PERFORMANCE OF SCREENING BIOMASS FEEDSTOCKS USING STAR AND DECK SCREEN MACHINES

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ABSTRACT. *The most commonly traded forms of biomass energy feedstock are chipped (wood chips) and ground (hog fuel) materials. Of these two feedstocks, particle size distribution is one of the key characteristics that affect efficient feedstock handling and biomass conversion. This paper compares productivity and effectiveness of star screener and deck screeners in separating chipped and ground material. Both machines were set up to separate feedstock into three different size categories: unders (<10 mm), accepts (10-51 mm), and overs (>51 mm). Results from the study indicated that the star screener (62.61 and 50.95 tons/h) was more productive than the deck screener (26.80 and 15.63 tons/h) when separating wood chips and hog fuel. Also, there was additional cost to apply screening systems to distribute the size of the materials; $3.53/ton and $6.05/ton for deck screen with wood chips and hog fuel and $1.61/ton and $1.98/ton for star screen with wood chips and hog fuel. For size distribution of screened materials, the 13-mm size materials had the highest portion of the accept size class, and the 25-mm size materials were primarily found in the oversize class, and pan size materials (e.g., sawdust) had the highest portion of the under size class. The feedstock materials screened using star and deck screening machines still had size variations exceeding over or under sizes in the under, accept, and over size classes. To improve the quality of screened materials, definitions of the size (under, accept, and over) should to be further refined.*

Keywords. *Biomass feedstock, Deck screen, Hog fuel, Size distribution, Star screen, Wood chips.*

Forest residues including non-merchantable trees, small-diameter trees, tops, limbs, and chunks produced from mechanical thinning and conventional saw-timber harvesting operations provide an opportunity to produce bioenergy and bio-based forest products (Kizha and Han, 2016). Due to increasing fuel costs and environmental concerns, renewable biomass energy is an appealing alternative to fossil fuels (Han and Murphy, 2012). New technologies that are capable of converting forest residues into bioenergy and bioproducts are being developed. The most commonly traded forms of solid biomass feedstocks used to make these products are chips and hogfuel (ground material) (CEN/TS-14961, 2005). Each of these feedstocks have unique size characteristics that make them acceptable or not acceptable to different biomass conversion technologies (BCTs). Therefore meeting the feedstock specification requirements (e.g., size, moisture content, and contaminants) for specific BCTs becomes increasingly important.

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The distribution of particle sizes in a feedstock can directly affect its handling and utilization efficiency (Jensen et al., 2004). Fine materials, under 3 mm in length, have been shown to reduce air circulation during storage, which can increase the risk of combustion and affect decay rate and durability (Jirjis, 2005). Conversely, oversized materials, such as sticks or non-comminuted materials, often leads to bridging which blocks or hinders conveyance leading to ineffective handling (Mattsson, 1990).

To increase biomass feedstock quality and productivity of BCTs, matching the specific feedstock size to BCTs is necessary to improve consumer confidence in fuel quality assurance (Han et al., 2015). Emerging conversion technologies such as combustion, gasification, pelletization, pyrolysis, briquettes, and torrefaction require specific size, moisture content, species, and contamination levels. Using those BCTs and optimized biomass operations logistics can enhance the economic viability of forest residue utilization by converting forest residues into value added and quality energy feedstock (table 1).

Feedstock specifications for BCTs can be achieved by utilizing new chipping, grinding tools, and screening technologies. Chippers and grinders are common machinery used for biomass size reduction (Han et al., 2015). Wood chip material is produced by cutting wood using knives in a chipper while hog fuel is produced by hitting wood using bits (or hammers) in a grinder, and each of the processes has advantages and disadvantages. Wood chips (chipped material) produced by a chipper are usually more homogeneous in shape and particle size compared to hog fuel (ground material).

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Table 1. Desired feedstock specification for biomass conversion technologies.

