Penn State Extension

DSE 2013-186

extension.psu.edu

The Penn State Particle Separator

Jud Heinrichs

Department of Animal Science

TOPICS

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REVIEWERS

Virginia Ishler, Penn State
Alanna Kmicikewycz, Penn State

PENNSTATE
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INTRODUCTION

Having the proper particle size distribution of feeds is an important part of ration formulation. However, until recently, particle size has been difficult to measure on farms. Many dairy nutritionists have developed subjective measures of this aspect of the diet, and most have been quite effective making ration changes with respect to particle size measurements.

The Penn State Particle Separator (PSPS) provides a tool to quantitatively determine the particle size of forages and total mixed rations (TMR). The updated 2013 version of the PSPS adds the ability to estimate physically effective fiber (peNDF) to this tool. The concept of measuring feed particle size using a standard method is not new. The American Society of Agricultural and Biological Engineers' (ASABE) standard for particle size analysis and distribution has been available for many years. Unfortunately, the ASABE method is a cumbersome laboratory procedure that is impractical for farm use. The objective of developing the PSPS was to mimic the complex lab method with a simpler, on-farm method. The newest refinement allows for an estimation of the quantity (%) of a forage or TMR that provides physically effective fiber to the dairy cow.

Management of forage particle size begins with harvesting forages at the proper stage of maturity. Chopping the crop at the proper length produces forages that can be combined to achieve the desired particle length in a TMR. Measuring the particle length of individual forages is only one part of the solution. In fact, measuring single forages for particle size is similar to analyzing that forage for fiber. There are recommended ranges for individual forages, but the real value of the particle size measurement is in combining forages to achieve the proper TMR particle size, much like combining feeds to achieve the proper fiber level in the ration.

The goal of analyzing TMR particle size is measuring the distribution of feed and forage particles the cow actually consumes. The focus is not only on particles greater than a particular size, but also on the overall distribution of feed particles consumed by the cow. Measuring TMR samples fresh from the feed bunk before the cows eat or sort the feed is recommended. Mixing and distribution equipment can reduce particle size of feeds and forages and need to be accounted for by evaluating the actual diet being fed.

Physically effective fiber or peNDF

Measurement of peNDF has become widely used in dairy cattle nutrition and research. The original system of peNDF was developed by Dr. Dave Mertens of the US Dairy Forage Research Center. It measured fiber particle size using dry samples of feed in a 3-dimensional, vibrating sieve system (Ro-Tap separator) and had neutral detergent fiber (NDF) on the whole sample. Most forage is now measured in a 2-dimensional sieve device (such as the PSPS) and NDF is typically measured on the whole sample. However, each fiber fraction when sieved may contain varying levels of NDF and different amounts of hemicellulose, cellulose, and lignin. Digestibility is affected by plant species, maturity, and storage method. This probably partially explains the many contradictions in the literature about effects of peNDF on intake, milk production, milk fat content, and chewing behavior. However, using peNDF in ration balancing and troubleshooting, even using a single NDF value, may prove to be a useful tool.

Mertens' peNDF procedure used 1.18 mm as the critical size at which feed particles are considered physically effective for dairy cows. This number originated from earlier research that determined 1.18 mm was a threshold particle size determined with both cattle and sheep (at maintenance intakes) for greatly increased resistance to particles leaving the rumen and that less than 5% of fecal particles were generally retained on a 1.18-mm sieve.

Researchers from Penn State as well as Canada and Japan have studied particle size of diets and their impact on rumen metabolism, and have clearly shown in recent studies that the critical threshold for feed particles escaping the rumen of high producing cows is greater than 1.18 mm and more in the range of 4 mm. While there is no one perfect sieve size to measure particles for all diets and all forages, the data from three independent labs show that the 4-mm sieve is more accurate for the high producing dairy cow for estimating peNDF.

OVERVIEW OF THE AVAILABLE SIEVES

The original particle separator, first introduced in 1996, has proven valuable in measuring feed particle size. The 1996 PSPS contained sieves of 0.75 and 0.31 inches (19 and 8 mm). The 0.75-inch (19-mm) sieve was designed to capture forage or feed particles that would be buoyant in the rumen (form the forage mat) and provide material that would require substantial additional cud chewing by the cow. In theory this would supply additional buffering to the rumen and help modify rumen pH.

