Modelling of Energy Demand in a Sawmill

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Abstract

An empirical model was developed to predict the electrical energy used by a sawmill comprising of debarking, chipping, sawing and grading operations. The input parameters for the model were log volume, surface to volume ratio of timber products and conversion rate to timber and chips. The model can predict the energy requirements of the sawmill with an error of less than 5% for normal production levels.

1. INTRODUCTION

The wood processing industry in New Zealand consumes approximately 9% of the country's total primary energy supply. About half of this is from renewable biomass energy usually in the form of heat generated from waste and by-products. The remainder comes from geothermal, fossil fuels and purchased electricity. Only a small amount of electricity is supplied from biomass cogeneration.

Woody Biomass Integrated Gasification Combined Cycle (BIGCC) technology offers the potential for the wood processing industries to provide all of their thermal and electrical energy needs from a single energy plant utilising the self generated wood residues (Rutherford et al., 2006). The objective of the work presented in this paper was to develop a model to quantify the energy demand in solid timber processing which will be integrated into a BIGCC system model for assessing the technology feasibilities. Modelling of thermal energy demand in a sawmill is also underway.

1.1. The Sawmilling Process

The main operations in a sawmill are shown in Figure 1. The first operation is the logyard where the green logs from the forest are stored prior to processing. The logs are usually delivered by truck or train and unloaded using a front-end loader. The logyard also normally contains a log loading system that sorts and orientates the logs before they enter the debarker.

When logs are delivered to the sawmill they still retain some of the bark that was on the tree. This bark is removed before the log enters the sawmill as bark contamination can severely degrade chip quality as byproduct. The bark itself is also a valuable byproduct that is in demand from garden centres, which also require low wood content in the bark. The debarker is a once through process.

After debarking, the logs are sawn into green timber, with trims to chips and sawdust in the sawmill. The purpose of the log trimming operation is to remove the curvature on the log to aid the cutting of boards and to remove curved edges on the boards. The trimming operation also effectively removes the taper from the log as well. Wood chips are also a valuable byproduct that can be sold for pulp or MDF production.

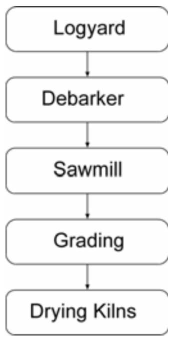

Figure 1. Simplified flow diagram of sawmill process

In most sawmills, the timber sawing is done either using bandsaws or circular saws. In the sawing process a fraction of the log volume is converted into sawdust. Usually there is a headrig that does the initial sawing of logs into cants and another gang-saw that reduces the cants into boards. In this case the log makes multiple passes through the headrig with a cant removed on each pass. There are also sawmills that have multiple saws so that the log only makes one pass through each saw. There are also edging saws that remove any remaining curvature from the boards.

After sawing the timber is graded based on dimensions and quality parameters. This is usually done manually using a rotating grading table, though in some cases a linear grading table is used. After grading the timber is put into filleted stacks where spacers (stickers) are put between the layers of timber to allow the drying air to flow through during timber drying. The timber is then dried in wood drying kilns. The sawmill may also contain other operations such as treatment and finishing.

The energy used in a sawmill is mostly electricity for the debarking, chipping and sawing operations with process heat required for the timber drying operation. Gifford & Anderson (2003) found an average energy intensity of 2.1 GJ/m^3 for NZ sawmills ranging from 1 GJ/m^3 to 18.8 GJ/m^3. The electricity demand model in this paper is only considering the debarking, chipping and sawing processes that are involved in the breakdown of a log into green timber.

2. THE MODEL

The model presented in this paper is based on an automated commercial sawmill operating in New Zealand. Details of the operation cannot be given due to the commercial sensitivity of the data but the plant is one of the most modern and energy efficient operations in New Zealand.

2.1. Data from Sawmill

Data was provided by the sawmill for the development of the empirical models. The majority of the data was provided for the entire 2005 year with more detailed data provided for the last 4 months of 2005.

The data included electricity use for the entire year in every half-hour intervals provided by the power company. Log data was also available from the sawmill computer showing average daily measurements of small end diameter (SED), length, taper, log volume, log volume based on SED, number of logs and total log volume and conversion to green boards.

The graph in Figure 2 shows the daily electricity use in the sawmill plotted with the volume of logs entering the mill. The data is for the entire 2005 year.

