Evaluation of novel drum chipper technology: pilot-scale production of short wood chips

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ABSTRACT: Impregnation of wood chips with acidic pulping liquors is improved when using short chip lengths. If the average wood chip length is too short, conventional chipping technology will generate excess small material, such as pin chips and fines. The possibility of using newly developed drum chipping technology to produce short-length wood chips was evaluated with a pilot drum chipper operating at different drum velocities and in-feed angles. With a drum velocity of 30 m/s, the average wood chip lengths and the combined fractions of pin chips and fines were 24 mm and 3.3%, 22 mm and 4.2%, and 17 mm and 8.5%. The highest fractions of total accept chips (large and small accepts), 89% to 90% without screening, were observed for drum velocities of 30–34 m/s and average wood chips lengths of 21–22 mm. The results indicate the potential of drum chipping technology for producing short wood chips with relatively high fractions of accept chips and tolerable fractions of pin chips and fines.

Application: Mills can benefit from the use of new drum chipping technology to produce short wood chips from softwood that are suitable for acidic pulping processes.

Except for the rather uncommon groundwood mechanical pulping process, the pulping processes of today typically use wood chips. Because the feedstock is a significant part of the operating costs, high pulp yield is an important aspect of such processes [1]. Therefore, the feedstock has to be converted to acceptable chips with high conversion yields. Wood chips that are too large can be further processed to accept chips, but it is more difficult to handle pieces of wood that are too small. Pin chips and fines that are generated from chipping and removed by screening form a reject stream, which is burned to produce heat. Hence, it is important to minimize formation of pin chips and fines to maintain high pulp yields.

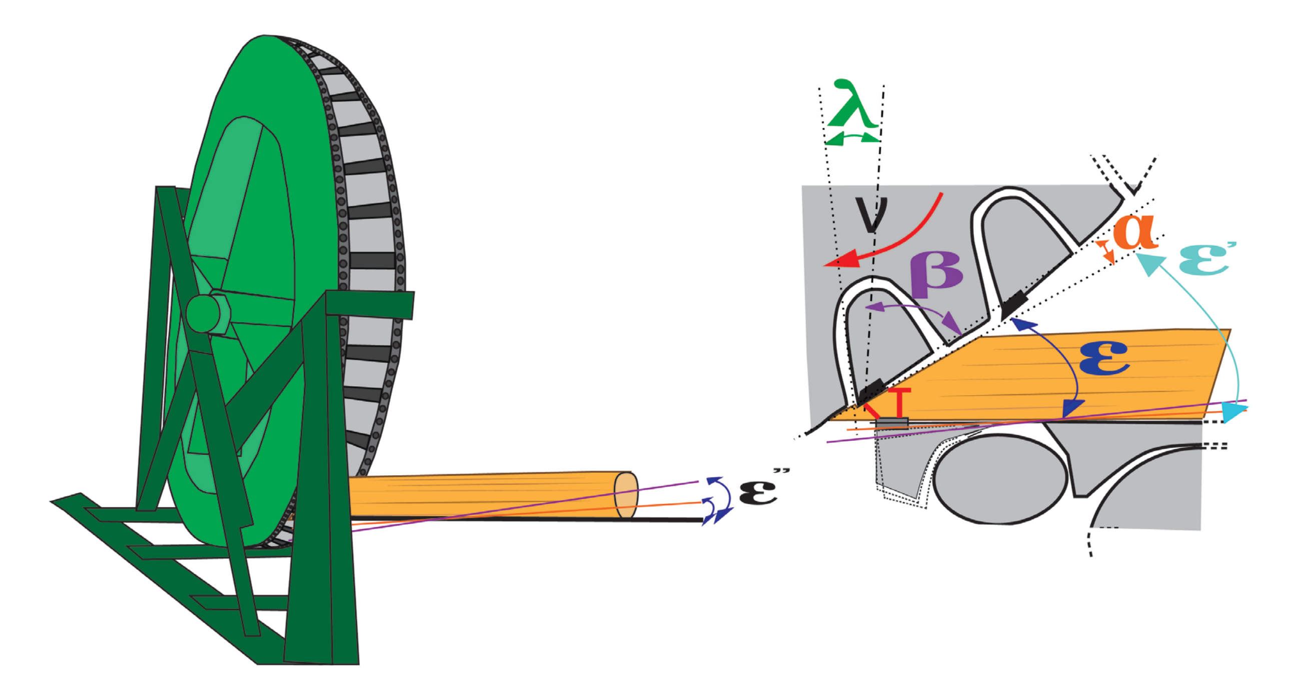
The properties of ideal accept chips vary depending on the pulping process used [1,2]. Current industrial wood chippers are mainly designed for the kraft process, which uses relatively long wood chips that are impregnated with alkaline white liquor. As long as the chips are not too thick, the chips can be long because the impregnation of white liquor occurs in both the fiber (longitudinal) direction and in other directions (tangential and radial). Hence, liquor impregnation during kraft pulping is mostly influenced by the chip thickness (radial) direction.

The situation is different for acidic pulping processes, such as acid sulfite. For such pulping processes, impregnation in the fiber (longitudinal) direction occurs more rapidly than in the other directions [1]; hence, shorter wood chips can be used. Using shorter wood chips can be beneficial for the impregnation of acidic pulping liquors, which results in less pulp rejects or shorter cooking time in the digester [2].