Research has shown that saliva production is very important to the dairy cow. When fed the right amount of dietary fiber of adequate particle size, the lactating cow produces approximately 25 to 50 gallons of saliva per day (98 to

190 L/d). The primary buffering compounds in saliva are carbonate (HCO_3^-) and phosphate (HPO_4^{2-}) ions, and these compounds are very strong buffers at high pH. Knowing the percentage or amount of the diet that will encourage cud chewing is therefore important in the overall goal of maintaining proper rumen pH in dairy cows.

The 0.31-inch (8-mm) sieve collects primarily forage particles that will be part of the forage mat in the rumen, but will be broken down faster with less cud chewing and will hydrate in the rumen faster to allow more rapid rumen microbial breakdown. Both the amount of cud chewing required and the hydration rate will depend on the digestibility of the forage contained in this fraction.

The newest sieve, found in the 2013 PSPS, is a 0.16-inch (4-mm) sieve. Feed particles found on this sieve will primarily be small forage pieces that are often, but not necessarily, high fiber in nature. Initially these particles will likely be trapped in the forage mat of the rumen, but they can be broken down easily with minimal rumination or by rapid microbial action. Typically they will hydrate quite rapidly and will not remain trapped in the fiber mat for a long period of time. In either event these feed particles will have a small, yet significant, impact on buffering the rumen. This sieve is designed to allow estimation of peNDF. It should be noted, however, that many feed ingredients and byproducts will also be trapped on this sieve. This is obvious and must be handled with the judgment of the operator. In some situations, this fraction must be discounted in its amount when using the PSPS for determining peNDF.

The peNDF can be estimated by adding the amount of feed on the top three sieves (all ≥ 4 mm) and multiplying by the NDF content of the feedstuff. This is an estimated value, as the NDF content and digestibility of each fraction are unknown. In addition, some portion of the contents on the smallest (0.16-inch; 4-mm) sieve will likely contain grain or rapidly digested carbohydrates. Furthermore, peNDF by itself will not guarantee that the diet is well balanced and that rumen pH will be correct, as diet starch or total carbohydrate levels have been shown to significantly impact rumen pH in high producing cows with high dry matter intakes.

The 2002 model of the PSPS included a 0.05-inch (1.18-mm) screen that was designed to look at the smallest fraction of the diet that would impact digestibility. Previous data had shown that this fraction captured the longest particle size of feeds leaving the rumen. However, more recent data show that this is not the case in high producing dairy cows. This fraction is still related to the average particle size of a feedstuff leaving the rumen if the soluble fraction is added to the total. While soluble and very fine feed particles do contribute to meeting the cow's nutrient needs, the impact of particles containing fiber (NDF) is more important and this smallest fraction is of less importance at our present level of understanding.

Measuring this fraction will still provide information about the level of very fine particles in a diet, and this fraction will easily hydrate and either sink in the rumen or pass out of the rumen with the fluid fraction. Our recommendations for this particle fraction remain the same. However, its value to estimating peNDF has recently been shown to be incorrect for many diets.

GUIDELINES FOR PARTICLE SIZE

Achieving adequate ration particle size requires using recommended guidelines for forages and TMR (Table 1). Original particle size guidelines were based on field data consisting of a large number of farms. Since that time, intensive research studies have been conducted at Penn State to further refine these guidelines. The results of determining forage and TMR particle size distribution can be used in formulating rations and when trouble shooting nutrition problems.

Corn silage

Corn silage can be quite variable, and the required particle size depends largely on the amount fed in the diet. If corn silage is the sole forage, at least 8 percent of the particles

Table 1. Corn silage, haylage, and TMR particle size recommendations for lactating cows.

Screen	Pore Size (inches)	Particle Size (inches)	Corn Silage	Haylage	TMR
Upper Sieve	0.75	> 0.75	3 to 8%	10 to 20%	2 to 8%
Middle Sieve	0.31	0.31 to 0.75	45 to 65%	45 to 75%	30 to 50%
Lower Sieve	0.16	0.16 to 0.31	20 to 30%	30 to 40%	10 to 20%
Bottom Pan		< 0.16	< 10%	< 10%	30 to 40%

should be found on the upper sieve of the separator, compared to a minimum of 3 percent when corn silage is not the sole forage.

The chop length of corn silage must balance good packing and fermentation with extremely short, pulverized forage. This equates to 45 to 65 percent of the silage material remaining on the middle sieve and 20 to 30 percent on the lower sieve of the separator. There should be no more than 10 percent in the bottom pan. As corn silage makes up a greater proportion of the ration, more material should remain in the middle two sieves and less in the bottom pan to ensure the majority of the corn silage provides effective fiber. Note however that corn grain remaining on the 4-mm sieve should be discounted when determining peNDF. The dry matter and maturity of silage as it is being harvested has to be considered when deciding what particle size to chop any given silage. Packing of the silage to ensure proper fermentation must be the highest priority when making decisions related to chop length.