Biomass Conversion Technology	Product	Desired Feedstock Specification Particle Size (mm)	Moisture Content (% wet basis)	Ash Content (%)
Gasfication	Biochar	15-102	<25	<20
Torrefaction	Torrefied chips	13-38	<30	No limit
Densification	Briquettes	<50	4-15	No limit
Gasfication	Electricity	15-50	10-30	<15

Particle size distribution is also affected by species (i.e., hardwood or softwood), type of logging residues (limbs, tops, stems, and chunk) (Spinelli et al., 2011), machine type (Spinelli et al., 2005), comminution device (Mattsson and Kofman, 2003), and cutting tool wear such as knives, bits, and anvils (Nati et al., 2010). Size distribution using mechanical screening is cost-effective (Sultanbawa et al., 2001) and is widely used in many different industries (Spinelli et al., 2011), and commonly used in handling and refining solid fuels such as coal (Govender and Van Dyk, 2003).

There has been increasing interest in incorporating new screening technologies into biomass operations to improve product quality and to meet feedstock size requirements for emerging BCTs. The goals of this study were: (a) comparing screening productivity of different types of screening machines (star and deck screens) for two feedstock material types (wood chips and hog fuel) and (b) comparing screening results of wood chips and hog fuel size distribution after sorting by two different screen machines.

Methods and Materials

Material Specification

Both ground material (hog fuel) and chipped material (wood chips) were classified into three different feedstock sizes. Wood chips used for this study were produced using a Peterson 5900EL disc chipper with a 765 horsepower engine. The chipper was a standard three knife configuration set to produce 22-mm (7/8 in.) size chips. The chipped materials were Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) tops that ranged from 6 to 17 cm in diameter. The hog fuel was ground with a horizontal Peterson 4710 grinder (Peterson Pacific Corp., Eugene, Ore.) that had a 765-hp engine. The grinder setting included a solid anvil and three grates with two different sizes (one 8-cm and two 10-cm grate holes) and produced hog fuel for our screening experiments. The outer bits on the rotor were carbide hammer bits, and the inner bits were chipper bits. The hog fuel and wood chips materials were stored separately and were each mixed before applying screen machines to reduce sampling bias. The ground materials included all types (tops, branches, and chunks) of logging residues from a mixed conifer stand in western Oregon.

Screen Machines Specification

Star Screen

The Terra select S6-E star screen Peterson (Peterson Pacific Corp., Eugene, Ore.) has a 74-hp engine with 3-fraction screening. The material was screened through each rolling star disc and was distributed out into three different size classes, under, accept and over. The Terra select S6-E star screen system is operated with star disc roller. The screening process is operated with controlling speed of star discs. The space between the star discs determine the range of the screened particle size. Also, the speed of star discs rotating of the shaft affect the size distribution of screened material. For instance, slower the rotating shafts, the more opportunity material has a chance to pass and screen through the gap between the star discs. Hog fuel and wood chips were screened with different disc rolling speed to find optimized screen settings.

Deck Screen

The DS6162 deck screen machine is assembled by Peterson Co. (Eugene, Ore.) and is a self-contained screening tool. The deck screener has a 130-hp engine and productivity up to 500 ton/h. The deck screen is assembled with four sets of screen sieves. The screen sieves are quick and simple to convert to different sieve sizes. The material size is controlled by different screen size settings on the top and bottom of the screening area. In this study, the screen sieve size was set to 5 × 5 cm on the top and 1 × 1 cm on the bottom (fig 1).

The under size class was defined as under 1 × 1 cm dimension, accept as 1 × 1 cm to 5 × 5 cm and over size was any material bigger than 5 × 5 cm.

Field Productivity Measurement and Feedstock Sampling

Productivity of Screen Machines

The screeners tested were set to sort three different size classes: under, accept, and over size. After a material type (wood chips or hog fuel) was screened, the different size classes were weighed independently in their bins using a nearby weigh station. These weights, along with the time it took to complete the screening were used to measure productivity. Only the screening operation time was recorded because the study was focused on screening machine operation productivity (i.e., not logistics of screening operations). Machine hourly costs were estimated based on methods described by (Miyata, 1980) (table 2).