Even though the kraft process is the predominant chemical pulping method, some mills utilize the acid sulfite process. Although the number of U.S. mills using the acid sulfite process decreased from 67 to 13 during 1950–2000, the statistical data indicated that the average mill capacity has increased from 136 to 336 tons/day [3]. Furthermore, interest in the acid sulfite process has been renewed during the past few decades because of increased demands for dissolving pulp by textile manufacturing [4] and for lignosulfonates to be used in concrete manufacturing (as well as other applications) [5]. This is a reason to further investigate alternatives to increase the yield of shorter accept chips for acidic pulping while minimizing the amount of pin chips and fines.

Most earlier studies on liquor impregnation and cooking for the acid sulfite process have emphasized pulp strength as an important parameter. Howard [6] discussed the proper size of wood chips for acid sulfite pulping and suggested that earlier studies had placed too much emphasis on shorter wood chips, causing fiber shortening and lower pulp strength. Howard suggested that the wood chips should have an average length of approximately 19 mm to obtain optimal packing in the digester and to obtain maximum pulp yield [6]. Other studies on acid sulfite pulping have been based on wood chips with an average length of 25 mm, wood chips with variable length of 20–30 mm, or laboratory wood chips or wood blocks specially designed for studies of impregnation [7–10].

Today, forest-industrial wood chipping is done using disc chippers. The design of conventional disc chippers results in a velocity gradient over the disc. The velocity close to the center of the disc is low, which results in increased formation of



1. Simplified scheme of the pilot wood chipper and the definition of the angles (ε + α + β + λ = 90°): ε (cutting or spout angle), α (clearance or pulling angle), β (sharpness or knife angle), λ (complementary angle), and T dimension (the clearance between the wear plate and the knives). The in-feed angle (ε'') is adjustable and affects the cutting angle (ε) and the complementary angle (λ).

large wood chips. The velocity close to the periphery of the disc is high, which results in increased formation of pin chips and fines. This limits how short the average length of wood chips can be without losing too much material to pin chips and fines [2,11]. Another disadvantage of disc chippers is that the knife-angle settings cannot be changed during operation; the chipper has to be stopped to change the knife-angle settings, which results in downtime [12].

The drum chipper is an alternative to the disc chipper, but drum chippers are used mainly for production of wood chips to be burned for energy generation rather than for pulping. More recently, a new type of drum chipper has been developed that has potential advantages when compared with both conventional disc and drum chippers. The new drum chipper is flexible, as it allows the cutting or spout angle (ε in **Fig. 1**) to be optimized without stopping the chipper, and has the same cutting speed across the entire knife edge. With regard to wood chips for kraft pulping, the new chipper generates significantly lower proportions of pin chips and fines [13]. A pilot chipper based on the new chipping technology has been developed. Because full-scale wood chippers are typically critical for pulp production and quality, it is advantageous to use pilot-scale wood chippers for studies of the impact of velocity, knife settings, and log in-feed angle (ε'' in Fig. 1) on the yield of accept chips, pin chips, and fines.

Wood chip quality is affected both by the quality of the wood and by the chipping process. Previous studies of the effects on wood chips quality of the wood chipping angles have been done using conventional disc chippers. The settings of the knife angles (Fig. 1) and the clearance between wear plates and knives (the T dimension) depend on the desired length of the wood chips. The settings can be changed during maintenance to compensate for changes in wood quality; however, this is seldom done due to complications and to the loss of production time [11]. At a constant complementary angle (λ), the average thickness of wood chips would increase in a nearly linear fashion as the wood chips length increased. If λ is increased, the thickness will decrease. Assuming that the clearance or pulling angle (α) is kept constant, changes in complementary angle are caused by changes to either the cutting angle (ε) or the sharpness angle (β) [2,14,15] (Eq. 1):

$$\varepsilon + \alpha + \beta + \gamma = 90° \quad (1)$$

The cutting angle affects the chip size distribution [11,14,16]. Increasing the cutting angle increases the fractions of small wood chips, increases chip thickness in relation to length, and increases bulk density. Decreasing the cutting angle is beneficial for the production of long and thin wood chips suitable for kraft pulping, but it also results in lower bulk density and lower limits for the maximum log diameter. When the cutting angle is increased from the conventional value of approximately 30°–40° or 50°, chip cracking and chip surface area increases. This leads to a reduction of accept chips and an increase of overthick and pin chips [11,14,16]. With novel in-feed technology, the cutting angle (ε) is adjustable during the chipping operation by changing the in-feed angle (ε'') in relation to the preset knife cutting angle (ε'), which is determined by the chipper's knife holder design (Eq. 2):

$$\varepsilon = \varepsilon' - \varepsilon'' \quad (2)$$

The velocity of the knives has an impact on wood chip quality [2]. The velocity of commercial disc chippers is typically 16–40 m/s depending on the size of the disc and where on the disc the wood logs are chipped. Higher disc velocities would typically result in generation of larger fractions of pin chips and fines.