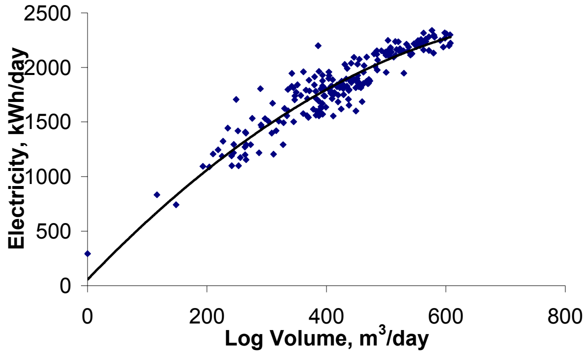

Figure 2. Electricity use in the sawmill modelled, including debarking, chipping and sawing operations

Records were also provided for the volume and dimension of sawn timber produced each day. Ideally the volume of sawn timber produced each day will be the same as the volume of timber sawn in the mill. This is not, however, always the case as in many sawmills, more timber is sawn than can be processed the same day so this results in the timber being processed and recorded the day after it was sawn. To eliminate this error data was only used from days when the volume of timber processed was the same as the volume of timber sawn in the mill.

2.2. Factors of Interest

There are a number of factors that affect the energy consumption of a sawmill. The first factor, already noted above, is the volume of logs entering the sawmill. This is also a measure of the capacity of the plant. The capacity of the plant can also be measured in terms of volume of sawn timber produced. This is related to the log volume by the conversion rate.

The conversion rate determines the fraction of the log volume entering the sawmill being converted into sawn timber. The properties of the logs, particularly the small end diameter (SED) and taper, and the dimensions of the timber being produced influence the conversion rate within the sawmill.

The dimensions of the timber produced will also have a more direct influence on the energy consumption as smaller dimensioned boards will require more saw cuts for the same volume of log and therefore the sawing energy will be greater. This means that the sawing energy in the plant can be related to the surface area of the timber produced.

2.2.1. Volume Effect

The electricity use data for the sawmill corresponds to an energy intensity range from 3.5kWh/m^3 for high log volumes to 7 kWh/m^3 for low log volumes as shown in Figure 3. This is low compared to the average energy intensity of 30kWh/m^3 (range 2kWh/m^3 to 62kWh/m^3) found by Gifford & Anderson (2003).

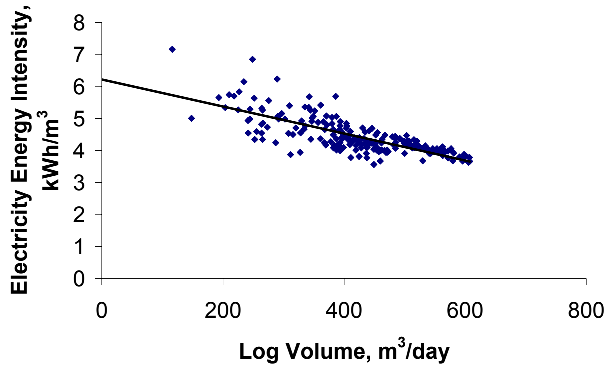

Figure 3. Change of energy intensity of sawmilling process with log volume through the mill

The trend in Figure 3 clearly shows that there is an increase in operational efficiency of the sawmill at high volumes. This needs to be reflected in the developed energy demand model. The increase in the energy efficiency is likely to be due to the reduction in energy consumption of idle processes for low log volume, which will normally run less efficiently if they use electric motors. An example of an idle process is a bandsaw spinning when it is not cutting timber. When the log flow is low the bandsaw will be idling for a greater proportion of the time than at high log flows. This model does not seek to go into the detailed causes of this trend but will characterize it empirically.

2.2.2. Conversion Rate

The sawmill has an average conversion of bark-free logs into green timber of 50% with the remainder converted into chips (36%) and sawdust (14%). The ratio of chips to sawdust varies depending on the dimensions of the timber being sawn and dimensions of logs to be processed. The number of factors affecting the conversion rate and limitations on data available from the sawmill have made it difficult to develop an empirical model to predict conversion. However, two techniques have been tried to overcome this.

The first method used to predict conversion rate in the sawmill was to develop a geometrical model based on the sawmill cutting pattern. This method was very good for predicting the proportion of chips produced but over-predicts timber volume and under-predicts sawdust volume.

The second method developed assumes a standard conversion of log to timber of 50%, which is independent of the log and timber properties. The volume of sawdust produced is calculated from the saw kurf and the surface to volume ratio of the timber produced. The volume of chips is the remainder of the log volume.

