Particle Size Reduction

Cereal grains are ground to increase nutrient digestibility by breaking the hard, protective outer layer of the grain. Concentrated nutrients in the endosperm and germ become more available as the surface area to volume ratio increases allowing more access for digestive enzymes. Factors that influence subsequent particle size of grains include grain growing conditions, grain moisture, mill type and settings, and mill maintenance. Therefore, measuring particle size becomes a critical step in quality feed manufacturing.

Hammermills and roller mills

Equipment

Prior to storage and grinding, grains can be sent through a pre-grind system or screener to remove foreign material to decrease the likelihood of foreign material entering the mill. Adding grates over the receiving pit to remove large physical hazards and magnets placed in the receiving flow can remove ferrous metals. The combination of grates and magnets help prevent damage to equipment and harm to animals and employees (Kalivoda, 2016). If foreign material is introduced to either mill type, this will increase equipment wear and decrease throughput beyond the normal wear pattern. Therefore, checking roll, hammer and screen wear should be performed weekly to maximize mill efficiency as part of a preventative maintenance schedule. A schedule for equipment part replacement can be established using system throughput and target particle size.

Hammermills

Hammermills reduce the particle size of ingredients by impact, causing grains to shatter (Pfost, 1976; Figure 1). This creates a more spherical particle shape and increases the number of fine particles, therefore producing a less uniform particle size distribution. Factors that influence hammermill particle size include hammer tip speed, hammer pattern, hammer setting, screen hole diameter, and air assist where the manipulation of any or all can provide a variety of particle sizes (Heiman, 2005a). Hammermill maintenance is generally less than that of a roller mill and largely focuses on screen and hammer replacement (Figure 2). Screen inspection should be done weekly, and magnets cleaned daily. Hammermill hammer rotation should be rotated every 2 to 4 weeks. However, consideration should be given to how much a feed mill produces, with higher production mills inspecting more frequently.

Figure 1. Hammermill example (from Heimann, 2014)

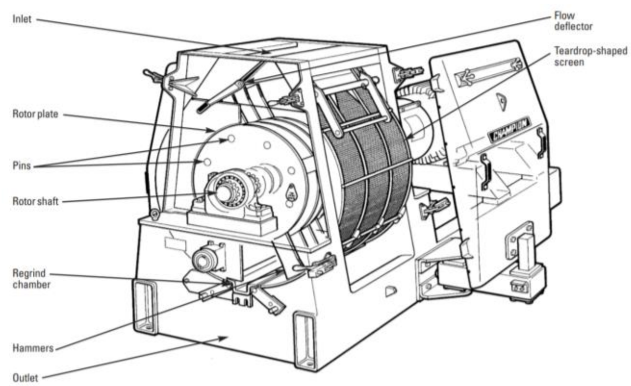
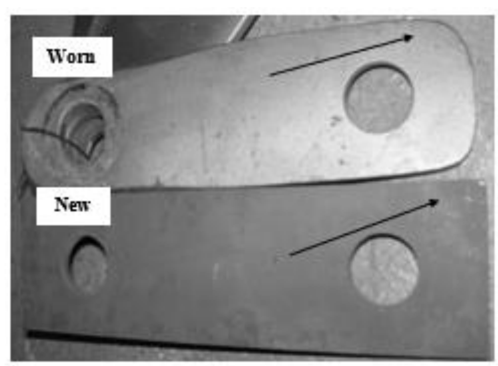


Figure 2. Example of worn and new hammers from a hammermill



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Roller mills

Roller mills reduce particle size by crushing, producing a small amount of fine material resulting in a more uniform particle size (Figure 3). Roller mills come with their own challenges such as expensive initial investment and higher maintenance costs. Roller mills are quieter for operation, have lower energy consumption when producing particle size greater than 400 to 500 microns and less moisture loss. Roller mill particle size is influenced by number of roll pairs, roll gap and roll speed (Heiman, 2005b; Figure 4). Roll parallel and gap width should be evaluated daily. Depending on wear, the re-corrugation of rolls should be done yearly and increased to 3 to 4 times a year with increased wear. Additionally, performing routine daily gap adjustments requires more maintenance time and frequent particle size analysis.