Disc chippers can produce relatively high fractions of pin chips and fines even during production of long wood chips for kraft pulping [13]. If the average wood chip length is decreased to a level that would be more suitable for acid sulfite pulping, the fraction of pin chips and fines could increase even further. By using the new drum chipping technology, it is possible to reduce the fraction of pin chips and fines by approximately 75% [13]. This observation suggests that this chipping technology could produce short wood chips specially designed for acid sulfite processes without producing excessive amounts of pin chips and fines. Thus, the aim of this study was to investigate this new chipping technology.

The production of softwood chips (Norway spruce), which is the predominant feedstock in the Nordic pulp and paper industry, was examined. The drum velocity and the in-feed angle were varied to obtain a broad range in the fractions of pin chips and fines when the T dimension was adjusted for the production of shorter wood chips. The size, thickness, length, and bulk density were determined using Scandinavian Pulp, Paper and Board (SCAN) Testing Committee's standard test methods. The ScanChip chip analyzer (PulpEye; Örnsköldsvik, Sweden), an automated method based on three-dimensional laser scanning, was used in some selected cases to obtain additional information about the distributions of chip length, thickness, and width.

MATERIALS AND METHODS

Wood chippers

The pilot-scale drum chipper, which was constructed by Multi Channel Sweden AB (Bredbyn, Sweden), has a drum diameter of 3 m and a width of 20 cm. It is equipped with 16 knives. The knife angles (α and ε'), which were adjusted to be suitable for the production of wood chips of an average thickness of 4 mm and an average length of 24–26 mm (SL24-26 setting), were not altered during the experiments.

Sampling of wood chips and analytical methods

Wood chips were produced from debarked wood logs of Norway spruce (*Picea abies*). The logs, which were of normal industrial quality, had a diameter of 100–200 mm. The logs were placed manually onto the in-feed system, which fed the logs into the pilot wood chipper at a velocity of approximately 0.9 m/s (400–450 rpm). The velocity of the in-feed system was always lower than the velocity of the drum so that the wood logs were pulled rather than pushed into the chipper.

Drum velocity and in-feed angle

The velocity of the pilot drum can vary between 122 and 275 rpm, which corresponds to cutting speeds between 20 and 45 m/s. Three cutting speeds were tested to determine the most suitable drum velocity for producing 24–26 mm chips: 148 rpm, 167 rpm, and 185 rpm (drum turns per min). These drum velocities corresponded to cutting speeds of 24 m/s, 27 m/s, and 30 m/s, respectively.

When a full-scale drum chipper of this type is used [13], the in-feed angle (ε'') can automatically be changed during production. When the pilot drum chipper is used, the change of in-feed angle has to be done manually. The pilot drum chipper can be adjusted to five different in-feed angles within the 0°–10° range. In this series of experiments, the effects of varying the in-feed angle between 0°, 2°, and 4° were studied. The change to the in-feed angle resulted in cutting angles of 30°, 28°, and 26°, respectively.

The logs (three to five for each setting) were chipped at different drum velocities and in-feed angles, and one sample of wood chips was collected from each log. Manual analyses of the wood chip samples were performed using the standard test methods SCAN-CM 40:01 (size distribution), SCAN-CM 47:92 (thickness and thickness distribution), SCAN-CM 46:92 (bulk density), and SCAN-CM 39:94 (dry matter content). For each setting, one sample was randomly selected for length distribution analysis using SCAN-CM 48:01 (length and length distribution and width and width distribution). The wood chips samples from SL24-26 appeared to be relatively homogeneous and were not further analyzed using methods other than the aforementioned SCAN standard test methods.

Producing shorter wood chips

The T dimension of the pilot drum chipper was changed for production of shorter wood chips of 22–24 mm (SL22-24 setting) and 18–20 mm (SL18-20 setting). The SL22-24 wood chips were produced at 185 rpm and 213 rpm (drum turns per min), which corresponded to 30 m/s and 34 m/s, respectively. The SL18-20 wood chips were produced at 148 rpm (24 m/s), 167 rpm (27 m/s), 185 rpm (30 m/s), and 213 rpm (34 m/s) to determine whether a lower speed would decrease the fraction of pin chips and fines generated.

Manual analyses of wood chips were performed using SCAN-CM 40:01 and SCAN-CM 47:92. For each length setting, one sample was randomly selected for length distribution analysis (SCAN-CM 48:01). In addition, image analysis was performed using a ScanChip chip analyzer that was located at the Metsä Board Husum mill (Husum, Sweden); this was done to monitor the distributions of length, thickness, and width of selected chip samples. The samples were inserted manually into the automated chip analyzer.