The cost of the loader operation was assumed to be \$121.5/PMH for both screeners (Harrill and Han, 2012). Fuel consumption of the operation was estimated by starting the screen machine with a full fuel tank and recording the refilled fuel level using a 1000-mL marked container at the end of each cycle. To estimate the screening productivity of each machine, a time-motion study was conducted during the screening operations. The operation was repeated three times for each screener and material type (wood chips and hog fuel) for a total of 12 trials. Each screening operation cycle time started when the 20 yd^3 container was empty and ended when it was fully loaded.

The wood chip and hog fuel piles used for this experiment weighed approximately 5 tons each. They were independently

Figure 1. Deck and star screen machines (left: Deck screen setting with 5 × 5 cm top screen sieve size and 1 × 1 cm bottom screen sieve size; right: star screen rolling disc).

mixed with a front-end loader before screening to reduce sampling bias. The initial material pile for each material type was divided into two piles for the star and deck screen machines. Screened materials (wood chips and hog fuel) were collected during the screening operation to evaluate size distribution and moisture content (MC) for each size class (under, accept, and over). Moisture content samples were collected from each size categories for each cycle and were then stored in 0.5-L plastic bags with tight lids. Each bag was sampled at the beginning of the fill of the bin container, the middle of the fill, and when the bin container was full. Ten samples were collected using 3-L plastic bags for evaluating size distribution. Each sample consisted of 3 L of chips and hog fuels, which were tightly sealed after collection to avoid drying. The bags were marked with the sequence of sampling, material types and machine types. In total, 120 samples were collected for moisture content and 240 samples were collected for size distribution. Moisture content was measured based on the European standard (CEN/TS-14774-1, 2004). Moisture content samples were placed in paper bags and weighed with a precision balance before putting the samples the air drying oven at 103±2°C. The biomass samples were dried for no longer than 24 hours to minimize losses of volatile compounds. Also according to standards, constancy in mass is defined as a change not exceeding 0.2% of the total loss in mass (CEN/TS-14774-1, 2004).

Table 2. Data used for calculating machine rates ($/h) of Deck and Star screen machines.

	DS6162 Deck Screen	Terra Select S6E Star Screen
Purchase price ($)	340,000	495,000
Salvage value (%)[a]	20	20
Economic life (year)	8	8
Interest (%)	4.5	4.5
Insurance (%)	3	3
Taxes (%)	0	0
SMH[b]/year	1500	1500
PMH[c]/year	1275	1275
Maintenance & repair (% of D)	30	100
Fuel use (L/PMH)	23.05	7.38
Fuel cost ($/L)	0.87	0.87
Lube (% of fuel cost)	1	1
Wages ($/SMH)[d]	20.00	20.00
Fringe benefits (% of wage)	25	25
Utilization rate (%)	85	85
Machine rate($/PMH)	94.6	100.8

[a] % of purchase value at time of disposal.
[b] Scheduled machine hour.
[c] Productive machine hour excluding all delays (i.e., not operating the machines).
[d] Operator for a loader feeding materials into the screening machines.

To analyze the accuracy of size distribution performance of the screen machines, the samples were brought into the laboratory and rescreened using an oscillating sieve shaker (fig. 2). There were six, seven, and eight different sieve sizes combination used in the shaker for under-, accept-, and over-sized materials, respectively (table 3). Oscillating screening operation time was set to 2 min for each screening performance. Each screened material in the fraction mass was measured to the nearest 0.1 g with precision mass balance (15149-1, 2006).

Statistical Analysis

Data analysis was performed using R statistics package. T-tests were used to compare productivity, fuel consumption of machines, and moisture content. One-way analysis of variance (ANOVA) was used to evaluate the effect of moisture content and size classes (under, accept, and over) on screening productivity for each screening machine.

