

Effects of Storage on Fuel Parameters of Piled and Comminuted Logging Residues

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Figure 1 - Tubgrinder converting green logging residue into hog fuel.

Abstract

In order to describe changes in fuel quality parameters over time, in raw and comminuted logging residues, piles of both types of residue from a radiata pine clearfell were created. They were regularly sampled and analysed to collect data on moisture content, inorganic content, heat value, fuel characteristics.

The most significant results were seen in moisture content. The raw residues dried substantially during the six months of the trial, from around 60% wet basis down to 32% to 33% wet basis. However, the comminuted residues which started at a similar moisture content (60% to 62%) increased in moisture content, rising to a peak of over 70% wet basis before falling to around 68%.

These results indicate that there may be a benefit in storing residues in an uncomminuted form to gain increased fuel value from air-drying.

Other changes which occurred in the residues were in the inorganic content and fuel characteristics. The most notable change in inorganics was the substantial drops in the levels of K in both raw and comminuted residues and P in the raw residues.

The fuel analysis of the two types of residue showed that there were few changes over time but that the two fuels were different, with the comminuted residues having higher ash content. This was ascribed to differences in handling during fuel processing.

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Introduction

When planning the use of logging residues as bio-energy fuels there is a decision to be made about where and when to convert the residue from its raw form to fuel (comminution) (Figure 1). Comminuted residues are easier to handle and transport as they will flow and can be tip unloaded. They also have moderate bulk density (30% to 33%). The bulk density of the material affects the tonnes per unit volume in transport and storage. However, once the residues are comminuted they need to be used quickly as dry matter losses, mould and fungi growth and pile heating can occur in just a few weeks (Kofman 1988, Nurmi and Jirjis, 1999). Piles of comminuted residues have little capacity to dry without forced ventilation (Nellist, 1997) and may absorb more moisture (Nurmi, 1999, White et. al., 1983).

If the residues are left uncomminuted they are bulky to store and transport (Anderson 1995, Norden 1995). They are also difficult to handle during loading and unloading (Bjorheden, 1999). However, uncomminuted residues also tend to dry out over storage and handling time (Nurmi and Jirjis, 1999). Uncomminuted residues have been shown to dry under a variety of conditions, piled, covered and baled (Hudson and Hudson, 1999). The drying of the residues raises the net calorific value of the fuel (Baines, 1993). There are less dry matter losses and fewer pile heating problems and mould and fungi growth is minimal (Nurmi and Jirjis, 1999) in piles of uncomminuted residues.

The decision about when and where to comminute the residue is further complicated by transport and comminution costs which vary by comminution location and by the need to integrate with other forest activities (Bjorheden, 1999).

In order to make good decisions about where and when to comminute, it is necessary to have good information about the effects of storage on comminuted and uncomminuted residues under New Zealand conditions.

This trial was designed to provide data on changes in fuel quality parameters over time in radiata pine residues in raw and comminuted forms.

Methods

In August 1999 (late winter) a site with fresh logging residue at a landing was chosen. The residue had been produced by a mechanised log processor working at a landing in conjunction with ground-based stem extraction. The residues were two to three days old when the trial was installed.

The residues were treated in two ways:

- some was piled on the landing edge in the raw form (Figure 2). The piles were quite loose and had plenty of air space; such piles typically are estimated to be from 25% to 30% solid wood and the rest air ("raw residue").
- some was loaded into trucks (Figure 3), transported to a central landing, processed by a tub-grinder into boiler fuel (Figure 1, "Comminuted residue"). It was then trucked back and piled on the landing (Figures 4 and 5) adjacent to the raw residue.

Initial samples were collected from the two different piles:

- raw residues, by cutting in towards the middle of the pile with a chainsaw and cutting sections from material with a range of diameters. Needles and bark were also gathered. This material was then put through a small electric hogger to reduce the pieces to an analysable size.
- comminuted residues, by taking ten randomly located samples by scraping the exposed top layer off then taking handfuls of hogged material from the interior of the heap.

These samples were analysed using standard laboratory methods to determine:

- composition
- moisture content (wet basis)
- inorganic content (Fe, Ca, K, P, Si, Al, Mg, Na)
- fuel analysis including fixed carbon, ash content, volatiles content (proximate analysis)
- carbon, oxygen, nitrogen, hydrogen, and sulphur (ultimate analysis)
- ash fusion temperature and gross calorific value (Gross CV)

The inorganic, ultimate and proximate analyses were done at initial setup and then monthly for six months.

