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Understanding and minimizing powder segregation

Gary Liu DowDuPont

Particle size or particle density differences between a mixture's particles can mean that your material will be subject to a disturbing force or deforming influence and segregation is inevitable. The question becomes how to minimize segregation effects rather than totally avoiding or preventing them. This article aims to provide a better understanding of what causes bulk solid material segregation and techniques to minimize or mitigate segregation in your bulk solids processing and handling operations.

The industrial sector handles extraordinary quantities of loose bulk solid materials. Bulk solid materials account for half the total volume and one-third of the value of all the materials handled by large industrial processing companies.[1] During the various manufacturing processes, most materials go through multiple stages of storage and handling. The final products are required to conform to specific quality standards and sometimes very tight specifications. In my experience, powder segregation is a common occurrence during bulk storage and handling processes. *Powder segregation* can be defined as the undesirable modification of a material's particle size distribution or the involuntary separation of portions of a bulk solid that were homogeneously dispersed.

The circumstances that cause segregation are as varied as the methods of moving bulk powders. Some typical segregation-inducing activities include material storage and flow in hoppers, gravity flow in chutes, changing material flow direction at equipment transfer points, particles sliding down the angled surface of existing material piles, and material falling through the air to land on a growing material pile. Any circumstance whereby the mass of material is subject to a disturbing force or deforming influence offers an opportunity for the discriminatory motion of *fractions*, which are groups of particles with a certain particle size or bulk density in a mixture or bulk solid.

A mixture made of particles of different dimensions or bulk densities will always tend to separate, resulting in the particles of one size or density to group in one area and the particles of another size or density to group in another area. Note that all industrial mixing is made of particles of different dimensions, which means that all mixes will be subject to segregation in processing steps downstream from the mixer.

In principle, powder segregation can occur at any stage of industrial production and can be very difficult — if not impossible — to avoid. Adverse segregation effects include reduced blend quality and flow problems in bulk solids handling equipment. According to Bates,[2] segregation can occur because of differences in particle size (as stated previously) and particle density, shape, surface texture, electrostatic charge, micromechanical properties, molecular surface effects, and other factors.

Variables influencing segregation

Many particle properties play a role in segregation, including particle size, density, shape, and cohesivity. When particles are handled in bulk, the material's powder bulk properties, such as angle of repose, cohesiveness, and wall friction also have an important role in segregation. However, particle size differences are the dominant factor in most segregating mechanisms, and for homogeneous materials particle size is typically the only factor. As a rule of thumb, segregation will be a problem for a ratio of particle size diameters greater than 1.3-to-1. However, segregation is typically not a serious problem when all particles in a mixture are 30 microns or less. In such fine powders, interparticle forces generated by electrostatic charging, van der Waals forces, and forces influenced by moisture have a larger impact compared with gravitational and inertial forces. These various interparticle forces cause particles to stick together preventing segregation as particles aren't free to move relative to one another.

Due to its influence on inertial and fluid drag forces, particle density has a role, particularly with respect to mixtures of differing materials and in highly dilated conditions of the bulk materials, such as with a fluid bed. Particle shape and surface roughness influence both fluid drag effects and the tendency for the particles to roll, shear, or experience both rolling and shearing effects. Rounded particles tend to move more

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freely than sharp, angular, irregular, rod, plate-like, dendritic, or fibrous materials. If particles have complex shapes that can cause interlocking and poor flow, the particles will be difficult to mix. But once mixed, the interlocking effect will reduce segregation problems in the mixture compared to the segregation problems experienced when handling a mixture consisting of free-flowing particles.

Hard, dry, cohesion-less particles separate more easily and cause segregation of the constituent particles in a mixture compared to a soft sticky material with cohesive properties. Therefore, cohesive powders and those with high internal shear strength resist the relative movement of particles and, hence, are difficult to segregate after being well mixed.