RESULTS AND DISCUSSION

Drum velocity and in-feed angle

The first series of experiments (with the SL24-26 setting) was performed to investigate whether it was possible to produce

Parameter/ Fraction	Def.[3]	24 m/s [1,2]			27 m/s [1,2]			30 m/s [1,2]		
		0°	2°	4°	0°	2°	4°	0°	2°	4°
Bulk density[4],kg/m[3]	–	137.2±5.4	133.9±2.0	139.2±2.6	128.7±4.2	137.3±11.1	138.2±3.3	**139.8±8.9**	133.1±9.3	136.1±1.7
Average thickness[5], mm	–	5.5± 0.5	5.2±0.2	5.0±0.0	6.0±0.9	5.3±0.4	5.1±0.0	**5.3±0.4**	5.9±0.4	5.4±0.1
Moisture content[6], %	–	49.5±3.0	57.1±11.2	55.3±0.8	64.8±14.6	55.1±15.3	50.1±1.7	**54.0±9.1**	60.6±11.2	65.2±0.4
Oversized, %	>Ø45	0.85±0.68	1.05±0.60	0.00±0.00	2.24±2.65	0.83±0.94	0.11±0.12	**1.43±1.17**	3.29±0.86*	2.75±0.01
Overthick, %	>//8	9.4±2.5	9.2±2.9	8.4±0.2	15.1±7.6	10.0±2.5	8.8±0.6	**10.1±3.9**	14.2±4.7	12.3±0.6
Large accepts, %	>Ø13	72.0±3.8	74.1±3.4	71.3±0.4	66.9±3.8	72.6±2.1	74.3±1.1	**71.4±0.8**	70.7±0.8	67.4±0.5
Small accepts, %	>Ø7	12.7±3.9	10.6±0.7	13.4±0.2	11.2±4.5	12.4±3.4	13.4±0.6	**13.7±4.05**	9.1±4.4	14.0±1.1
Pin chips, %	>Ø3	4.3±2.1	3.9±1.0	5.5±0.2	4.1±2.1	3.6 ±0.4**	3.1±0.0	**2.9±0.3**	2.2±0.7	2.9±0.2
Fines, %	<Ø3	0.78±0.41	1.12±0.56	1.39±0.12	0.56±0.07	0.69±0.39	0.29±0.02	**0.43±0.17**	0.43±0.12	0.83±0.26
Total accepts[7], %	–	84.7±1.6	84.7±3.7	84.7±0.3	78.1±8.3	85.0±4.0	87.7±0.5	**85.1±4.7**	79.8±4.3	81.39±1.5

[1] Significant differences (*t*-test) compared with wood chips from in-feed angle 0° and velocity 30 m/s (in bold font) are indicated: ***$p \leq 0.01$; **$0.01 < p \leq 0.05$; and *$0.05 < p \leq 0.1$.
[2] Average values for size fraction distribution calculated using SCAN-CM 40:01.
[3] Definitions: Ø = screen hole diameter in mm; // = screen slot distance in mm.
[4] Average values for bulk density calculated using SCAN-CM 46:92.
[5] Average values for thickness distribution calculated using SCAN-CM 47:92.
[6] Average values for moisture content calculated using SCAN 46:92.
[7] Sum of large and small accept chips.

I. Data for wood chips produced using the SL24-26 setting with different drum velocities and in-feed angles (ε'').

wood chips of good quality when the drum velocity was decreased from the reference setting, 30 m/s, to 27 and 24 m/s while modulating the in-feed angle. Slower drum velocity is anticipated to save energy. A drum velocity of 30 m/s and an ε'' of 0° was used as the reference setting when statistically analyzing the initial experimental data.

The average lengths of the wood chip samples with SL24-26 setting were within the 23–25 mm range. **Table I** shows the analysis of bulk density. The differences in the average bulk density with the various settings from the reference were determined to be insignificant ($p > 0.10$ (*t*-test)). All samples had values in the 128–140 kg/m^3 range; these values are somewhat less than values for softwood as described in SCAN-CM 46:92 (153–157 kg/m^3). Variations with regard to bulk density depend on differences in wood chip dimension, shape, and moisture content [17]. The mean thickness values of the wood chip samples were in the 5–6 mm range and the differences with regard to the reference setting were not significant (p>0.10 [t-test]).

Wood chip size and thickness distribution

The size fraction distributions and the thickness distributions were determined using SCAN-CM 40:01 and SCAN-CM 47:92, respectively (Table I). The fractions of oversized chips ranged from 0% to 3.3%. Only one sample, at drum velocity 30 m/s and in-feed angle 2°, was determined to be significantly different from the reference sample (i.e., $0.05 < p < 0.10$); nevertheless, it was not possible to discern any meaningful trends. This observation was probably due to variations in log quality rather than to the variations in the drum chipper settings (drum velocities of 24–30 m/s and in-feed angles of 0°–6°). The fractions of overthick chips ranged from 8%–15%, and there were no significant differences in the various samples when compared with the reference ($p > 0.10$). The pilot drum chipper produced very large proportions of large accept chips (67%–74%), and there were no significant differences when compared with the reference ($p > 0.10$). The proportions of small accept chips were low (9%–14%), and there were no significant differences when compared with the reference ($p > 0.10$). The combined fractions of large and small accept chips (i.e., the total accepts) ranged from 78% to 88%. For six out of nine of the settings, the value for total accept chips was ≥85%, which is an industrial standard value for total accept chips after screening. Nevertheless, there were no significant differences for total accept chips when compared with the reference ($p > 0.10$).

The fractions of pin chips and fines were small, which ranged from 2% to 5% and from 0.3% to 1.1%, respectively. The combined fractions of pin chips and fines were in the 2.6%–6.9% range, which was, even without screening, below the acceptable range for pulping in digesters (i.e., 8%–11%) [11]. Of note, 30 m/s drum velocity resulted in pin chips fractions of <3.0% and 27–30 m/s drum velocities resulted in fines fractions of <0.9%.