In addition two sets of stem and branch sticks, with a range of diameters, were set up under exposed conditions (Figure 6). Moisture content of the piles and the sticks were sampled fortnightly for six months.

Meteorological data from four weather stations in the region around the storage site were collated and summarised.



Figure 2 – Pile of log processing waste at landing



Figure 3 – Loading log processing waste into truck



Figure 4 – Pile of comminuted logging residues



Figure 5 – Comminuted logging residue



Figure 6 – Stem wood and branches under exposed drying conditions

Results

Residue composition

The two forms of residue were sampled and separated into the different components (wood, bark, needles and soil) to determine the physical composition of the residues (Table 1). The high percentage of bark (compared to a tree typically 8% to 10%) was due to the mechanised processor used in this operation. When it delimbed the stems a substantial amount of bark was removed at the same time. The residue piles at the landings therefore contained not only the bark attached to the stem residue and branches but also the bark removed from the merchantable material during stem to log processing. The low percentage of needles (on a stand basis 1% to 2%) was due to breakage of the upper stem during felling, which results in much of the branches and needle matter being broken off from the extracted stem prior to extraction and left on the cutover. The comminuted residues pile had double the amount of soil of the raw residue, although the proportion was still less than 1%.

Table 1 – Percentage composition of residues

	Wood	Bark	Needles	Soil
Comminuted	80.7	18.4	0.3	0.6
Raw Residue	81.7	17.6	0.4	0.3

Meteorological Data

Mean Annual Climate Conditions (4 weather stations in region surrounding trial site)

Elevation	375 m	Rainfall	1300 mm
Mean wind speed	13 m/sec	Rain days	127 per annum
Sunshine hours	1943 per annum		
Summer temperature	Min 12° C Max 24° C	Winter temperature	Min 3° C Max 12° C

The trial began in mid-August and ran until mid-February. The weather was fairly typical for spring/summer, with the exception of November, which had abnormally high rainfall (Table 2).

Table 2 – Meteorological data: August 1999 to February 2000 (mean of 4 stations)

	August	September	October	November	December	January	February
Max temp, °C	13.1	15.9	18.0	19.2	20.6	22.4	23.0
Min temp, °C	2.3	4.4	7.6	10.2	10.2	12.3	12.7
Mean temp, °C	7.8	10.2	12.8	14.7	15.5	17.3	17.8
Rain, mm	119	110	37	202	70	116	15
Rain Days	17	13	11	15	10	11	5
Sunshine hours	156.5	178	176.5	142	202.5	178	205

Moisture Content

The moisture content, wet basis (MCW) of the residues was assessed at the beginning of the trial, approximately three days after harvesting had been completed (Table 3). Moisture contents were typical of those for freshly harvested radiata pine.

Table 3 - Initial Moisture content (wet basis)

	Raw Residue	Comminuted Residue
Stem	58%	-
Large Branch (50mm+)	59%	-
Medium Branch (20-50 mm)	61%	-
Small branch (<20mm)	60%	-
Needles	51%	-
Bark	59%	-
Weighted average	58.5%	62%

Two sets of stem wood and branch material were set out under exposed drying conditions (Figure 6), raised above ground and uncovered. The initial moisture content of these was determined and the samples were then weighed fortnightly to determine weight loss due to drying (Table 4). The exposed stem and branch residues dried substantially over the six months, from 58% moisture content (wet basis) to 29% (Figure 7).

Table 4 – Component weighted moisture content under exposed outdoor drying

	August	September	October	November	December	January	February
Raw residue	58.5	48.5	40.8	39.3	34.4	29.5	29.1

Raw and comminuted residues moisture content over time are in Table 5. The raw residues dried out over time. Samples were collected from the interior of the pile as much as possible, rather than the surface. Substantial drying occurred during the six months of the trial (Figure 8). The comminuted residues absorbed moisture from rainfall during November and little if any drying occurred during subsequent months with low rainfall.

