Particle-Size Distribution, Part III

Determination by Analytical Sieving

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Analytical sieving is one of the fundamental methods for the classification of powders, and it is probably the method of choice for granular or coarse powders. The method is fairly simple to perform, its validation is relatively straightforward, and the interpretation and presentation of results are fairly standard. Well-established procedures for analytical sieving are found in the *United States Pharmacopeia*, and appropriate apparatus for its use are relatively available.

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Now that some of the general precepts of particle size and shape have been outlined (1) and the all-important topic of powder sampling has been addressed (2), it is appropriate to move into a discussion of the experimental methods used to deduce information about particle size. Analytical sieving is one of the most conceptually simple methods for deducing the particle-size distribution of a powdered solid. In sieving analysis, one simply passes the sample through wire meshes that have openings of various sizes and then measures how much of the sample is retained on each sieve.

Sieving is one of the fundamental methods for the classification of powders, and it is the method of choice for determining the size distribution of coarse powders. Although sieving is most suitable for powders whose average particle size exceeds 25–50 μm, it can be used for finer grades of powders if the method is properly validated and executed. Sieving analysis is difficult to perform for oily or cohesive powders because they tend to clog sieve openings.

Sieve construction

Sieves are constructed from wire mesh that is sealed into the base of an open cylindrical container. The ideal sieve openings are apertures that are nearly square. Figure 1 shows examples of the two most commonly used types of mesh screen. Analytical sieving using wire-mesh sieves provides a two-dimensional estimate of size because the smallest lateral dimension of each particle dictates its ability to pass through a given sieve opening.

The Tyler Standard Scale is a widely used classification scheme for sieve sizes. In this system, the standard is based on a wire cloth with 200 openings per linear inch, which is known as a *200-mesh sieve.* The diameter of the wire used for a 200-mesh screen is 53 μm, and the size of the opening is 74 μm. The ratio between the adjacent sizes of the screen scale is the square root of two. Thus, the areas of the openings of each sieve are twice those of the next-finer sieve. In addition, the ratio between the widths of openings of alternate sieves in the series is two. Closer sizing can be attained using screens that have a fixed opening-width ratio equal to the fourth root of two.

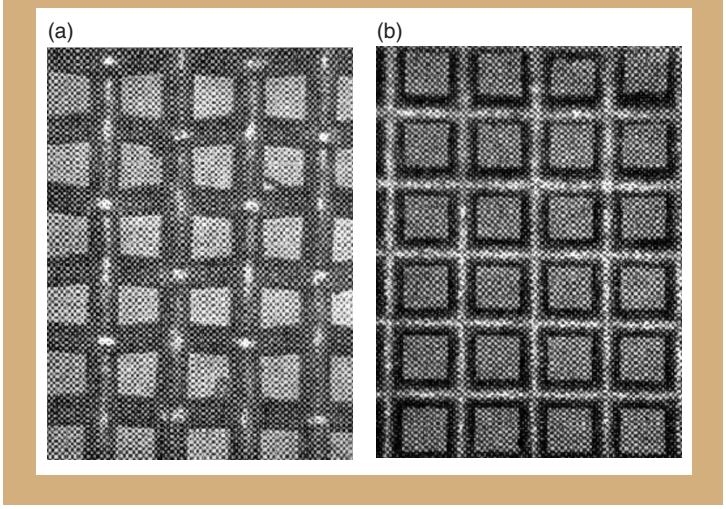

Figure 1: Photomicrographs of (a) woven-wire screen and (b) micromesh screen.

Table I: Sieve classifications within the US Standard and Tyler Series systems.

Mesh Number	Aperture Opening: US Standard Series (μm)	Aperture Opening: Tyler Series (μm)
18	1000	991
20	840	833
25	710	701
30	590	589
40	420	417
45	350	351
50	297	295
60	250	246
70	210	208
80	177	175
100	149	147
120	125	124
140	105	104
170	88	88
200	74	74
230	62	61
270	53	53
325	44	43
400	37	38

Another system was defined by the National Bureau of Standards using the same ratio as the Tyler Standard Scale, but it is based on an opening of 1 μm. This system is known as the *US Sieve Series*. The differences between Tyler and US sieves are small, and the sieves are often used interchangeably. However, *USP* General Test ⟨786⟩ specifies the use of sieves that meet the US Series definition (3).

