MOISTURE REMOVAL FROM GREEN SAPWOOD DURING PLATEN PRESSING

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ABSTRACT

The influence of initial degree of pore saturation (in the range 60–100%) and amount of compression (5–35% strain) on moisture expression and energy relationships during platen pressing of small rectangular blocks of sapwood from **Pinus radiata** D. Don and **Eucalyptus regnans** F. Muell. was investigated. The dependent variables were related to initial degree of pore saturation or initial moisture content and percentage strain by means of regression equations. Reductions in percentage moisture content ranged from 2% to 57% in **P. radiata** and from 0% to 62% in **E. regnans**. Energy ratios were greater in **P. radiata** (145–913) than **E. regnans** (46–622) and indicate the potential of compression drying in fuelwood production, especially for the pine.

Keywords: moisture content; compression; platen pressing; energy ratios; **Pinus radiata**; **Eucalyptus regnans**.

INTRODUCTION

Information on the process of removing water from wood by transverse compression is limited (Wingate-Hill 1983a). Haygreen (1981, 1982) studied compression drying of chip mats and small wooden blocks from the green undried wood of some North American species as a basis for developing commercial processes to upgrade the energy value of green wood-chip fuel. Jones (1982) developed a roll crusher for destructuring and dewatering residue wood in the forest. Wingate-Hill & Cunningham (1984a, b) assessed the potential of four Australian species for compression drying. Wingate-Hill (1983b) determined the extent of water removal and the influence of compression between platens of small *P. radiata* logs on pulping properties as part of a study to assess the value of a combined compression debarking, dewatering process for reducing pulpwood transport costs. All these studies on green wood showed that the important factors in compression drying are initial moisture content (IMC) or degree of pore saturation (S), amount of compressive strain, wood specific gravity, and the amount of strain which occurs before any moisture is expressed.

In the experiment described here water loss and energy input during platen compression of small specimens from *P. radiata* and *E. regnans,* were measured over a much wider range of S and strain combinations. The aim was to provide data, in the form of regression equations and three-dimensional graphs for assessment of the potential of compression drying to upgrade the energy value of fuelwood and/or reduce roundwood transport costs.

MATERIAL AND METHODS

The potential for energy-efficient removal of water from wood by compression is greatest in sapwood (Wingate-Hill 1983b), therefore green sapwood specimens were taken, cut to 20 × 20 × 60 mm, and conditioned according to the methods described by Wingate-Hill & Cunningham (1984a, c).

Degree of pore saturation (Wingate-Hill & Cunningham 1984a) was used as the basis for conditioning specimens because it is the proportion of the total pore space within wood occupied by water and, at the pressures applied, water was almost certainly removed from the pore spaces and not from the wood substance itself. Five nominal levels of initial percentage S were used – 60% (the lowest value likely to be found in freshly cut sapwood from *P. radiata* and *E. regnans* (Wingate-Hill & Cunningham 1984a), 70%, 80%, 90%, and as close to complete saturation as could be achieved, according to the method described by Bodig (1963). Strains (i.e., reduction in height of specimen/original specimen height), from 5% to 40%, in steps of 5% were imposed on *P. radiata* specimens; the upper limit for *E. regnans* specimens was 35%. Specimens were compressed on the tangential faces between flat platens at a deformation rate of 8 mm/min. Two specimens, each from a different tree, were tested for each initial S, strain, species combination. During compression the deformation/load graph for each specimen was plotted by an X-Y recorder.

RESULTS AND DISCUSSION

The ranges in initial properties and measured factors for the two species are listed in Table 1. Measured data were transformed into a number of ratios which are defined in the footnotes to Table 2. Percentage mass reduction (MR) is used because it may be significant in the transport of green wood (Wingate-Hill 1983b). Energy input per unit water loss (EI) and energy ratio (ER) are useful for comparing the energy efficiency of compression drying with other drying methods and for identifying those conditions where platen pressing is most energy efficient.

