CHAPTER 3

MODIFICATION OF THE PENN STATE FORAGE AND TMR PARTICLE SEPARATOR AND THE EFFECTS OF MOISTURE CONTENT ON ITS MEASUREMENTS

ABSTRACT

The Penn State Particle Separator (PSPS) has led to widespread measurement of forage and TMR particle size. Although the apparatus has proven valuable in measuring feed particle size, a large proportion of smaller particles may pass through both sieves when a TMR is analyzed. Additionally, throughout field experience with the PSPS, we have observed some differences in operation of the device. The objectives of this project were to develop an additional sieve containing a smaller pore size to more accurately describe sample fineness, to further define sieving movements, and to investigate the effects of moisture content on results. An additional sieve was constructed out of wire cloth, consisting of nominal size aperture 1.18 mm. To test the effect of shaking frequency on particle size measurement, samples of alfalfa haylage, corn silage, and a TMR were analyzed using three different frequencies: 0.9, 1.1 and 1.6 Hz and a 17 cm stroke length. Reducing sieving frequency below 1.1 Hz to 0.9 Hz resulted in significantly more material being retained on the 19.0 mm sieve and less on the 8.0 and 1.18 mm sieves for all sample types. As a consequence of these results X_{gm} (geometric mean) was significantly greater when material was sieved at 0.9 Hz compared to 1.1 Hz. In contrast, increasing frequency from 1.1 to 1.6 Hz did not result in significant differences in particle size measurements or X_{gm} for either alfalfa haylage or TMR samples but a greater amount of corn silage fell through the 1.18 mm sieve, however these differences were not reflected in X_{gm} which were not significantly different. We recommend the PSPS to be shook at a frequency 1.1 Hz or greater with a stroke length of 17 cm. To determine the effects of forage moisture level on particle size measurements, a samples of alfalfa haylage and corn silage were collected and partially dried at different times from 0 to 48 h to obtain samples of five different moisture contents. For alfalfa haylage samples, particle size measurements were not significantly different between 57.4 and 35.6 % moisture, indicating that small moisture loss in samples will not affect particle size measurements. In comparison, for corn silage the amount of particle mass < 1.18 mm was significantly different between 58.0 and 34.4 % moisture and resulted in a small but significant difference in X_{gm}. These results suggest that completely drying a sample resulted in either further size reduction on dry samples or adhesion of particles in high moisture samples during the sieving process result in differences in particle size results. **Key words:** Moisture, Particle Size, Sieve **Abbreviation key:** $\mathbf{X_{gm}}$ **=** Geometric Mean, **S** $_{\mathbf{gm}}$ = Geometric standard deviation **PSPS =** Penn State Particle Separator

INTRODUCTION

The ability of a ration to meet the nutritional needs of a high yielding dairy cow requires understanding of both the chemical and physical characteristics of the ration. Increasing fiber level and forage particle size has been shown to effectively increase chewing activity and is believed to increase saliva flow, rumen pH, acetate-to-propionate ratio and milk fat levels (Beauchemin et al., 1997). Although impaired rumen fermentation and function can result in rations lacking in physical structure, excessive amounts of long, coarse forage may also limit intake and digestibility, ultimately affecting the energy balance of the animal (Allen 1997). Additionally, as the particle size of grain particles decreases, the area available for microbial attack increases resulting in a greater extent of rumen fermentation (San Emeterio et al., 2000). Although the effects of particle size on rumen function and fermentation have been well-documented (Fischer et al., 1994; Grant et al., 1990 a, b), on farm routine analysis of this ration characteristic has only recently gained attention.

Based on properties of the standard S424 of the American Society of Agricultural Engineers (2001) for forage particle size determination, the Penn State Particle Separator (PSPS) is a quick and cost effective method of analysis. The manually operated PSPS is constructed out of two sieves and a bottom pan. Apertures of the two sieves measure 19.0 and 8.0 mm with a thickness of 12.2 and 6.4 mm. With its simple construction and size, the PSPS sieving method may be implemented on farm and used at the time of harvest or feeding to determine particle size of forages or TMR (Lammers et al., 1996). Even though the apparatus has been widely accepted and particle size measurements using the PSPS are now commonly reported in the literature, TMR's typically contain 40 to 60 % concentrate, most of which passes through the 8.0 mm sieve.

An additional sieve designed to further measure particles < 8.0 mm would be useful to more accurately measure ration particle size.

