the particles accelerate or decelerate, depending on the relative magnitudes of the cone angle, α (measured from horizontal), and the wall friction angle. The particles' acceleration, a, is measured as follows

$$a = g(\sin\alpha - \cos\alpha \tan\phi')$$

The particles will continue to accelerate — provided that the cone angle (α) is greater than the wall friction angle (ϕ') — and the particles' velocity upon reaching the cone's end, V_2, is determined by

$$V_2 = \sqrt{V_1^2 + 2as}$$

where s, the distance the particles traveled, is calculated from

$$s^2 = \left(\frac{D}{2}\right)^2 + H^2$$

where D is the cone's diameter, which is smaller than the ring's diameter, and H is the cone's height, as shown in Figure 3. The height can be calculated from the diameter and cone angle by

$$H = \frac{D\tan\alpha}{2}$$

The particles continue to accelerate after leaving the cone. The distance the particles travel horizontally and then vertically, marked as X and Y respectively on Figure 3, over time, t, can be calculated from

$$X = (V_2\cos\alpha)t$$

and

$$Y = (V_2\sin\alpha)t + \frac{g}{2}t^2$$

where g is the particles' acceleration due to gravity, X is equal to the difference between the radii of the cone and the ring, and Y, which is the vertical distance the particles travel after leaving the cone and reaching the ring and is dependent upon the ring's placement, should be chosen such that the particles impact the extensions from the ring. Combining equations for X and Y and then simplifying yields

$$Y = X\tan\alpha + \frac{g}{2}\left(\frac{X}{V_2\cos\alpha}\right)^2$$

where Y is still the vertical distance the particles travel after leaving the cone and reaching the ring. [***Editor's note:*** *For a list of each variable and its meaning, see Table I.*]

When determining the cone and ring size and placement, there are a few important things to keep in mind. The cone's diameter, D, should be approximately one-third of the bin's diameter. Then, the distance between the cone's bottom and the ring's top should be chosen so that the particles impact either the teeth in the ring or fall through the gaps between. Designing the dispersion cone device so that the ring's location can be moved is recommended. Also, *discrete element method (DEM)* modeling can be used to fine-tune the device's design but isn't required to do so. DEM is a software-operated numerical method for modeling the bulk behavior of granular materials, including those with a distribution of particles. **PBE**

References

1. Lyn Bates, *User Guide to Segregation*, British Materials Handling Board/Bartham Press, London, 1997.

For further reading

Find more information on this topic in articles listed under "Agglomeration" in *Powder and Bulk Engineering*'s article index in the December 2019 issue or the article archive on *PBE*'s website, www.powderbulk.com.

Greg Mehos, PE (greg@mehos.net, 978-799-7311), is a chemical engineering consultant who specializes in bulk solids handling, storage, and processing and is an adjunct professor at the University of Rhode Island. He received his BS and PhD in chemical engineering from the University of Colorado and his masters from the University of Delaware. He's a Fellow of the American Institute of Chemical Engineers.

TABLE 1

Legend for equation variables

Variable	Value
V_0	Velocity before impact (free-fall velocity)
g	Acceleration due to gravity
h	Drop height
V_1	Velocity after impact
θ	Impact angle
ϕ'	Angle of wall friction (the inverse tangent of the friction coefficient)
a	Particle acceleration
α	Cone's angle (measured from horizontal)
V_2	Velocity upon reaching the cone's end
s	Distance the particles travel
D	Cone's diameter
H	Cone's height
X	Difference between the radii of the cone and the ring
t	Time
Y	Vertical distance the particles travel after leaving the cone and reaching the ring