

Characterization of the Performance of Bin Blenders

Part 1 of 3: Methodology

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In this series of articles, bin blender performance is comprehensively reviewed using both free-flowing and cohesive mixtures.

In part 1, an introduction to tools and techniques is presented, followed by an examination of parameter effects, mixing mechanisms, and the effects of cohesion on mixing.

Blending powder and granular constituents plays a vital role in the production of a wide array of consumer and industrial products, including ceramics, plastics, food-stuffs, and pharmaceuticals. Among the available equipment for powder mixing, tumbling blenders remain the most prevalent. A number of different geometries are available from blender manufacturers, including V-blenders, cube blenders, and double cones. However, a more recent addition to tumbling blender geometries is the bin blender, which is also known as an intermediate bulk container (see Figure 1). The bin blender was originally designed so that after blending is completed the container can be removed from the drive and transported to the next process of operation without discharging its contents into a secondary vessel (i.e., hopper, barrel, etc.). This added functionality eliminates the need for additional transport containers and avoids tying up the production line. Furthermore, this design minimizes operator contact with the blender contents, which can be hazardous. This series of three articles provides an overview of recent

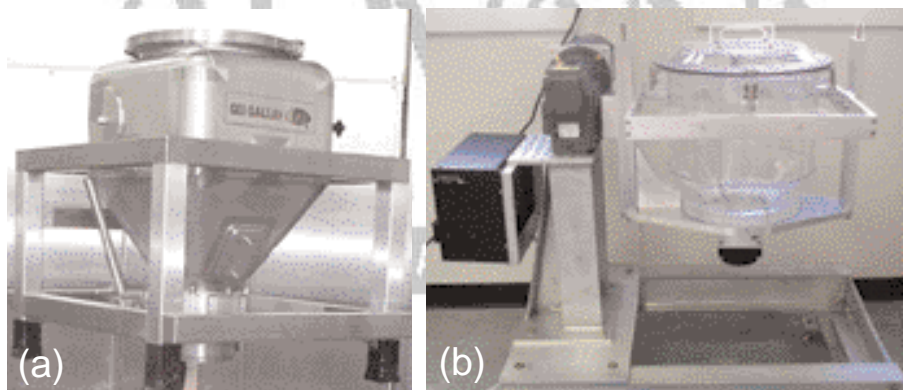


Figure 1: Two variations of the bin blender. (a) is a rectangular design by Galloway (Birmingham, UK), and (b) is a cylindrical design by L.B. Bohle (Ennigerloh, Germany).

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computational and experimental findings regarding the performance of bin blenders over a range of processing conditions and mixture types.

Characterization of mixing processes

Mixing in tumbling blenders. The simplest function of a tumbling blender is to blend all the constituents of a given mixture in a single processing step. In this function, each ingredient is loaded separately into the blender, and the blender rotates until a homogenous mixture has been formed. The tumbling blender also may be used to blend lubricants into an already homogenous powder mixture. In addition, tumbling blenders can be used as preblenders for mixing a low-dose active ingredient (often cohesive) with a portion of the excipients. Once this preblending step is completed, the mixture then is transferred to a larger blender (tumbling, convective, pneumatic,

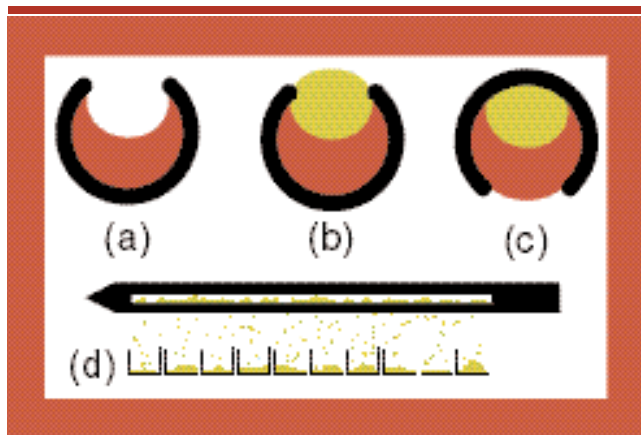


Figure 2: The cross section of the groove sampler when the sampler is open and empty (a), open and full (b), closed and full (c). The sample collection procedure (discharge into trays) is illustrated in (d).

etc.) and mixed with the rest of the excipients before further processing.

Many experimental investigations regarding the performance of tumbling blenders have appeared in the literature over the past few decades. Some studies have used broad comparisons of the utility of different blender types (2 or more at a time) for one or two particular mixtures (1–3). Other studies have investigated the mixing efficiency of one or two blenders for multiple mixtures to compare efficiency (4–6). Only a few studies have used a single blender with a single mixture to determine the effects of various operational parameters on blender efficiency (7–10).

Bin blenders have only recently been specifically examined (11–13). However, these studies found bin blenders to be similar in geometry and functionality to double cone blenders, which have been more extensively covered (8, 14–17). Essentially, a bin blender is a “single cone blender”—a double cone blender cut in half. In the investigations of double cones, radial mixing (i.e., perpendicular to the axis of rotation) has been found to be more than an order of magnitude faster than axial mixing (parallel to the axis of rotation). Furthermore, inserting baffles to increase axial displacement has been shown to markedly increase mixing rates. These generic characterizations of double cone blender performance are similar to the mixing performance in bin blenders for some materials and processing conditions. However, for other mixtures, certain baffle configurations, and processing conditions, differences in blending performance occur, which will be discussed in detail throughout this article.