Material size distribution was analyzed using a linear model on distributed size weight with categorical variables of machine type, material type, screen setting, and size classes. The model used a general linear model (GLM) with a logit transformation function to fit the 0 to 1 distribution of proportions (proportion of size distributed materials) into a normal distribution (Hoffmann, 2004). To avoid the inherent problem of applying the log function to a zero value, 0.16667 was added to all zero values (Mosteller and Tukey, 1977). A linear regression model was used to determine the relationship among size distribution and machine types, material types, screen setting at a 95% confidence interval (α= 0.05). To test interaction terms between independent variables, two-way interactions (machine types with size distribution and material types with size distribution) were tested. In addition, the model tested 3- and 4-way interaction terms in the analysis, however, there were no significant interactions terms in 3- and 4-way interaction terms test. Because of this, 3- and 4-way interaction terms were not included in the results of this analysis.

Sampling efficiency was evaluated for each size distribution class based on bootstrap variances generated with data

Figure 2. Size distribution of screened materials from each size class: under, accept and over using an oscillating sieve shaker.

sampled from each material types (wood chips and hog fuel) and machines types (star and deck screen). Sample size was determined using bootstrap analysis by randomly sampling points with replacement from the original dataset (Kane et al., 2009). For this study, 2000 random data points were generated from bootstrap repetition through the sample size for each material type (wood chips and hog fuel) and machine type (star and deck).

Results and Discussion

Productivity, Cost, and Fuel Consumption of the Screening Machines

The star screener's productivity was two times greater than the deck screener, and fuel consumption was three times less than the deck screener (table 4). The screening productivity and fuel consumption for both machines were highly affected by the screening mechanisms and engine sizes used in each machine. There were differences in the screening mechanism processes between deck and star machines, the deck screener required feeding time to completely screen materials, while the star screen rolling disc supported feeding process from the hopper onto the screen. In addition, the deck screen machine was equipped with a larger-sized engine compared to the star screen. The star screen also used efficient diesel-electric drives. The deck screen used less efficient diesel-hydraulic drives with open-loop flow control valves. The less efficient drive system on the deck screen was part of the reason for the increased fuel consumption. The results also showed that wood chips had a higher productivity than hog fuel for both machines, but hog fuel consumed less fuel compared to wood chips in the deck screen.

As a results, there was an additional cost to apply the screening system to distribute the size of the materials; $3.53/ton and $6.05/ton for the deck screen with wood chips and hog fuel and $1.61/ton and $1.98/ton for star screen with wood chips and hog fuel, respectively. The star screen is a better option for maximizing the productivity of screening products compared to the deck screen system. However, the maintenance cost of the deck screen is less than the star screen. To improve the system balance, the deck screen is suitable for small scale biomass size distribution.

Table 3. Screener size class and sieve screen sizes used to fractionate samples for evaluation of size distribution.

Size Class[a]	Sieve Screen Sizes (mm)[b]
Under	>25, 25-19, 19-13, 13-10, 10-6, and <6
Accept	>51, 51-38, 38-25, 25-19, 19-13, 13-10, 10-6, and <6
Over	>102, 102-76, 76-51, 51-25, 25-19, 19-13, 13-10, and <6

[a] Size distribution from first screen machines (star and deck screens).
[b] Materials distributed from first screening were rescreened using shaker screen to analyze size distribution in each size class.

Moisture Contents of the Biomass Materials among the Size Class

The results of the mean moisture content values among the size classes and different materials are shown in table 5. Oversize material has the highest moisture content proportion in both wood chips (54%) and hog fuel (58%) materials. The results of the ANOVA test of size classes shows that there was a significant difference between accept-, over-, and under-size materials. When comparing wood chips and hog fuel moisture contents, hog fuel had higher moisture contents than wood chips in all size classes. Unfortunately, effect of moisture contents of screening performance was not tested in this research. To test effect of moisture contents of screening operation, the biomass feedstock samples were to be controlled with different contents of moisture. However, this experimental design was not captured controlling moisture contents of the biomass feedstock.