A summary of Tyler and US Standard sieve classifications and the corresponding sieve openings has been documented (4), and Table I compares the systems. For fine sieves, the difference between the two systems is very small. However, for coarser sieves the difference between the Tyler and US Standard sieves is more pronounced.

Conducting sieving analysis

Conducting analytical sieving for the classification of pharmaceutical materials has been fully described in *USP* General Test ⟨786⟩ (3). The general method describes the use of both dry-sieving (Method I) and wet-sieving (Method II) procedures. In either method, sieves are stacked on top of each other in ascending degrees of coarseness, and the powder to be tested is placed on the top sieve. The nest of sieves is completed by a well-fitting pan at the base and a lid at the top. The literature provides additional sources of information about the performance of sieving analysis (5–8).

The nest of sieves is subjected to a standardized period of agitation, which causes the powder sample to distribute between the sieves. Agitation can be conducted using vibration, rotation–tapping, or ultrasound. The horizontal sieve motion loosens the powder packing and permits subsieve particles to pass through. Vertical motion mixes the particles and brings more of the subsieve particles to the screen surface. Although *USP* General Test ⟨786⟩ allows agitation by hand, it does not favor the use of this method.

In a properly designed sieve test, the sample is partitioned in approximately equal weights on each of five or six sieves and on the bottom pan. The sieving analysis is complete when the weight on any of the test sieves does not change by more than 5% of the previous weight on that sieve. Performance of a sieving test yields the weight percentage of powder retained in each sieve size range.

Summary of *USP* General Test ⟨786⟩ Method I. *USP* General Test ⟨786⟩ Method I gives the procedure to be followed when conducting the sieving analysis of dry powdered solids. The steps are as follows:

- Tare each test sieve to the nearest 0.1 g.
- Place an accurately weighed quantity of test specimen on the top (coarsest) sieve and replace the lid.
- Agitate the nest of sieves for 5 min.
- Carefully remove each sieve from the nest without losing material.
- Reweigh each sieve and determine the weight of material on each sieve.
- Determine the weight of material in the collecting pan in a similar manner.
- Reassemble the nest of sieves and agitate it for 5 min.
- Remove and weigh each sieve as previously described.
- Repeat these steps until the end point criteria are met (the weight on any of the test sieves does not change by more than 5% of the previous weight on that sieve).

When the analysis is completed, the analyst reconciles the weights of material. The total losses must not exceed 5% of the weight of the original test specimen. If particles retained on any sieve are aggregates (rather than single particles), then the use of dry sieving is not likely to be an easily reproducibile method. At that point, the analyst could consider the use of Method II as an alternate technique.

Summary of *USP* General Test ⟨786⟩ Method II. *USP* General Test ⟨786⟩ Method II gives the procedure to be followed when conducting the sieving analysis of wet or suspended solids. The steps are as follows:

Table II: Analytical sieving results.

Sieve Mesh Number	Sieve Size Opening (μm)	Mass of Sample Retained on Each Sieve	Percentage of Sample Retained on Each Sieve	Cumulative Percentage of Sample Retained on Each Sieve	Cumulative Percentage of Sample Passing through Each Sieve
40	425	7.49	5.2	5.2	94.8
50	300	13.55	9.4	14.7	85.3
60	250	21.38	14.9	29.5	70.5
70	212	32.87	22.9	52.4	47.6
100	150	41.32	28.8	81.2	18.8
140	106	22.47	15.6	96.9	3.1
270	53	3.26	2.3	99.1	0.9
Pan	—	1.24	0.9	100.0	0.0
Total		**143.58**	**100.0**		

