Modelling of Energy Demand in an MDF Plant

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Abstract

A computer model was developed to quantify the energy demand in a medium density fibreboard (MDF) plant based on the commercial production process from chip preparation, refining, fibre drying, mat forming, hot pressing to product finishing. Thermal energy was theoretically calculated in each unit operation while electricity demand was correlated empirically based on an MDF plant energy audit. With the inputs of MDF production, grade, log moisture content and fibre drying method, the model is able to predict the energy demand for both heat and electricity. The model prediction also includes processing parameters such as log consumption, resin requirement, and wood residues generated for a given production. This facilitates evaluation of the thermal energy self-sufficiency relative to the different. Validation of the model using plant data shows that the model is able to predict the energy demand in satisfied accuracy with discrepancy of -5% to 7% for thermal energy and ±4% for electricity.

1. INTRODUCTION

Production of medium density fibre board (MDF) requires a large amount of thermal energy and electricity. Quantifying the energy consumption is important for managing energy supply. Recently a research programme has been established at the University of Canterbury to develop a biomass integrated gasification combined cycle (BIGCC) system for generating electricity and heat using wood residues from the wood processing industry. The energy generated by the BIGCC can be supplied back to the wood processing plants or sold onto other users. The objective of the work presented in this paper is to establish an energy demand model for MDF production and to provide a case study for a feasibility analysis of a BIGCC bio-energy plant. Description of the BIGCC system and the feasibility study can be found from the paper of Rutherford and Williamson (2006) also in this proceeding.

According to the authors' knowledge, there has not been any energy demand model published for a commercial MDF plant. Process models for MDF manufacturing have primarily considered how panel properties are affected by pressing conditions in the hot press (Gupta et al 2006, Carvalho et al 2003, Thoemen and Humphrey 1999) or how dry fibre production is controlled by various drying parameters (Pang 1999). Therefore, the energy demand model presented in this paper is the first effort to predict energy consumption in an MDF plant.

1.1. MDF Production in NZ

In New Zealand, there are four major commercial MDF plants including Carter Holt Harvey Panels, Dongwha (previous Rayonier) Patinna NZ, Fletcher Wood Panels and Nelson Pine Industry with total seven production lines. The MDF production capacity of each line ranges from 85,000 to 160,000 m^3/yr to give a total national capacity up to 875,000 m^3/yr (Sunds Defibrator, 1999). All of the seven production lines use one-stage fibre drying and pendistor vacuum mat forming, while two lines use a batch panel press and the rest five use a continuous press. MDF in New Zealand is all manufactured from young radiata pine fibres, bonded with urea formaldehyde (UF) resin, though melamine-formaldehyde (MF) or urea-melamine-formaldehyde (UMF) resins are used in some cases for specially required products. MDF is usually graded according to the panel density ranging from 450 kg/m^3 of super light grade (thick panel) to 880 kg/m^3 of high density (thin grade) (Sturgeon 1992). Standard or regular grade MDF panels have an average density of 720-730 kg/m^3 (NPI 2005, Patinna 2005, French 2002).

1.2. Process of MDF Production

The MDF production process is shown in Figure 1.

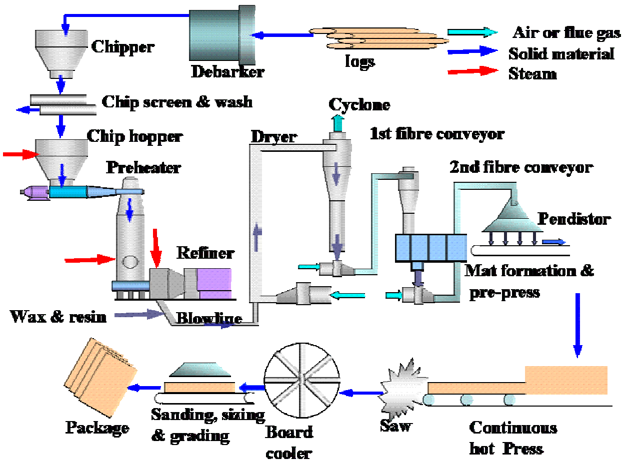

Figure 1 MDF Production Process.