Although the rationale behind all published sieving methods is similar; equipment, method, or physical form of the sample may vary and affect particle size measurement (Murphy and Zhu, 1997). Operation of the PSPS has been previously described (Lammers et al., 1996). However, during our field experience we have observed that the rate of shaking, and as a result, the degree of sieving, often differs between users. This observation suggests that directions for use of the PSPS may require further refinement. Furthermore, because the PSPS has been adopted as an analytical technique by some feed testing laboratories, the procedure must be clearly defined so that calibration is possible for accurate and repeatable results to be obtained. Few studies have evaluated the effects of sample moisture content on particle size measurements. Because moisture content often differs depending on harvest time, weather and other factors, the effect of moisture content on particle size measurements should be further investigated.

The objectives of this project were as follows: (1) to modify the PSPS so that smaller particles can be further partitioned during measurement, (2) so that optimal sieving movement can be defined and calibrated, and (3) to determine the effect sample moisture content on sieving results.

MATERIALS AND METHODS

Modifications of the Penn State Forage and TMR Particle Separator

An addition to the PSPS was developed to more accurately measure and describe the small particle portion (< 8.0 mm) of a forage or TMR sample. The third sieve was inserted in the identical casing of the original sieves but contained stainless steel wire cloth, consisting of nominal size apertures of 1.18 mm and diagonal apertures of 1.67 mm (Gilson Company, Lewis Center, OH).

Method of Separation

In testing the effects of shaking frequency and sample moisture on measurements taken by the PSPS, operation of the device was similar to that described by Lammers et al., (1996). The sieves were stacked in the following order: 19.0 mm plastic sieve on top, 8.0 mm plastic sieve second, followed by 1.18 mm metal sieve, and the plastic pan fitted to the bottom of the last sieve. Approximately 1.4 $\pm$ 0.5L of sample was spread out on the top 19.0 mm sieve. The sieve set was shaken horizontally five times in one direction, then rotated one fourth turn, and again shaken five times. The procedure was then repeated eight sets of five replications for a total of 40 shakes. Rotation of the separator ensured that the sample is thoroughly shaken and that particles were not be stacked upon each other. One shake was considered as a forward and backward motion over a distance of 17 cm. Samples were assumed to be logarithmically normally distributed and geometric mean (X_{gm}) and standard deviation (S_{gm}) was calculated as outlined by the ASAE Standard (2001).

Testing Effect of Sieving Frequency on Particle Size Measurement

In order to test the effect of shaking frequency on particle size measurement, samples of alfalfa haylage, corn silage, and a TMR were collected and analyzed in duplicate for particle size using three different frequencies. The three frequencies used in the experiment were 0.9 (slow), 1.1 (medium) and 1.6 Hz (fast). All replications were timed so that sieving frequencies were consistent between duplications. Sample moisture contents of alfalfa haylage, corn silage, and a TMR were 64.6, 67.4 , and 46.0 % respectively.

Testing Effect of Sample Moisture in Particle Size Measurement

In order to test the effect of sample moisture content on particle size measurement, samples of alfalfa haylage, and corn silage, were collected and analyzed for particle size at five different moisture levels. Samples of alfalfa haylage and corn silage were evenly spread out on aluminum pans and placed in a large forced air oven set at 55°C. Five times over a 24h period approximately three 1.4 L sub samples were removed from the oven and analyzed for particle size. Alfalfa haylage samples were removed from the oven and analyzed for particle size at 0, 2, 6, 12, 48 h, while corn silage samples were removed at 0, 3, 6, 18, 48 h.

Statistical Analysis

All data were analyzed as a completely randomized design with model effect of treatment (moisture content) using the REML variance component and MIXED procedure of SAS Version 8.1 (2001). Mean separation was determined using the PDIFF procedure and significance was declared at $P < 0.05$. The model used in to evaluate effect of sieving frequency and sample moisture content on particle size measurements was:

$$y_{ij} = \mu + \delta_i + \varepsilon_{ij}$$

Where:

y_{ij} = percent of sample retained on each sieve, geometric mean or standard deviation,

μ = overall mean,

δ_i = fixed effect of treatment (sieving frequency or percent moisture),

ε_{ij} = residual error, assumed to be normally distributed.