The comparison of different drum velocities (24–30 m/s) and in-feed angles (0°– 6°) indicated that it is possible to lower the drum velocity to <30 m/s while still maintaining a high fraction of total accepts (especially large accepts) and a low fraction of pin chips and fines. Thus, it is possible to achieve higher productivity at the low speeds with the potential to lower energy consumption during drum chipping. Furthermore, variation of the in-feed angle between 0° and 6° did not result in any discernible trends. For this reason, the in-feed angle was kept constant at 0° in subsequent experiments in this study.

The initial results of this study were compared with an earlier study based on a full-scale demonstration drum chipper producing chips for kraft pulping [13]. The average length of the wood chips from the demonstration-scale drum chipper was 23.3 mm [13], which was within the range of the average length of the wood chips from the pilot drum chipper with the SL24-26 settings (23–25 mm) (Table I). The average thickness of wood chips from the demonstration chipper was 4.3 mm [13], which was somewhat thinner than the average thickness of the SL24-26 chips in this study (5.0–6.0 mm) (Table I). The bulk density of the wood chips from the demonstration drum chipper (140 kg/m^3) was similar to the bulk density of the wood chips from the pilot chipper (128–140 kg/m^3). The fractions of oversized wood chips was 2.6% for the demonstration chipper and 0%–3.3% for the pilot chipper, whereas the fraction of overthick wood chips was 8.7% for the demonstration chipper and 8.4%–15.1% for the pilot chipper. The differences probably reflect differences in log quality, such as the content of wood knots. The values for large accepts (73%) and small accepts (12%) for the demonstration drum chipper [13] are within the intervals obtained with the pilot drum chipper (67%–74% large accepts and 9%–14% small accepts). The fraction of total accepts was 85% for the demonstration chipper and 78%–88% for the pilot chipper. Also, the values for pin chips and fines from the demonstration chipper (2.7% pin chips and 0.5% fines) were within the interval obtained with the pilot chipper (2.2%–5.5% pin chips and 0.3%–1.4% fines). These findings indicated that the pilot unit can be used for producing similar chips as a full-sized unit; hence, the pilot unit can be used to carry out smaller trials before attempting full-scale trials.

One way to decrease the proportions of pin chips and fines is to increase the complementary angle, λ, as suggested by Hartler and Stade [2]. In this study, this approach was tested by increasing the in-feed angle (ε''). Within the range of settings investigated, the fractions of pin chips and fines did not decrease with increasing in-feed angle; however, the average thickness did decrease. This approach could be useful for producing chips for kraft pulping whereby a low average thickness is desired. An online automatic system, such as the one mentioned in the Materials and Methods section, could be used to control chip thickness with a narrower distribution around the average going to the digester.

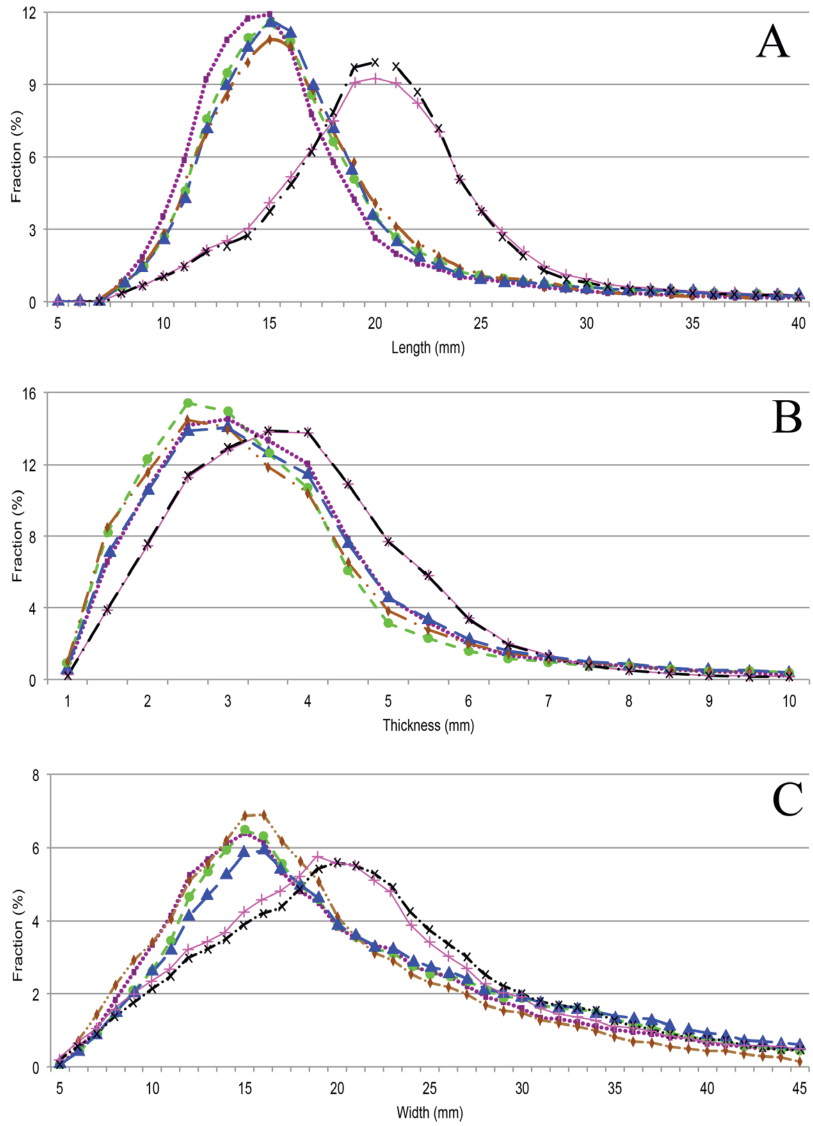
In an industrial wood chipper, a low cutting speed (around 20 m/s) and a small cutting angle (around 30°) is desirable [11]. Increased velocity leads to an increase of small fractions, such as pin chips and fines, especially when frozen wood is used [2, 11]. If the velocity of the disc is too low, the production capacity of the chipper will be negatively affected. The use of a drum chipper rather than a disc chipper is a potential option to resolve this dilemma.

