Energy demand in wood processing plants

Jingge Li, Murray McCurdy, Shusheng Pang[*]

Abstract

Computer models were developed to quantify the energy demand in a sawmill and a medium density fibreboard (MDF) plant, based on the production processes. For the sawmill, an empirical model was developed using mill data collected from a local sawmill near Christchurch. The model requires further practical data from more sawmills for validation. For the MDF plant, thermal energy demand was theoretically calculated and electricity demand was simulated empirically based on an energy audit. The MDF energy demand model was validated by plant data and the results showed a satisfactory accuracy with the discrepancies being -5% to 7% for the thermal energy prediction and ±4% for the electricity prediction.

With the inputs of product production and grade, the models are able to predict the energy demand, the log volume required, the wood residues generated and the energy self-sufficiency. The wood residues generated are usually be able to provide more than enough energy to meet demand including heat and electricity in a sawmill, but only 80-90% of the thermal energy demand in an MDF plant. The difference is due to the much lower energy demand in a sawmill.

Introduction

The wood processing industry consumes a large amount of energy in the forms of electricity and heat. The latest survey showed that in 2002 the New Zealand wood processing industry consumed 69 PJ of primary energy. Of the energy consumed, 53% (36.6 PJ) was derived from woody biomass including wood processing residues and black liquor generated within the industry. The majority of the energy derived from the woody biomass is heat and only a small proportion of electricity (20%) consumed in the wood processing sector is generated from the woody biomass cogeneration plants (Gifford and Anderson 2003).

A research programme being undertaken at the University of Canterbury aims at establishing a biomass integrated gasification combined cycle (BIGCC) system for generation of electricity and thermal energy using the woody biomass from both the wood processing and forests (Pang and Li 2006). The energy generated can be supplied back to the wood processing industry to improve the energy self-sufficiency, especially in the form of electricity. The objectives of the work presented in this paper are to construct energy demand models for a sawmill and an MDF plant. The models are able to predict energy consumption, the ratio of electricity to thermal energy, the amount of wood residues generated and the energy self-sufficiency in a particular wood processing plant. Ultimately, the models will be integrated into a biomass energy system model for feasibility studies which will determine the optimum size and location for construction of a commercial BIGCC bioenergy plant.

Modelling of energy demand in a sawmill

The primary product from a sawmill is kiln-dried sawn timber but there are also byproducts in the form of bark, wood chips, sawdust and off cuts. These byproducts, or wood processing residues have a sale value and are also a potential onsite fuel source for a BIGCC bioenergy plant. A sawmill usually consists of four main unit operations including log debarking, timber sawing, side-cuts chipping and timber drying. The operations all consume energy in the form of electricity while the drying operation also consumes thermal energy (heat). Therefore the operation as a whole in the sawmill consumes both heat and electricity.

---

[*] Department of Chemical and Process Engineering, University of Canterbury.
jingge.li@canterbury.ac.nz

The energy demand model for the sawmill was developed using mass and energy balances based on the production line in a local sawmill near Christchurch. The sawmill is relatively new and comprises a modern automated sawing operation and new timber drying kilns using the ACT (accelerated conventional temperature) drying schedule.

Method

The model presented here is an empirical one developed using mill data collected from one sawmill operation, and the equations were derived from recorded operational data over a period of one year (2005). The electricity used in the sawmill was recorded by three separate electricity meters. One of these covered the entire sawing operation and another only recorded the kiln drying operation. The electricity usage was recorded every half hour and provided by the sawmill in a spreadsheet.

The sawmill also supplied data on log flows and log dimensions recorded by the log scanner on a daily basis. The timber volume and dimensions both in green and after kiln drying were also available on the daily basis.

In the sawmill, kiln drying operation is the key unit controlling the overall wood flow in the process because the kiln drying is a batch process and the bottleneck in the sawmill. The kilns operate 24h a day, 7 days a week. The sawing operation is essentially a continuous process that converts green logs into timber of required dimensions. The sawing operation can easily meet the demand in a single 8-hour shift, 5 days a week. The mass and energy balances for the sawing operation were determined using an empirical model developed for the sawmill (McCurdy et al., 2006).