Sampling tools and methods

The opacity of granular materials often requires the extraction of spot samples for compositional analysis to determine mixture quality. Currently, the characterization of granular mixtures is limited by the errors and biases associated with most available means of sample extraction. The most commonly used devices for sample retrieval are thief probes. End-sampling and side-sampling thieves have been shown to produce erroneous information regarding spot sample compositions (18, 19). A

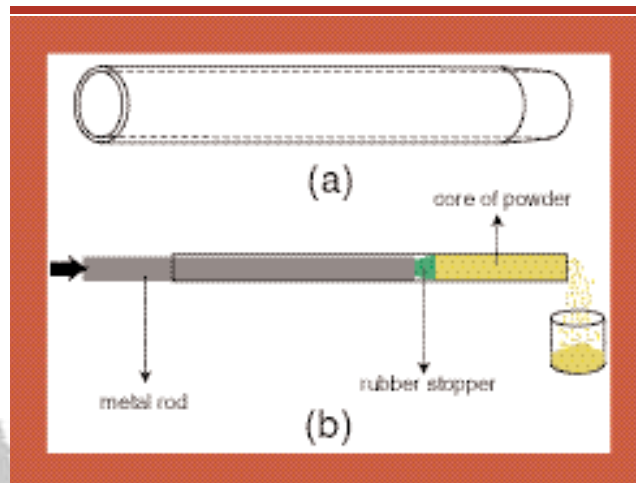


Figure 3: A sketch of a core sampler is shown in (a). The sample collection procedure is shown in (b). The metal rod is pushed by hand or by a threaded rod, and sample size is controlled by placing a scale under the sample collector. As the powder emerges from the sampler, a spatula is used to scrape powder into the collection vial, which enables better control of sample weights.

major problem with most thieves is that the retrieved sample is not representative of the true concentration at the location from which the sample was supposed to be obtained. These sampling errors are caused by contamination with material from other locations in the mixture during probe insertion. Also, nonuniform flow of different components into the sampling cavity can skew the sample concentrations (which is common when different size particles are present). Recent work has shown that two samplers—the groove sampler and the core sampler—which are used exclusively in this article, are more effective, accurate, and reliable than typical side-sampling or end-sampling thieves (19, 20).

The groove thief consists of a hollow sleeve (1 in. in diameter) surrounding a solid inner steel rod with a groove bored along most of the length of the pipe (19). The inner pipe has a sampling cavity that is $\sim 1/2$ in. deep and wide along the middle 80% of the rod. Rotating the inner pipe relative to the outer pipe opens and closes the sampler. The sampler is inserted into the powder bed while open; rotating the inner tube traps material within the sampler (see Figure 2a–c). After being removed from the powder bin, the sampler is then placed horizontally on a stand while open, and the entire device is rotated to discharge the collected material into a series of small trays (see Figure 2d). Sample size can vary depending on the size of the sampler or the width of the containers into which the material is discharged.

The other sampling technique uses a core sampler (a hollow tube filed to a thin edge at one end) to gather samples. The tube is thrust into the mixture and retrieved, leaving a core of material in the sampler that is held in place by static friction forces, and is then extruded in a last-in–first-out manner (see Figure 3). The use and accuracy of this sampler has been described extensively (20). This sampler has proven to give more accurate representations than typical thief probes of mixture dis-

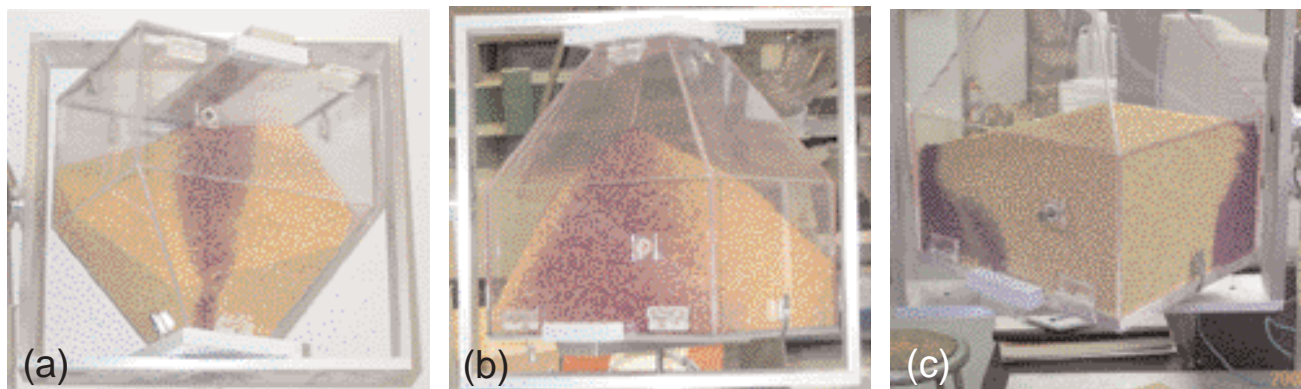


Figure 4: Segregation patterns in a 14-L bin blender for a mixture of 1800 μ gold and 800 μ purple glass beads. Different patterns are noted when the blender is run at 5 rpm (a), 15 rpm (b), and 25 rpm (c).

tributions while simultaneously causing less disturbance of the powder bed.

Avoiding contamination during sample collection is vital, but determining the location and number of samples to extract from the mixture is equally important. Often, samples are taken from throughout the bed to ensure complete coverage of the entire mixture. Although this approach guarantees thoroughness, it can lead to wasted time, effort, and material if more efficient means are available.

