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# High-Specific Separation of Biomass Materials by Sieving

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**Abstract.** *Improved physical separation of biomass concentrates higher value components, returns unused plant components to soil, and provides more efficient platform for downstream industrial users. Sieving is identified as a top emphasis in this study. Understanding factors controlling sieving, such as biomass particle density, shape, size, and moisture content would improve the design and application of sieves for irregular-shaped biomass materials. Particle properties and sieving interactions in the separation processes would greatly benefit the design of separation units for improve separation efficiency.*

*Results showed that about 25% difference by weight of switchgrass nodes retained by sieves when separated with a standard sieving test. Also using image analysis, the geometric mean diameter calculated was much closer to the manual observation than the standard calculations by the ASAE S424.1. A conclusion was that standard summary statistics calculated by various consensus standards may not provide the greatest accuracy for biomass.*

**Keywords.** Biomass material, Sieving, Particle size distribution, Separation, Geometric mean diameter.

## Introduction

World production of biomass is estimated at 146 billion metric tons a year, mostly wild plant growth. Some of them, such as biomass with high glucose content, are highly preferable in the industrial productions. Generally, plant parts with high content in the cellulose, hemicellulose, fructose, and glucose are considered as good source for feed stock, energy, and bio-based productions. There are several ways of biomass energy and products conversion: thermo-chemical, fermentation, microbial digestion, etc. All these energy conversion processes or the bio-products producing are involved with pre-sorting or pre-purification since the chemical composition is so entangled with biomass itself. Almost every single energy conversion or bio-production practice involved with pre-sort processes.

Chemical based separation is one of the common practices for the pre-sorting biomass materials. Concentrated acid hydrolysis is based on concentrated acid decrystallization of cellulose followed by dilute acid hydrolysis to sugars at near theoretical yields. Separation of acid from sugars, acid recovery, and acid re-concentration are recognized as critical unit operations. High energy input is required to separate the acid from the products as well as dry the products.

Physical based separation is another promising separation approach which is based on biomass physical properties. The main advantage of using physical separation is simple and low cost. There are much lower energy inputs compared with wet chemistry separation processes.

Sieving and screening have been applied in the industries for large-scale separating particles and in the laboratories for testing particle distributions as one of the physical separation techniques (Coulson and Richardson 1991). Due to their simple construction, screens are used in various engineering applications, ranging from coal particles to the pharmaceutical materials. However, most research studies reported sieve opening dimensions instead of actual particle retained on the sieves as one of the judging factors. One reason for such decision is when particles get smaller and smaller, it would be extremely difficult to measure their sizes as well as the particle size distributions (PSD). As a result, little information is available as to the exact dimensions for particles retained on the sieves after separation. Another issue is most studies only focused on the behavior of homogeneous and regular shape particles interact with the screen based on the theoretical model, behavior of heterogeneous irregular particles, such as biomass materials, remains un-clear. Fowler and Lim (1959) and Gluck (1966) pointed out that the particle shape, moisture content, and tendency for particles to stick together could affect screen efficiency. There is no simple model to addresses such issues with respect to separation of biomass particles.

Image analysis (IA) has been recognized as one of the low cost and robust methods for analyzing wide range of applications. The analysis is basically composed of two components: hardware and software. The applications of IA have been growing rapidly during the past years. Flatbed scanning (FBS) was used to determine spray droplet size (Wolf et al., 2000), to analysis air void in concrete (Peterson et al., 2001), and to quantify microbial growth (Gabrielson et al., 2002).

Combining sieving and IA gives quick analysis of biomass material PSD, shape characterizations, and gives more information than the current common methods. The objective of this research is to develop an accurate method to rapidly quantity and determine the size of biomass which is retained by particular sieve sizes using IA.

## Material and Methods

Two groups of biomass materials were tested in the experiment. One group contained hand-cut biomass materials, representing biomass materials share with similar size, shape, density, and other physical properties. The switchgrass were cut by 12.5mm, 25mm, 37.5mm, 50mm, and 62.5mm in length. Experiment was set up using 67.53 g (512 particles total with equal number of internodes and nodes cut) switchgrass samples, with the moisture content of 5%.

The second group of testing materials was prepared by a knife mill with a 2.5-cm screen, representing biomass particles with irregular size, shape, density, and other physical properties. This group of particles shared some similar properties with the particles grinded in the large scale size reduction process as used in the industries.