Result of Biomass Feedstock Size Distribution

In the accept-size class (10 to 50 mm), material type had a significant effect on the proportion of materials captured on the different sieves ($P<0.05$). There was a significant interaction between material type (hog fuel and wood chips) and machine type (deck and star screen) ($P<0.05$) (table 6). This was primarily caused by two different reasons. First of all, star and deck screens have different mechanical systems to distribute the size of biomass material. Deck screens are operated with different settings of screen sieves which have modular decks wire or punch plates. However, the star screen controls feedstock size by changing the speed of the star disc roller. The characteristics of hog fuel materials, which include a spear shape and small-sized wood chips, caused it to dive into sieve holes and it produced less accurate results in deck screened products. The differences in the

Table 4. A summary of T-test on average productivity and fuel consumption of the star and deck screener for two different material types (wood chips and hog fuel).

Screening Machines	Material Types	Productivity (tons/h)[a]	Productivity (BdT/h)[a]	Fuel Consumption (L/h)[a]	Screen System Cost ($/tons)	P-value
Deck	Wood chips	26.80 (±2.1)	13.40	25.00 (±0.8)	3.53	<0.01
Star		62.61 (±3.8)	31.30	5.90 (±3.0)	1.61	
Deck	Hog fuel	15.63 (±0.6)	7.81	23.75 (±1.3)	6.05	<0.01
Star		50.95 (±3.9)	25.47	9.00 (±1.0)	1.98	

[a] Mean productivity and fuel consumption reported with standard deviation (SD).

Table 5. Result of significance tests for moisture content mean values and variance for the comparison size classes in different materials.

	Wood Chips				Hog Fuel			
	Mean Value (%)	t-value	p-value	n	Mean Value (%)	t-value	p-value	n
Accept	51.7571	28.392	<0.01	21	57.4696	2.95	<0.01	21
Over	54.3333	0.96	<0.3	21	58.3428	-1.268	<0.24	21
Under	48.3375	-1.37	<0.01	21	54.2309	-0.283	<0.01	21

combination of machines and materials caused the interaction term in accept- and under-size classes.

Based on size distribution results, star screening is recommended for screening hog fuel material. The heterogeneous size and shape of the biomass materials, especially in hog fuel, make it necessary to study the relation between shape and size distribution of screening materials.

The different machine and material combinations tested in this experiment showed similar size distribution patterns in the accept size class (fig. 3). The star screen with wood chips showed the highest amount of 13- and 19-mm size materials. The deck screen with wood chips showed the second highest amount for 13- and 19-mm sizes. The star screen with hog fuel had the highest amount of materials within pan sizes (under 6-mm), 19-, 25-, 38-, and 51-mm sizes. The deck screener and hog fuel in combination showed the highest proportion in 6- and 51-mm sizes. The 13-mm size material had the highest proportion in overall machine and material combinations. In the accept size class, 13- and 19-mm size materials were the dominate size classes.

In the over-size class, size distribution of samples was significantly influenced by material type and machine type. There wasn't a significant two-way interaction between material type (hog fuel and wood chips) and machine type (deck and star screen) ($P>0.44$). In the deck and wood chips combination the 25- and 51-mm materials dominated the oversize class. In this combination there were no materials from pan (<6-mm), 6-, 10-, 13-, and 19-mm size materials. The star screen and wood chip combination had similar patterns to the deck and wood chip combination. The dominant size materials were found in 38- to 25-mm and 76- to 51-mm size sieves. Also, there were no materials from pan (<6-mm) and 6- to 13-mm size materials. The combination of the deck screen and hog fuel had the highest proportion in the 25- to 38-mm size sieve. Compared to wood chip materials, hog fuel materials were found in all different sieves except the 10- to 6-mm sieve size. Except for the 19- to 13-mm, 25- to 19-mm, and 38- to 25-mm sieve sizes, the hog fuel and star screen combination had a higher proportion in material in all sieve size classes than the hog fuel and deck screen combination.