Mixing in tumbling blenders is often limited by the axial transfer of material or by segregation of the components (usually caused by variations in particle characteristics such as size or shape). Previous work has shown that segregation of mixtures in some tumbling blenders creates axial gradients in concentration (16, 21). Similar results occur in a bin blender when a binary-distributed mixture of glass beads is run at constant rotation rate. Figure 4 shows the three types of segregation patterns that form in a binary mixture of 1.6mm and 600 μ glass beads when run at different rotation rates. These segregation patterns correspond exactly to those seen in double cone blenders over a wide range of rotation rates and particle sizes. The mechanisms and effects of particle size and particle size ratio have been discussed in detail (16).

These data imply that axial sampling of the blender is vital whereas *radial* sampling (sampling at multiple locations on the same line perpendicular to the axis of rotation) may be superfluous. This concept has been tested in a 56-L bin blender. Figure 5a shows a typical total sampling scheme for a circular opening using 14 core sampler locations. In Figure 5b, the variance measured using only the axial samples (i.e., cores 1, 8, 9, 12, 13) is compared to the results obtained from using all the probes. Although the number of samples has been reduced by almost a factor of 3, the resulting variance versus revolutions data show very good agreement, indicating that limited axial sampling gives information equivalent to that obtained from total sampling (19).

Statistical methods

Typically, a measure based on total mixture variance has been used as the means to track the evolution of mixture quality in tumbling blenders. When generating total mixture variance, all of the samples from a given time point are used to generate vari-

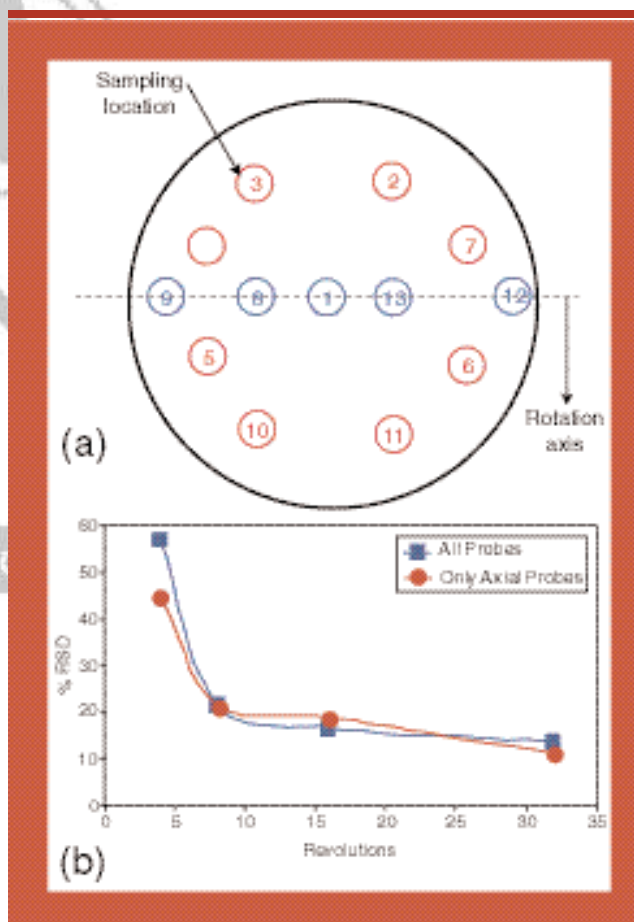


Figure 5: (a) A typical sampling scheme for a blender with a round opening on the top. The sampling locations highlighted in blue are the axial samples and the locations in red are the radial samples. The number corresponds to the order in which cores were taken from the mixture. The decrease in variance for measurements using all samples or just axial samples is shown in (b), using a top-to-bottom loaded mixture of ~400 μ sand run at 10 rpm.

ance (σ^2), standard deviation (σ), or relative standard deviation ($RSD = \sigma/M$ where $M = \text{mean}$), which can be inputted into a suitable mixing index and tracked over time. In laboratory-

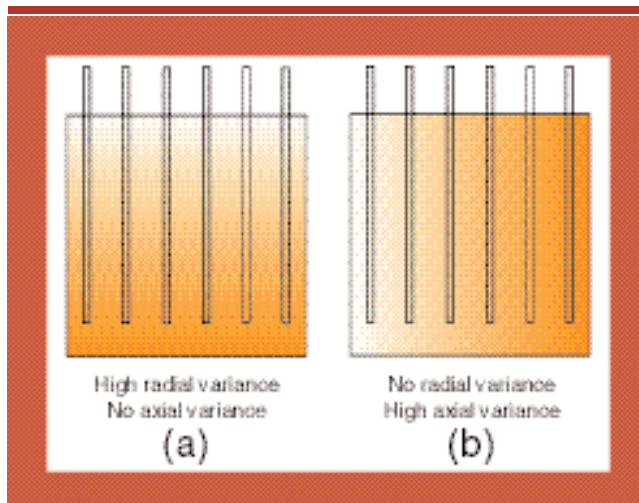


Figure 6: Two mixture distributions are shown corresponding to high radial variance (a) and high axial variance (b). In mixture (a), each core has the same average concentration, but the sample concentrations within the core vary considerably. In mixture (b), each core has a different mean concentration, but every sample within each core is uniform in concentration.

scale experiments, the blender is commonly loaded anew for each time point, and at larger scales, the blender often is periodically stopped and sampled. This experimental/statistical approach provides broad insight into the rate at which different materials will mix in a single blender, or can distinguish one blender from another for similar parameter settings (fill, rotation rate, etc.). The drawback is that using a single measure of mixture quality does not give much insight into mixing mechanisms within a specific blender. For instance, a poor mixture can result from different regions of the blender containing material with moderately different concentrations or from a few wayward samples (very high or very low) caused by agglomeration of the active substance or dead zones in the blender. A single measure of variance may not differentiate between these situations, which is important because radically different approaches are needed to fix these different classes of mixing problems.

