Evaluating Particle Size

Scott Baker
Graduate Research Assistant

Tim Herrman
Extension State Leader
Grain Science and Industry

Department of Grain Science and Industry

The particle size of ground grain performs a critical role in determining feed digestibility, mixing performance, and pelleting. Therefore, periodic particle size evaluation is a necessary component of a feed manufacturing quality assurance program. The purpose of this bulletin is to describe the equipment, procedure, costs, and interpretation of particle size analysis.

Equipment

The equipment required for particle size analysis includes a scale, shaker, sieves, sieve cleaners, and brushes.

A **scale** that is accurate to ±0.1 grams is required (ASAE, 1993). There are two types of scales available: electronic and triple-beam balance. A triple-beam balance costs approximately $600 less than an electronic top-loading balance.

The recommended sieve **shaker** is a Tyler RoTap (Mentor, OH). The RoTap mechanically reproduces the circular motion that occurs during hand sieving, while at the same time tapping the sieve stack to help the particles fall through the mesh screens. It is designed to hold a maximum of six full-height (13 half-height), 8-inch diameter sieves and a pan (Tyler, 1976).

A less expensive portable sieve shaker also is manufactured by the Tyler company. It is similar to the RoTap, but it does not have the tapping mechanism. It has the same capacity as the RoTap. When using a portable sieve shaker, sufficient action is produced if the wing nuts are tightened approximately 1/16 inch above the sieve stack.

A **stack** of sieves (each sieve possessing a different diameter opening) separates feed particles according to size. In the United States, there are two commonly recognized standard sieve series: Tyler and USA. The Tyler Standard Screen Scale sieve series was introduced in 1910 by W.S. Tyler Inc. The original USA Series was proposed by the National Bureau of Standards in 1919. After some changes in wire diameter specifications, the current USA series was adopted by the International Standards Organization (ISO). Both sieve series meet the standards set forth in the American Standards for Testing Materials Standard E11 (Tyler, 1976).

These sieve series are differentiated based on the method used to express the diameter opening. The Tyler series identifies sieves by the number of meshes (openings) per inch. The USA sieves are most commonly identified by an arbitrary number that does not necessarily represent the number of meshes per inch. They also are identified by size opening in millimeters or microns. Tyler Standard Screen Scale sieves and USA Series sieves can be used interchangeably. Each sieve has the appropriate equivalent printed on the name plate (Tyler, 1976). Table 1 shows a comparison of the Tyler and USA Standard sieve numbers in a "full-set."

Table 1. Comparison of Tyler and USA sieve numbers

Opening in microns	Tyler Number (meshes/inch)	USA Number
3360	6	6
2380	8	8
1680	10	12
1191	14	16
841	20	20
594	28	30
420	35	40
297	48	50
212	65	70
150	100	100
103	150	140
73	200	200
53	270	270

Sieves vary in diameter and height and may be constructed of brass or stainless steel. Full-height sieves are 2 inches from the rim to cloth. Half-height sieves are 1 inch from the rim to the cloth. It is recommended that the USA Standard, 8-inch diameter, half-height sieve with a brass frame and cloth be used (Tyler, 1976).

Screen cleaners should be used to ensure that every particle has the same chance to pass through the openings. If the RoTap is used, the authors recommend using two carmicheal sieves on USA Number 16 and finer sieves. If the portable shaker is used, it is recommend to use three carmicheals. If the feed has a high fat or whey content, a dispersion agent may be required to prevent clogging (blinding) of the screens.

It also is important that sieves be properly cleaned during weighing. Literature from Tyler (1976) recommends that a soft brass wire brush be used to clean sieves coarser than 100 mesh (USA Number 100) and a nylon bristle brush for sieves finer than 100 mesh. The authors have found that a circular vacuum attachment brush also works well for the finer sieves. Exerting too much pressure should be avoided because it will cause the screens to sag, and their accuracy will decrease. Tapping the sides of the sieve can be used to dislodge particles.

It also may be necessary to wash the sieves to remove particles that cannot be removed with a brush. Sieves should be washed in a warm, soapy water.

In the feed industry, **computer software** provides the easiest method for calculating particle size. Pfost and Headley (1976) have described equations that can be used to calculate D_{gw}, S_{gw}, surface area, and particles per gram based upon a log-normal distribution of ground grain samples. Particle size can be determined by plotting the data on log-probability paper (Behnke, 1985).

A personal computer program for particle size analysis has been developed at Kansas State University. It is based upon the **Tyler** sieve set used by Headley and Pfost (1976). The program also allows the user to define a "nonstandard" sieve set. The authors have created a program for particle size analysis using a spreadsheet (see Case Study). This program is based upon the same sieve set used by Headley and Pfost, but it eliminates the first two sieves in the series. The program identifies the sieves using the **USA Number**, since the USA series is specified by the ISO for international publication. The spreadsheet program also includes a graph of the distribution.