Production of shorter wood chips

In a second series of experiments, shorter wood chips (SL18-20 and SL22-24) were produced using two different drum velocities (30 and 34 m/s). For the shortest length (SL18-20 setting), low drum velocities of 24 and 27 m/s were investigated. A high drum velocity of 34 m/s was included because such a speed might be advantageous to achieve high chipping productivity. The lower drum velocities were included to investigate the hypothesis that low velocity would suppress the excessive formation of pin chips and fines at a shorter chip length (e.g., SL18-20 setting). Chips produced at the SL18-20 and SL22-24 settings, which are shorter than what is typically used in the industry, were characterized using SCAN standard test methods and the automated chip analyzer was used to obtain a comprehensive view of the length, width, and thickness distributions (**Table II** and **Fig. 2**).

The average lengths determined by SCAN-CM 48:01 were ~17 mm (SL18-20) and ~22 mm (SL22-24), whereas the automated chip analyzer afforded similar values (~17 mm and ~21 mm, respectively). The average range of thickness was 4.6–5.2 mm by SCAN-CM 47:92, whereas it was somewhat lower (3.6–4.1 mm) as measured by the automated analyzer. As expected, the average thickness was lower for SL18-20 than for SL22-24, although the differences were rather small, and in most cases, statistically insignificant.

The distributions for chip length, thickness, and width with SL18-20 and SL22-24 settings are shown in Fig. 2. The mode values for length, thickness, and width for SL22-24 chips were always larger than those for SL18-20 chips. Differences in drum velocity did not significantly affect the average chip length (Fig. 2 and Table II); however, it did affect chip size distribution in the various fractions (Table II). For the SL22-24 setting and 30 m/s, the average fraction of total accept chips reached almost 90% (before screening). This observation demonstrated that short accept chips can be produced in very high yields using the new chipper technology. The SL18-20 setting and 30 m/s were used as the reference settings for statistical analyses. Chips produced using the SL22-24 setting had



2. Analysis of size distribution using the ScanChip analyzer. The figure shows fractions of wood chips as a function of (a) length, (b) thickness, and (c) width. Settings and indicators for SL22-24 are 30 m/s, solid line and plus signs (+), and 34 m/s, dashed/dotted line and cross signs (×). Settings and indicators for SL18-20: 24 m/s, dashed/double-dotted line and diamonds (♦); 27 m/s, dashed line and triangles (▲); 30 m/s, dashed line and circles (●); and 34 m/s, dotted line and squares (■).

significantly larger proportions of large accept chips, smaller proportions of small accept chips, and larger proportions of total accept chips than the control setting (Table II). Furthermore, the averages for the fractions of pin chips and fines were significantly smaller for the SL22-24 setting at 30–34 m/s than for the SL18-20 setting at 30 m/s (Table II).

The combined fractions of pin chips and fines with the automated analyzer were 4.9% for the SL22-24 setting at 30–34 m/s and 10.6%–10.8% for the SL18-24 setting at 30– 34 m/s. SCAN 40:01 afforded similar results for the combined fractions of pin chips and fines (3.2%–4.2% for the SL22-24 setting at 30–34 m/s and 7.1%–8.5% for the SL18-24 setting at 30–34 m/s). Although a significant increase of pin chips and fines was observed when the settings were decreased from SL22-24 to SS18-20, the combined fractions of pin chips and fines for the drum chipper operating at 30–34 m/s were always lower or within the acceptable range of 8%–11% [11]. The average fractions of oversized chips were always ≤0.43% and there were no statistically significant differences for the various operating conditions versus the reference (Table II). For the drum velocity range of 30–34 m/s, the values of the overthick chips were always lower for the SL22-24 setting than for the SL18-20 setting, but the differences were not always statistically significant (Table II).