One way to gather more information without the need for more sampling is to split up the total variance measurement into separate dependent measurements of axial variance and radial variance. Rather than use all obtained samples to generate a single measure of mixture quality (i.e., total variance), samples are grouped together in such a way to generate individual measurements of axial variance and radial variance. Radial variance can be interpreted as WL (within location) variance and axial variance as BL (between location). The use of core or groove sampling greatly aids this differentiation because the average value of entire cores (grooves) can be used to determine axial variances whereas the variance of samples taken from a single core (groove) can determine radial variances (22). Figure 6 shows two mixtures that would give similar results for total sampling but very different results when the variance is split into axial and radial components. For Figure 6a, high radial variance and low axial variance would be measured, whereas

for Figure 6b, the opposite, low axial and high radial variances would be detected. The extra information supplied from axial and radial variance measurements would give important clues on the best means for approaching a specific mixing problem.

The splitting of variance is established by first defining an axial zone j as

$$\bar{x}_j = \frac{\sum_i x_{ij}}{N_j} \quad [1]$$

in which the local (core) mean is \bar{x}_j , x_{ij} is a given sample, and N_j is the number of samples within that zone/core. The standard definition of variance is

$$\sigma^2 = \sum_j \sum_i \frac{(x_{ij} - \bar{x})^2}{N} \quad [2]$$

in which σ^2 is variance, N is the number of samples, and \bar{x} is the mean composition. Substituting equation [1] into equation [2] and rearranging, leads to

$$\sigma^2 = \frac{1}{N} \sum_j N_j (\bar{x}_j - \bar{x})^2 + \frac{1}{N} \sum_j \sum_i (x_{ij} - \bar{x}_j)^2 \quad [3]$$

In equation [3], the first term is a measure of axial variance and the second term radial variance.

To quantitatively compare mixing efficiency, it is useful to determine the rate of variance (or RSD) decrease at different processing conditions. A quantitative measure of the rate of variance decrease can be obtained by assuming exponential decay (7, 8) and defining a mixing constant k such that

$$\sigma_M^2 = \sigma_N^2 e^{-k(N-M)} \quad [4]$$

in which σ_M^2 is the variance at revolution M , σ_N^2 is variance at revolution N , and $(N-M)$ is the elapsed number of revolutions (RSD can be substituted for σ^2 in equation [4]). The mixing constant k yields a quantitative measure that can be used to evaluate how changes in process parameters or mixture composition affect mixing rates in the blender.

The use of variance-related measurements is the most common way to assess mixture quality. In some cases, however, other variables can be used to aid in the assessment of mixing phenomena in the blender. For example, tracking the sample mean (average of all the extracted samples) can indicate that the blend is not uniform if the sample mean deviates significantly from the expected mean. Another strategy is to track the change in minimum and maximum samples over time. If the minimum and maximum samples are highly aberrant from the mean, this could indicate agglomeration or the presence of dead zones in the blender, both of which can be extremely detrimental to overall blender performance. When analyzing mixing performance in a

blender, it is important to use all available information to build the best possible understanding of the dynamics within the blender.

Parameter effects: speed, loading, fill

For mixing in bin blenders (or any tumbling blender), perhaps the most important aspects to assess are the effects of the basic parameters (i.e., those that can be varied for a single blender using one or many mixtures) on the mixing process. Two parameters, the loading method (how the constituent materials are put into the blender) and the fill level (the percentage of total blender capacity occupied by the material) are always variable, while in some cases, the rotation rate of the blender also can be adjusted. General guidelines and caveats regarding the effects of fill, loading, and rotation rate are described below.

Lower fill levels induce faster mixing rates. When the amount of material in the blender is reduced, mixing should be faster. However, very low fill levels (<~25%) interfere with natural mixing mechanisms and hinder mixing rates. Filling the blender to more than 60% of its capacity can lead to dead zones in the middle of the mixture that do not interact with the rest of the mixture.

Loading. Symmetrical top-to-bottom loading will stress radial mixing and, hence, mix faster than loading the blender left-to-right, which emphasizes slower axial mixing.

Rotation rate. Changing the rotation rate has been shown to have no effect on mixing rates for free-flowing materials at moderate rotation rates (<25 rpm) using relatively small blenders (7, 8). However, these findings have not been adequately tested using cohesive mixtures. For very cohesive mixtures, shear becomes the dominant factor and rotation rates may play a decisive role in determining mixing rates.

Mixing mechanisms

Before discussing specific mixing mechanisms for bin blenders, it is useful to examine some common rules that apply to tumbling blender performance. Perhaps the most obvious (and most important) observation is that radial mixing has been found to be more than one order of magnitude faster than axial mixing (8). Radial mixing is believed to occur as the mixture winds around a central point at the interface between the cascading layer and material undergoing solid-body rotation, forming striations and layers that become finer with increasing rotations (23). Axial mixing is believed to be dependent on random axial fluctuations in particle velocities as the particles flow down the cascade, generating a slow dispersive mixing process (24). However, these generic mixing mechanisms fail to provide any insight into approaches for improving mixing performance beyond preference for radial mixing over axial mixing. Another feature that has not been addressed is the critical role of mixture properties (especially cohesion) in generic mixing mechanisms. A major running theme throughout this series of articles is that mixture characteristics (however poorly defined they may be) can be much more important for determining mixing rates and overall performance than blender or operational specifics. This observation indicates that the development of effective methods for defining and measuring critical material properties will be crucial for a more comprehensive under-