ANOVA tests for the under size class showed that there were significant effects on the amount of under size class materials by material size (s2), material types (M), and machine types (MT) ($P < 0.05$). The pan size (<6-mm) and 10- to 6-mm materials were the most prominent classes in under-size material. The deck screener and hog fuel combination had the highest amount in the pan size and star-hog fuel, star-chip, and deck-chip combinations had the next greatest amounts, respectively. There were few materials obtained from 13- to 10-mm, 19- to 15-mm, and 25- to 19-mm size classes. Also, there were no materials from the above 25-mm size class. The deck and wood chip combination had the highest proportion in the 10- to 6-mm size sieve, followed by deck hog fuel, star hog fuel, star chip, respectively.

When separating wood chips, the deck screener had an overall 84% accuracy in the accept-size class. This means that 84% of the total sample consisted of particles within the accept size range (10 to 51 mm) after being screened. Among the different material types (wood chips and hog fuel) and screen machines (deck and star), deck screen with wood chip material had the highest accuracy in the accept class. The deck screen with hog fuel material had the lowest accuracy compared to the other combinations. This was due to the high variability in the particle size of hog fuel. Among accept-, under-, and over-size classes, the under-size class had the greatest accuracy for all machine and material combinations (table 7).

When separating hog fuel the deck screener had a problem with long and narrow "spear-like" particles "diving" or vibrating end up and in the small screen holes. The deck screen had a 9% accuracy when screening over size with wood chip materials. Based on the size distribution results, 38- to 51-mm size materials should belong in the over-size material class. When using screen machines for size distribution, the screened size should be further defined as under <10 mm, accept 10 to 38 mm, and over >38 mm.

In the accept size of hog fuel materials using the star screen, 77% of the hog fuel materials were located in the 10- to 51-mm range. Compared to hog fuel deck screening, star hog fuel screening had an increased accuracy of 17%. The characteristics of hog fuel materials, which include a spear shape and small-sized wood chips, caused it to dive into sieve holes in the deck screen. This produced less accurate results in the screened products. The star screen would be a better option to use if diving long, spear-shaped hog fuel materials became an issue in feedstock quality in size distribution. However, star screen maintenance costs are much higher than deck screen, and the maintenance cost needs to be considered in machine selection.