Newer systems for harvesting corn silage (chopping and processing) can create silage with a large percentage of long forage particles without large pieces of whole cobs or stalks. This forage can be excellent quality because it packs and ferments well in the silo. Typically when conventional choppers are set to harvest corn silage at a long particle size, forage is predisposed to poor silo compaction and mold formation. The material usually has large pieces of cob, dry stalks, and leaves that allow a great deal of sorting and often are refused by high producing cows.

Haylage

There is a lot of variability with haylage due to the type and use of machinery, sward type and density, and most of all, the dry matter of the crop harvested. Ten to 20 percent of the crop should be in the upper sieve of the particle separator. Particle size recommendations may need to be altered based on silo type. Forages stored in upright, sealed silos would likely fall at the lower end of the range (10 percent). Bunker silos can handle appreciably longer material, up to 20 percent on the upper sieve. The middle sieve should contain 45 to 75 percent of the material and the lower sieve 30 to 40 percent. As with corn silage, no more than 10 percent of the material should be retained on the bottom pan. The majority of the haylage should provide effective fiber (peNDF) with a good amount of longer particle size material.

Total Mixed Rations

Field investigations conducted at Penn State have found considerable variability in overall rations. Feeding management plays an important role in the particle length needs of the cow. Ideally no more than 8 percent of the material should be retained on the upper sieve. Guidelines for TMR for high producing dairy cows are 2 to 8 percent of the particles in the upper sieve, 30 to 50 percent in the middle sieve, 10 to 20 percent on the 4-mm sieve, and no more than 30 to 40 percent in the bottom pan. Sixty to 70 percent of the TMR should be classified as physically effective. Obviously, many whole or partially processed grains, many byproducts, and feeds such as pelleted grains will be above the 4-mm sieve. These must be discounted when calculating effective fiber and taken into consideration when balancing diets for lactating cows. Only forage and high fiber byproducts should be classified as effective fiber sources.

PARTICLE SEPARATOR INSTRUCTIONS

The Penn State Forage Particle Separator is currently available from Nasco (free phone order service at 1-800-558-9595). To use the separator an accurate scale is needed to weigh the samples and the boxes. A spreadsheet that automates all of the calculations has been developed; several versions are available. To complete calculations by hand, blank data sheets and blank lognormal paper are also available in several forms. These resources can be found at http://extension.psu.edu/animals/dairy/health/nutrition/forages/forage-quality-physical/separator.

Using the separator

Stack the four plastic separator boxes on top of each other in the following order: sieve with the largest holes (upper sieve) on top, the medium-sized holes (middle sieve) next, then the smallest holes (lower sieve), and the solid pan on the bottom. Place approximately 3 pints of forage or TMR on the upper sieve. Moisture content may cause small effects on sieving properties, but it is not practical to recommend analysis at a standard moisture content. Very wet samples (less than 45 percent dry matter) may not separate accurately. The separator is designed to describe particle size of the feed offered to the animal. Thus, samples should not be chemically or physically altered from what was fed before sieving.

On a flat surface, shake the sieves in one direction 5 times, then rotate the separator box one-quarter turn. There should be no vertical motion during shaking. Repeat this process 7 times, for a total of 8 sets or 40 shakes, rotating the separator after each set of 5 shakes. See the sieve shaking pattern shown in Figure 1.

The force and frequency of shaking must be enough to slide particles over the sieve surface, allowing those smaller