Segregation mechanisms

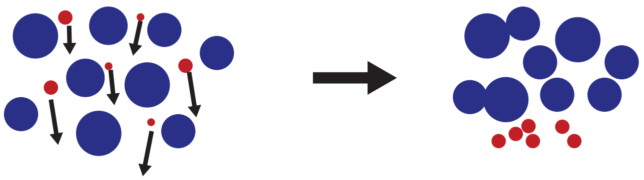
Segregation tends to occur whenever bulk material moves. Every handling or processing operation therefore gives rise to conditions in which segregation can take place. Segregation occurs where differential forces act on different fractions of the mass of bulk material. The differential forces at play are determined by the mechanics prevailing in specific material handling operations. For example, when materials in large bulk quantities move within a process or into a silo, this movement permits the particles within the mixture a large degree of freedom to relocate, resulting in segregation. Whether a bulk solid material has uncompacted, free-flowing particles or compacted, non-free-flowing particles is an important determinant for which type of segregation mechanism can occur in a process.

Previously mixed bulk solid materials can segregate during material moving, pouring, conveying, or other handling processes. Though many different segregation mechanisms have been classified,[2-4] the most important ones are: sifting segregation or percolation, trajectory segregation, fluidization or elutriation segregation, dusting or air-current segregation, angle-of-repose segregation, and agglomeration segregation.

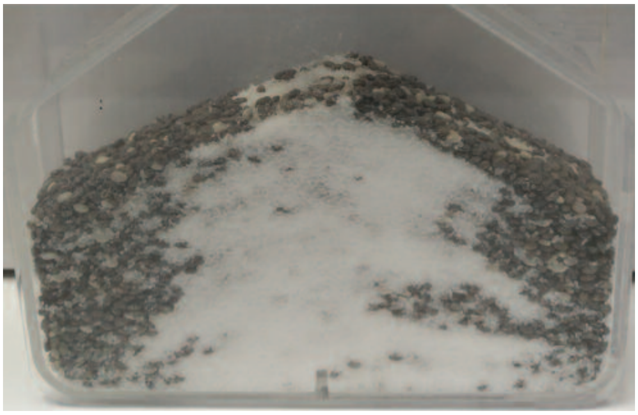
Sifting segregation also called *percolation* is a type of up-and-down segregation that occurs when there's a particle size difference between the particles in a mix. Interparticle motion causes the finer particles to sift through the coarser ones. When the mixture is moved, the gaps in between large particles open and small particles can travel between the larger particles and settle below them. Repetition of the movement allows the mixture's small particles to concentrate at the bottom of the mixture while coarse ones remain at the top, as shown in Figure 1a. A very small difference in particle sizes in a material, even a particle size diameter ratio as low as 1.3-to-1, can give rise to significant segregation.

Figure 1

a. Sifting segregation



b. Sifting segregation when pouring material into a container



Segregation by sifting can occur whenever the mixture is disturbed, which causes the rearrangement of particles. This effect can happen during material stirring, shaking, vibration, or when pouring particles into a heap, such as when filling and discharging a silo. In order for sifting segregation to occur, the powder mixture must be free-flowing with coarse particles larger than 150 microns. Figure 1b shows an example of the result of sifting segregation when filling a container with free-flowing material and a wide particle size distribution difference between the materials.

Trajectory segregation occurs during the transfer and pouring out of powders and is a type of side-to-side segregation where larger and heavier particles fall farther away from the material's origin than the finer and lighter particles, as shown in Figure 2a. This is because the inertia of the particles will depend on their size and density. Depending on these variables, the particles will adopt different trajectories. Typically, a particle with a diameter that's twice as large would travel four times as far as a particle with half the diameter before coming to rest.

Trajectory segregation happens in many types of bulk solids handling equipment, such as belt conveyors and screw conveyors. For example, Figure 2b shows the trajectory segregation that occurs when a screw conveyor is removing corn stover from a hammermill. This segregation may jeopardize the downstream operation.

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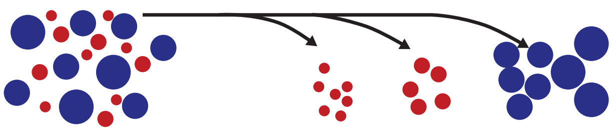
Figure 2

a. Trajectory segregation



b. Trajectory segregation in a screw conveyor

Fluidization segregation, also called *elutriation segregation,* is a type of up-and-down segregation that can occur when a powder mixture containing an appreciable proportion of fine particles or *fines* under 50 microns is fed into a storage vessel or hopper and air in the vessel is displaced upward. The upward velocity of air may exceed the terminal free-fall velocity of the finer particles, which may leave the particles in suspension longer than coarser particles and form a "fluidized" fines layer. Only coarser particles can penetrate the fluidized fines and the finer particles will remain in the top material layer, as shown in Figure 3.