The second method has been used for the results presented in this paper. The first method will be further developed for the final model to be integrated into the overall BIGCC model.

2.2.3. Timber Dimensions

The dimension of the timber produced in a sawmill varies depending on the demand for product and to a lesser degree on the properties of the logs entering the mill. As noted above smaller dimensioned timber requires more energy due to more saw cuts per volume. This can be seen in Figure 4 for the sawmill tested. In this graph each point represents the data for a day, so the surface to volume ratio is averaged over the day.

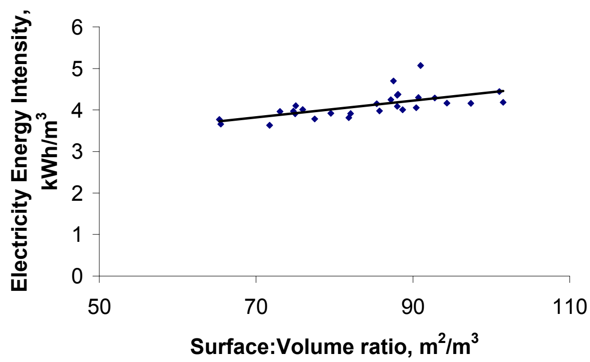

Figure 4. Change of electricity energy intensity with surface:volume ratio for the sawmill

2.3. Unit Operations

As previously noted, the sawmilling process comprises three main unit operations in the production of green timber. This section describes the unit operations and assumptions made in modelling them.

2.3.1. Debarking

The plant modelled used a ring debarker, which is very effective for removing all of the bark with minimal wood contamination. The bark contamination in the chip was 0.38% which is well within the 1% limit for grade 1 chips. For the purpose of modelling it is assumed that the debarker removes the bark perfectly with no contamination of either the chip or the bark.

The energy requirement of the debarking process is assumed to be directly proportional to the volume of bark removed. Gifford & Anderson (2003) give the energy intensity of the debarking process as around 2kWh/m^3 with a range from less than 1kWh/m^3 to 17kWh/m^3. For this model an energy intensity of 1kWh/m^3 was assumed due to the high energy efficiency of the plant.

The bark volumes produced by the sawmill are not recorded on a daily basis by the operators and the bark is removed before the logs are scanned for sawing. Based on monthly data the average bark volume is approximately 3% of the bark-free log volume. Much of the variation in the bark content of the logs is due to the harvesting method used in the forest, which cannot easily be accounted for in a model. For this reason a standard value of 3% has been used in this model. The energy use of the debarking operation, N_{db} (kWh), is therefore given by:

$$N_{db} = 0.03V_{\log} \qquad 1.$$

In this equation the energy intensity (1kWh/m^3) and the bark content (0.03) have been combined.

2.3.2. Chipping

As with the debarker the energy requirement of the chipping operation is assumed to be directly proportional to the volume of chips produced. The average energy intensity of the chipping process was found by Gifford & Anderson (2003) to be 10kWh/m^3 though many plants reported energy intensities of closer to 5kWh/m^3. For this model an initial value of 4kWh/m^3 was chosen with the final value adjusted to produce the best fit to data. The equation to determine the energy used in the chipping operation, N_c (kWh), was therefore:

$$N_c = X_c V_{\log} E_c \qquad 2.$$

In this equation X_c is the fractional conversion of the bark free log volume, $V_{\log}$, into chips. E_c is the energy intensity of the chipping process which was calculated to be 3.5kWh/m^3 to get the best fit to data.

2.3.3. Sawing

It has been assumed in this model that the non-linearity seen in the actual plant data can be confined to the sawing process.

In the sawing model it was necessary to account for the effect of timber volume on energy use and the effect of sawn timber dimensions on energy use. The relationship between sawing energy intensity and sawn timber volume is shown in Figure 5. The energy intensity was calculated by dividing the sawing energy by the sawn timber volume for each data set. The sawing energy was calculated as the total energy minus the debarking and chipping energy.