- Modify the lid and collecting pan of the sieve nest to permit the addition of a liquid onto the surface of the top sieve and the collection of the liquid from the pan.
- Select a liquid in which the test specimen is insoluble and modify the sieving method as follows.
- Thoroughly disperse the dried test material in the liquid by gentle agitation and pour this dispersion onto the top sieve.
- Rinse the dispersion equipment with fresh liquid and add the rinsings to the top sieve.
- Feed the sieving liquid through a suitable pumping mechanism to the nozzle(s) in the lid and collect the sieving liquid from the pan in a suitable container.
- Continue the wet-sieving process until the emerging liquid appears to be free of particles.
- Remove each sieve from the sieve nest and dry each sieve to constant weight at the same temperature as that previously described.
- Determine the weight of dried material on each sieve.

The results are analyzed in the same manner as those that are obtained using Method I.

Validation of sieving methods. One of the most important experimental parameters to be determined in a sieving analysis is the time required to completely equilibrate the sample between all of the sieves. This time typically is determined by repeating the analysis with a fresh sample and continuing the mechanical agitation for successively longer periods of time. The proper sieving time is the smallest amount of time that leads to conformance with the requirements for end point determination. When this end point has been validated for a specific material, then a single fixed time of sieving can be used for future analyses, providing the particle-size distribution does not change significantly. The determination of the proper sieving time is part of the robustness evaluation of the method.

The two most important analytical performance parameters to be determined during the validation of a sieving procedure are the precision and the accuracy associated with the analysis. To evaluate precision, one repeats the particle-size determination of a properly subdivided sample three to five times (2) and compares the percentages associated with each size fraction. The accuracy of a sieving analysis is usually evaluated using standard powders consisting of micron-sized glass spheres of known particle-size distribution. The size openings in a sieve can be verified according to the amount of passage of the reference material or with a microscopic study of the screens themselves.

In sieving analysis, it is usually not possible to determine the analytical performance parameters of specificity, limits of detection and quantitation, linearity, or range.

Data interpretation and presentation

In addition to including information about the weights on the individual sieves and in the pan, the raw data must include the weight of the test specimen, the total sieving time, and the precise sieving methodology. The raw data are converted into a cumulative weight distribution, and if one wishes to express the distribution in terms of a cumulative weight undersize, then the range of sieves used should include a sieve through which all the material passes.

In many cases, the particle-size distribution of a real sample turns out to be adequately represented by a log-normal distribution. In such cases, the distribution can be specified by the geometric median particle size (d_g) and the geometric mean standard deviation (σ_g). One could conclude that two samples with identical d_g and σ_g values were drawn from the same total population. The value of d_g is equal to the 50% value of the cumulative distribution, and the value of σ_g is obtained by dividing the 84.1% value of the distribution by the 50% value.

Sieving results are most commonly plotted on 3-cycle log paper to compare the particle size with the cumulative percentage of undersize particles. If the plot is linear throughout the entire range, then the material is characterized by a log-normal distribution. If the line is curved or consists of two or more linear segments, then the distribution is polymodal. These concepts are described later in this article.

Table II shows the sieving results obtained from a powdered sample exhibiting a classic log-normal distribution. The data are typically presented by listing them as a function of both the sieve mesh number and associated sieve size opening (typically described in microns). For each sieve in the nested series, one details the mass of sample retained on each sieve, the percentage of sample retained on each sieve, and usually the cumulative percentage of sample retained on each sieve. The cumulative percentage of sample passing through each sieve can also be summarized, although this quantity is not ordinarily used in an analysis.

To illustrate the sieving results, one can plot either the percentage of sample retained (from Table II) on each sieve in a histogram plot (see Figure 2a) or the cumulative distribution as a function of sieve size (see Figure 2b). A 3-cycle plot is the most illustrative means for representing these data (see Figure 3c) because any departure from linearity that would indicate the existence of a polymodal distribution is readily apparent.