The kiln drying uses the ACT schedule for all loads thus drying time is the sole key factor affecting the energy use in the drying operation. However, the drying time is, in turn, dependent on timber thickness. Considering the average green moisture content of all of the loads are similar, the timber thickness has been used as the basis for comparison of different mass and energy balance scenarios. The sawmill data has shown that the drying time (in hours) is approximately linearly related to the board thickness (in mm) in the range of 15 to 60mm. The electricity demand for the kilns was determined empirically using the mill data. On average, the electricity consumption is approximately 50kW for each kiln which dries 50 m^3 timber (25 mm thick) in each load. In practice the electricity consumption in the kiln drying varies throughout the schedule if the air speed within the stack is changed. However, by managing for the kilns to start at different times, the air speed effects were smoothed out on average, so load variation has been ignored in this analysis.

For modeling of heat demand, the mill data was again used where the pressurized hot water at 160°C was used as the heating source. On average, a 2MW startup load and a 0.75MW running load were recorded in the normal kiln drying operation. The peak energy demand has also been smoothed out due to the different start times of each kiln, resulting in an average heat consumption of 5.75MW for 6 kilns. The average thickness of the boards dried in the sawmill is 25mm so the process heat requirements are adjusted based on the volumes of timber dried for different thickness boards.

Results and Discussion

The simulation results given in this section are for a sawmill comprising 6 kilns, drying approximately 300m^3 in total in one batch, but this volume varies with the timber thickness. Table 1 shows the wood mass flow in the sawmill with a sawing conversion factor of 50% although this factor is relatively low in a modern sawmill. The total timber production and log volume increase as the board thickness is reduced. This is because drying thinner timber takes less time so a greater volume of timber can be processed through the drying kilns.

Table 2 shows the energy demand variation with the timber thickness for the sawmill. The greater volume of timber being processed for thinner timber means that the process heat requirements and the electricity demand are higher for the sawmill although the electricity demand in kilns was assumed to be constant for the different thicknesses. The ratio of electricity to heat increases with the board thickness, in spite of the thicker boards requiring less electricity in sawing but they consume a greater proportion of electricity due to the longer drying time. The peak load is the total electricity demand when the timber drying kilns and the sawing machinery are operating at the same time. The greater throughput for the thinner boards translates into the higher peak load.

The index value of energy demand per unit volume of timber produced can be derived from the data given in Tables 1 and 2. The thermal energy demand is constant at 422 kWh/m³ for all of the board thicknesses, but electricity demand ranges from 26 to 41 kWh/m³ with the board thickness from 20 to 50 mm.

Table 1: Wood mass flows in the sawmill on a daily green basis for different thicknesses of timber.

Thickness	20mm	32mm	40mm	50mm
Logs in, t/day	715	546	472	404
Timber out, t/day	357	273	236	202
Chips out, t/day	200	194	179	162
Sawdust out, t/day	157	79	57	40
Bark out, t/day	21	16	14	12

Table 2: Energy demand in the sawmill on a daily basis for different thicknesses of timber.

Thickness	20mm	32mm	40mm	50mm
Process heat GJ/day	561	429	370	317
Electricity(kiln), GJ/day	26	26	26	26
Electricity (sawing), GJ/day	9	7	6	5
Electricity(total), GJ/day	35	33	32	31
Ratio of electricity to heat	0.062	0.077	0.087	0.098
Peak Load, kWh	612	555	522	490

The wood residues from the sawmill have different heating and commercial values. Cost analysis by Robertson and Manley (2006) indicates that the green sawdust stream would be the preferred source of biomass energy in the plant as it has the least commercial value. Table 3 shows the biomass availability and energy supply for different board thicknesses. The energy supply was determined from the process heat and total electricity requirements using conversion efficiencies of 0.64 and 0.25, respectively. The results in Table 3 show that for all of the board thicknesses the sawmill produces more than sufficient wood residues to meet its energy requirements. It is probably possible to derive most of the energy required from the cheaper fuel (e.g., sawdust) and to sell some of the extra bark and chips for value recovery. Overall the results show that when designing and sizing a bioenergy plant for a sawmill the peak loads should be considered based on the production of the thinnest boards. When considering the availability of the wood residues within the sawmill it is necessary to account for fluctuations due to the different thicknesses of the timber produced.

Table 3: Biomass availability and energy demand on a daily basis.