Each testing biomass particles group was subject to the PDS analysis following ASAE standard S424.11 and ASTM standard E799-92 for calculating summary statistics (geometric mean diameter, etc).

ASTM standard separator Gilson TS-1 was purchased from Gilson (Lewis Center, OH, USA). Low amplitude shaft with adapter was used in the test. Screen openings corresponded with ASAE sizes (19.0mm, 12.5mm, 6.3mm, 4mm, and 1.18mm). The standard testing time was fixed at 10 minutes per test.

All input and output biomass was subjected to the particle analysis using IA. The IA was conducted with a desktop scanner, which was used to obtain images of biomass particles, with a image analyzing software, which was Scion Image (V4.0.3) from the Scion Corporation running under Windows XP Pro. Scion Image is available on the official website at www.scioncorp.com. In addition to IA, manual measurements and observations were used to re-verify IA as well as to provide additional information, such as particle shape, etc. The software gave the prediction of major axis and minor axis by an ellipse fit. The major axis and minor axis were easily converted back into particle length and particle width by a factor of $0.5 \times \sqrt{\pi}$.

The size of biomass particles can be reported in terms of geometric mean diameter as:

$$X_{gm} = \log^{-1} \frac{\sum \left( M_i \cdot \log \overline{X_i} \right)}{\sum M_i} \qquad (1)$$

$$S_{gm} = \log^{-1} \left[ \frac{\sum M_i \left( \log \overline{X_i} - \log X_{gm} \right)^2}{\sum M_i} \right]^{1/2} \qquad (2)$$

Where

$X_i$ is the diagonal of screen openings of the $i^{th}$ screen

$X_{(i-1)}$ is the diagonal of screen openings in the next larger than $i^{th}$ screen (just above in a set)

$X_{gm}$ is the geometric mean length

$\overline{X_i}$ is the geometric mean length of particles on $i^{th}$ screen = $\sqrt{X_i \times X_{i-1}}$

Mi is the mass on $i^{th}$ screen (actual mass at the conditions of screening of percent of total)

$S_{gm}$ is the standard deviation

Since the geometric mean diameter is the diameter of a particle that has the logarithmic mean for the size distribution, it can be also calculated by:

$$\log d_g = \frac{\log d_{pa(1)} + \log d_{pa(2)} + \log d_{pa(3)} + \cdots + \log d_{pa(n)}}{n} \tag{3}$$

$$d_g = \sqrt[n]{d_{pa(1)} \times d_{pa(2)} \times d_{pa(3)} \times \cdots \times d_{pa(n)}} \tag{4}$$

Where

$d_{pa}$ is particle diameter

$d_g$ is geometric mean diameter

$n$ is number of particles in distribution

Comparisons were performed between $X_{gm}$ calculated for screened particles and IA determinations.

## Results and Discussion

Figure 1 shows the weight difference in the separation of switchgrass nodes and internodes particles from hand cut samples. There are 25% more nodes by weight trapped on the upper sieve than on the lower sieve, which suggesting that the nodes could be separated from internodes using the ASTM separator.

