CHANGES IN FUEL QUALITY OF LOGGING RESIDUES DURING FIELD STORAGE IN NORTHWESTERN ONTARIO

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ABSTRACT

Logging residues are recognized as a low hanging fruit in regard to biomass for energy production. However, the feasibility of procurement is sensitive to moisture content, thermal value and ash content of the feedstock. Studies in Europe have demonstrated that biomass can be stored in the field to improve fuel quality.

This study was performed to investigate the effect of storage method and duration on fuel quality of logging residues. The fuel qualities assessed were moisture content (MC), thermal value and ash content. The MC was reduced from a green state to 27% after 1 year of storage and to 21.9% (dry weight basis) after 2 and 3 years of storage in roadside slash piles. In cut-to-length blocks, the MC was reduced from a green state to 30.1% after 1 year of storage and to 24.8% after 2 and 3 years of storage. Windrows displayed lower MC values than beehives and softwoods generally displayed lower MC values than hardwoods with few exceptions. The thermal values ranged from 19.5 to 23.1 $MJ \cdot kg^{-1}$; the number of storage years had no significant effect on the thermal value, but diameter and species did. Generally, smaller diameter stems displayed higher thermal value than larger diameter stems and softwoods contained higher values than hardwoods. The ash content ranged from 0.4% to 8.4%; diameter produced significantly different ash contents in logging residues of both cut-to-length blocks and roadside slash piles, with smaller stems having significantly higher ash conent. In cut-to-length blocks, the ash content was reduced significantly with an increase in the number of storage years.

In northwestern Ontario, the storage of logging residue in the field for as short as one summer period can lead to a significant reduction in moisture content and thus improvement in the fuel quality, consequently leading to an overall cost reduction of the biomass feedstock.

Keywords: Biomass; bionenergy; cut-to-length; moisture content; thermal value; ash content

INTRODUCTION

Logging residue is produced year-round, however its immediate transport is costly due to high moisture content at green state and high bulk (Gigler *et al.* 2000; Pettersson and Nordfjell 2007).

Studies in Europe have shown that logging residue can be stored in the field to improve the fuel quality (Jirjis 2005). The form, duration of storage and the weather conditions affect fuel quality (Pettersson and Nordfjell 2007). There has been no such research done on fuel quality of logging residues in northwestern Ontario. Knowledge gained in Europe is transferable to northerwestern Ontario to a certain extent, but due to the differences in stored material and weather conditions it is not completely valid.

The objective of the study is to determine how storage pile form, time, species and logging residue diameter affect fuel quality (moisture content (MC), thermal value and ash content). It was investigated whether there are statistical differences in the MC, thermal value and ash content of logging residue stored in various pile configurations for a range of durations.

METHODOLOGY

The study materials were located in harvest blocks to the west of Atikokan, Ontario, Canada. The mean annual temperature and precipitation accumulation recorded by the Atikokan weather station (AUT) (Lat. 48^0 45.667' N, Long. 91^0 37.683'W) was 2.7^{o}C and 645 mm, respectively.

Analysis of variance (ANOVA) test was carried out using the General Linear Method in SPSS to test the null hypothesis: harvest year, species, pile shape and pile height have no effect on the mean moisture content , thermal value and ash content of full tree (FT) roadside logging residue. Storage years included materials stored for 1, 2 and 3 drying seasons. The shape of the slash piles selected in the study fall either under the general category "half-section of sphere" or "half-ellipsoid" referred to as beehive and windrow, respectively (Hardy 1996). Species were divided into the general categories of softwoods and hardwoods. The heights of the piles were recorded as being either greater or less than 2 m; the width ranged from 8 m to 16 m. The experimental design of the model is a full factorial design. ANOVA was also carried to determine if storage years, species and logging residue diameter led to a significant difference in the moisture content, thermal value and ash content of logging residue in cut-to-length (CTL) blocks.