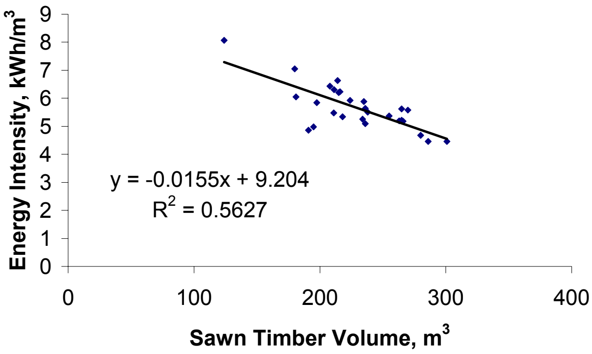

Figure 5. Change of energy intensity of the sawing operation with sawn timber volume

To determine the relationship between sawing energy and sawn timber dimensions the average surface to volume ratio of the boards in each data set was calculated. The sawing energy for each data set was then divided by the surface to volume ratio. These values are plotted against sawn timber volume in Figure 6.

The data analysis above results in two empirical equations for the energy intensity of the sawing operation. The first, E_s, based on sawn timber volume is:

$$E_s = -0.0155 X_s V_{\log} + 9.204 \qquad 3.$$

In this equation X_s is the conversion rate for turning the log volume into sawn timber volume. The second, E_{sv}, based on the surface to volume ratio of the sawn timber (S/V) is:

$$E_{sv} = 0.0667 S/V \qquad 4.$$

To determine the relative influence of the two equations for energy intensity the following equation was developed for sawing energy, N_s:

$$N_s = E_{sv}{}^a E_s{}^b X_s V_{\log} \qquad 5.$$

where a + b = 1. These exponents were determined using solver in Excel to best fit the sawmill data. The best fit was found with a = 0.44 and b = 0.56.

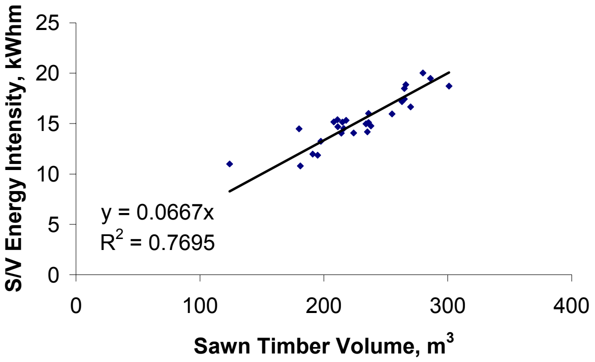

Figure 6. Change of S/V energy intensity with sawn timber volume for the sawing operation

2.4. Overall Model

The total electricity use in the sawmill, N_m, is given by the following equation:

$$N_m = N_{db} + N_c + N_s \qquad 6.$$

Substituting equations 1, 2 and 5 into equation 6 gives:

$$N_m = 0.03V_{\log} + 3.5X_cV_{\log} + E_{sv}^{0.44}E_s^{0.56}X_sV_{\log} \qquad 7.$$

2.5. Results

The results from the model are compared with the data set from the sawmill in Figure 7. The model results were calculated for an S/V range from 60 m^2/m^3 to 120 m^2/m^3 which corresponds to timber dimensions of 50×100 mm and 20×100 mm respectively. The log volume range is from 100 m^3 to 800 m^3.

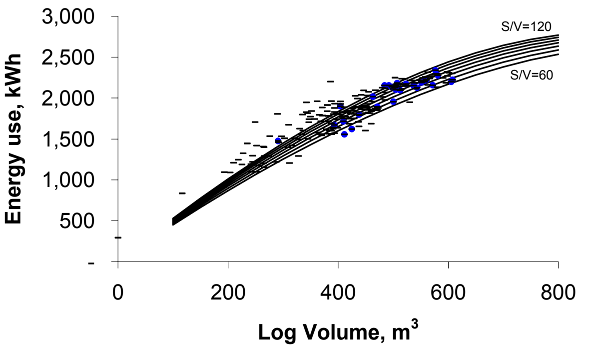

Figure 7. Results for the model (lines) plotted with data points from the sawmill. The dots represent the data points used to derive the model

The results for the predicted energy use in the sawmill is compared with the actual energy use in Table 1. The values shown are also the data set used to derive the model. The mean error is 3%.