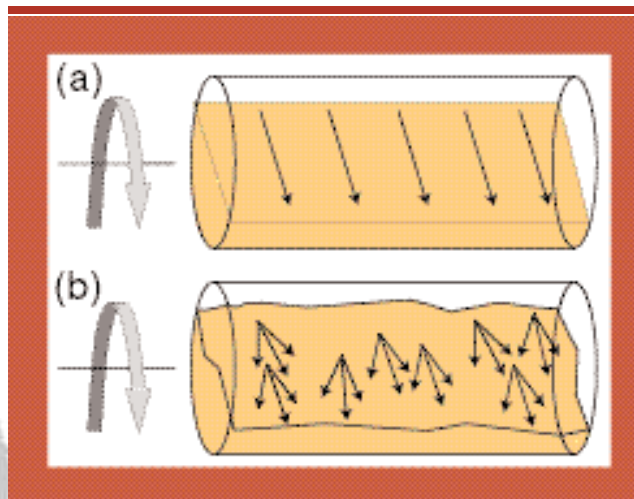


Figure 7: Sketches of the visible flow patterns on the surface of mixtures in rotating cylinders for mixtures of free-flowing (a) and cohesive particles (b). For free-flowing mixtures, the flow is straight, regular, and downstream. For cohesive mixtures, groups of particles avalanche down the cascade in multiple directions and these failures can start from almost any point on the surface of the mixture.

standing of tumbling blender operation.

Effects of mixture characteristics on mixing mechanisms. The major obstacle plaguing the definition of mixture characteristics is the lack of available means for meaningful comparisons of mixture cohesion. The inability to usefully and quantitatively define particle and/or mixture characteristics means that mixtures become qualitatively characterized as *free-flowing*, *cohesive*, *somewhat cohesive*, *mostly free-flowing*, etc.

A *free-flowing* mixture is one for which flow is determined by the dynamics of individual particles. In essence, each particle can be tracked and accounted for separately and mixing mechanisms arise from the time-averaged flow of these individual particles. A *cohesive* mixture is one for which single particles do not flow independently; rather, groups of particles act in concert when force is applied to the entire mass (avalanching). Hence, mixing mechanisms derive from the motions of groups of particles rather than single particles and there may not be any meaningful time-averaged flow field.

Outside of spherical glass beads, very few materials are truly free-flowing. Granulated lactose and sand both exhibit some avalanching tendencies but are still considered free-flowing. Other typical pharmaceutical materials such as microcrystalline cellulose and micronized lactose clearly are cohesive and exhibit strong avalanching dynamics. These differences in mixture characteristics have a significant effect on the resulting flow characteristics and mixing mechanisms.

The most recognizable change in mixture behavior that results from the degree of cohesion is the flow patterns that are observed in transparent vessels, illustrated here as a rotating cylinder (see Figure 7). For rotation rates in the rolling regime (25), free-flowing mixtures are characterized by a regular flow with a nearly flat surface and little or no variability in bed height perpendicular to the mean flow; particles travel along pathlines

nearly perpendicular to the axis of rotation. In contrast, cohesive mixture flow is characterized by a series of failures on the surface of the mixture, which mark the onset of flow for a discrete portion of the mixture (the size of the failures is most likely dependent on mixture properties and blender rotation rate). The flow of these avalanches is typically both downward and outward. Thus, the surface of the cohesive mixture is marked by many hills and valleys, and the flow down the cascade is rarely straight or perpendicular to the axis of rotation.

Characterization of flow patterns is further complicated because mixtures are often composed of many compounds with different degrees of cohesion. Different complicated flows can occur depending on the fractional composition of each constituent, the relative cohesion between the components, the degree of dilation, electrostatic charging, and the distribution of these materials in the mixture (especially the initial conditions). In mixtures for which actives and excipients have similar flow properties, the general flow types discussed previously will prevail. However, when one part of the mixture is cohesive and the other part is free-flowing, less predictable behavior will occur. Furthermore, the relative amounts of the various components will play an important role in determining the flow behavior and mixing mechanisms of the mixture. In general, experience indicates that even small amounts of highly flowable materials can significantly improve flow properties of the whole mixture, but more work is needed before a clear theory emerges.

Computational methods: discrete element method

One avenue that may eventually lead to a fast and effective means for testing new blender designs and process parameter effects on blender performance is the use of computer simulation. Some promising results have been obtained comparing bin blender performance in experiments and simulations for the mixing of large free-flowing glass beads.

A commonly used particle dynamics method for the modeling of granular flow is the discrete element method (DEM). DEM uses Newtonian physics to determine the velocity, angular momentum, and position of particles. Each particle is tracked in the system and particle-particle and particle-boundary interactions are computed. DEM simulations are often thought of as a macroscopic equivalent of short-range molecular dynamics in which the inelastic nature of particle collisions is taken into account. In recent years, the use of particle dynamic simulations has proliferated (26–29), and currently is being applied to certain complex industrial problems (30–32).

DEM simulations consider granular material as a collection of frictional, partially elastic spherical particles (33). Each particle may interact with its neighbors or with the boundary of the blender through both normal and tangential forces. The elastic modulus and computational time-step are chosen so that deformations of particles remain small when compared with their displacements and diameters. Particle interactions are tracked using linked list algorithms and the resulting equations of motion are integrated using a “leap-frog” algorithm.