A list of blocks containing slash piles was obtained from the AbitibiBowater Inc. office in Fort Frances. This list included harvest blocks from three different Annual Work Schedules (AWS): 2006/2007, 2007/2008 and 2008/2009. Harvest blocks and piles were randomly selected from the list. Slash piles were measured for MC at various depths and in CTL blocks, a line intersect method was used to collect moisture content information using Protimeter Surveymaster Moisture Meter. Samples were brought back to the lab to determine thermal value and percentage ash content. Data was collected during June and July, 2008 and 2009. In the laboratory, a Parr 6200 Bomb Calorimeter was used to determine the thermal values of the samples collected in the field. Ash content was determined using the methodology outlined in Sluiter *et al*. (2008).

RESULTS & DISCUSSION

Moisture Content

A summary of moisture content observed in FT roadside slash piles is presented in Table 1 along with corresponding standard deviations. The average moisture content on a oven dry basis (OD) basis ranged from 14.1% to 35%. The average moisture content observed in this study is lower than values observed in the Scandinavian countries (Nurmi 1999; Lehtikangas 2001; Jirjis 2005; Petterson and Nordfjell 2007). The lower moisture content achieved in this study can be attributed to the continental climate in northwestern Ontario (Gamble 1997). Hot summers in our study area lead to feedstock drier than those presented in studies above. Comparatively, in the Nordic countries the climate is moderated due to maritime influences and thus do not reach similar extremes.

Table 1: Summary of average moisture content (OD basis) values from top 1.5 m of FT roadside slash piles.

Drying Seasons	Shape	Species	Pile Height			
			< 2 m	Standard Deviation	> 2 m	Standard Deviation
1	Windrow	Softwood	20.9	2.56	20.3	3.42
		Hardwood	26.8	3.78	29.7	7.81
	Beehive	Softwood	27.8	4.27	22.9	1.56
		Hardwood	35.0	7.77	32.4	2.00
2	Windrow	Softwood	23.6	2.28	21.5	2.72
		Hardwood	16.5	2.74	22.1	4.25
	Beehive	Softwood	14.1	1.25	16.9	4.01
		Hardwood	26.9	3.37	30.9	3.87
3	Windrow	Softwood	18.2	0.78	18.7	6.76
		Hardwood	21.8	2.90	22.6	5.19
	Beehive	Softwood	16.6	2.01	18.9	4.16
		Hardwood	29.4	14.34	31.6	5.12

A summary of moisture content observed in the cut-to-length blocks is presented in Table 2 along with the standard deviation values. Logging residue in cut-to-length blocks show a higher variation in moisture content than logging residue in FT roadside slash piles, the average moisture content ranged from 11.9% to 40.7% OD basis.

Analysis of variance indicates that storage period has a significant effect on the mean MC of FT roadside slash piles and also of logging residue spread in the cutover. Post hoc analysis of slash pile MC using Duncan test showed that, year 1 piles displayed significantly higher (p<0.001) MC of 27% (OD) compared to year 2 and 3 piles which displayed an average MC of 21.9% (OD). CTL blocks showed a comparable trend; logging residue from year 1 showed significantly higher (p<0.05) MC with MC value of 30.1 % (OD). Year 2 and year 3 had an average MC of 24.7% (OD).

Table 2: Summary of average moisture content (OD basis) values of logging residue from cut-to-length blocks.

Storage Years	Species	Diameter*			
		Large	Standard Deviation	Small	Standard Deviation
1	Softwood	26.5	13.9	18.0	4.8
	Hardwood	40.7	17.8	35.1	22.2
2	Softwood	20.3	8.8	11.9	1.4
	Hardwood	35.1	19.8	28.6	17.8
3	Softwood	27.9	15.4	16.2	5.6
	Hardwood	38.0	15.2	19.8	10.2

*Large = > 4 cm in diameter
Small = ≤ 4 cm in diameter

Once cut, green wood gradually approaches an equilibrium state that fluctuates with temperature and relative humidity (Siau 1995). It is the hygroscopic nature of cell walls that allows the equilibrium moisture content to fluctuate in this manner. Our results suggests that the average MC of logging residue drops further in the second drying season, indicating that equilibrium moisture content itself decreases further. Our results are similar to the trends found by Millet (1953), Hall and Rudolph (1957) and Truman (1959) on pulpwood drying rates.