Thickness	20mm	32mm	40mm	50mm
Chip, GJ/day	1305	1265	1171	1053
Sawdust, GJ/day	1185	597	428	304

Bark, GJ/day	234	179	155	132
Demand, GJ/day	1017	802	706	619

Modelling of energy demand in an MDF plant

In the modelling of energy demand in an MDF plant, four MDF grades are defined according to the density. These are Ultra-light with a density of 500 kg/m³, Light (600 kg/m^3), Regular (725 kg/m^3) and Thin (800 kg/m^3). The MDF production process has been divided into six unit operations for the convenience of calculation, and these operations include:

1) Chip preparation (log debarking, chipping and screening);
2) Pre-heating and refining (chip washing, plug screw feeding, pre-heating and refining);
3) Fibre drying (blowline and fibre drying);
4) Mat forming and pressing (mat forming, pre-pressing and hot pressing);
5) Finishing (cutting, sanding, grading and packaging); and
6) Miscellany (thermal oil circulating, air compressing, lighting and waste water treatment).

Method

The model was constructed based on the above unit operations to calculate the energy demand based on the assumptions and facts below.

- Radiata pine is the only species and urea formaldehyde (UF) is the only resin used in the New Zealand MDF industry.
- Ratio of bark on logs is 5% based on weight;
- Ratio of solid UF resin applied to dry fibre ranges from 8% to 17% based on weight depending on the MDF grade;
- Ratio of fines in chip screening is 2% based on weight;
- Ratio of weight loss in chip washing is 4% based on weight;
- Ratio of panel trim off is 4% based on weight;
- Ratio of panel rejected is 3% based on weight;
- Ratio of sander dust is 10% based on weight.

Thermal energy demand in the form of flue gas heat was calculated theoretically considering the following factors:

- Heat input to heat up wood chips, fibres and resin to the required processing temperatures;
- Heat input to evaporate moisture in the fibres and resin;
- Heat generated from mechanical action in the refiner;
- Heat released during resin curing;
- Heat loss to ambient in delivery systems, fibre drying and exhaust venting.

Electricity demand is quantified from the production rate (odt/h) and the specific electricity requirement (SER kWh/odt) of the primary equipment. The SERs have been identified from the energy audit of an MDF production line, called Plant 1.

Results and discussion

The model was run in MS Excel for a typical MDF production line with annual production of 120,000 m^3 regular grade. For such a plant, the predicted total thermal energy demand is 120 GWh if direct flue gas is used for fibre drying or 136 GWh if hot air is used for fibre drying, and the total electricity demand is 37.7 GWh.

Energy demand varies with MDF grade as shown in Table 4 with the index values of energy demand and raw material consumption based on unit volume of MDF product. The results have shown that the lighter panel production consumes less energy and less logs, but needs more resin to achieve the required internal bonding. The ratio of electricity to heat for all of the product grades is fairly constant at 0.32, which provides a good case for feasibility studies of a BIGCC system.

Table 4: Index value of energy and raw material demand

MDF grade	UltraLight	Light	Regular	Thin
Electricity, kWh/m³	211	257	314	358
Heat, kWh/m³	684	822	998	1108
Logs, m³/m³	1.13	1.62	2.01	2.27
UF solid, kg/m³	80	81	79	65
Ratio of electricity to heat	0.32	0.32	0.32	0.32

In practice, MDF production normally has a mix of grades depending on the market demands. In this case, the model could be run separately for each type of grade for a particular period of time. Regular grade is usually the majority product in all of the plants, and thus this paper has focused on the regular grade for analysis of energy demand in the following sections.

Energy demand by unit operation is illustrated in Figs 1 to 3. Thermal energy is mainly consumed by the pre-heating and refining, fibre drying, and hot pressing unit operations as shown in Figs 1 and 2. Fibre drying is the biggest consumer and consumes 48% of the total energy demand when the flue gas is directly used as drying medium or 54% of the total thermal energy when the hot air is used. In the latter case, 16 GWh/y extra heat is consumed for the fibre drying. This extra heat demand is due to the fact that more heat is lost in the flue gas venting for heating the air (French 2002), whereas when the flue gas is directly used this loss is eliminated.