Logs are first debarked and fed to a chipper. The chips are then screened, washed and fed to a hopper. In the hopper they are heated by low pressure steam (≤4 bar) before being fed to the pre-heater/digester where saturated steam (~10 bar, 180°C) further heats and softens the chips. The softened chips and entrained steam are then fed to a refiner in which they are broken down into wood fibres at 180°C by the heat and the mechanical action of the refiner. A small quantity of paraffin wax (0.5 to 1% of the dry fibres) is added by direct injection at the refiner entrance (Pang 1999) as a moisture repellent.

From the refiner, the steam/fibre mixture enters the blownline, where resin solution is injected (Allen et al 1988). The resinated fibres and steam then flow into a tube drier where hot clean flue gas or hot air (~160°C) dries the fibres to a target moisture content of 10-12% (oven dry base). From the drier outlet, the dry fibres are conveyed to storage bins before they are sent to the vacuum forming station for mat formation. Then the mat thickness is reduced through a continuous cold pre-press (Maloney 1993). The mat is then either cut to size and compressed in a batch press or fed directly to a continuous press, to achieve the target board thickness and density. In both cases, hot oil filled platens heat and compress the mat/panel to achieve a core temperature of about 100°C for resin curing

After the hot pressing, the panels from the batch press are cooled directly in a star dryer and those from the continuous press is cut to length before cooling in the star dryer. The panels are stored for two to three days prior to final sanding, trimming and cutting into market sizes for packaging.

2. MODEL DEVELOPMENT

To develop the energy demand model, the whole process is divided into six unit operations:

1) Chip preparation including 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;
6) Miscellaneous: thermal oil circulating, compressed air supply, lighting and waste water treatment.

The model is constructed in Microsoft Excel based on the above unit operations. The model input and output parameters are listed in Table 1.

Table 1 Inputs and Outputs of the Model.

Model Inputs	Model Outputs
Plant Production, m^3/yr	Thermal Energy Demand
Operating Hours	Electricity Demand
MDF Production Grade	Degree of Self Sufficiency
Log Moisture Content	Logs Required
Flue gas drying or hot air drying	Resin Required
	Residues Generated

General modelling considerations and assumptions include:

- One stage fibre drying and continuous hot pressing.
- Radiata pine wood and UF resin are used for the production.
- Moisture content for chips and fibres are expressed in oven dry base (od).
- 120,000 m³/yr MDF production as reference base.
- 22.5 h/d and 350 d/yr operation time as reference base (Maloney 1993).
- Four MDF density grades are Ultra-light = 500 kg/m³, Light = 600, Regular = 725 and Thin = 800.
- Diesel demand for on-site vehicles etc. is not considered.
- Specific heat of chips or fibres is a function of moisture content (M) and estimated by $Cp(kJ/odt\cdot°C) = 4184\times(M+0.324)$ (Pang 1999).
- Mass balances are based on the mass ratios of 5% bark on log; 8-17% UF resin applied to the dry fibre depending on the MDF grade; 2% fines in chip screening; 4% loss in chip

washing, 4% panel trim off; 3% panel rejected and 10% sander dust of the panel for sanding.

Thermal energy demand is modelled theoretically based on energy and material balances for the three unit operations (2-4) that require heat input. The model needs input values for overall production, MDF grade, log moisture content and drying method. Using these input values, the model calculates the material flow rates in each unit operation. Combining these with the process temperatures (taken from plant observations) and heat consumption streams, the thermal energy demand per oven dry tonne of woody material flowing through each unit is then calculated. Flue gas (850°C base inlet temperature) from a wood waste furnace is taken as the primary heat-source in the process. It is used to heat up thermal oil (280°C) which is partly used for the hot press and partly to generate steam for the pre-heating and refining. After giving heat to the thermal oil, the flue gas with a temperature of 380°C is either further cleaned and mixed with air (still called flue gas), or to a heat exchanger to heat up air for fibre drying. In the fibre drying either using flue gas or hot air as the drying medium, an exhaust temperature of 60°C from the dryer is taken to achieve the target fibre moisture content. However, when hot air is used for fibre drying, the flue gas is used to heat up the air and then vented from the heat exchanger at a minimum temperature of 150°C. Both of these temperatures are based on plant observations. The model is able to simulate the energy demand for either of the two drying methods. The thermal energy demand calculation from the heat and mass balances includes the following considerations:

- Heat input to bring wood chips, fibres and resin to the required processing temperature;
- Heat input to evaporate moisture in fibres and resin;
- Heat generated from mechanical action in the different unit operations driven by electricity;
- Heat released by the resin cure reaction;
- Heat loss to ambient due to insufficient insulation, delivery system and exhaust venting.

Electricity demand is quantified from the production rate in oven dry tonnes per hour (odt/h) and the specific electricity requirement (SER kWh/odt) of the primary equipment determined from an energy audit. Total plant electricity demand is divided between the primary equipment items based on the detailed energy audit. These power demands are scaled to the flow of woody material (in odt/h) through each unit operation as the basis for extending the model to other operating conditions. This assumption is not expected to introduce any significant errors.

3. RESULTS AND DISCUSSION

For the reference case with 120,000 m^3/yr production of regular grade of MDF, the model predicts a total thermal energy demand of 120 GWh in flue gas heat if direct flue gas is used for fibre drying or 136 GWh if hot air is used for fibre drying. The total electricity demand is predicted to be 37.7 GWh.

3.1. Energy demand by grade

The calculated energy and raw material demand per volume of MDF are given in Table 2. It shows that the lighter panel production consumes less energy and less logs, but needs more resin to achieve good internal bonding properties. The ratio of electricity to heat for all of the product grades is fairly constant at 0.32, which provides a good input for feasibility studies of a BIGCC system.

Table 2 Energy and Raw Material Demand for Various MDF Grades (flue gas for fibre drying)

MDF	UltraLight	Light	Regular	Thin
Electricity kWh/m^3	211	257	314	358
Heat kWh/m^3	684	822	998	1108
Logs m^3/m^3	1.13	1.62	2.01	2.27
UF solid kg/m^3	80	81	79	65
Ratio of electric to heat	0.32	0.32	0.32	0.32

As noted earlier, the model predicts the energy demand based on the energy consumption per tonne of dry fibre material processed in each unit operation. With the same production volume, higher density grades result in higher production weights. Therefore, the energy demand is proportional to the grade primarily through the density variation. However, in practice, annual MDF production is a mixture of grades rather than a single one. The proportion of each grade is determined by the market and the information is generally not available as input for the model.

Since the regular grade is usually the majority product and already used in the industry to analyse energy demand, it is used in this study as well.

3.2. Energy demand by unit operation

Thermal energy is mainly consumed by pre-heating and refining, fibre drying, and hot pressing as shown in Figures 2 and 3 for the two drying methods. Fibre drying is the biggest consumer taking 48% of the total thermal energy for direct flue gas drying and 54% for hot air drying. All of the additional thermal energy (16 GWh/y) is consumed by the fibre drying when air is used for drying, while thermal energy demand in the pre-heating and refining, and the hot pressing is constant. The higher energy demand with the hot air drying method is due to the fact that more heat is lost in the flue gas venting at 150°C. In some cases, this flue gas venting temperature can be as high as 250 to 300°C which will result in even higher heat consumption for hot air drying of the fibres (Allen et al 1988). Direct flue gas for fibre drying is a new technology, which can significantly reduce energy loss due to the lower flue gas exhaust temperature of 60°C. However, clean flue gas is needed to prevent the fibre contamination and darkening.

Electricity demand for each of the unit operations is shown in Figure 4. Pre-heating and refining is the biggest consumer with 44% of the total electricity demand. The electricity consumption for the other unit operations are fibre drying (20%), finishing (17%), mat forming and pressing (10%), chip preparation (4%) and miscellaneous (5%). The energy centre usually consumes 7-8% of the total electricity demand to drive the fans for air supply, the pumps for oil recirculation and the hydraulics for fuel feeding.