Analysis of variance reveals that species had a significant effect ($p<0.001$) on the mean MC value of logging residue in both FT roadside slash piles and cut-to-length blocks. In both FT roadside slash piles and CTL blocks, softwoods produced lower moisture content than hardwoods. The lower MC values displayed by softwood species is best explained by the differences in the chemical composition and anatomical construction between hardwood and softwood species. In hardwoods, hemicelluloses constitute approximately 25-40% as opposed to 20-30% in softwoods (Siau 1995). Hemicellulose is the most hygroscopic component of cell wall followed by cellulose and lignin (Christensen and Kelsey 1959). Consequently, the cell walls of hardwoods will have more potential bonding sites available for water.

An added factor that may have contributed to the lower MC values in softwoods is transpiration drying (Angus-Hankin *et al.* 1995). The stomata of the leaves and needles are the main pathways for evaporation of moisture from a living tree (Raven *et al.* 1999). It was observed that needles were intact in softwoods for longer durations than leaves on hardwoods. A similar observation was made by Simola and Makela (1976), and Rogers (1981).

FT roadside slash pile height showed no significant effect on the MC. However, since the measurement was only performed to a depth of 1.5 m, no conclusions on the material below this depth can be made. In the literature on pile heights, Jirjis (1995) and Pettersson and Nordfjell (2007) report that smaller piles lose moisture rapidly when the vapour pressure deficit of the ambient air is high in the summer. However, the reports also state that when the temperature and RH drop, smaller piles regain moisture more rapidly.

There was a significant effect (p<0.001) of pile shape on the MC of logging residue in FT roadside slash piles. In addition, the interaction between storage year, shape and species is significant (p<0.01. With regard to hardwoods, beehives display higher MC values than windrows in all storage years. Similar trends are not prevalent in FT roadside slash piles of softwoods; in storage year 1, windrow piles show lower moisture content than beehive, in year 2 beehive piles show the lower moisture content and in year 3 the values are equivalent.

The lower moisture values displayed by windrows can be attributed to the greater surface area to volume ratio compared to beehive piles. In a study conducted by Hall and Rudolph (1957) on jack pine pulpwood piles, the moisture content fluctuation was much higher in the exposed wood than the inside wood. Also, the widths of windrow piles are much smaller compared to beehive piles; smaller width translates to less resistant to airflow, leading to faster drying of the piles.

The significant interaction is most likely due to the level of compaction in the piles. Hardwood piles had a greater amount of void space compared to softwood piles. The more pronounced branching of hardwoods allows less compaction hence there is a higher percentage of void space in hardwood piles which translates to a lower airflow resistance by hardwood piles. Therefore in hardwood piles, beehives show a higher MC than windrows. However, in softwood piles, the reduced void space leads to higher airflow resistance especially in the beehive piles. Consequently, the majority of logging residue in softwood beehive piles is protected from interface with the ambient air; it takes longer period for logging residue in these piles to reach EMC but once it is achieved, the fluctuations occur at much slower rate compared to windrow piles.

Thermal Value

A summary of thermal values and the corresponding standard deviation of samples from FT roadside slash piles of both types, windrows and beehives, are presented in Table 3. The values ranged from 19.9 to 23.1 $MJ \cdot kg^{-1}$. A summary of thermal values and the corresponding standard deviation values of logging residue from cut-to-length blocks is presented in Table 4. The values ranged from 19.5 to 22.8 $MJ \cdot kg^{-1}$.