Over the 5–35% compressive strain range, the ranges in IMC reduction and MR were similar for the two species. Nevertheless, the EI is generally lower in *P. radiata*

TABLE 1—Ranges in initial* properties of **Pinus radiata** and **Eucalyptus regnans** sapwood blocks

Property	Pinus radiata	Eucalyptus regnans
Initial degree of pore saturation (%)	57–100	58–99
Initial moisture content (%)	77–133	96–160
Initial basic density (kg/m^3)	500–570	430–490

* "Initial" refers to the condition of specimens immediately before compression.

TABLE 2—Means and ranges in the measured factors for **Pinus radiata** and **Eucalyptus regnans** sapwood

Factors	**Pinus radiata** Compressive strain (%)*			**Eucalyptus regnans** Compressive strain (%)	
	5	35	40	5	35
Reduction in percentage moisture content†	2	57	70	0	62
Mass reduction (%)‡	1	26	31	0	25
Energy input per unit initial mass (J/g)§	0.1	2.1	2.7	0.2	2.8
Energy input per unit water loss (J/g)	3.0	16.6	16.6	4.6	62.7
Energy ratio‖	145	913	913	46	622

* (Reduction in specimen height/Initial specimen height) × 100.
† (Initial moisture content (%) - Final moisture content (%)).
‡ (Reduction in mass due to water loss/Initial mass of specimen) × 100.
§ (Area below load, deformation graph/Initial mass of specimen).
‖ (Increase in available energy due to water loss/Energy input to obtain water loss) (Wingate-Hill & Cunningham 1984a).

than *E. regnans* and the differences in ER values were even more marked. Thus compression drying is more energy-efficient in sapwood from *P. radiata* than that from *E. regnans.*

Regression equations fitted the derived data well (Table 3). The general shape of the surfaces represented by some of the equations is shown in Fig. 1–4. For simplicity, they are based on one initial specific gravity, 0.50; to find any required value of a variable listed in Table 3, within the ranges given in Tables 1 and 2, the appropriate regression equation should be used.

The regression equations for reduction in IMC and MR are of the same form but there is a marked difference in the shape of the surfaces represented by the equations for *P. radiata* and *E. regnans* (Fig. 1, 2). As strain is increased for a given IMC the increase in IMC reduction or MR is approximately linear. This is similar to Haygreen's (1981, 1982) data for a number of North American species.

S rather than IMC was used for the energy input relationships because the resulting regression equations accounted for a higher percentage of the variance in each case. EI of the specimens was not influenced to any appreciable extent by S, especially in *P. radiata.* Up to *c.* 30% strain the shape of the curves for a given S is similar to those presented by Haygreen (1982).

The general increase in EI as S is reduced was expected because as the amount of "free" water is reduced the strain required to remove more water increases. The indication of an optimum level of strain for minimum EI, especially at the lower levels of S, may be related to the fact that, except at 100% saturation, a certain level of strain has to be reached before any water is expressed (this is why all the strain axes start at 5% instead of 0%). Hence, before there is any water loss, the EI value is infinite

TABLE 3 — Regression equations

Variable	Species*	Type of equation†	Constants a	b	c	d	e	f	Percentage of variance accounted for
Reduction in percentage moisture content (ΔMC)	PR	1	–8.2825	1.0789	2.1772	2.8410			98.2
	ER	1	–19.1970	1.3171	4.4079	4.1032			95.6
Mass reduction (R, %)	PR	1	–6.5491	1.0436	1.6067	2.3065			98.5
	ER	1	–13.9698	1.1001	3.2957	3.9705			96.6
Energy input per unit initial mass (E, J/g)	PR	2	–1.44700	0.13858	–0.02348	–0.00144	0.00013	0.00000	98.2
	ER	2	–3.81860	0.17341	0.03941	–0.00204	–0.00025	–0.00017	97.9
Energy input per unit water loss (EI, J/g)	PR	2	6.18478	–0.05634	–0.07804	0.00064	0.00030	0.00049	89.0
	ER	2	9.36127	–0.16013	–0.08038	0.00099	0.00004	0.00141	95.6
Energy ratio (ER)	PR	2	1.69475	0.05501	0.08002	–0.00062	–0.00031	–0.00049	88.9
	ER	2	–1.48637	0.15502	0.08288	–0.00085	–0.00005	–0.00142	94.9