3.3. Wood residues and thermal energy self-sufficiency

Assuming all of the wood fibre comes from logs, a plant making 120,000 m^3/yr of regular grade MDF will generate wood residues of 25,691 odt/yr. The wood residues include bark, chip fines, trim-off, sander dust and panel rejected. Sander dust and

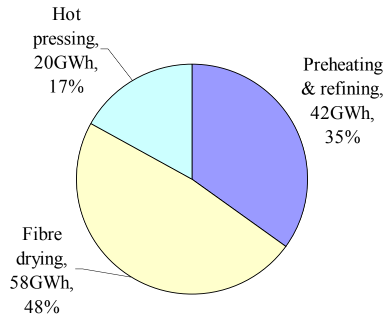

Figure 2 Annual Thermal Energy Demand by Unit operation Using Flue Gas For Fibre Drying

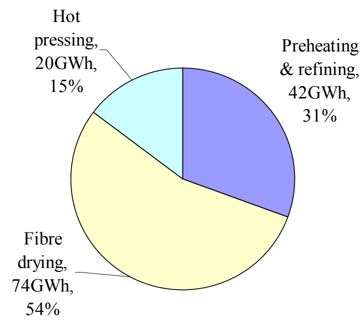

Figure 3 Annual Thermal Energy Demand by Unit operation Using Air For Fibre Drying

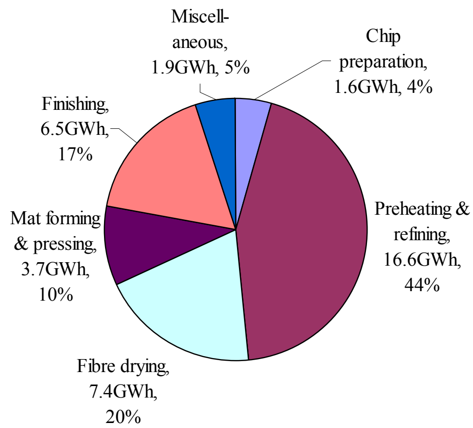

Figure 4 Annual Electricity Demand by Unit operation

bark account for over 50% of the total residues. Bark and rejected panel need to be further hogged before burning. Care should also be taken to control the moisture content (MC) to maintain stable furnace operation. Mixing of the various residues may be necessary to achieve a homogeneous MC within the required limits for combustion or gasification.

MDF generated wood residues have an energy value of 135 GWh/yr based on a calorific value of 19 MJ/odt for pure oven dry wood. Assuming 80% thermal conversion efficiency in a furnace, they can generate thermal energy of 108 GWh/yr in flue gas heat. This energy is able to provide 91% of the total requirements for direct flue gas fibre drying plants, or 80% for plants using air fibre drying.

3.4. Validation of thermal energy demand

Because the thermal energy demands are different in flue gas and hot air fibre drying, model validation is conducted separately for each case. The energy demand of MDF Plant 1 (flue gas fibre drying) is compared with the model result in Figure 5. The actual thermal energy demand is close, with the model result is 7% higher than the real plant. For the individual unit operation, the model predicts a lower thermal energy consumption in the pre-heating and refining but the thermal energy demands in both of the fibre drying and hot pressing are overestimated. Such differences are inevitable since for Plant 1, thermal energy data was statistically averaged over a year.

For the hot air drying method, Figure 6 illustrates the validation of the energy demand relative to three MDF plant references including Plant 2 detailed audit (French 2002), a draft plant design (personal communication) and a general plant reported by CAE (1996). Thermal energy demand simulated by the model is 5 to 28% lower than that for the plants. The lowest part of the prediction is in pre-heating and refining. This discrepancy is considered to be the result of heat generated from the mechanical action driven by electricity being counted in the model but not in either the draft plant design or the CAE reference. Nevertheless, the discrepancy is not considered to be significant as the energy demands vary for all the plants. In addition, Plant 2 audit included some information from discussions with engineering staff (French 2002) which may have caused errors. The general figure published by CAE is assumed to be a statistical value as there is no description of the data source or data collection method (CAE 1996). The energy demand for the draft plant design is higher than expected because of the safety factor usually present in such draft designs. Thus Plant 2 audit data is considered to be most reliable for the validation.