Dusting segregation or *air-current segregation* occurs when air currents strong enough to carry fine and light particles cause air entrainment, moving the smaller particles within a silo or other vessel. Particles that are falling in a silo can induce these air currents and cause the air-entrained particles to settle where the airflow velocity is lower in the silo, such as near its walls. Coarser particles are less affected by the airflow and will settle under the filling point, as shown in Figure 4. The effect, a type of side-to-side segregation, becomes common when a mixture's fine particles are below 10 microns in diameter. Dusting segregation can also occur with larger, flake-shaped particles.

Angle-of-repose segregation occurs when a mixture of two materials with different angles of repose are filled into a container or open-air storage, forming a pile. The angle of repose of the most dominant mixture component has the greatest effect on the flow pattern and resulting segregation. For various reasons, either the fine or the coarse material fractions may form the lower repose conditions. Figure 5a shows a segregated pile with the fine particles having a higher angle of repose than the coarse particles. In general, angular granules hold together at steeper slopes compared to more spherical particles.

Figure 3

Fluidization segregation

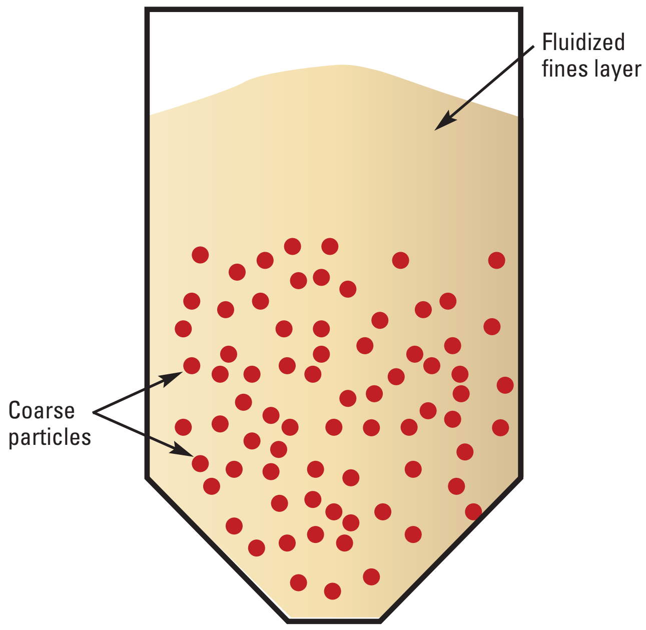


Figure 4

Dusting segregation effect during silo filling

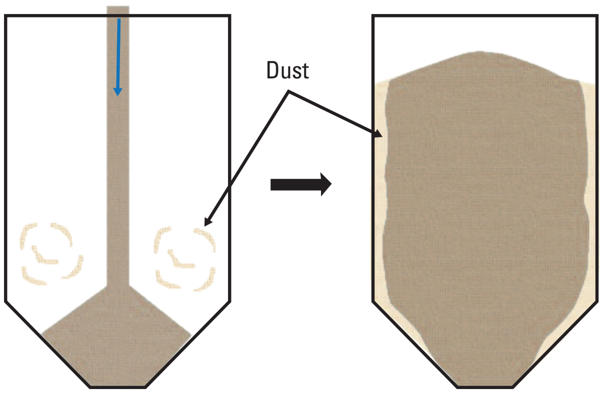


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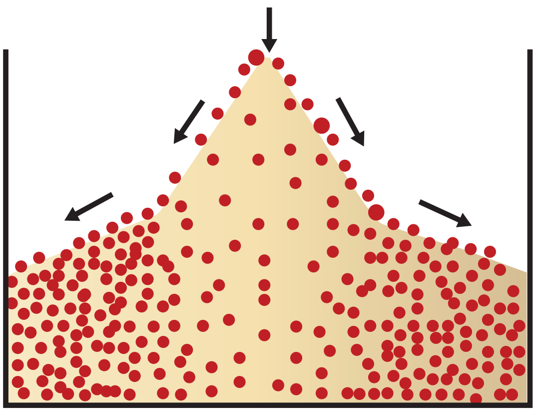
Figure 5b shows the effect of angle-of-repose segregation when dumping a mix of large stones and fines from a belt conveyor to a pile. Since the fines material has a high moisture content, the angle of repose of the fines fraction is very high.