* PR = **Pinus radiata**; ER = **Eucalyptus regnans.**

† Equation 1: $\mathrm{Log}_e\,(\Delta MC + 1)$ OR $\mathrm{Log}_e\,(R + 1) = a + b.\mathrm{Log}_e\,C + c.\mathrm{Log}_e MC + d.\mathrm{Log}_e SG.$

Equation 2: $\mathrm{Log}_e E$ OR $\mathrm{Log}_e EI$ OR $\mathrm{Log}_e ER = a + bC + c.S + d.C^2 + e.S^2 + f.C.S.$

Where, C = compressive strain (%)

MC = moisture content (%)

SG = specific gravity

S = initial degree of pore saturation (%)

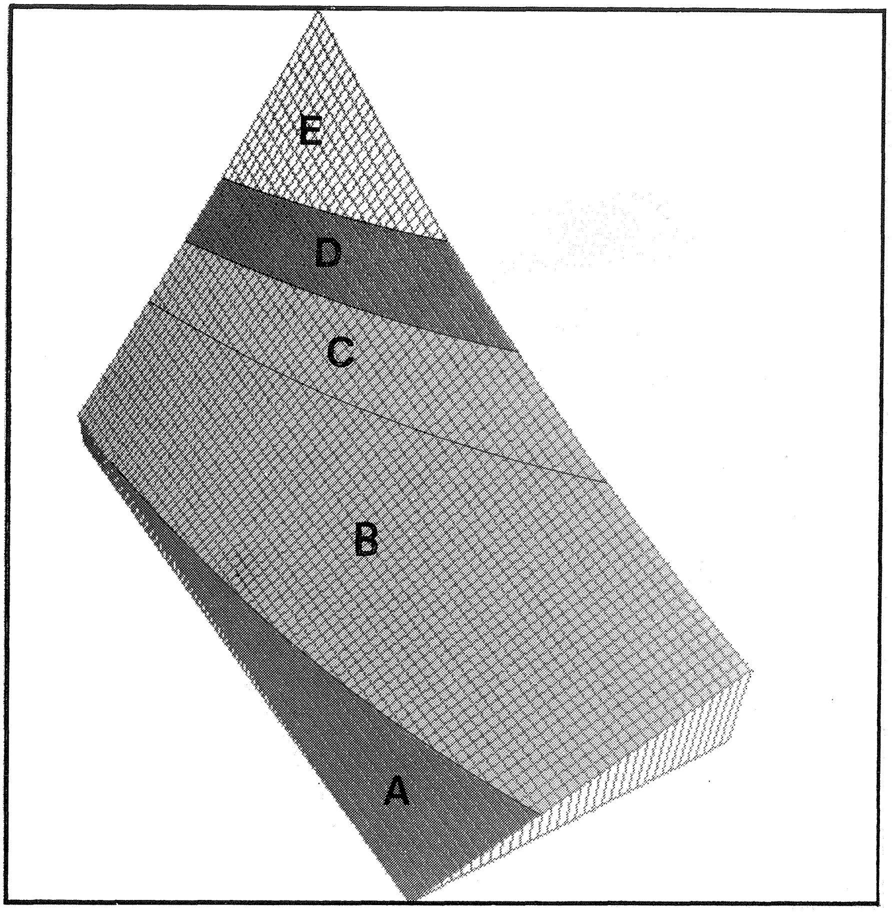

FIG. 1—Moisture content reduction surface during platen pressing of **Pinus radiata**: effect of changes in initial moisture content and strain. Reduction in percentage moisture content: A below 11; B 11–44; C 44–61; D 61–77; E above 77.

but as water loss increases with strain the ratio falls. However, since energy input also increases with strain, the negative slope of the EI strain curve is reduced, passes through zero, and then begins to increase.