Figure 3. Roller mill (from Heimann, 1999)

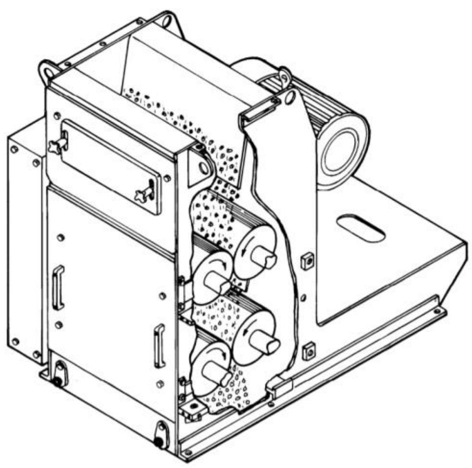
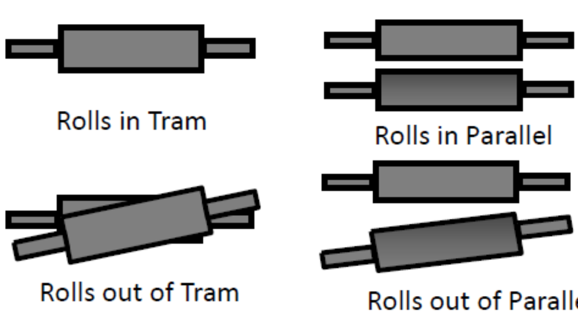


Figure 4. Roller configuration for roller mills (from Heimann, 1999)



Monitoring and Testing Particle Size

Sample collection

Daily grab sampling should be performed to visually assess particle size looking for evidence of whole grains or larger than expected particles. Particle size should be evaluated daily for roller mills and weekly for hammermills with at least the 3-sieve short stack and monthly using the full 13-sieve stack (Figure 5 and 6, respectively). Mill type evaluation is based on typical higher maintenance associated with roller mills. Large deviation of target particle size, or changes in grain moisture calls for particle size evaluation using the 13-sieve method. Additionally, any adjustments made to the mill with roll parallel, screens, or hammers; particle size should be retested with the 13-sieve method. Sampling to test particle size should be after the rolls or hammers where there is a steady flow of material. It is important to collect away from any air assist or movement of the cut stream. Areas with air movement will cause fine particles to become airborne and will lead to an inaccurate measurement of the particle size.

Table 1. Sourcing particle size and flowability equipment

Equipment	Supplier
Tyler RoTap Sieve Shaker	Fisher, Seedboro
Electronic scale (to 0.1g)	Fisher, Seedboro
Sieves	Fisher, Seedboro
Sieve cleaners	H.R. Williams
Brass sieve brush	Fisher
Nylon sieve brush	Fisher
Sieving agent	Gilson Company Sieving Aid

Figure 5. 3-sieve stack

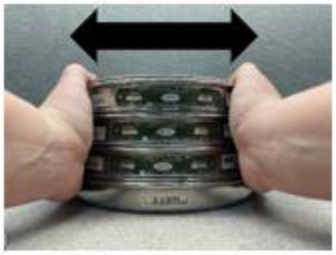


Figure 6. Tyler RoTap sieve shaker with 13-sieve stack

Testing

Particle size testing procedures can be found in "MF3342 Evaluating Particle Size of Feedstuffs – Kansas State University" (ANSI/ASAE S319.4 FEB 2009 R2012, Table 2). However, there have been several alternative methods such as the 3-sieve short stack, developed for use in smaller feed mills and integrated mills (Table 3). It is extremely important to document which particle size method was used. Only particle sizes run with the same method should be compared. Some changes include the number of sieves used in a stack, length of agitation time, and use of sieve agitators or dispersion agents, all of which can provide greater analytical variations. A common sieving agent used is silica powder (Gilson Company). It is recommended to use sieve agitators and sieving agent to decrease mean particle size and increase the standard deviation (Kalivoda et al. 2016). This will result in a more accurate representation of particle size. Cleaning of sieves and sieve balls and brushes must be done between each sample run. A soft brass wire brush can be used to clean sieves coarser than 100 mesh and a nylon bristle brush for sieves finer than 100 mesh (Baker and Herrmen, 2002). A circular vacuum attachment brush also works well. To avoid damaging screens, the tester should only apply light pressure. If ingredients become caked or hard to remove, sieves, sieve brushes and balls should be washed in warm soapy water and completely air-dried before running another sample. An additional option for measuring particle size is using near inferred reflectance spectroscopy (NIRS) but only if the specific NIRS has calibrations for particle size, ask your NIRS supplier.