At the lowest drum velocity (24 m/s), the combined fractions of pin chips and fines were 15.8% as measured by the

Parameter/ Fraction	Def.[3]	SL18-20 [1,2]				SL22-24 [1,2]	
		24 m/s	27 m/s	30 m/s	34 m/s	30 m/s	34 m/s
Manual SCAN Standard Test Method Results							
Thickness[4], mm	–	3.9±0.0*	4.8±0.3	**4.6±0.5**	4.8±0.4	4.9± 0.1	5.2± 0.2*
Oversized, %	>Ø45	0.13±0.19	0.58±0.52	**0.12±0.29**	0.12±0.21	0.20 ± 0.29	0.43 ± 0.40
Overthick, %	>//8	5.7±1.4	10.4±2.8	**10.8±4.7**	8.1±0.8	6.4 ±0.5	6.7 ± 1.8*
Large accepts, %	>Ø13	52.1±4.9***	67.0±4.2	**64.9±1.5**	65.3±4.8	75.8± 1.8***	77.8 ± 1.1***
Small accepts, %	>Ø7	23.7±3.2**	15.4±3.2	**15.5±3.3**	19.4±2.3	13.4 ± 0.5	11.8 ± 1.3**
Pin chips, %	>Ø3	15.7±3.1***	5.7±2.2	**6.6±1.4**	6.2±2.0	3.4 ± 1.0 ***	2.7 ± 0.4***
Fines, %	<Ø3	2.7±0.2	0.9±0.4**	**1.9±0.7**	0.9±0.6*	0.76 ± 0.41**	0.53± 0.15***
Total accepts[5], %	–	75.8±1.7*	82.4±1.8	**80.2±2.9**	84.7±2.6 *	89.2 ± 2.0***	89.7±1.7***
Automated Chip Analyzer Results							
Length[6], mm	–	17.5±0.5	17.6±0.4	**17.5±0.3**	16.7±0.3	21.2± 0.6***	21.1± 0.2***
Thickness[6], mm	–	3.7±0.2	3.8±0.0***	**3.6±0.0**	3.7±0.1	4.1± 0.2**	4.0± 0.0***
Width[6], mm	–	19.3±0.1*	21.7±1.4	**21.0±0.7**	20.6±1.0	22.3±1.1	21.8± 1.0
Oversized, %	>Ø45	0.05±0.07	0.40±0.10	**0.22 ±0.30**	0.24±0.07	0.09 ± 0.10	0.16 ± 0.11
Overthick, %	>//8	9.1±3.2	8.9±2.2	**7.5±0.8**	6.0±0.3	5.2 ±1.3	4.8±0.5**
Large accepts, %	>Ø13	47.9±0.3**	59.4±5.1	**56.6±2.5**	54.2±6.0	72.5± 4.8**	72.0±3.1**
Small accepts, %	>Ø7	27.1±0.8	22.6±4.6	**24.8±1.0**	29.0±3.1	17.3 ± 4.6**	18.1±2.6**
Pin chips, %	>Ø3	14.2±2.2	7.9±2.7	**9.1±1.9**	9.7±2.7	4.3 ± 1.7*	4.4±1.7**
Fines, %	<Ø3	1.61±0.56	0.88±0.53	**1.75±0.84**	0.89±0.42	0.58 ± 0.44	0.50±0.19*
Total accepts[5], %	–	75.0±0.5**	81.9±1.7	**81.4±1.5**	83.1±2.9	89.8 ± 2.1**	90.1±0.5***

[1] Average values for size fraction distribution calculated using SCAN-CM 40:01 or automated chip analyzer.
[2] Significant differences (t-test) compared to wood chips from SL18-20 setting and velocity 30 m/s (in bold font) are indicated: ***$p \leq 0.01$; ** $0.01 < p \leq 0.05$; and * $0.05 < p \leq 0.1$.
[3] Definitions: Ø = screen hole diameter in mm; //= screen slot distance in mm or measurements and calculations using the automated chip analyzer.
[4] Average values for thickness distribution calculated using SCAN-CM 47:92.
[5] Sum of large and small accept chips.
[6] Average values for length, thickness, and width calculated using automated chip analyzer.

II. Data for wood chips produced using the SL18-20 and SL22-24 settings.

automated analysis and 18.4% as measured by SCAN 40:01. When the drum velocity was increased to 27 m/s, the fractions of total accepts and combined fractions of pin chips and fines were comparable to the reference. The SL18-20 setting at 34 m/s resulted in higher fractions of total accepts than the SL18-20 setting at 30 m/s by both chip characterization methods (Table II). Thus, lowering the drum velocity did not improve the yield of accept chips for the SL18-20 settings. These results indicated that as long as a normal or relatively high drum velocity (27–34 m/s) was maintained, the combined fraction of pin chips and fines (6.6%–10.8%) could be kept within or below the 8%–11% interval [11] for the SL18-20 setting.

The values obtained for a drum velocity of 30 m/s and an ε'' of 0° were compared for all three chip settings. By SCAN 40:01, the combined fractions of pin chips and fines were 3.3% for SL24-26 (24 mm), 4.2% for SL22-24 (22 mm), and 8.5% for SL18-20 (17 mm). By SCAN 40:01, the fractions of total accept chips were 85.1% for SL24-26, 89.2% for SL22-24, and 80.2% for SL18-20. These observations with the SL22-24 setting are favorable when compared with the SL24-26 setting; however, there was a tendency for a lower fraction of total accepts and a higher fraction of pin chips and fines when using the SL18-20 setting even though the latter fraction value was still within the industrial acceptable range of 8%–11% [11]. Although a certain fraction of small material is acceptable, previous studies of cooking liquor impregnation indicated the importance of minimizing formation of such material. This fraction is difficult to pulp because the acidic pulping liquor does not penetrate compressed particles very well [6].