Steps in Particle Size Analysis

The first step in particle size analysis is to obtain a representative sample. A 100-gram sample is recommended when using a full stack of sieves to avoid accumulation of more than 20 grams over any one sieve. Procedures for collecting and splitting down a representative sample are describe in the Kansas State University Extension bulletin MF-2036. After the 100-gram sample has been obtained, the following steps are required:

- arrange the sieve stack so the coarsest is on top and the finest on bottom (as the USA Sieve number increases, the opening becomes smaller)
- put the sample on the top sieve and place sieve stack on the shaker
- allow shaker to run for 10 minutes
- remove the sieves stack from shaker
- clean and remove carmicheals
- gently tap the sides of each sieve with the brush before removing from the stack
- place the sieve with the retained material on the scale
- tare the scale (if using a triple beam balance, weigh the sieve and retained material together)
- remove and thoroughly clean the sieve
- weigh back the empty sieve and record the weight; the weight should be negative, but only the value needs to be recorded (if you are using a triple beam balance, subtract the difference between the sieve with and without material)
- enter the weight values in the appropriate columns of the spreadsheet

Equations

The average particle size of material retained on a sieve is calculated as the geometric mean of the diameter openings in two adjacent sieves in the stack (Pfost and Headley, 1976). Equation 1 shows this calculation.

Equation 1

$$d_i = (d_u \times d_o)^{0.5}$$

d_i = diameter of i^{th} sieve in the stack
d_u = diameter opening through which particles will pass (sieve proceeding i^{th})
d_o = diameter opening through which particles will not pass (i^{th} sieve)

Because it is not practical to count each particle individually and calculate an average, the average particle size can be calculated on a weight basis. This can be done with the following equation.

Equation 2

$$D_{gw} = \log^{-1} \left[\frac{\sum (W_i \log d_i)}{\sum W_i} \right]$$

The standard deviation can be calculated as follows:

Equation 3

$$S_{gw} = \log^{-1} \left[\frac{\sum W_i (\log d_i - \log D_{gw})^2}{\sum W_i} \right]^{0.5}$$

The number of particles per gram and amount surface area can be calculated from the D_{gw} and S_{gw}. This information can be used by an animal nutritionist in determining the rate of digestibility or by a process engineer to calculate grinding efficiency in terms of the surface area created per unit of input (Behnke, 1985). For these calculations, the shape factors β_s and β_v are assumed to be 6 and 1 respectively (Pfost and Headley, 1976). The specific weight is assumed to be 1.320 centimeters per gram. Since the specific weight is expressed in centimeters per gram, it is necessary to convert the D_{gw} to centimeters. This can be done by multiplying by 0.0001.

Equation 4

$$Particles/gram = \left(\frac{1}{\rho\beta_v}\right)^{4.5 \ln^2 S_{gw} - 3 \ln D_{gw}}$$

Equation 5

$$SA\ (cm^2/gram) = \left(\frac{\beta_s}{\rho\beta_v}\right)^{0.5 \ln^2 S_{gw} - \ln D_{gw}}$$

β_s = shape factor for calculating surface area of particles
β_v = shape factor for calculating volume of particles
ρ = specific weight of material

Equipment Comparison

A study was conducted to compare the RoTap performance to the portable shaker performance and a full set of sieves to a short stack of sieves (USA Numbers 16, 30, 50, 100, 200, and a pan). The intent of this study was to explore the feasibility of using a less expensive option compared to the standard 14 sieves described in the official ASAE procedure for particle size evaluation. We used 50-gram samples to avoid accumulations of more than 20 grams over any one sieve. Table 2 presents the results of this study.

Study results indicated that the portable shaker produced similar results to the RoTap when using either stack of sieves. Reducing the number of sieves from 13 to five resulted in particle size estimates that were approximately 20 to 40 and 25 to 60 microns less when using the RoTap and portable shaker, respectively. The standard deviation was approximately 0.2 to 0.3 points higher when using the short stack.

Table 2. Comparison of the RoTap and portable sieve shakers using a full stack and a short stack of sieves

	Average Particle Size (D_{gw}) Microns	Standard Deviation (S_{gw})
Sample 1		
RoTap		
Full Stack	461	2.29
Short Stack	421	2.55
Portable		
Full Stack	480	2.16
Short Stack	417	2.52
Sample 2		
RoTap		
Full Stack	920	1.80
Short Stack	897	2.00
Portable		
Full Stack	925	1.76
Short Stack	900	1.94

Case Study

Appendix A shows a Lotus 1-2-3 spreadsheet that can be used to calculate particle size. The first column identifies the screen number. The second column refers to the diameter opening of the sieves in microns. In the third column, the amount of feed or ground grain retained over each sieve is recorded. The "%" and "% less than" columns are not necessary for the calculations, but are useful when graphing. The "%" is used to create the histogram, and the "% less than" can be used when graphing using probability paper. The "log dia" column represents the log transformation of the average particle size retained over each sieve (Equation 1). The "wt*log dia" and "wt(log dia – log D_{gw})^2" columns contain the values whose summation are used to calculate D_{gw} (Equation 2) and S_{gw} (Equation 3), respectively. The "log dia – log D_{gw}" is an intermediate step for calculating the last column.