Expressions for calculating the strain corresponding to minimum EI at a given S may be found by taking the parial differential with respect to strain of the appropriate regression equations (Table 3) and equating to zero, viz,

For *P. radiata:*

$$C_{opt.EI} = 44.09657 - 0.38405 \text{x} S$$
$$5 < C < 40, \quad 60 < S < 100 \text{ and,}$$

For *E. regnans:*

$$C_{opt.EI} = 80.99283 - 0.71503 \text{x} S$$
$$5 < C < 35, \quad 60 < S < 100$$

where C is percentage compressive strain.

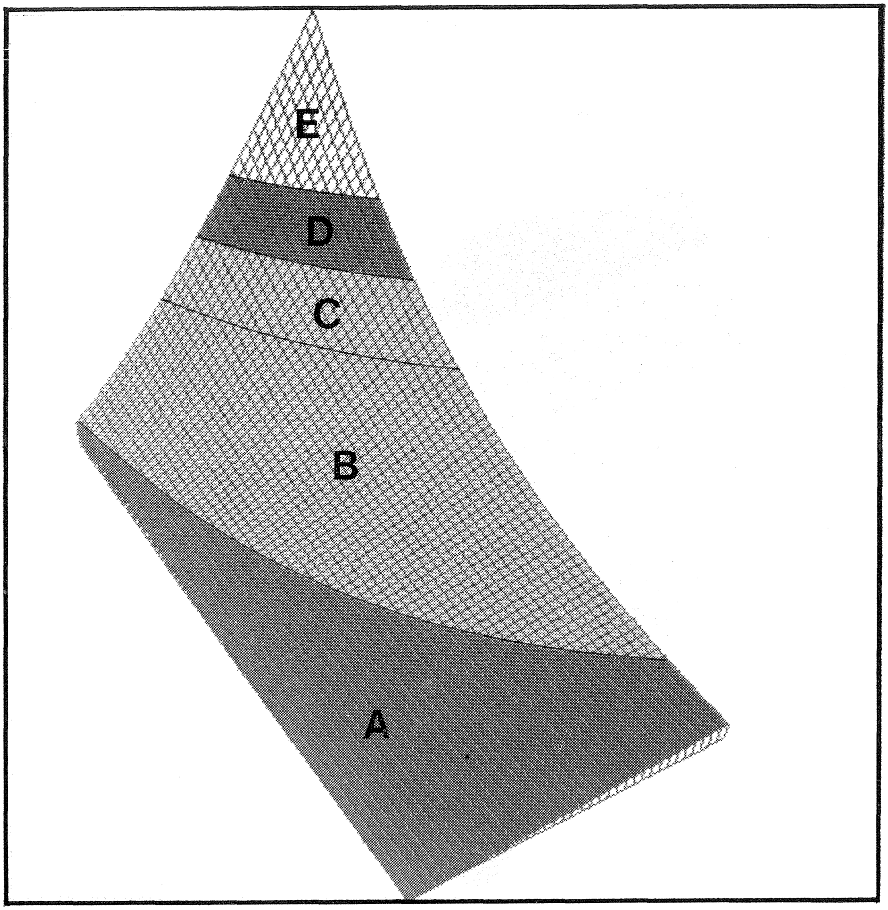

FIG. 2—Moisture content reduction surface during platen pressing of **Eucalyptus regnans**: effect of changes in initial moisture content and strain. Reduction in percentage moisture content: A below 13; B 13–65; C 65–90; D 90–116; E above 116.

The compressive strains corresponding to minimum EI are 21.1%, 17.2%, 13.4%, and 9.5% respectively for *P. radiata*, and 38.1%, 30.9%, 23.8% and 16.6% respectively for *E. regnans* for S values of 60%, 70%, 80%, and 90%. Haygreen (1982) presented EI strain graphs for white birch and balsam fir, each at two different IMCs. All four graphs show very definite minima for EI and the minima occur at lower strains in the higher density species (white birch) than in the lower density species. This same feature is also apparent here with *E. regnans* sapwood which is less dense than that from *P. radiata* (Table 1).