Table 2. Sieve and agitator arrangement (Adapted from Stark and Kalivoda 2016)[1,2]			
U.S. Sieve Number	Tyler Number	Sieve opening	Sieve Agitators
6	6	3,360	None
8	8	2,380	None
12	10	1,680	Three rubber balls
16	14	1,190	Three rubber balls
20	20	841	Three rubber balls
30	28	595	One rubber ball; one bristle sieve cleaner
40	35	420	One rubber ball; one bristle sieve cleaner
50	48	297	One rubber ball; one bristle sieve cleaner
70	65	210	One rubber ball; one bristle sieve cleaner
100	100	149	One bristle sieve cleaner
140	150	105	One bristle sieve cleaner
200	200	74	One bristle sieve cleaner
270	270	53	One bristle sieve cleaner
Pan		-	None

[1] Sieves should be cleaned between EACH sample for accurate depiction of particle size. Ideally, use of compressed air can be used to clean, however a vacuum can work as well. There should be no evidence of particles of the remaining sample on the sieves prior to another sample run.
[2] Should the sieves establish buildup of material or fat occur, sieves should be washed in warm, soapy water and thoroughly dried before additional use.

Table 3. Sieve and sieve agitator method (from Kalivoda 2016)[1,2]		
US Sieve Number	Sieve opening (μm)	Sieve agitator
12	1,680	None
30	595	One rubber ball; one bristle sieve cleaner
50	297	One rubber ball; two bristle sieve cleaner
Pan	-	None

[1] Sieves should be cleaned between EACH sample for accurate depiction of particle size. Ideally, use of compressed air can be used to clean, however a vacuum can work as well. There should be no evidence of particles of the remaining sample on the sieves prior to another sample run.
[2] Should the sieves establish buildup of material or fat occur, sieves should be washed in warm, soapy water and thoroughly dried before additional use.

Interpreting Results

Particle size and standard deviation

Once sieves have been weighed back those weights can be used to determine geometric mean diameter d_{gw} and geometric standard deviation S_{gw}. The d_{gw} will determine the specific micron size which will represent the target particle size where S_{gw} will provide the standard deviation. Standard deviation can be calculated as unitless (ANSI/ASAE S319.2) or in microns (ANSI/ASAE S319.4). Excel spreadsheet calculators for 3-sieve and 13-sieve can be found on the KSU Feed Science Research and Extension website. Percent of sample recovery should be 100% ± 5%, samples should be rerun if outside of those limits. Results can then be copied from “results” to “results archive” for consistent monitoring of particle size.

Particle variation

As standard deviation increases the number of large and fine particles increases, therefore determining S_{gw} is an important part of evaluating particle size. Particles < 150 microns are the particles seen in the bottom 3 sieves of a 13-sieve stack. In addition, to sgw, if flow issues occur, consider monitoring particles < 150 microns where the majority of material would be recovered in the bottom 3-sieves for a 13-stack or the pan of a 3-sieve stack. In general, grinding grains with a roller mill will have lower S_{gw} compared to those ground with a hammermill. Having too many fine particles can increase the amount of dust in a facility and lead to challenges such as flowability on farm. Previous research has determined that the larger amount of percent fines generated when grinding grains using a hammermill results in poorer flowability (Groesbeck et al., 2006). The compaction of fine particles decreases ingredient flow capabilities. Removing fine particles can improve flowability but isn't always practical.

Summary

There are many factors that influence particle size and manipulation of any can produce a variety of particle sizes. For a complete particle size analysis both geometric mean diameter d_{gw} and geometric standard deviation S_{gw} must be evaluated. Using the same of particle size testing method (3-sieve or 13-sieve stack) is important to remain consistent to compare results to previous particle sizes and observe changes when manipulating equipment and equipment wear.

Additional resources

MF3342 Evaluating Particle Size of Feedstuffs – Kansas State University

- https://bookstore.ksre.ksu.edu/pubs/MF3342.pdf

13-sieve particle size calculator

- https://www.grains.k-state.edu/research/AnimalFeedandPetFood/feed_science_research_extension/index.html

3-sieve particle size calculator

- https://www.asi.k-state.edu/research-and-extension/swine/particle-size-information.html

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