Feed manufacturers are generally only interested in the D_{gw} and S_{gw}. The recommended D_{gw} for swine diets is 600 to 800 microns (MF-2050). The S_{gw} is the standard deviation. It is a measurement of the particle size variation about the average. Most feed samples will have a S_{gw} ranging from 2.0 to 2.4. The best possible S_{gw} is 1.0. By dividing and multiplying the D_{gw} by the S_{gw}, a range into which 68 percent of the particles will fall can be calculated. In our example, D_{gw} = 754 microns and S_{gw} = 2.23. Therefore, the range into which 68 percent of the particles will fall is 338 to 1681 microns.

Suppliers

Table 3 lists the required equipment and suppliers and the approximate costs of the equipment for particle size analysis.

Table 3. Equipment, Suppliers, and Prices for Particle Size Analysis

Equipment	Supplier[A]	Price[B]
RoTap Sieve Shaker	Fisher, Seedburo	$1,500
Tyler Portable Shaker	Fisher, Seedburo	$540
Scale		
Balance	Fisher,	$160
Electronic	Seedburo	$850
Sieves (each)	Fisher, Seedburo	$50
Sieve Cleaners (each)	H.R. Williams	$5
Brass Sieve Brush	Fisher	$12
Nylon Sieve Brush	Fisher	$10
Software	Kansas State	$20

[A]These are suppliers known to the authors and there could be others. The authors have no preference of suppliers.
[B]Prices are approximate.

- Fisher Scientific
  711 Forbes Avenue
  Pittsburgh, PA 15219-9919
  1-800-776-7000
- Seedburo Equipment Company
  1022 West Jackson Blvd.
  Chicago, IL 60607-2990
  1-800-284-5779
- H.R. Williams Mill Supply Co.
  208 West 19th Street
  Kansas City, MO 64108
  (816) 471-1511
- Kansas State University
  Cooperative Extension Service
  (913) 532-4082

References

ASAE, 1993. *Method of determining and expressing fineness of feed materials by sieving*. ASAE Standard ASAE S319.2.

Behnke, K. 1985. *Measuring and defining particle size of feedstuffs*. In: First International Symposium on Particle Size Reduction in the Feed Industry. Kansas State University, Manhattan, KS.

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Pfost, H. and V. Headley. 1976. *Methods of determining and expressing particle size*. In: H. Pfost (ed), Feed Manufacturing Technology II - Appendix C. Am. Feed Manufacturers Assoc., Arlington, VA.

Tyler Industrial Products. 1976. Handbook 53: *Testing sieves and their uses*. W.S. Tyler, Inc. Mentor, OH.

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Appendix A

Particle Size Analysis

Material:

Date:

U.S. Sieve	Micron Size	Wt. grams	%	% less than	log dia	wt*log dia	log dia – log D_{gw}	wt(log dia – log $D_{gw})^2$
6	3360	1.60	1.62	98.38	3.601	5.762	0.724	0.839
8	2380	3.20	3.24	95.15	3.451	11.045	0.574	1.055
12	1680	7.90	7.99	87.16	3.301	26.077	0.424	1.418
16	1191	19.40	19.62	67.54	3.151	61.122	0.273	1.450
20	841	18.00	18.20	49.34	3.000	54.006	0.123	0.273
30	594	15.00	15.17	34.18	2.849	42.739	–0.028	0.012
40	420	11.60	11.73	22.45	2.699	31.303	–0.179	0.370
50	297	8.00	8.09	14.36	2.548	20.384	–0.329	0.867
70	212	6.60	6.67	7.68	2.400	15.837	–0.478	1.506
100	150	3.40	3.44	4.25	2.251	7.654	–0.626	1.332
140	103	3.20	3.24	1.01	2.094	6.702	–0.783	1.961
200	73	0.90	0.91	0.10	1.938	1.744	–0.939	0.794
270	53	0.10	0.10	–0.00	1.794	0.179	–1.083	0.117
Pan	37	0.00	0.00	–0.00	1.646	0.000	–1.231	0.000
Summation		98.90	100.00			284.556		11.995

Particle Size, D_{gw}	754	Surface Area (cm^2/gram)	83.2
Standard Dev., S_{gw}	2.23	Particles/gram	31953