Fig. 1: Annual thermal energy demand by unit operation when flue gas is directly used as drying medium in the fibre drying

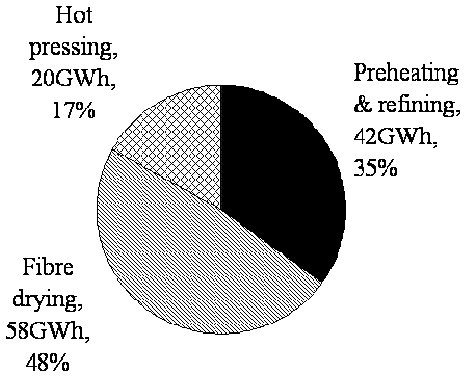
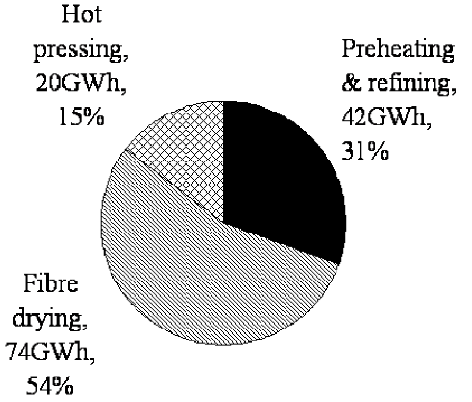
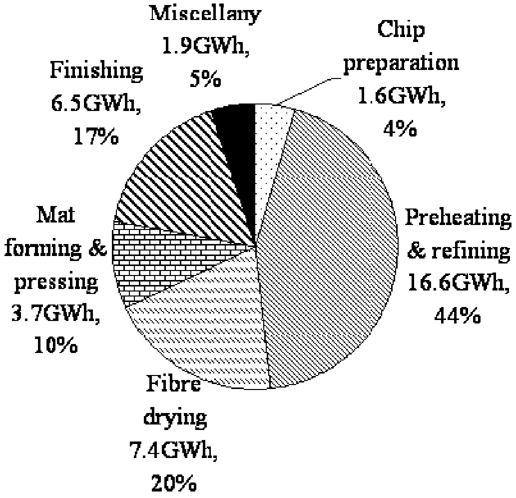


Fig. 2: Annual thermal energy demand by unit operation when hot air is used as drying medium in the fibre drying



Electricity is required by all of the six unit operations from chip preparation to finish and miscellany as shown in Fig. 3 regardless of the fibre drying medium used. Pre-heating and refining is the biggest consumer and consumes 44% of the total electricity demand. The electricity consumptions for other unit operations are as follows: fibre drying 20%, finishing 17%, mat forming and pressing 10%, chip preparation 4% and miscellany 5%. Energy centre usually consumes 7-8% of the total electricity demand for air supply, oil recirculation and fuel feeding. Of the three, only the electricity consumption for thermal oil recirculation is included in the model.

Fig. 3: Annual electricity demand by unit operation



Supposing the MDF is processed from logs, a plant with a production of 120,000 m³/yr regular grade MDF will generate of 25,691 odt/yr wood residues including bark, chip fines, trim-off, sander dust and panel rejected. Sander dust and bark are the major residues accounting for over 50%. Mixing of the various residues may be necessary in practice to achieve the required moisture content for a bioenergy plant. However, the quantity of residues in this paper is expressed in oven dry tonne.

The above generated wood residues have an energy value of 135 GWh/yr at an average calorific value of 19 MJ/odt, which is slightly lower than the normal value of 19.2-19.7 MJ/odt for soft wood and bark stated by Baines (1993) due to the MDF panel rejected contains about 10% resin and has a lower calorific value (Wilson 2006). Assuming 80% overall thermal conversion efficiency, they can generate thermal energy of 108 GWh/yr in flue gas heat. This amount of energy is able to provide a thermal energy self-sufficiency of 91% for the MDF production when the flue gas is directly used for the fibre drying. However, the self-sufficiency is reduced to 80% when the hot air is used. This means that no more residues are available for generation of electricity which is different from the sawmill, where the wood residues are more than enough to provide both thermal energy and electricity. The difference is due to the much lower energy demand in the sawmill.