For the particle-size distribution shown in Figure 2, the value of the geometric median particle size (d_g) is 210 μm, and the geometric mean standard deviation (σ_g) is 1.57. As discussed in Part I of this article series (1), several other mean-particle values can

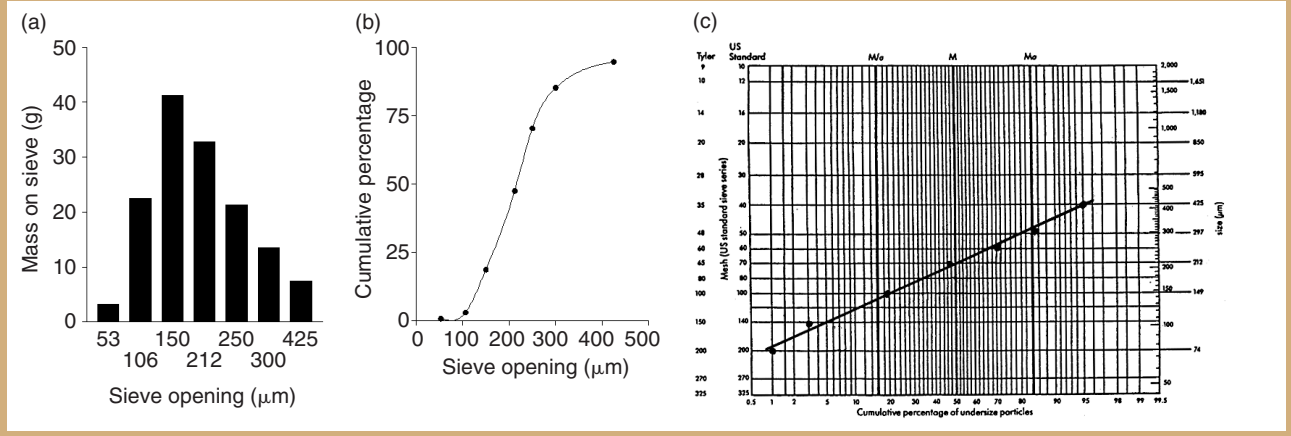

Figure 2: Representations of the particle-size distribution of a sample consisting of a unimodal distribution: (a) histogram plot, (b) cumulative distribution plot, (c) 3-cycle log plot.

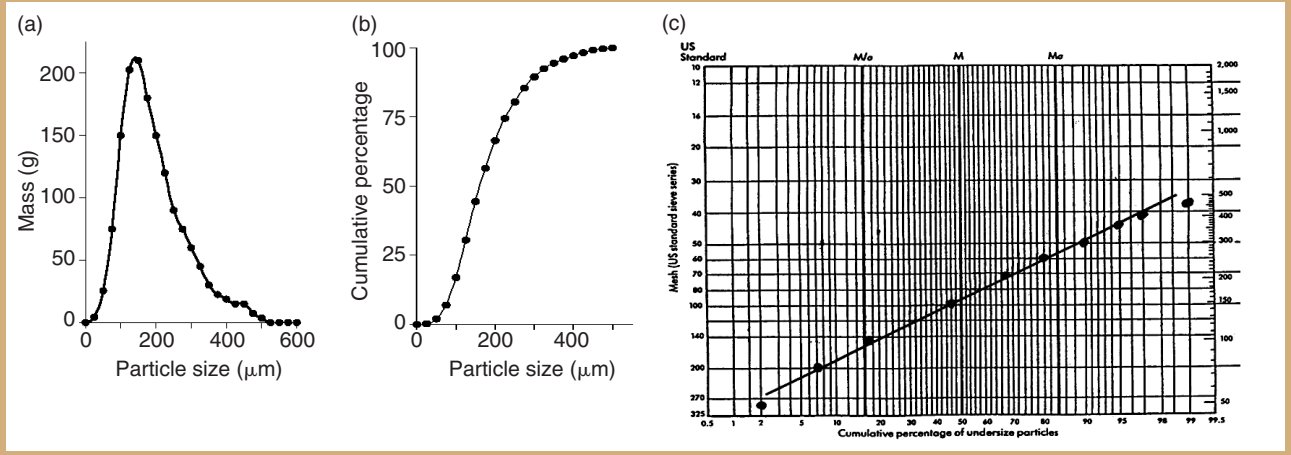

Figure 3: Log-normal representation of a sample consisting of a unimodal distribution.