In FT roadside slash piles there was a significant difference in thermal value between species, but not in the CTL blocks. Additionally, species had an interaction effect with storage years and location in pile. Softwood constantly showed slightly higher thermal value than hardwoods with one exception; year 3 hardwoods at the surface of the piles showed higher average thermal value than softwoods but the difference was not significantly different. The highest average thermal value was displayed by softwoods from inside of the pile and the lowest value was displayed by year 2 hardwoods at the surface of the piles. The higher thermal value per kg displayed by softwoods can be attributed to the higher percentage of lignin and resin present in softwoods compared to hardwoods (Hakkila 1989; Plomion *et al.* 2001). Lignin and resins have considerably higher thermal values than cellulose and hemicellulose (GCEP 2005). However, also need to take into consideration that most hardwoods have a higher specific gravity than softwoods, and thus significantly impacts thermal value per m^3.

Table 3: Summary of average thermal values in MJ·kg^{-1} of logging residue from FT roadside slash piles.

Drying Seasons	Location*	Species	Diameter**			
			Small	Standard Deviation	Large	Standard Deviation
2	Inside Pile	Softwood	21.2	0.4	22.4	0.5
		Hardwood	20.3	0.6	21.7	0.8
	Surface	Softwood	21.2	1.0	22.3	0.5
		Hardwood	20.4	0.5	20.9	0.9
3	Inside Pile	Softwood	20.8	1.0	23.1	0.2
		Hardwood	20.0	0.0	21.4	0.4
	Surface	Softwood	19.9	0.2	21.7	1.2
		Hardwood	20.7	1.0	22.5	1.1

* Inside pile is logging residue samples from depth of 1.5 m

**Small = ≤ 4 cm diameter, Large = > 4 cm diameter

Table 4: Summary of average thermal values in MJ·kg^{-1} of logging residue from cut-to-length blocks.

Storage Years	Species	Diameter*			
		Large	Standard Deviation	Small	Standard Deviation
1	Softwood	20.1	0.12	21.3	0.06
	Hardwood	20.4	0.22	21.4	0.57
2	Softwood	21.6	1.86	22.0	2.10
	Hardwood	20.2	0.83	20.8	0.45
3	Softwood	19.5	0.50	22.8	1.76
	Hardwood	20.7	0.89	22.1	0.37

*Large = > 4 cm in diameter

Small = ≤ 4 cm in diameter

Diameter led to significant difference (p<0.001) in the mean thermal value in both FT roadside slash piles and logging residue within cut-to-length blocks. Smaller diameter branches display higher thermal values than larger diameter branches in both cases. Similar results were observed by Singh and Kostecky (1986) in samples collected in Manitoba. In softwoods, the higher thermal values in smaller samples can once again be attributed to the presence of compression wood and also a higher percentage of bark. The percentage of bark increases sharply as the branch diameter decreases (Wellwood 1979; Hakkila 1989). Bark generally has a higher heat value than stem wood because it is richer in lignin, resin, terpenes and other combustable elements (Hakkila 1989). In hardwoods, although smaller branches contain lower amount of lignin due to the presence of tension wood, lignin content in hardwood bark is three to four fold compared to softwood bark (Nurmi 1993). The higher percent of lignin in bark coupled with the fact that there is a greater percentage of bark gives smaller branches the higher thermal value.

There is no significant difference in the mean thermal values of logging residue due to storage durations 1 to 3 years in FT roadside slash piles or cut-to-length logging residue. Hakkila (1989) mentions that although the heat value of logging residue changes during storage, the change is insignificant. This can be accredited to low MC which limits microbial activities thus decay of wood. Decay in wood can be initiated only at MC of over 26-32% (OD basis) (Hudson 1992).

Ash Content

A summary of ash content and the corresponding standard deviation values of logging residue from FT roadside slash piles are presented in Table 5. The values range from 2.7% to 8.4%. There was a noticeable difference in the ash content between large diameter samples and small diameter samples. A summary of ash content and the corresponding standard deviation values of logging residue from cut-to-length blocks are presented in Table 6; the values ranges from 0.4% to 4.2%.

Table 5: Summary of average ash content values of logging residue samples from FT roadside slash piles.