ER graphs are shown in Fig. 3 and 4. The ratios are generally very large, except at low S's, and indicate the potential for using compression to dry wood with high moisture content, e.g., freshly cut fuelwood. Haygreen (1981) also measured high ER values (67–240) when platen pressing loblolly pine, yellow poplar, and red oak to

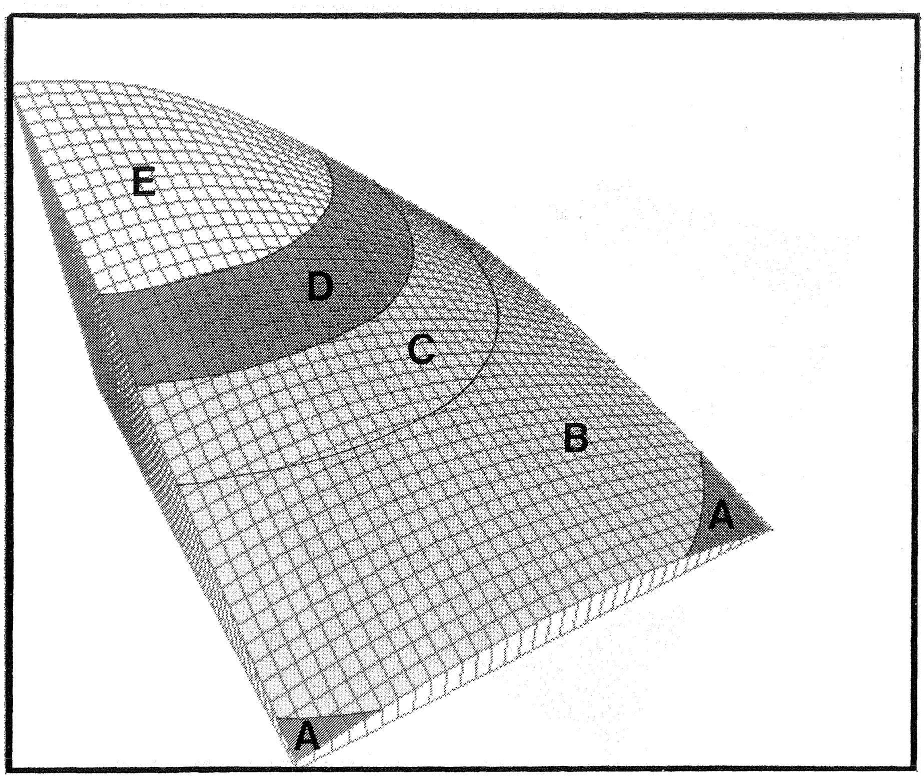

FIG. 3—Energy ratio surface during platen pressing of **Pinus radiata**: effect of changes in initial degree of pore saturation and strain. Energy ratio: A below 265; B 265–414; C 414–488; D 488–563; E above 563.

65% strain, although his method of calculating ER differed somewhat from that used here. Expressions for the strain corresponding to maximum ER may be derived in the same way as for EI. The equations for minimum EI and maximum ER at given S values are very similar and for practical purposes the strains are the same in both cases.

CONCLUSIONS

The EI values for *P. radiata* are generally lower than for *E. regnans* at a given S and strain, because of the tendency for the corresponding energy inputs in *P. radiata* to be lower and IMC reductions greater than those in *E. regnans*. Corresponding ER's are usually higher in *P. radiata* than *E. regnans* for the same reason. Hence, in general within the range of strains used in this experiment, compression drying of *P. radiata* sapwood is likely to be more energy-efficient than compression drying sapwood of *E. regnans*. Also, since sapwood generally forms a larger proportion of the stem in *P. radiata* than *E. regnans*, the benefits of compression drying will be greater in the pine. Nevertheless, the sapwood in the *E. regnans* logs used for this experiment formed a ring