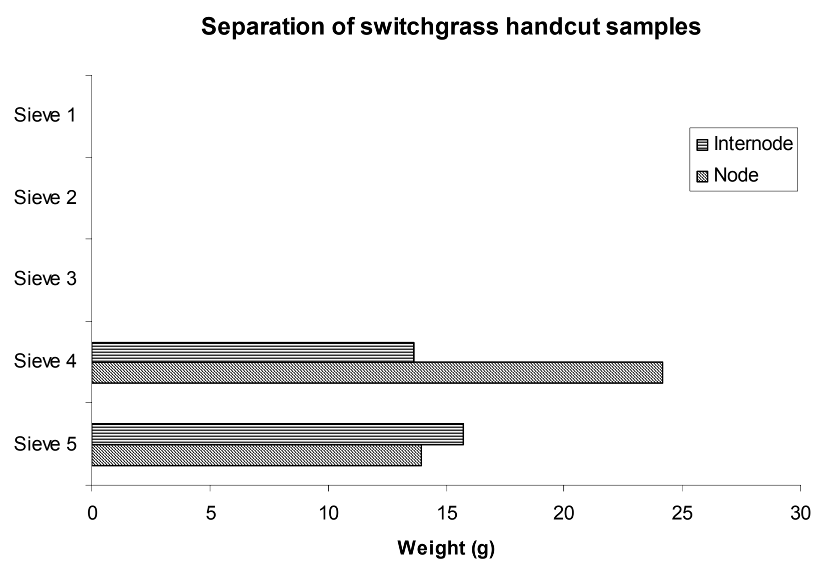


Figure 1. Comparison of internode and node cut switchgrass samples by ASTM standard sieve (sieve1=19.0mm, sieve2=12.5mm, sieve3=6.3mm, sieve4=4mm, and sieve5=1.18mm)

Table 1 shows the result of data calculation following ASAE S424. Top three sieves did not retain any switchgrass particles since the openings of sieves were much larger compared with switchgrass samples.

Table 1. Percent mass distribution of hand cut switchgrass sample.

| Screen no | Screen diagonal, mm | Percent total mass on screen, % | Cumulative undersize, % |
|---|---|---|---|
| 1 | 26.9 | 0 | 100 |
| 2 | 18 | 0 | 100 |
| 3 | 8.98 | 0 | 100 |
| 4 | 5.61 | 63.3 | 36.7 |
| 5 | 1.65 | 36.7 | 0 |
| Pan | ______ | 0 | ______ |
| | | 100 | |

Table 2 lists the comparison results of geometric mean diameter calculated by ASAE standard S424 and IA determination. It is obvious that the geometric mean diameter calculated by the equation (1), which was 5.20 mm, gave much large prediction of geometric mean diameter than the IA, which can be explained by the fact that the diameter in the equation using diagonal dimension of the adjacent screens. Equation (1) assumes that the average particle size is the square root of upper and lower screen openings. It is interesting that from the manual measurements of particles retained on sieve 4, the switchgrass particle ranged from 5.05 mm down to 2.53 mm; while the sizes ranged from 4.11 mm down to 1.63 mm for those particles retained on sieve 5. This also indicates that the geometric mean diameter calculated by the IA may be more accurate in reporting the actual biomass particle sizes on particular sieve.

Table 2 Comparisons of the geometric mean for screened particles and IA determination of hand cut switchgrass particles.

| Screen no | Number of particles | Geometric mean diameter by calculation based on handcut size input (mm) | | Geometric mean diameter by ASAE standard (mm) | Geometric mean diameter by IA (mm) | |
|---|---|---|---|---|---|---|
| | | Length | Width | | Length | Width |
| 1 | - | - | - | - | - | - |
| 2 | - | - | - | - | - | - |
| 3 | - | - | - | - | - | - |
| 4 | 217 | - | - | 7.10 | 33.19 | 3.99 |
| 5 | 295 | - | - | 3.04 | 34.59 | 3.07 |
| Pan | - | - | - | - | - | - |
| Overall | 512 | 50.32 | 3.77 | 5.20 | 33.68 | 3.32 |

Table 3 shows the difference in the calculated particles geometric mean diameter and IA determination for the grinded switchgrass particles by the knifemill.

Table 3 Comparisons of the geometric mean for screened particles and IA determination of grinded switchgrass particles by knifemill.

| Screen no | Number of particles | Geometric mean diameter by ASAE standard (mm) | Geometric mean diameter by IA (mm) | |
|---|---|---|---|---|
| | | | Length | Width |
| 1 | 1 | 96.8* | 96.8 | 2.21 |
| 2 | 7 | 22.0 | 32.25 | 3.11 |
| 3 | 33 | 12.7 | 19.39 | 2.78 |
| 4 | 643 | 7.10 | 19.42 | 1.75 |
| 5 | 3970 | 3.04 | 14.61 | 1.69 |
| Pan | 4845 | 0.82 | 6.78 | 1.00 |
| Overall | 9499 | 3.05 | 10.08 | 1.30 |

* The average measured length of the particles on screen 1, which was 96.8 mm.

## Conclusions

1. It is suggested that potential separation of biomass material, such as nodes, could be separated based on slightly difference in the physical properties.
2. Combination of IA and standard sieving test gives fast determination of biomass particle properties, such as length, width, geometric mean diameter, etc.
3. Standard summary statistics calculated by various consensus standards may not provide the greatest accuracy for the biomass.

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