Storage Years	Species	Diameter*			
		Large	Standard Deviation	Small	Standard Deviation
1	Softwood	3.5	0.29	3.8	0.20
	Hardwood	2.7	0.88	8.4	0.22
2	Softwood	4.9	0.63	6.1	0.59
	Hardwood	4.6	0.96	7.6	0.16

*Large = > 4 cm in diameter
Small = ≤ 4 cm in diameter

Table 6: Summary of average ash content values of logging residue samples from cut-to-length blocks.

Storage Years	Species	Diameter*			
		Large	Standard Deviation	Small	Standard Deviation
1	Softwood	2.6	1.9	3.5	0.5
	Hardwood	1.7	0.2	4.2	0.0
2	Softwood	0.7	0.6	2.1	1.2
	Hardwood	1.9	0.0	4.2	0.2
3	Softwood	0.4	0.1	1.7	1.0
	Hardwood	1.5	1.8	1.8	0.2

*Large = > 4 cm in diameter
Small = ≤ 4 cm in diameter

Once again the difference in the ash content between large diameter samples and small diameter samples is noticeable. Storage years showed no significant difference in the ash content of FT roadside slash piles, however, in CTL blocks, storage years did show a significant difference

($p<0.01$) in the ash content values. The percentage ash content has a decreasing tendency with the number of storage years. Storage years 1 and 3 have values significantly different ($p<0.05$) from each other but neither of the year show a significant difference from year 2. Similar significance due to storage duration was not observed in FT roadside slash piles because the majority of logging residue is protected from weather factors. In CTL blocks, the majority of logging residue is exposed to environmental factors resulting in leaching of elements by rainfall (Jenkins *et al.* 1998; Vamvuka *et al.* 2008).

Diameter had a significant effect ($p<0.05$) on the mean ash content of logging residue from both FT roadside slash piles and CTL blocks. There was also an interaction effect between diameter and species in logging residue from FT roadside slash pile. Large diameter branches show lower ash content than small diameter branches. In large branches, softwoods show higher ash content but in small branches hardwoods show higher ash content than softwoods. In the cut-to-length blocks softwood shows lower ash content than hardwood and smaller diameter branches show significantly higher ash content ($p<0.05$) than larger diameter branches. Ash content is inversely proportional to the stem diameter. Majority of ash in a tree is concentrated in the bark tissues because of its importance to physiological functions (Bowyer *et al.* 2002). As discussed earlier, smaller diameter branches have much higher proportion of bark compared to larger branches and stems (Hakkila 1989). The ash content in barks of softwoods is reported to be approximately 2% whereas in hardwoods it averages 5%. Therefore the proportion of bark in LR is closely related to the ash content. This also explains the large difference in the ash content between softwood and hardwood in small branches compared to larger stems. In fact, our result suggests that in larger stems, softwood ash content may exceed that of hardwood.

SUMMARY

This study demonstrated that quality of logging residue changes during storage and consequently the net energy yield. The moisture contents (OD basis) ranged from 14.1-35% in FT roadside slash piles and 13.9-40.7% in CTL blocks. There was a significant drop in moisture content after 1 year of storage. Hardwood windrow piles showed lower moisture content than hardwood beehive piles but such generalization could not be made in softwood piles. Smaller diameter logging residue displayed lower moisture content and higher thermal value but higher ash content as well. Softwood species demonstrated higher thermal value, lower moisture content and lower ash content. The thermal values ranged from 19.5 to 23.1 $MJ \cdot kg^{-1}$ and ash content ranged from 0.4% to 8.4% for all species, components and number of storage years. However, density of the material has to taken in to account prior to determining the superior feedstock. Furthermore the handling practices can also influence the quality of biomass. It was observed in the field that there were soil contaminants in logging residues that can add to the ash content. Therefore, it is important that slash be handled with the proper equipment. Handling logging residues with blades of skidders should be avoided as it may mix in contaminants from the forest floor. Driving skidders or other equipments over logging residues can result in mud from tires on logging residue.

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