Table 5 – Moisture content under pile conditions

	August	September	October	November	December	January	February
Raw	60.7	44.3	42.6	39.0	34.6	32.9	34.6
Comminuted	62.0	61.0	61.6	68.4	68.8	70.6	68.3

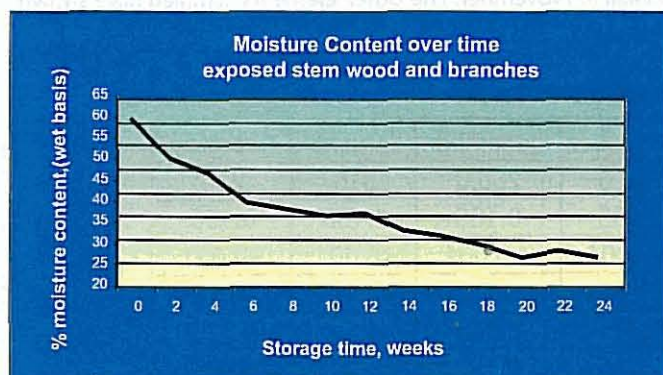


Figure 8 – Moisture content over time of residues in piles

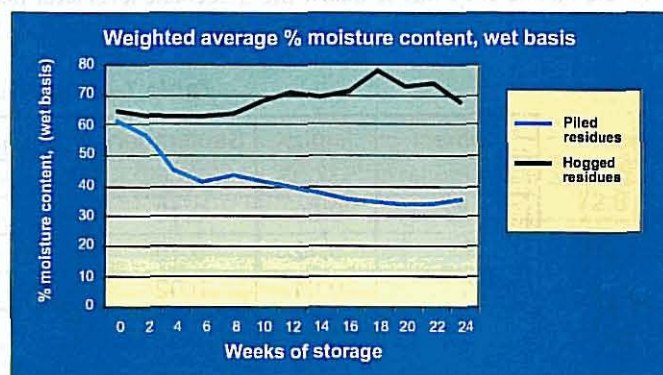


Figure 9 – Moisture content change by component

The moisture content figures for the piled residues in Figure 8 are a weighted average.

Figure 9 shows the variation in moisture change between the various components of the piled raw residues. The stem material has dried the least and the fine material, needles and small branches the most. The needles and small branches also showed the most variation, re-absorbing moisture during periods of rain. The large diameter material which makes up the bulk of the volume in the piled residues has dropped to around 40% moisture content, the smaller diameter residues have dropped to 21% to 25% moisture content.

The drop in moisture content had a substantial effect on the net calorific value (NCV) of the wood as fuel. The residues at 60% MCW had a NCV of approximately 6.3 MJ per kg, at 35 % it would be approximately 11.7 MJ per kg (Figure 10, derived from Baines 1993).

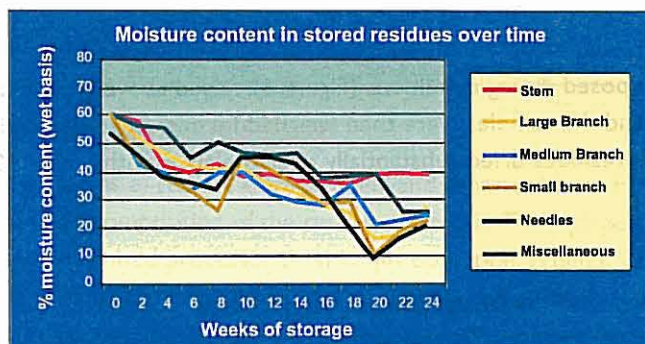


Figure 9 - Moisture content change by component

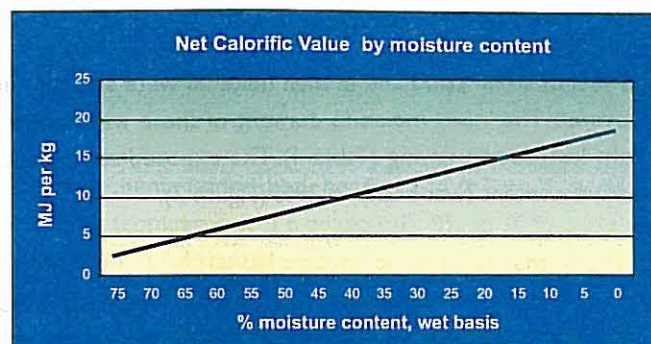


Figure 10 - Net calorific value by moisture content, wet basis

There have been no changes in percent of carbon or nitrogen in either the raw or comminuted residues over the six-month storage period (Table 6).

Table 6 - Carbon and Nitrogen content in raw and comminuted residues

	August	September	October	November	December	January	February
C% Raw	52	54	53.2	49	51	50	52
C% Comm	51	46	49	47	47	48	50
N% Raw	0.18	0.21	0.11	0.15	0.15	0.13	0.11
N% Comm	0.21	0.29	0.13	0.13	0.27	0.19	0.18

Inorganics analysis

Note: all results in inorganic and fuel analysis are on an oven dry basis.