Agglomeration segregation occurs when one of the components of a mixture is very fine and the small particles agglomerate and form lumps, becoming unmixable using ordinary mixing mechanisms. These agglomerates will create nonhomogeneity in the mixture since they will locally concentrate material from a single mixing component. Agglomeration segregation can have an incredibly detrimental effect on product quality. For example, a dry food product that contains fine lumps can immediately bring the negative attention of the customer. The phenomenon of agglomeration segregation is shown in Figure 6. In this case, the fines are supposed to form a coating of small particles on the larger, coarser particles. Instead, the fines form agglomerates and cause incomplete ordered mixing.

Figure 5

a. Angle-of-repose segregation



b. Angle-of-repose segregation in a stone pile

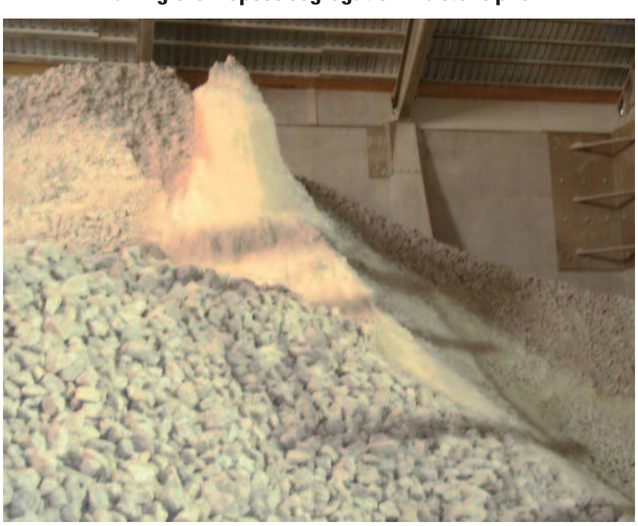
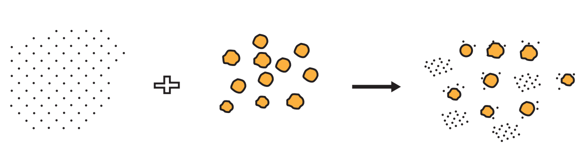


Figure 6

Agglomeration segregation causes incomplete ordered mixing



Preventing and minimizing segregation

Segregation is the most influential common factor that adversely affects the uniformity of bulk materials, raising problems of product suitability and giving rise to many types of handling and processing difficulties. Because of these negative impacts on products and the production process itself, the reduction or even elimination of segregation is crucial. Techniques to minimize and avoid segregation may be divided into two categories: minimizing the tendency of a materials to segregate and reducing segregation by changing the process and operation.

Minimizing tendency to segregate: As explained previously, the inclination of a material to segregate depends upon various factors, including the particle's characteristics in relation to the specific segregation mechanism occurring and what processing the material is undergoing. When the type of segregation relative to the application has been identified, you can consider how to modify the particle to reduce or even eliminate its tendency to segregate. Particle modification methods that can reduce segregation include: reducing the particle size difference among components; reducing particle size overall for each component (such as less than 30 microns); modifying particle shape, texture, or surface condition to make the particles more cohesive; and adding moisture or a weak binding agent into the mixture.

Reducing segregation by process adjustments: You can also change the process itself to minimize the tendency for segregation to take place during the production process or to reduce segregation's overall effect in the material. To minimize segregation, reduce the number of process steps performed after the mixing step and prior to the point of material use (for example at a bag filler or a dosing machine prior to further processing) and avoid free fall, mechanical transport, and pneumatic conveying. Other segregation-prevention techniques include: changing the material flowrate; changing the batch size; altering the operational sequence; using a mass-flow hopper; rearranging the equipment layout; using an alternative material handling method; and deferring mixing (hence potential segregation) until a later stage of production, if possible. **PBE**

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For further reading

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***Gary Liu** is principle consultant for solids processing and handling at DowDuPont (302-695-7627, gary.liu@dupont.com). He has more than 18 years of experience in solids handling and processing, both in research and development and commercial manufacturing. He's a registered Professional Engineer in the state of Delaware and holds a PhD in mechanical engineering from the New Jersey Institute of Technology, Newark, NJ.*

DowDuPont
Wilmington, DE
302-695-7627
www.dow-dupont.com