Validation of the model

From theoretical analysis, it was found that the thermal energy demand in the fibre drying was different when flue gas was used as the drying medium compared to when hot air was used. In order to verify this result, model validation has been conducted for the two cases separately. The MDF Plant 1 uses the direct flue gas for the fibre drying and its recorded energy consumption is compared with the model result as shown in Fig. 4. The predicted thermal energy demand agrees closely with the actual data with the model result being only 7% higher than the actual value. Looking at the individual unit operations, the model predicted thermal energy consumption in the pre-heating & refining is less than the actual value but the thermal energy demands in both of the fibre drying and hot pressing are overestimated. These differences are understandable considering that the thermal energy in the plant was estimated by taking the values statistically over a period of one year.

Fig. 4: Validation of Thermal Energy Demand in Case of Flue Gas for Fibre Drying

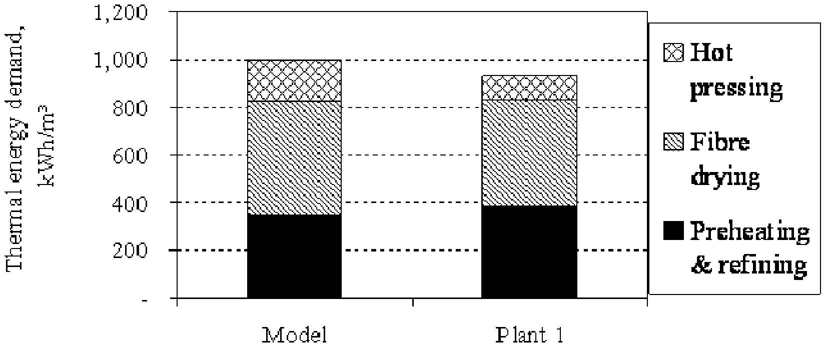
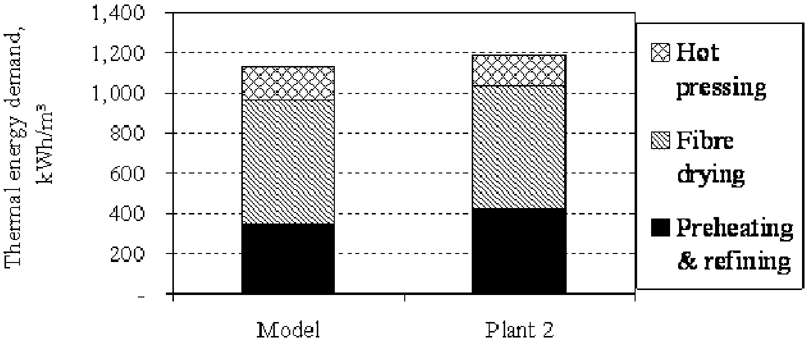


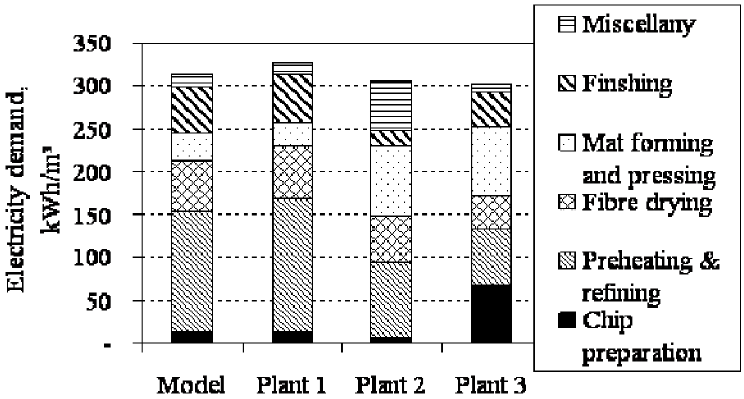
Fig. 5: *Validation of Thermal Energy Demand in Case of Air for Fibre Drying*



Another validation was undertaken by using audit data from MDF Plant 2 where hot air was used for fibre drying. Fig. 5 illustrates the comparison between the model simulation results and the actual values of the energy demand by Plant 2. Thermal energy demand simulated by the model is 5% lower than that audited values with the lowest predicted result being in the pre-heating & refining. This discrepancy is probably due to the heat generated from the mechanical action being deducted in the model.