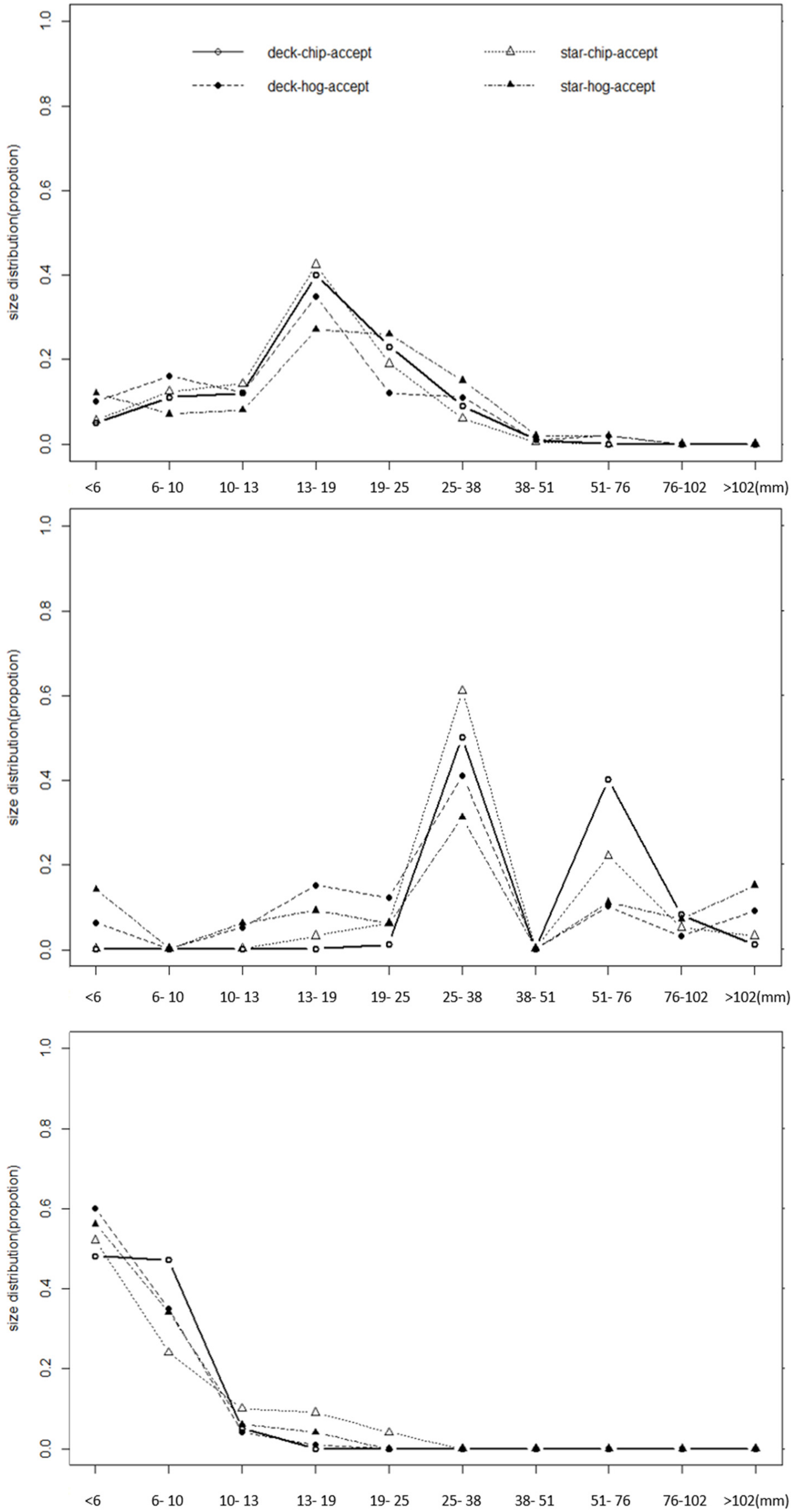

Figure 3. The size distribution result of accept-, over-, under-size class with combination of wood chips and hog fuel and deck and star screen.

Table 6. ANOVA for the size distribution in accept, over, under size class (n = 192).

Size class	Variables	DF	Sum of Square	Mean Square	F value	Pr(>F)
Accept	Sieve size	6	3,600,808	600,135	117.04	<0.05
	Machine types (MT)	1	13,576	13,576	2.64	0.11
	Material types (M)	1	105,591	105,591	20.59	<0.05
	MT*M	1	223,643	223,643	43.61	<0.05
Over	Sieve size	7	2,151,947	307,421	21.13	<0.05
	Machine types (MT)	1	199,369	199,369	13.70	<0.05
	Material types (M)	1	78,215	78,215	5.38	<0.05
	MT*M	1	8,904	8,904	0.61	0.44
Under	Material size (S2)	5	10,158,246	2,031,649	315.64	<0.05
	Machine types (MT)	1	138,610	138,610	21.53	<0.05
	Materials types (M)	1	27,557	27,557	4.28	<0.05
	S2:MT	5	186,505	37,301	5.79	<0.05

Table 7. Percent of materials observed in each sieve for three different size classes: under (<10 mm), accept (10-51 mm), and over (>51 mm);