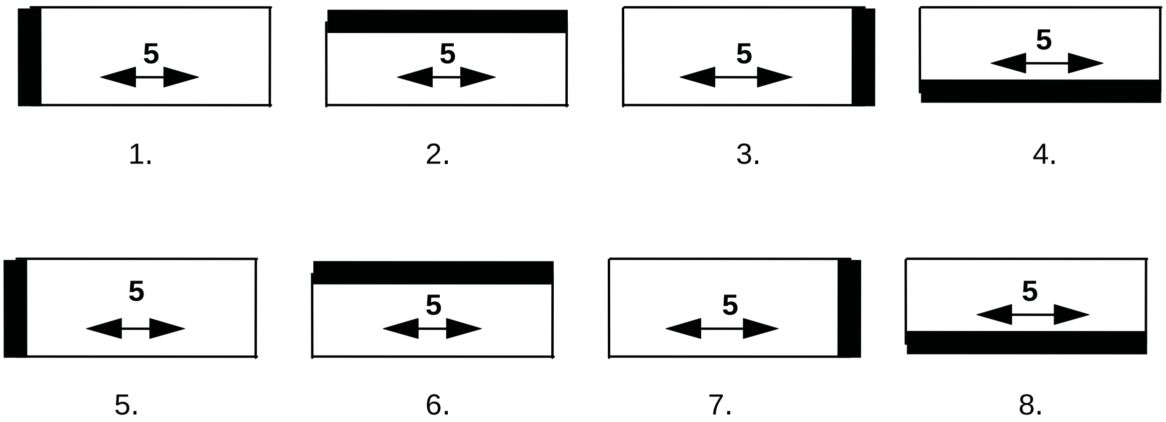

Figure 1. Shaking pattern for particle size separation.

than the pore size to fall through. It is recommended to shake the particle separator at a frequency of at least 1.1 Hz (approximately 1.1 shake per second) with a stroke length of 7 inches (or 17 cm). For best results, calibrate the frequency of movement over a distance of 7 inches for a specified number of times. The number of full movements divided by time in seconds results in a frequency value that can be compared to the 1.1 Hz recommendation. For a brief demonstration of the proper force used in separating samples, watch the particle separator movie at http://extension.psu.edu/animals/dairy/health/nutrition/forages/forage-quality-physical/separator/movie. After shaking is completed, weigh the material on each sieve and on the bottom pan. See Table 2 for data entry and procedures to compute the percentage under each sieve.

Using lognormal paper

The size of forage and TMR particles in a sample does not follow a normal distribution pattern; however, it can be plotted as a straight-line distribution using lognormal graphing paper. Lognormal paper is recommended for graphing the distribution of forage and TMR particle size, as this is the simplest method and it fits most data accurately.

The cumulative percentage undersized for each sieve is plotted on lognormal paper and an appropriate line drawn between the three points (best-fit line). Referring to Table 2, value [f] refers to 0.75 inches, value [g] to 0.31 inches, and value [h] to 0.16 inches (graphed in Figure 2).

On the graph paper, the horizontal axis represents particle size and the vertical axis represents the cumulative percentage undersized. The axes are not linear. For the example given in Table 2, the following deductions or statements can be made:

Table 2. Example of the calculation of total weight and cumulative percentages under each sieve.

	Record and Calculate Data	
Sample	Weight Retained	Proportion Remaining On Each Sieve
Upper sieve (0.75 inches)	10 grams [a]	a/e * 100 = 10/200 * 100 = 5%
Middle sieve (0.31 inches)	80 grams [b]	b/e *100 = 80/200 * 100 = 40%
Lower sieve (0.16 inches)	40 grams [c]	c/e * 100 = 40/200 * 100 = 20%
Bottom pan (< 0.16 inches)	70 grams [d]	d/e * 100 = 70/200 * 100 = 35%
Sum of Weights	200 grams [e]	
	Compute Cumulative Percentage Undersized[1]	
% Under upper sieve	f = 100 – (a/e *100)	100 – 5 = 95% undersized
% Under middle sieve	g = f – (b/e*100)	95 – 40 = 55% undersized
% Under lower sieve	h = g – (c/e*100)	55 – 20 = 35% undersized

[1]Cumulative percentage undersized refers to the proportion of particles smaller than a given size. For example, on average, 95% of feed is smaller than 0.75 inches, 55% of feed is smaller than 0.31 inches and 35% of feed is smaller than 0.16 inches.

- Approximately 5% of the feed is more than 0.75 inches in length.
- Approximately 40% of the feed falls between 0.31 and 0.75 inches in length.
- Approximately 20% of the feed falls between 0.16 and 0.31 inches in length.
- Approximately 35% of the feed is less than 0.16 inches long.

Another interpretation could be:

- Approximately 95% of the feed is less than 0.75 inches in length.
- Approximately 55% of the feed is less than 0.31 inches in length.
- Approximately 35% of the feed is less than 0.16 inches long.

PARTICLE SIZE EFFECTS ON THE DAIRY COW

Adequate forage particle length is necessary for proper rumen function. Reduced forage particle size has been shown to decrease the time spent chewing and cause a trend toward decreased rumen pH. When cows spend less time chewing, they produce less saliva, which is needed to buffer the rumen. In comparison, when feed particles are too long, animals are more likely to sort the ration, and ultimately the diet consumed is very different than the one originally formulated.

If rations or forages are too fine, feeding a small amount of long hay or baleage can improve the average ration particle size. Farms feeding 5 or more pounds of long hay per cow daily would not likely have problems with overall particle size. Many farms, however, do not have long hay as an option. In these situations, the distribution of particle size in the total ration is likely more important than the proportion of particles greater than a certain length.