RESULTS AND DISCUSSION

Modification of the Penn State Forage and TMR Particle Separator

The forage and TMR particle size separator was originally developed to mimic the ASAE Standard device (ASAE, 2001) and was constructed out of two sieves (19.0 mm and 8.0 mm) and a bottom pan with apertures selected to match the expected distribution of feed samples. The original PSPS has proven valuable in measuring feed particle size, but in a survey of 831 TMR samples Heinrichs et al., (1999) reported an average of 57.7% of the material passes through both sieves. Better characterization of these smaller feed particles requires a more detailed measurement a sieve designed to further partition particles < 8.0 mm may prove useful. Additionally, it has been suggested that 1.18 mm is the critical length governing retention in the reticulo-rumen, thus measurement of particle mass < 1.18 mm may be useful in interpreting results of experiments evaluating the effects feeding diets of different physical form (Poppi and Norton, 1980; Mertens, 2000). To address these, an additional sieve containing a nominal aperture measuring 1.18 mm and diagonal aperture of 1.67 mm was added to the sieving device.

Presentation of Sieving Results and Particle Size Measurements

Particle size analysis attempts to determine the actual frequency distribution of particles according to size (Irani and Callis, 1963). Material retained on each sieve is expressed in tabular form as seen in Tables 3-1, 3-2, and 3-3. Because of the wide variety of feeds analyzed and the various types of sieving techniques employed a variety of mathematical forms of particle size distribution have been investigated. Finner et al., (1978) described a method of sieving based on a lognormal distribution, which was subsequently adopted by the American Society of Engineers for describing forage particle size (ASAE, 2001). Smith et al., (1984) determined that an exponential distribution might fit data for alfalfa, grass and corn silages. Fisher et al., (1987) found an exponential distribution fit particle size data of digesta of cattle grazing bermuda grass and Allen et al., (1984) reported a gamma fit distribution as more accurate than lognormal distributions in describing ground hay. Lastly, the original description of the PSPS recommended a Weibull distribution rather than lognormal because plots were more linear and did not require transformation, thereby simplifying plotting and interpretation (Lammers et al.,1996) and is agreement with the analysis of Pitt (1987).

Although the best fit of a specific mathematical distribution likely depends upon the method of sieving, sample type, and nature of processing, the lognormal approach may be the most convenient approach over other distributions, which are more mathematically complex due to parameter estimation. Kolmogoroff (1941) was the first to describe a lognormal distribution with respect to ground particles. This approach is simple and results in derivation of two useful parameters, the log mean (log μ) and log standard deviation (log σ) resulting in estimates of the sample geometric mean (X_{gm}) and standard deviation (S_{gm}) (O'Dogherty 1984). Consequently, if the lognormal fits the actual distribution closely, information to describe the distribution can be calculated, easily interpreted and reported. Data presentation in this study includes both geometric mean and standard deviation with data assumed to be logarithmically normally distributed, an idea concurrent to the ASAE standard (ASAE, 2001).

Sieving Frequency and Particle Size Measurement

The force and frequency of shaking motion must be sufficient so that the particles slide over the sieve surface allowing those smaller than the pore size to fall through. According to the ASAE standard (S424) the sieve stack should be driven with a frequency of 2.4 $\pm$ 0.08 Hz (144 $\pm$ 5 cycles /min); however the PSPS is manually operated and this specification is not practically possible and may explain occasional differences between the devices (Lammers et al., 1996). Because sieving frequency of the PSPS has never been specified we evaluated the effect of frequency on particle size measurements so that recommendations could be formulated. Results of the study indicated that sieving alfalfa haylage, corn silage and TMR at different frequencies resulted in significant ($P \leq 0.05$) differences in particle size measurements (Table 3-1). Reducing sieving frequency below 1.1 Hz to 0.9 Hz resulted in significantly ($P \leq 0.05$) more material being retained on the 19.0 mm sieve and less on the 8.0 and 1.18 mm sieves for all sample types. As a consequence of these results X_{gm} was significantly ($P \leq 0.05$) greater when material was sieved at 0.9 Hz compared to 1.1 Hz. In contrast, increasing sieving frequency from 1.1 to 1.6 Hz did not result in significant differences ($P > 0.05$) in particle size measurements of X_{gm} calculations for either alfalfa haylage or TMR samples. Although increasing sieving frequency from 1.1 Hz to 1.6 Hz for corn silage significantly increased the amount of material falling through the 1.18 mm sieve, these differences were not reflected in X_{gm} which were not significantly ($P > 0.05$) different (11.2 and 11.6 mm)

As a result of this study, we recommend the PSPS to be shook at 1.1 Hz (66 cycles/min) or greater with a stroke length of 17 cm. It is recommended that operators of the device calibrate the frequency of movement over a distance of 17 cm for a specified number of times. Number of full movements divided by time in seconds results in a frequency value that can be compared to this recommendation.