		<6	6-10	10-13	13-19	19-25	25-51	>51		Accuracy[a]	Total
Under											
	Dchip[b]	48	47	5	0	0	0	-	-	95	100
	Dhog	60	35	4	1	0	0	-	-	95	
	Schip	52	24	10	9	5	0	-	-	76	
	Shog	56	34	6	4	0	0	-	-	90	
Accept											
	Dchip	5	11	12	40	23	9	0	0	84	100
	Dhog	10	16	12	35	12	11	2	2	60	
	Schip	6	12	14	42	19	6	1	0	81	
	Shog	12	7	8	27	26	16	2	2	77	
Over											
	Dchip	0	0	0	1	50	40	8	1	9	100
	Dhog	6	5	15	12	41	10	2	9	11	
	Schip	0	0	3	6	61	22	5	3	8	
	Shog	14	6	9	6	31	11	8	15	23	

[a] Accuracy denotes the total percent of material that was expected in that size class (Unit:%).

[b] Dchip = deck screener with wood chips, Dhog = deck screener with hog fuel, Schip = star screener with wood chips, and Shog = star screener with hog fuel.

Common screens used for wood chips and hog fuel include deck, trommel, and star screen machines. Each screener has various factors that affect screening performance. For instance, the unbalanced rotating weights that generate the screen box vibration can rotate about a horizontal axis or a vertical axis. The type of screening (various wire designs, punch plate, plastics medium) also affects the deck screen productivity and accuracy. The screen openings in the top deck are typically varied so the first section of the deck screen sieve has smaller openings to minimize spearing. The results from these experiments on both deck and star screeners are specific to the setups listed within this paper and should not be generalized for all deck and star screeners. The deck angles, frequency and hopper of the DS6162 were optimized for compost screening. Changing any of the variables listed above could have a significant effect on the productivity and classification results if they were optimized for wood chips or hog fuel.

Inclined deck screens DS6162 are very common, economical, and productive. They are commonly used in the aggregate industry where most material is closer to a spherical shape. Wood chips typically have one short orthogonal dimension (thickness). The length/thickness ratio is typically 4 to 5. Hog fuel typically fractures into long cylindrical shapes with two of the three orthogonal dimensions much smaller than the third dimension. Deck screens of the DS6162 type screen the material such that longer slender particles can "spear" through the screen openings (Cummings, 2015).

The star screens and disc screens separate material based on the space between the stars or discs. The rotational speed and inclination of the screening deck also impact the classification accuracy. Star screens, especially if they are lightly loaded can also be susceptible to "spearing". Both star and deck screens will produce more uniform classification if they are optimally and uniformly loaded. If they are overloaded, some of the fine and accept fractions will end up in the overs fraction. It they are under loaded, more "spear" will end up in the fine and accepts fraction.

CONCLUSIONS

The results of this study show similar patterns in size distribution between star and deck screens but the star screen had more accurate size distributions in hog fuel materials. The star screener also had significantly greater productivity compared to the deck screener. When looking at the productivity of the machines with different material types wood chips had a higher productivity than hog fuel in both machines. The star screener also consumed significantly less fuel compared to the deck screener. Fuel consumption of the star and deck screener were affected by the different size of engines and the less efficient diesel hydraulic system of the deck screener compared to diesel electric drives on the star screener. To test the effect of screening performance of moisture contents, the biomass feedstock samples are should to be controlled with different contents of moisture. In future study, controlled moisture contents of the biomass feedstock are needed to test for effect of moisture contents on the screening performance. When looking at size distribution of the screened material, there were size variations in both wood chip and hog fuel materials among under, accept, and over size. To increase the accuracy of size distribution results using screen machines, the definition of the size range can be modified as under <10 mm, accept 10 to 38 mm, and over >38 mm. The results of this study provide valuable information when considering the supply of quality (i.e., uniform in size) biomass feedstock that meets the requirements for various biomass conversion technologies such as torrefaction and gasification.

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