In addition to analysis of both forage and TMR particle size, the particle separator may also be used to monitor the possibility of feed bunk sorting and may aid in trouble shooting feeding, metabolic, or production problems. To evaluate sorting, measure the TMR remaining in the bunk several times throughout the day (e.g. 4, 8, 12, and 48 hours after feeding). The resulting particle size distribution should not differ more than 3 to 5 percent from the original TMR. If cows are sorting throughout the day, pH may fluctuate more than expected and may

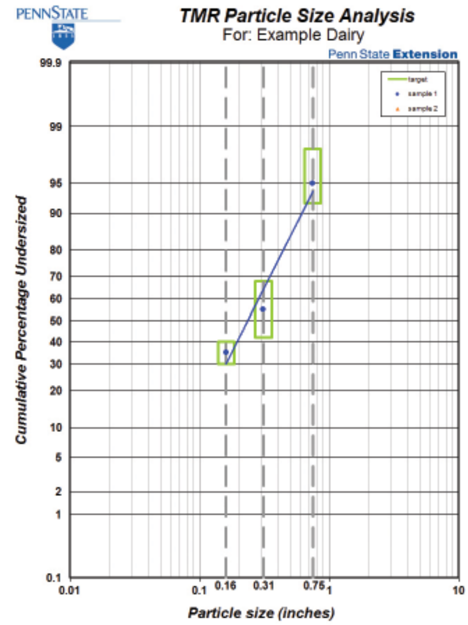

Figure 2. Data from example in Table 2 plotted on lognormal paper.

affect intake, rumen fermentation, or overall digestion. Problems may be more pronounced if bunks are overcrowded or if first-calf heifers are grouped with older cows. In these situations more aggressive animals may preferentially consume grain and other more palatable, readily fermentable feeds leaving high fiber, poorly digestible feeds for the other animals.

Measuring TMR particle size also can be helpful when evaluating a TMR mixer and how the mixer is being used. Over mixing leads to reduced particle size, while under mixing can cause the TMR to be very different at various points along the feed bunk. By testing TMR particle size in several locations along the feeding route, the PSPS can be very useful in evaluating the TMR equipment, operator, and feeding routines.

Feeding a ration containing extremely fine or coarse particle size is not recommended. Diets on either end of the spectrum can predispose cows to rumen acidosis and other associated problems and should be avoided. Particle size analysis is not a crystal ball for determining ration problems. However, the Penn State Particle Separator does provide an objective measurement of particle size, and it can be a useful tool to improve the overall nutrition of the dairy cow.

Recommended fiber intakes

Adequate NDF intake by the dairy cow is necessary for normal rumen function, production, and health. A majority of the NDF in the ration must be in the form of forage NDF along with sufficient ration particle size to maintain a healthy rumen environment. Under conditions of marginal particle size, special attention must be paid to maintaining adequate levels of total NDF and forage NDF intakes (Tables 3 and 4).

Suggested ranges for total NDF are at least 1.10 to 1.20 percent of body weight. Forage NDF intake can range from 0.75 to 1.10 percent of body weight. However, if the forage or TMR particle length is too fine, then a higher minimum (less than 0.85 percent of body weight) should be used.

Table 3. Guidelines for forage NDF intake.

Forage NDF, % BW[1]	Intake level
0.75%[2]	Minimum if ration provides 1.30 to 1.40% total NDF by use of byproduct feeds.
0.85%[2]	Minimum if ration provides 1.00 to 1.20% total NDF by use of grains or starchy feeds.
0.90%	Moderately low
0.95%	Average
1.00%	Moderately high
1.10%	Maximum

[1]Forage dry matter intake should range between 1.40% and 2.40% of body weight (BW), regardless of forage NDF intake parameters.
[2]Higher minimum may be necessary if forage is chopped too fine.

Table 4. Guidelines for total NDF and forage NDF intakes as a percent of the total ration dry matter when feeding concentrates with low NDF.

Milk production	Total NDF intake	Forage NDF intake
High (> 80 pounds)	28 to 32%	21 to 27%
Medium (60 to 80 pounds)	33 to 37%	25 to 32%
Low (< 60 pounds)	38 to 42%	29 to 36%

ACKNOWLEDGEMENTS

The initial development and continual improvement of the Penn State Particle Separator would not have been possible without the work of former graduate students Brian Lammers, Paul Kononoff, and Daryl Maulfair.

This publication replaces DAS 02-42.

Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.