In the raw residues the only elements to show consistent change were K and P. Levels of these elements have dropped (Table 7). The drop was to below the detectable level after heavy rainfall in November. The other elements sampled have shown no consistent change, as results from separate samples have been variable.

Table 7 - Inorganic content – raw residue

Element	August	September	October	November	December	January	February
Fe mg/kg	537.33	826.67	320.0	220.0	260.0	310	230
Ca %	0.09	0.16	0.09	0.185	0.165	0.165	0.155
K %	0.12	0.15	0.11	< 0.001	< 0.001	< 0.001	< 0.001
P %	0.01	0.02	0.012	< 0.001	< 0.001	< 0.001	0.005
Si %	0.07	0.43	0.135	0.265	0.205	0.225	0.310
Al %	0.02	0.10	0.023	0.065	0.06	0.045	0.065
Mg %	0.03	0.05	0.035	0.055	0.04	0.015	0.045
Na %	0.03	0.05	0.027	0.07	0.12	0.085	0.060

In the comminuted residues the levels of K also dropped, especially from November (Table 8). P has shown large variation between samples with no consistent drop in levels found. The significant drop in K verified that rainfall would wash out the leachable elements.

Table 8 - Inorganic content – comminuted residue

Element	August	September	October	November	December	January	February
Fe mg/kg	1192	3600	1600	2560	2520	1360	1750
Ca %	0.13	0.39	0.137	0.24	0.245	0.190	0.230
K %	0.17	0.37	0.156	0.065	0.08	0.050	0.070
P %	0.02	0.04	0.016	0.15	0.01	0.005	0.025
Si %	0.95	3.72	1.27	1.48	1.51	0.870	1.10
Al %	0.13	0.88	0.175	0.23	0.23	0.130	0.165
Mg %	0.05	0.10	0.044	0.06	0.07	0.025	0.065
Na %	0.12	0.25	0.136	0.195	0.19	0.180	0.115

There are substantial differences between the two types of residue treatments. The comminuted residues had higher levels of Fe, Ca, Si, and Na. Levels of K and P were similar.

The higher levels of elements such as Ca, Si and Fe may have been due to soil contamination of the comminuted residues during loading for processing. The higher level of ash in the comminuted samples would tend to support this.

Fuel analysis

The fuel analysis results, when compared between the two types of residue, were very similar except for ash and MCW. The raw residues had an ash content of between 1% and 3% and very low levels of S (Table 9).

Table 9 - Fuel analysis – raw residue

	August	September	October	November	December	January	February
Moisture content, %	60.7	50.0	56.6	50.5	53.7	38.7	29.0
Ash, %	1.25	1.15	1.00	1.4	1.2	2.6	2.6
Volatiles, %	79.1	77.9	80.9	81.4	82	78.8	78.7
Fixed Carbon, %	19.60	20.95	18.10	17.2	16.8	18.6	18.7
Gross CV, MJ/kg	20.5	20.4	20.4	20.0	20.1	19.9	20.2
Sulphur, %	0.01	0.03	0.02	0.00	-	-	0.01
Hydrogen, %	6.15	5.47	6.09	6.21	-	-	5.9
Oxygen, % (by difference)	41.17	41.65	41.9	42.0	-	-	41.8
Ash Fusion temp, °C	1220	1236	1225	1270	-	-	1220
Volatiles to fixed carbon ratio	4.0	3.7	3.7	4.7	4.9	4.2	3.8

The comminuted residues had an ash level of between 4% and 9% (Table 10). The result for ash for September is ascribed to a sampling error.

Table 10 - Fuel analysis – comminuted residue

	August	September	October	November	December	January	February
Moisture content, %	63.9	65.4	68.0	69.7	69.9	72.5	72.8
Ash, %	5.2	20.5*	4.4	8.1	8.1	5.9	8.6
Volatiles, %	74.6	61.2	77.1	73.9	72.3	75.3	70.6
Fixed Carbon, %	20.2	18.3	18.5	18.0	19.6	18.8	20.8
Gross CV, MJ/kg	19.8	16.7	19.7	18.9	19.1	19.3	19.2
Sulphur, %	0.01	0.02	0.01	0.02	-	-	0.02
Hydrogen, %	5.8	4.3	6.36	5.73	-	-	5.41
Oxygen, % (by difference)	39.3	32.7	44.4	38.3	-	-	38.6
Ash Fusion temp, °C	1230	1310	1225	1255	-	-	1250
Volatiles to fixed carbon ratio	3.7	3.3	3.3	4.1	3.7	4.0	3.4

There was little variation between the piles in ash fusion temperature, and no significant trend over time in either pile.