Good agreement can be obtained with experiments for free-flowing particles. Experiments were run at 10-rpm and 60% of total capacity with 8-mm glass beads in a 14-L bin blender of

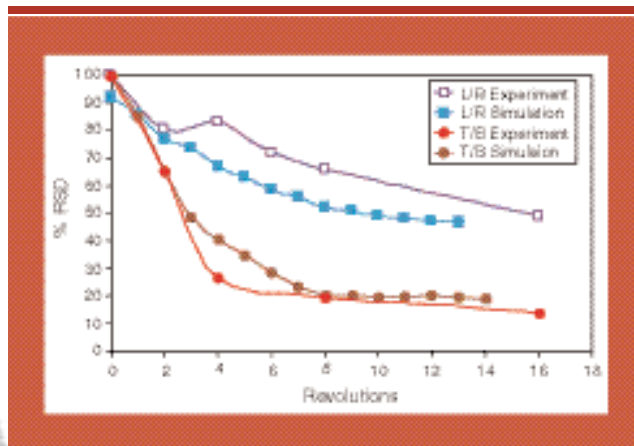


Figure 8: The RSD is plotted against the number of revolutions for simulations and experiments of 8-mm spherical particles, which ran at 10 rpm in a 14-L bin blender. The mixing rates show good agreement between simulation and experiment.

the same geometry as shown in Figure 1a. A vacuuming and counting technique was used to generate concentration data (33). Simulations were performed at the 1:1 scale used in the experiments. The simulation was “sampled” by defining cubic sampling boxes in the simulation. Each box was considered a separate sample and contained, on average, 40 particles. In Figure 8, the evolution of mixture variance is shown for top-to-bottom and left-to-right loading for both simulations and experiments. The DEM and experiments showed very good agreement in both the degree and rate of mixing under these processing conditions. However, we must caution that these encouraging results have been obtained for perfectly spherical, free-flowing particles. Simulations are currently hampered by both the lack of good models for cohesive forces and the limited number of particles that can be simulated in a reasonable amount of time. Furthermore, dealing with nonspherical particles or size distributions increases the computational time needed for even a relatively small number of particles. At present, simulations are far from close to being applicable to real-world applications and are only useful for small-scale theoretical investigations of specific granular phenomena.

An example

A preliminary example of how to dissect and analyze mixing data is presented: the mixing of 1% w/w% diphenhydramine HCl with an excipient matrix in a 56-L Gally bin blender run at 10 rpm (see Figure 1a). The excipient matrix is composed of microcrystalline cellulose (PH102 Avicel, FMC Corp., Philadelphia, PA), granulated lactose (Fast-Flo, Foremost Farms, Baraboo, WI) and magnesium stearate (nonbovine, Mallinckrodt, Hobart, NY) with a formulation of 39%, 60%, and 1% w/w%, respectively. Core sampling was used to gather samples; nine cores from throughout the blender surface (i.e., total sampling) were taken for every time-point and each core yielded 15–25 samples of 0.8g. In this study, UV spectroscopy was used to determine the composition of samples extracted from the blender. To use UV spectroscopy, a linear calibration curve of absorbance

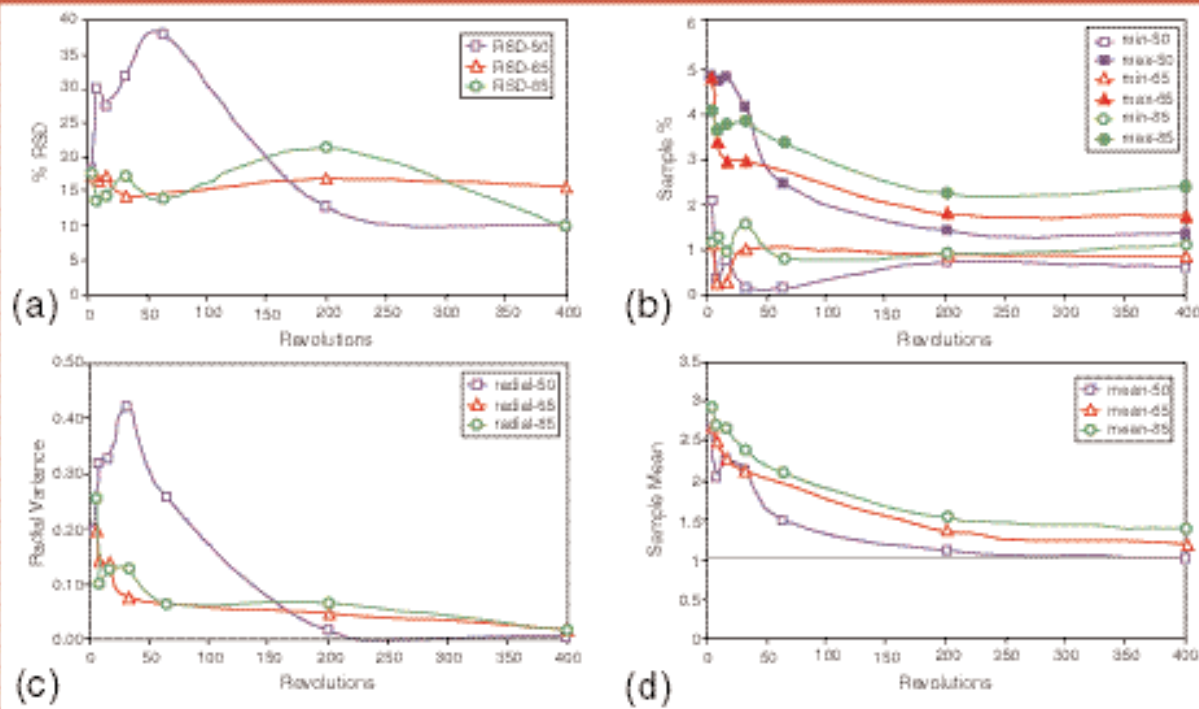


Figure 9: Mixing performance of Benadryl in a 56-L bin blender is assessed by examining total variance decrease (a), variation in maximum and minimum sample concentration (b), radial variance decrease (c), and the time evolution of the sample mean (d). The grey line is the mixture mean.

versus active concentration was obtained for a series of 1:500 dilutions in de-ionized water. A sharp peak was observed at 215 nm and shown to correspond solely to the active and not the excipients.