Sample Moisture Content and Particle Size Measurement

Although moisture content may affect sieving properties, it is not practical to recommend analysis at a standard moisture content (Finner et al., 1978). The PSPS is designed to describe particle size of the feed offered to the animal; thus it is recommended that samples should not be chemically or physically altered before sieving. Because sample moisture loss may occur during storage or transport, a study was carried out to determine the effects of forage moisture level on particle size measurements made by the PSPS. Tables 3-2 and 3-3 outline the effect of forage moisture content on particle size measurement for both alfalfa haylage and corn silage. For alfalfa haylage oven drying times of 0, 2, 6, 12, 48 h resulted in moisture concentration 57.4, 35.6, 10.4, 2.5, and 0.0 %. Similarly, for corn silage oven drying times of 0, 3, 6, 18, 48 h resulted in moisture concentrations of 58.0, 34.4, 14.6, 3.5, and 0.0 %. For alfalfa haylage samples, particle size measurements were not significantly different ($P > 0.05$) between 57.4 and 35.6 % moisture indicating that moisture loss in samples within this range will not affect particle size measurements. Conversely, for corn silage the amount of particle mass < 1.18 mm was significantly different ($P \leq 0.05$) between 58.0 and 34.4 % moisture and resulted a small but significant differences in X_{gm}. These results suggest that small moisture loss from corn silage may affect particle size results; but these differences, when observed, are small. For alfalfa haylage, compared to 57.4 and 35.6% moisture, the amount of material > 19.0 mm was significantly lower in samples containing 10.4, 2.5, and 0.0% but this difference was not observed for corn silage as most material > 19.0 mm contained cob particles for which size measurement appeared to be unaffected ($P > 0.05$) by moisture content. For both forages, amount of material < 1.18 mm was greatest at 0.0 % moisture content while X_{gm} decreased with decreasing moisture content. These results are similar to Finner et al., (1978) who suggested that completely drying a sample results in shattering of particles and further size reduction during the sieving process. In the current study, differences in sieving results across moisture levels may have been due to drying which resulted in a more brittle particle that may shatter during sieving and/or increased sample moisture increasing the likelihood of particle adherence.

Because it would be impractical to recommend a constant sample moisture level for measuring forage or TMR particle size, it is advantageous to know that slight losses of moisture have only limited effects on measurements according to the moisture range of this study. Although it is recommended that samples be analyzed in the same physical form as that fed to the animal and moisture loss in samples should be minimized, based on our results only small differences result when sample moisture loss was approximately 40 % of the original sample.

CONCLUSIONS

The PSPS has resulted in a useful analytical method designed for measurement of forage and TMR particle size. An additional sieve containing a smaller pore size was described herein to more accurately describe sample fineness. Additional we have further investigated and described operation procedures of the PSPS and recommend that it be shook at a frequency of 1.1 Hz or greater (66 cycles/min) with a stroke length of 17 cm. Lastly, we have investigated the effects of sample moisture on measurements. These results suggest that small moisture loss from collected samples may affect particle size results but these differences, when observed are small. Conversely, completely drying a sample resulted in further size reduction during the sieving process and that different particle size results would be obtained.

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Table 3-1. Effects of sieving frequency on particle size measurements of alfalfa haylage[1], corn silage[2], and TMR[3] samples as measured by the modified PSPS using a 17 cm stroke.