There were variations in the volatiles to fixed carbon ratio (V:FC) within and between the two piles of residues over time. Due to limited replication and sampling, no specific conclusions can be drawn. However, the data suggests that in the raw residues pile, there was enhanced bio-degradation of the wood occurring after three months, causing increases in volatile matter. This influence is relatively short term. This area needs further research.

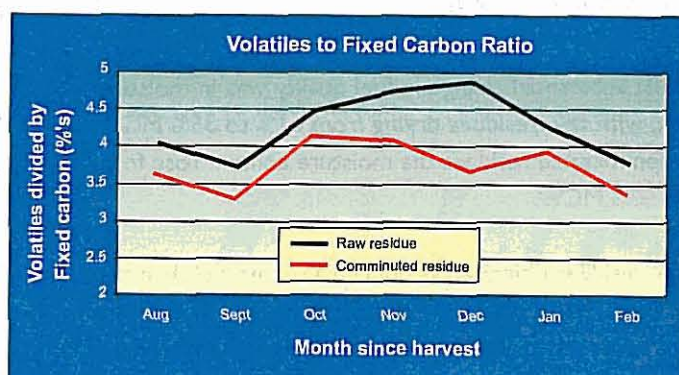


Figure 11 - Ratio of volatiles to fixed carbon in residues over time

Discussion

The key finding of the trial was the drop in moisture content over time of the piled raw residue and the rise in moisture content of the comminuted residues.

If the residues are to be used as boiler fuels, the moisture content of the wood has a substantial effect on the fuel value of the wood, expressed as net calorific value (NCV). If the moisture content of the wood is assumed to be 60% (wet basis) at harvest this material has a NCV of 6.3 MJ/kg (GJ/tonne). After the six months in storage the changes in moisture content meant that the NCV of the raw residues had risen to 11.7 GJ/tonne and the comminuted residues had fallen to 4.5 GJ/tonne. This is a gain in fuel value of 5.4 GJ/tonne for the raw residues, an increase of 85%. The comminuted residues lost 29% of their fuel value by absorbing moisture from rainfall. These figures would become significant when the cost of delivering the fuel is measured in dollars per Giga Joule of energy as opposed to dollars per tonne which is used for traditional forest products. The removal of the water from the residues for a relatively low cost (storage at landing) has the potential to substantially affect the delivered cost of energy.

The higher levels of Fe, Ca and Si in the comminuted residues could lead to slagging and fouling problems during combustion (Dare et al., 1999). The iron is a particular problem. It is possible that there was iron contamination from the processing and transport equipment. There were also differences in the handling of the residues during the trial, which could have caused the comminuted residues to have higher levels of soil incorporated in the fuel. This highlights the need for careful handling of this material to avoid this contamination if it is to be used operationally. The higher ash content of the comminuted residue would also lead to a larger ash disposal problem.

The higher moisture content of the comminuted residues could also affect the combustion emissions. High MCW fuels tend to produce more green house gases such as methane and carbon monoxide than lower MCW material. Wetter fuels may also produce higher particulate emissions (Dare et al., 1999) although this is also affected by the particle size of the fuel.

Conclusions

The most substantial change in fuel quality was in moisture content, with raw residues drying from 61% to 35% MCW. In the comminuted residues the moisture content rose from 62% to 68% MCW.

The raw residues ultimately produced a better fuel than the comminuted residues as during the study the drop in moisture content increased the net calorific value with its associated improved combustion characteristics.

Smaller diameter material dried more (to 20% to 25% MCW) than the larger diameter pieces (40% MCW). The smaller diameter pieces showed more variations in moisture content than the large diameter material and these variations coincided with periods of rain.

The levels of K dropped in both storage piles. Levels of P dropped in the raw residues only. Other inorganic elements, Fe, Ca, Si, Al and Na showed no consistent change, but the comminuted residues had higher levels of these elements than the raw residues.

Levels of C and N showed little change, with a slight drop in N in the raw residue pile.

Further research is required to fully explain bio-degradation occurring in the piles.

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