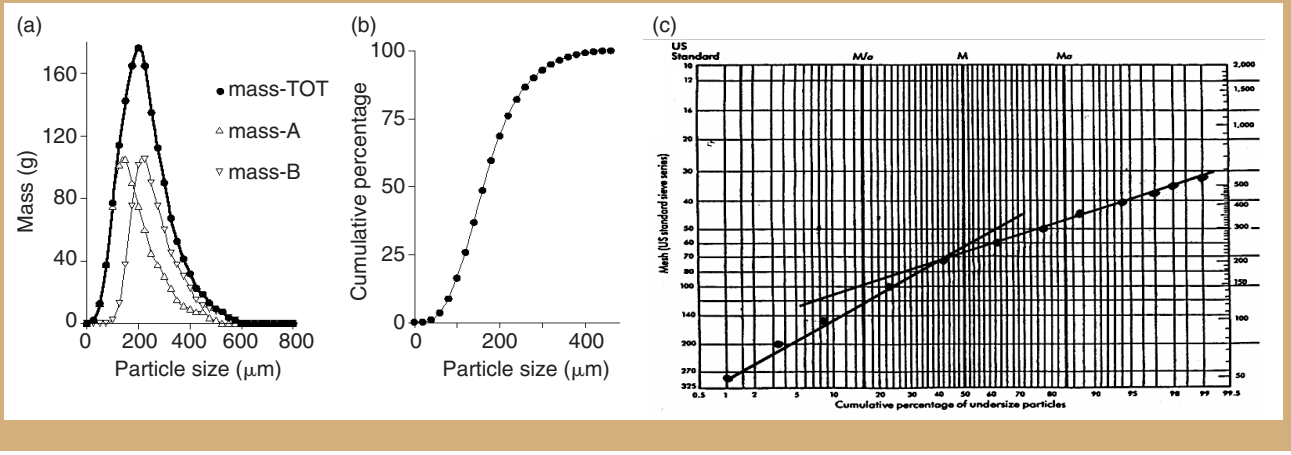

Figure 4: Representation of a sample consisting of a bimodal distribution, the modes of which differ by 100 μm.

be calculated. For this distribution, the surface mean-particle size is 215 μm, the volume mean-particle size is 231 μm, and the volume-surface mean-particle size is 267 μm. Depending on the intended use for the information about particle size, one mean value can have more significance to the analyst than another.

Sieving analysis of samples characterized by polymodal distributions

When the particle-size distribution of an analyzed sample is adequately characterized by a single (i.e., unimodal) distribution, then the method of data presentation described in the pre-