Table 1. Results showing the predicted energy use compared to the actual energy use recorded in the sawmill for the data set used to derive the model

$V_{\log}$ m^3/day	S/V m^2/m^3	Xs	Xc	Actual kWh	Predicted kWh	Error
410	102	44%	42%	1714	1806	5%
605	72	50%	40%	2199	2255	3%
471	76	46%	43%	1891	1921	2%
581	80	45%	44%	2277	2280	0%
577	90	47%	40%	2340	2304	2%
438	75	48%	41%	1797	1804	0%
560	73	47%	42%	2222	2170	2%
558	75	48%	42%	2214	2171	2%
608	65	47%	44%	2223	2260	2%
425	82	46%	43%	1620	1791	11%
513	88	46%	42%	2095	2108	1%
505	94	44%	43%	2105	2116	1%
498	93	43%	45%	2136	2086	2%
551	86	46%	42%	2191	2213	1%
543	82	43%	46%	2126	2192	3%
537	89	44%	44%	2151	2194	2%
505	97	47%	40%	2102	2120	1%
411	77	46%	43%	1556	1725	11%
572	65	49%	41%	2155	2144	1%
500	75	47%	42%	1955	2005	3%
291	91	43%	46%	1474	1307	11%
404	88	45%	44%	1899	1738	8%
484	101	44%	42%	2153	2071	4%
492	88	42%	47%	2154	2051	5%
393	87	50%	37%	1670	1700	2%
507	91	42%	47%	2183	2114	3%
463	88	46%	41%	2017	1946	4%
523	85	51%	36%	2171	2100	3%

The graph in Figure 8 shows how the error between actual and predicted energy use varies with log volume. The errors are higher with low log volumes. Above 450m^3/day the error is less than 5%.

The graph in Figure 9 shows the relative influence of the two energy intensity equations used to calculate the sawing energy. This is for a surface to volume ratio of 90m^2/m^3. The graph shows the transition from the linear S/V relationship at b=0 to the quadratic relationship based on sawn volume at b=1. The main effect of the S/V relationship is to shift the curve along the y-axis but this plot shows that it also flattens out the effect of the quadratic relationship.

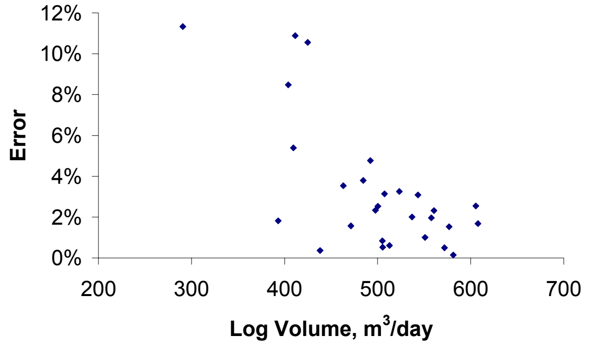

Figure 8. Error of predicted energy use compared to actual energy use

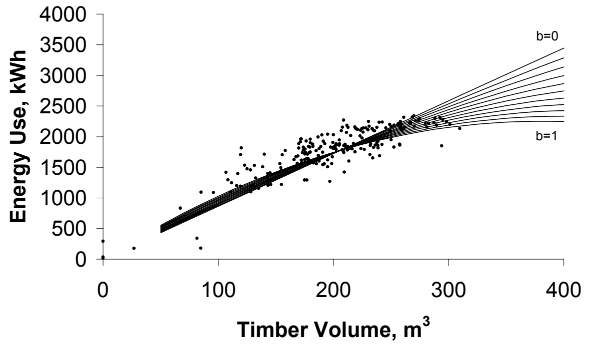

Figure 9. The model results for different values of b to show the relative influence of the two energy intensity equations on the energy use

2.6. Discussion

The model developed can predict the energy use for the sawmill modeled accurately (within 5%) for normal production levels (500-600m^3/day). At lower production levels the accuracy of the model is not as good. This is most obvious at production levels around 400m^3/day where the error ranges from 2% to 11%. This error is probably due to the sawmill not operating as smoothly at low volumes compared to high volumes. Unpredictable factors such as operator influence are more likely to affect the energy efficiency of the process at low volumes.

The criteria for selecting data was that the volume of timber sawn be the same as the volume of timber graded. When these two volumes are not the same it means that green timber is being left in the green chain for processing the next day or timber has been process that was left from the previous day. The latter could explain the fact that in Figure 7 the low volume production days generally show a higher than predicted energy use.

Another reason for the error discrepancy is that the majority of the data suitable for deriving the model was from high volume production. This means that the model will be biased towards high volume production. This bias is not a problem under the objectives of the project as the sizing of a BIGCC system would be based on the maximum production of the sawmill.

3. CONCLUSIONS

The model developed predicts sawmill energy demand accurately at normal production levels based on the volume of logs entering the mill, the conversion rates and the timber dimensions. The model is specific for the plant it was derived for but could be fitted to other sawmills if the $V_{\log}$, S/V and electricity data is available.

4. ACKNOWLEDGMENTS

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5. References

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