The total electricity demand is relatively constant and consistent for the MDF production. For the development and validation of the electricity demand model, another MDF plant, Plant 3, was audited in addition to the above two plants and the comparison between the plant audit data and the model simulation results is shown in Fig. 6. This shows that the predicted electricity demand index value of 314 kWh/m³ is only 4% different from the measured values from the three plants. However, the comparison of the electricity demand for individual unit operations reveals that the difference between the model prediction and the plant data is noticeable. This is partially due to the different ways of recording in the practical operation in different plants.

Fig. 6: Validation of Electricity Demand



Conclusions

An empirical model of energy demand in a sawmill has been established based on one commercial operation. With timber production and board thickness as input parameters, the model predicted that unit thermal energy demand is constant at 422 kWh/(m³ timber) regardless of timber thickness. When the timber drying kilns are operating at full load, the timber production increases with decreasing timber thickness. The unit electricity demand varies with the timber thickness, increasing from 26 kWh/m³ for producing 20mm timber to 41 kWh/m³ for 50mm timber. The corresponding timber production decreases from 357 to 202 t/day. The ratio of electricity to thermal energy thus increases from 0.062 to 0.098. With 50% of the logs converted to dry timber, wood residues generated in a sawmill is more than enough to meet the energy demand in the forms of both heat and electricity. Therefore, more valuable residues such as bark and chips can be sold to recover value for the sawmill. The model needs to be further developed by including theoretical analysis and validation with more plant data.

An energy demand model for an MDF plant was also constructed, with the thermal energy based on theoretical calculation and the electricity based on plant audit data. In MDF production, the fibre drying consumes a significant proportion of the thermal energy demand and this proportion varies depending on whether flue gas or hot air is used as the drying medium. In a typical MDF production line of 120,000 m³/y of regular grade, the model predicts that the thermal energy demand is 998 kWh/m³ for using the flue gas and 1136 kWh/m³ for using the hot air. The electricity demand is relatively constant and consistent at a value of 314 kWh/m³ regardless of the fibre drying medium. The energy demand also varies with the MDF grade, but the ratio of the electricity to the thermal energy is constant at 0.32 when using the flue gas as the drying medium in fibre drying. The wood residues generated in MDF production are not sufficient to meet all the energy demand, with a self-sufficiency of only 80-90% for thermal energy depending on the fibre drying medium. Validation of the model using plant data shows that the model is able to simulate the energy demand in satisfied accuracy with discrepancy of -5% to 7% for the thermal energy and ±4% for the electricity.

The production of MDF consumes much more energy than the production of sawn timber. For the MDF production, thermal energy demand is 3 times and electricity demand is 11 times of that for the timber production on basis of unit volume of product.

Acknowledgment

The study presented is funded by the Foundation for Research, Science and Technology New Zealand under the contract of UOCX0402. The authors also appreciate the help from the various plants where the energy data were taken.

References

Baines, J.T. 1993: New Zealand Energy Information Handbook, Energy Data Conversion Factors Definitions. Energy and Resources Division, Ministry of Commerce, Fisher & Paykel Ltd, and Southpower.

French, C. 2002: *Energy Analysis of a Medium Density Fibreboard Production Facility*, Thesis of a Post Graduate Diploma of Science, Department of Physics, University of Otago, Dunedin.

Gifford, J.; Anderson, C.J. 2003: Energy use in the New Zealand wood processing industry. www.eeca.govt.nz/renewable-energy/bioenergy/biomass.html visited on 16 May 2006.

Maloney, T. 1993: *Modern Particleboard and Dry-process Fiberboard Manufacturing*. San Francisco, Miller Freeman.

McCurdy, M.C.; Li, J.; Pang, S. 2006: Modelling of energy demand in a sawmill. Paper submitted to the Conference of CHEMECA 2006 in Auckland 17-20 September 2006.

Pang, S. 1999: *Development and application of a mathematical model for MDF fibre drying*. Research Report, Forest Research Institute, Rotorua.

Pang, S.; Li, J. 2006: BIGCC system for New Zealand: an overview and perspective. NZ Journal of Forestry, this issue.

Robertson, K.; Manley, B. 2006: Estimation of the availability and cost of forest biomass for bioenergy in Canterbury. NZ Journal of Forestry, this issue.

Wilson, P. 2006: Personal communication. Philip.Wilson@nelsonpine.co.nz