The evolution of the RSD for experiments run at 50%, 65%, and 85% of total blender capacity is shown in Figure 9a. In the early phases of the mixing process, the 50% case had the highest mixture variance, which is contrary to the expected results. At later times, the 50% case “caught up” and eventually became the lowest RSD (best-mixed) mixture after 200 revolutions. At 65% and 85% fill, the RSD was nearly constant throughout the mixing process, which appears to indicate that mixing was complete after only 4 revolutions. This curious result at short mixing times can be better understood by analyzing other computed statistics rather than conjecturing solely based on interpreting the decay of the RSD. In this case, tracking the change in the minimum and maximum sample concentrations provides more insight into mixture distributions (see Figure 9b). At early mixing times (<64 revolutions), the difference between the maximum and minimum values was greater for the 50% case than for either the 65% or 85% case. This distribution implies that the 50% case was radially mixed more poorly than the other cases, which is confirmed by examining the evolution of radial variance (see Figure 9c).

Early in the mixing process, the mixture became radially well-mixed at both 65% and 85%, but remained radially unmixed at 50% fill. These results contradict the expected outcomes that lower fill levels would mix faster than higher fill levels. Evalu-

ating the evolution of sample mean provides more insight into the cause of this quandary (see Figure 9d). For all three fill levels, the data in Figure 9d, indicate that early in the mixing process the sample mean is much higher than the expected mean, which appears to indicate that the blend is superpotent in the sampled region. In time, the sample mean decreases for all three fill levels, but only at the 50% fill level does the sample mean approach the true mean.

The loading procedure involved the use of a hopper to deposit material in the center of the blender. The active was loaded last and, hence, initially was concentrated in the middle of the blender. Sampling was limited to the middle ~40% of the mixture because of limited access from the opening of the blender to the mixture. This loading and sampling methodology placed a premium on axial transport to the edges of the blender for achieving a uniformly well-mixed product. Apparently, at higher fill levels, this axial transport was diminished and the active remained trapped in the middle of the blender, which rapidly led to a well-mixed but superpotent blend in the middle of the mixture while leaving the blender extremes deficient in active (leading to fast declines in radial variance but high sample means). In the 50% case, however, axial transport was more efficient at moving the active to all portions of the mixture, but led to increased radial variances because active concentrations were constantly in flux as higher potent material from the center intermingled with subpotent material from the edges. This example illustrates that using multiple means of determining mixture quality can provide important insight into the

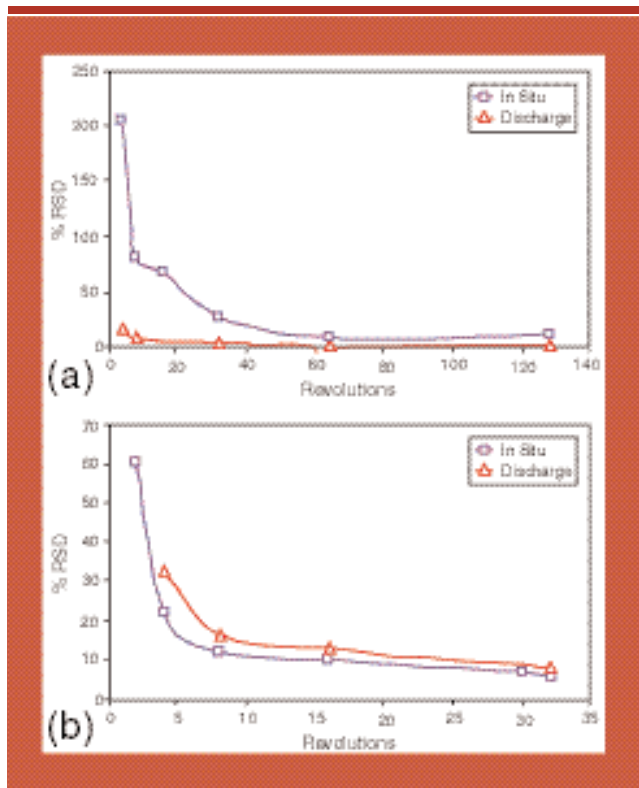


Figure 10: Measured RSD in situ and in a container post-discharge for a cohesive mixture of salt and microcrystalline cellulose (a), and a free flowing sand mixture (b), both at 60% fill level.

mixing mechanisms within the blender. In addition, it serves as a warning that relying on a single measure of mixture quality can lead to misleading and erroneous conclusions about the mixing process in the blender. Finally, this example also shows that loading and sampling methods must be included in the analysis of any mixing process.