Electricity demand predicted from the model is validated with the audit results from three MDF plants as shown in Figure 7. It shows that the electricity demand of 314 kWh/m³ in the model has a discrepancy of only ±4% from the observed values of the three plants.

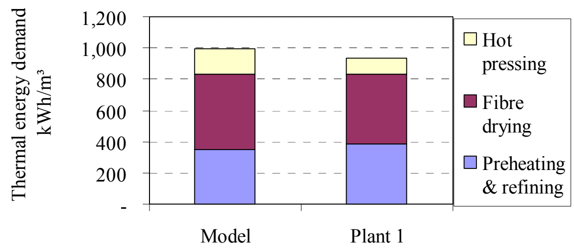

Figure 5 Validation of Thermal Energy Demand in Case of Flue Gas for Fibre Drying

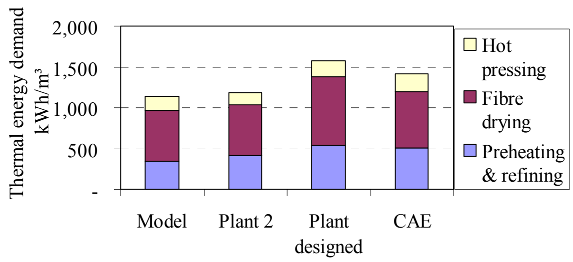

Figure 6 Validation of Thermal Energy Demand in Case of Air for Fibre Drying

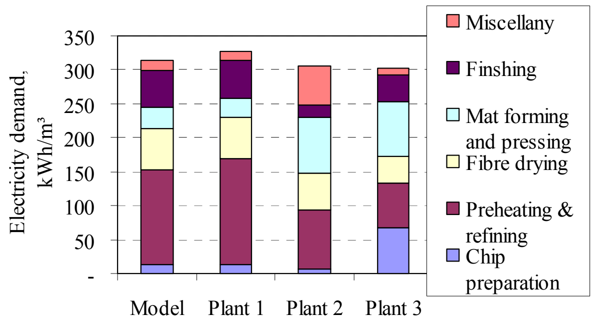

Figure 7 Validation of Electricity Demand

Although the overall demand is consistent, the comparison of electricity demand for individual unit operation reveals noticeable differences between the model prediction and the plant data. This is possibly due to the different ways of recording the data in the three plants. It is not surprising that the model result is compatible with that of Plant 1 as the primary equipment SERs in the model were based on the energy audit in this plant. Slight differences can be seen in the preheating & refining where a lower SER value for the refiner is used in the model. Energy demand for the wastewater treatment is counted in the model under the miscellaneous category.

4. CONCLUSION

An energy demand model is established for a commercial MDF plant. The heat demand is modelled theoretically based on heat and material balances, and operation conditions. The electricity demand was simulated based on the energy audit data of a commercial plant. The model inputs are MDF annual production, product grade, log moisture content, and fibre drying method. With the regular grade MDF, thermal energy demand is 1136 kWh/m³ when hot air is used for fibre drying and over 10% of thermal energy (138 kWh/m³) can be saved if direct flue gas fibre drying is used instead. Electricity demand is 314 kWh/m³ for both drying methods. At constant MDF production, energy demand increases for the higher density grades, but the ratio of electricity to heat demand is constant for all of the different product densities.

An MDF plant producing 120,000 m³/yr regular MDF, generates ~25,700 odt/yr wood residues including bark, fines, trim-off, sander dust and reject panel. Based on combustion of this residue, an air dried fibre plant is predicted to be 80% self sufficient in thermal energy while a flue gas dried fibre plant is predicted to be 91% self sufficient.

Validation of the model using energy audit results from commercial Plants 1 to 3 shows that model is able to simulate the energy demand with a discrepancy of -5 to +7% for thermal energy and ±4% for electricity. The developed model has great potential for energy management in an MDF plant and for feasibility studies in construction of a bioenergy plant.

5. ACKNOWLEDGMENTS

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