	Frequency (Hz)[4]				
	0.9	**1.1**	**1.6**	**SEM**	***P* - value**
Alfalfa Haylage[1]					
> 19.0 mm	85.3[a]	20.6[b]	16.5[b]	3.78	< 0.01
19.0 – 8.0 mm	6.8[b]	50.1[a]	56.5[a]	3.14	< 0.01
8.0 – 1.18 mm	7.5[b]	27.3[a]	24.6[a]	0.64	< 0.001
< 1.18 mm	0.40[b]	2.0[a]	2.4[a]	0.27	0.03
X_{gm} (mm)[6]	23.8[a]	10.1[b]	10.4[b]	0.66	0.001
S_{gm} (mm)[7]	1.85[b]	2.3[a]	2.2[a]	0.05	0.02
Corn Silage[2]					
> 19.0 mm	71.2[a]	9.0[b]	10.9[b]	1.60	< 0.001
19.0 – 8.0 mm	23.4[b]	77.2[a]	77.1[a]	1.81	< 0.001
8.0 – 1.18 mm	5.3[c]	13.4[a]	11.2[b]	0.35	< 0.01
< 1.18 mm	0.10[c]	0.40[b]	0.80[a]	0.03	0.03
X_{gm} (mm)[6]	21.8[a]	11.2[b]	11.6[b]	0.15	< 0.0001
S_{gm} (mm)[7]	1.77	1.71	1.74	0.03	0.49
TMR[3]					
> 19.0 mm	40.9[a]	6.4[b]	6.9[b]	4.87	0.02
19.0 – 8.0 mm	24.6[b]	42.9[a]	43.8[a]	3.50	0.05
8.0 – 1.18 mm	31.5	36.7	35.3	2.00	0.31
< 1.18 mm	3.0[b]	14.0[a]	14.0[a]	0.56	0.001
X_{gm} (mm)[6]	11.2[a]	5.8[b]	5.7[b]	0.63	0.01
S_{gm} (mm)[7]	2.70	2.76	2.78	0.07	0.74

[1] 64.4 $\pm$ 0.6 % moisture
[2] 67.4 $\pm$ 0.3 % moisture
[3] 46.0 $\pm$ 1.6 % moisture
[4] means in the same row with different letters differ ($P \leq 0.05$)
[5] TMR containing 50:50 forage to concentrate ratio and 9.5% DM grass hay, 25.3% DM corn silage, and 14.6% DM alfalfa haylage.
[6] X_{gm} = geometric mean length as calculated by the ASAE (2001)
[7] S_{gm} = standard deviation as calculated by ASAE (2001)

Table 3-2. Effects of alfalfa haylage moisture content on particle size measurements according to the PSPS shaken at 1.2 Hz with a stroke length of 17 cm.

	Percent Moisture[3]					SEM	*P* - value
	57.4	**35.6**	**10.4**	**2.5**	**0**		
Particle Size							
> 19.0 mm	61.5[a]	63.0[a]	45.2[b]	40.3[b]	27.5[c]	2.87	< 0.001
19.0 – 8.0 mm	25.3[c]	24.4[c]	35.4[b]	37.3[a,b]	44.5[a]	2.25	< 0.001
8.0 – 1.18 mm	11.3[d]	10.6[d]	15.1[c]	18.0[b]	22.6[a]	0.69	< 0.001
< 1.18 mm	1.9[c]	2.1[c]	4.3[b]	4.4[b]	5.4[a]	0.27	< 0.001
X_{gm} (mm)[1]	17.7[a]	17.9[a]	13.7[b]	12.6[b]	10.3[c]	0.54	< 0.001
S_{gm} (mm)[2]	2.3[b]	2.3[b]	2.6[a]	2.6[a]	2.6[a]	0.04	< 0.001

[1] X_{gm} = geometric mean length as calculated by the ASAE (2001)
[2] S_{gm} = standard deviation as calculated by ASAE (2001)
[3] means in the same row with different letters differ ($P \leq 0.05$)

Table 3-3. Effects of corn silage moisture content on particle size measurements according to the PSPS shaken at 1.2 Hz with a stroke length of 17 cm.

Particle Size	**Percent Moisture**[3]					**SEM**	***P* - value**
	58.0	**34.4**	**14.6**	**3.47**	**0.0**		
> 19.0 mm	14.3	11.0	9.5	9.6	12.87	2.16	0.317
19.0 – 8.0 mm	74.0[a]	74.5[a]	73.2[a]	70.4[a]	52.3[b]	2.08	<0.001
8.0 – 1.18 mm	11.4[d]	13.1[c,d]	15.4[b,c]	18.0[b]	31.5[a]	1.36	< 0.001
< 1.18 mm	0.23[d]	1.36[c]	1.96[b]	2.03[b]	3.39[a]	0.16	< 0.001
X_{gm} (mm)[1]	12.1[a]	11.2[b]	10.6[b,c]	10.2[c]	8.62[d]	0.33	< 0.001
S_{gm} (mm)[2]	1.7[d]	1.8[c]	1.9[b,c]	2.0[b]	2.3[a]	0.03	< 0.001

[1] X_{gm} = geometric mean length as calculated by the ASAE (2001)
[2] S_{gm} = standard deviation as calculated by ASAE (2001)
[3] means in the same row with different letters differ ($P \leq 0.05$)