CONCLUSIONS

The results of this study show that it is feasible to use a new industrial drum chipper to produce wood chips with very low average length without producing excessive amounts of pin chips and fines. This technology can produce short wood chips for acid sulfite pulping, as well as other acidic pulping processes, where liquor impregnation occurs mainly in the fiber direction and where the use of shorter wood chips would be advantageous. Investigations in this area have the potential to reduce raw wood demand, increase pulping efficiency through improved cooking liquor impregnation, and reduce operating costs. Further studies are needed to evaluate production of short wood chips with the drum technology with regard to liquor impregnation rate, ease of pulping, pulp yield, and energy requirements. In addition, further studies should examine this wood chipping technology with regards to log quality, tree species, log moisture content, and thawed vs. frozen wood. **TJ**

ACKNOWLEDGEMENTS

The authors are grateful to Sten Häggström at Multi Channel Sweden AB and Torbjörn Sjölund at MoRe Research AB (Örnsköldsvik, Sweden) for their help with the pilot drum chipper and analysis equipment and to Metsä Board Husum for providing access to their PulpEye ScanChip analyzer. This research was supported by the Kempe Foundations, the Swedish Energy Agency (P40512-1), the Umeå University Industrial Doctoral School, Bio4Energy, and RISE Processum AB.

LITERATURE CITED

1. Rydholm, S.A., *Pulping Processes*, Robert E. Krieger Publishing, Malabar, FL,1965, pp. 263–274, 294.
2. Hartler, N. and Stade, Y., *Sven. Papperstidn.* 80(14): 447(1977).
3. Smith, B.R., Rice, R.W., and Ince, P.J., “Pulp capacity in the United States, 2000,” *Gen. Tech. Rep. FPL–GTR–139*, U.S. Department of Agriculture, Forest Products Laboratory, Madison, WI, USA, 2003. https://doi.org/10.2737/FPL-GTR-139.
4. Sixta, H., Iakovlev, M., Testova, L., et al., *Cellulose* 20(4): 1547(2013). https://doi.org/10.1007/s10570-013-9943-1.
5. Rødsrud, G., Lersch, M., and Sjöde, A., *Biomass Bioenergy* 46(Nov.): 46(2012). https://doi.org/10.1016/j.biombioe.2012.03.028.
6. Howard, E.J., *Pulp Pap. Mag. Can.* 52(7): 91(1951).
7. Wirspa, V.J. and Libby, C.E., *Tappi* 33(5): 225 (1950).
8. Samuelson, O. and Wennerblom, A., *Sven. Papperstidn.* 56(19): 745(1953). https://doi.org/10.1016/S0031-8914(53)80083-2.
9. Dorland, R.M., Leask, R.A., and McKinney, J.W., *Pulp Pap. Mag. Can.* 58(6): 135(1957).
10. Aurell, R., Stockman, L., and Teder, A., *Sven. Papperstidn.* 61(21): 937(1958).
11. Hartler, N., *TAPPI J.* 79(2): 259(1996). https://doi.org/10.1016/S0379-6779(96)80202-5.
12. Abdallah, R., Auchet, S., and Méausoone, P.J., *Biomass Bioenergy* 35(2): 843(2011). https://doi.org/10.1016/j.biombioe.2010.11.009.
13. Gard Timmerfors, J., Sjölund, T., and Jönsson, L.J., *Holzforschung*. [Online ahead of print April 8, 2019.] In press. https://doi.org/10.1515/hf-2018-0279.
14. Hartler, N., *Sven. Papperstidn.* 65(9): 351(1962).
15. Twaddle, A., *TAPPI J.* 80(6): 123(1997).
16. Hellström, L., Gradin, P., Engstrand, P., et al., *Holzforschung* 65(6): 805(2011). https://doi.org/10.1515/HF.2011.087.
17. Edberg, U., Engström, L., and Hartler, N., *Sven. Papperstidn.* 76(14): 529(1973).

ABOUT THIS PAPER

Cite this article as:
Gard Timmerfors, J., and Jönsson, L.J., *TAPPI J.* 18(10): 585(2019). https://doi.org/10.32964/TJ18.10.585

DOI: https://doi.org/10.32964/TJ18.10.585

ISSN: 0734-1415

Publisher: TAPPI Press

About this journal

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We chose this topic to research because we think that improved wood chipping technology has great potential to promote more resource efficient forest industrial processes. This study was focused on pilot-scale chipping for acidic processes, whereas previous work was focused on demonstration-scale chipping for kraft processes.

Installation of the pilot wood chipper was a challenge but was made possible through support from the Kempe Foundations and the Swedish Energy Agency. Through this study, we learned that R&D on wood chipping, an area that has not received a lot of attention during the past few decades, has great future potential. It was interesting to find that high drum velocity and changes in cutting angle did not have any major impact on formation of pin chips and fines.

A benefit is that pulp mills can achieve higher pulp yields from a given amount of feedstock and shorten the residence time. Further studies are needed to evaluate energy consumption at different drum velocities and to evaluate the impact of the quality of the wood logs.

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