Discharge

Mixing materials in a tumbling blender does not end the processing of that mixture. At some point, the mixture has to be discharged from the mixer into a conveyer, a larger mixer, a tablet press, etc. Experiments were run that compared the measured variance in the blender (in situ) to that in a container that collected the discharged material from the blender. Two mixtures were used: a 50/50 mixture of 450- μm of sand of two colors and a 3% mixture of sodium chloride with 96% microcrystalline cellulose and 1% magnesium stearate. Figure 10 shows the results of sampling the blender before discharging and then sampling the discharged matter in a bucket for both mixtures. For the cohesive salt mixture, discharging into a secondary container had a mixing effect and the RSD declined. For the sand mixture however, the RSD increased slightly after the mixture was discharged.

Logically, there is little apparent reason for the mixture to separate when discharged unless the mixture had strong segregation tendencies, which was not the case. Examining the difference between radial and axial variances for the sand mixture gives some

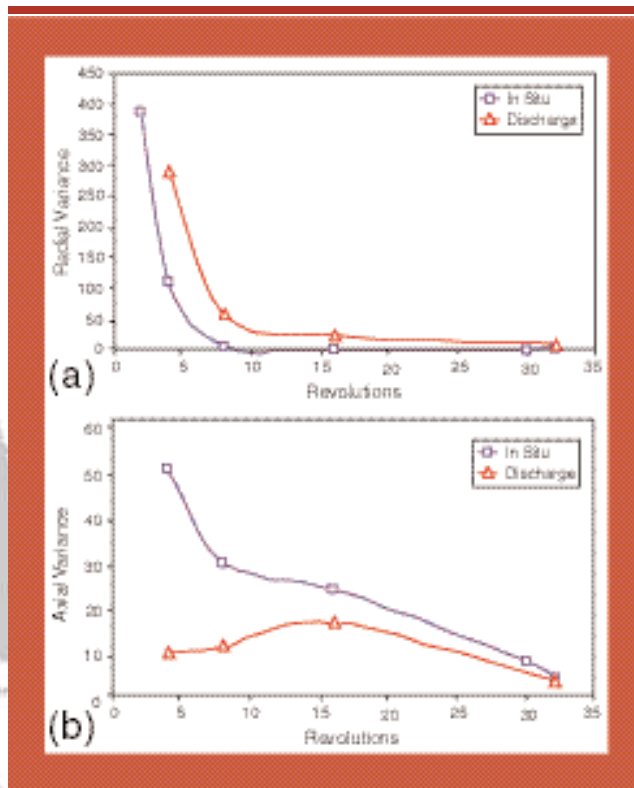


Figure 11: For the sand mixture, the radial variances (a) and axial variances (b) are compared before and after discharge.

clues (see Figure 11). On discharge the measured radial variance increased while the axial variance decreased; the RSD increased because the rise in radial variance was greater than the drop in axial variance. There are two likely causes of the increasing RSD with discharge: initial conditions and sampling bias. The blender was loaded top-to-bottom to produce an axially symmetrical initial condition. However, because the blender is not symmetric in a top-to-bottom sense, the initial conditions produced a gradient in concentration from the middle of the blender outward (see Figure 12). As sampling in situ was limited to the middle of the blender, this axial gradient was overlooked and the mixture may have appeared to be better blended than it really was. After discharge, the mixture was more thoroughly sampled which results in this apparent separation during discharge that was actually the result of better sampling techniques. During discharge, the axial variability was transformed into radial variability. Although in this case (a nonsegregating mixture) the quality of the mixture was expected to improve upon discharge, the apparent decrease in quality was solely a function of improved sampling of the mixture. The difference between the axial and radial variances in situ and post-discharge virtually disappeared as the mixture approaches a well-mixed state (32 revolutions). Thus, when discharging a nonsegregating mixture from a bin blender, it can be expected that well-mixed products will not be affected but that poorly mixed blends may actually improve in mixture quality. Any results that contradict these general expectations are likely caused by sampling biases or segregation.

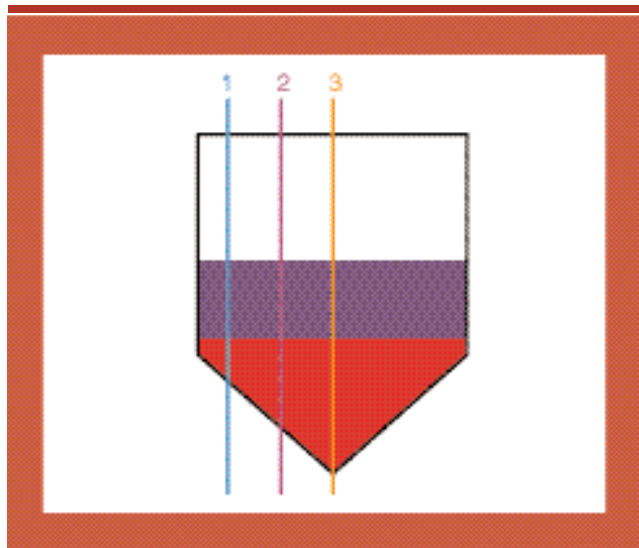


Figure 12: For a top-to-bottom loading in a bin-blender, the initial radial concentrations are not equivalent. At position 1, the mixture is mostly blue, at position 2, it is equivalently blue and red, and at position 3 it is mostly red.

Conclusion

Bin blenders continue to play an increasingly important role in the processing of granular and powdered materials. The dearth of specific information about the performance of bin blenders (and other tumbling blenders) makes it important to determine the performance of these devices in a variety of processing situations.

In this article, the basic approaches to gathering and analyzing performance data have been addressed along with a summary of basic operational guidelines both in terms of blender parameters and mixture types. An example of mixing analysis has been presented and the effects of discharge have been discussed, along with some cautionary information about mixture sampling. The next two articles in this series will describe, in detail, bin blender performance using free-flowing and cohesive materials.

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