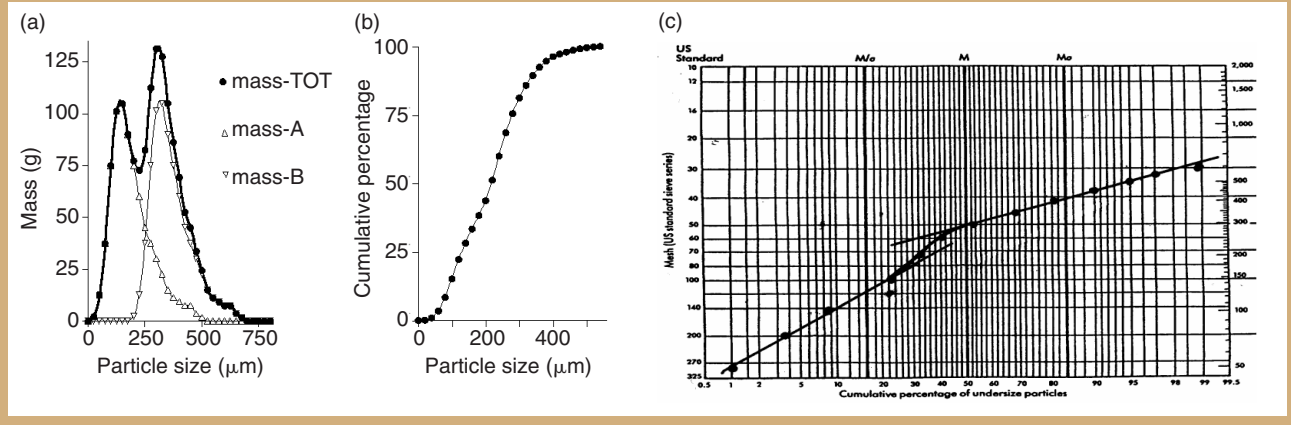

Figure 5: Representation of a sample consisting of a bimodal distribution, the modes of which differ by 200 μm.

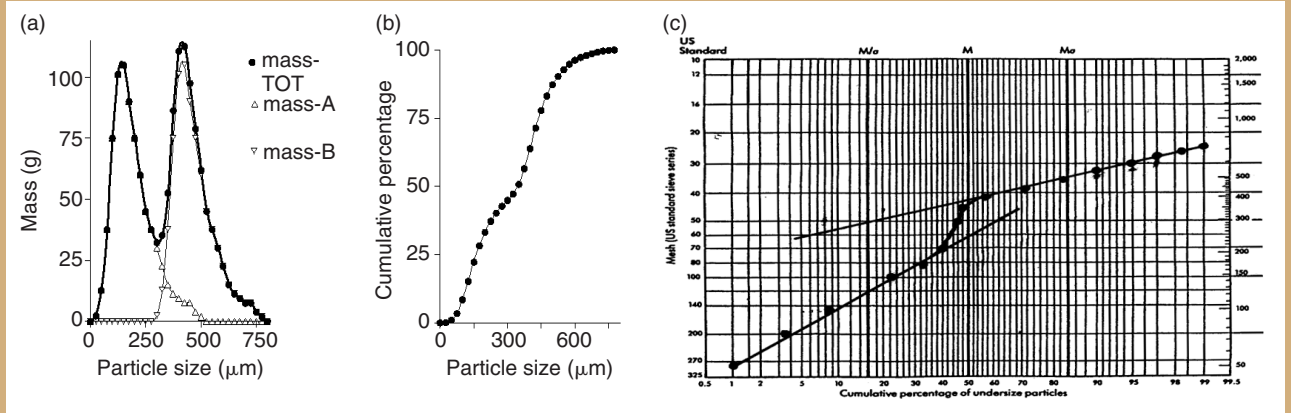

Figure 6: Representation of a sample consisting of a bimodal distribution, the modes of which differ by 300 μm.

ceding section works very well. However, it is equally important to be able to recognize when the sample contains more than one population in its distribution.

To illustrate this situation, a series of model distributions consisting of two populations has been simulated and the distributions have been analyzed according to the usual technique. Figure 3 shows the representation of a unimodal distribution, and Figures 4–6 show the representations for samples consisting of bimodal distributions in which the modes differ by 100, 200, and 300 μm, respectively. The figures illustrate the power of the log plot in which the presence of the two particle-size populations is far more discernable than in either the histogram or cumulative-distribution plots.

Summary

Sieving is one of the fundamental methods for the classification of powders, and it is the method of choice for classifying coarse powders. The general consensus is that sieving is most suitable for granular solids or powders whose average particle size exceeds 25–50 μm. One must remember that the particle-diameter information obtained using analytical sieving represents the minimum square aperture through which the particle can pass. Details of particulate shape will influence the separation of particles by sieving because particles will pass through openings on the basis of their cross-sectional diameter. Nevertheless, analytical sieving, when it is properly performed, is a valuable method for determining the size distribution of granular and coarse powders.

References

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