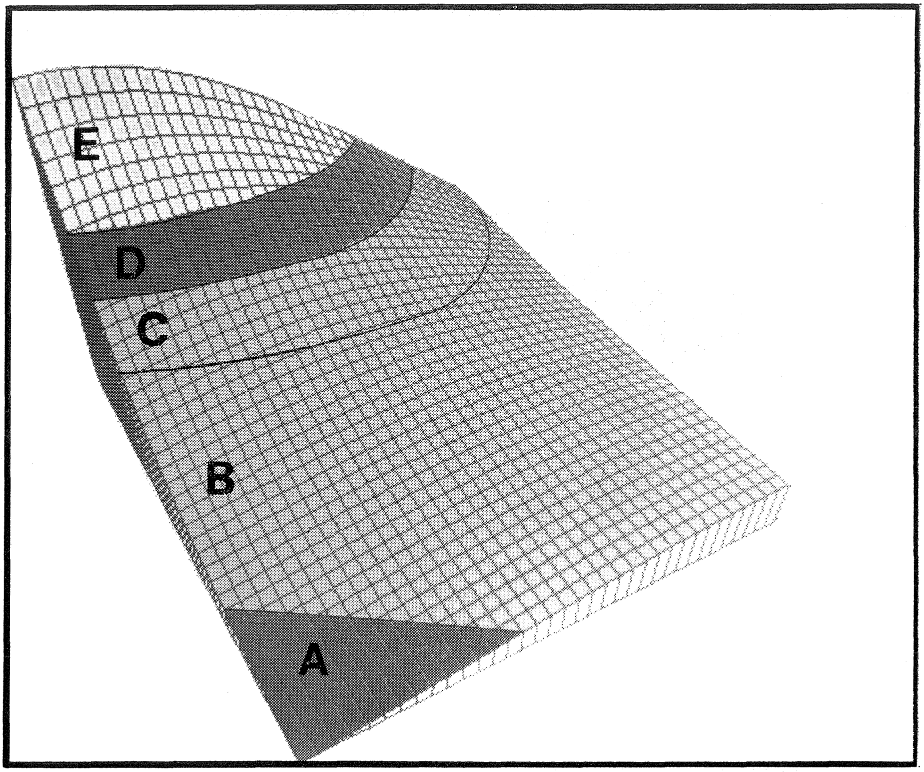

FIG. 4—Energy ratio surface during platen pressing of **Eucalyptus regnans**: effect of changes in initial degree of pore saturation and strain. Energy ratio: A below 76; B 76–230; C 230–307; D 307–383; E above 383.

c. 25 mm wide and this represented about one-third of the stem cross-sectional area. In addition, specific gravity decreases towards the pith in young *E. regnans* stems (Frederick *et al.* 1982) and heartwood moisture contents can be quite high (135%, mean for sixty 23-year-old trees, Hillis & Brown 1984) so there may be potential for compression drying young *E. regnans* stems or chips. Experiments on green *E. regnans* heartwood similar to the one described here need to be carried out before a firm conclusion can be reached.

Compression drying could be applied to logs from young trees (because of their relatively high moisture contents and low densities), or wood chips produced from these logs. Because of the high ER values compression drying is suited to fuelwood production, especially if used in the forest to take advantage of the mass reductions which ranged up to 25% and 30% in the *E. regnans* and *P. radiata* specimens, respectively. However, before the applicability of the process to pulpwood for reducing transport costs and/or energy requirements in pulping can be assessed, the extent and significance of any damage to the wood structure must be determined.

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REFERENCES

BODIG, J. 1963: A study of the mechanical behaviour of wood in transverse compression. Ph.D. thesis, University of Washington.

FREDERICK, D. J.; MADGWICK, H. A. I.; OLIVER, G. R. 1982: Wood basic density and moisture content of young **Eucalyptus regnans** grown in New Zealand. **New Zealand Journal of Forestry Science 12:** 494–500.

HAYGREEN, J. G. 1981: Potential for compression drying of green wood chip fuel. **Forest Products Journal 31:** 43–54.

——— 1982: Mechanics of compression drying solid wood cubes and chip mats. **Forest Products Journal 32:** 30–8.

HILLIS, W. E.; BROWN, A. G. (Ed.) 1984: "Eucalypts for Wood Production". CSIRO, Canberra.

JONES, K. C. 1982: Roll-crushing of wood. Sixth International Forest Products Research Society Industrial Wood Energy Forum '82. Vol. 1 Proceedings 7334: 132–6.

WINGATE-HILL, R. 1983a: A review of processes which involve compressing wood perpendicular to the grain. **Australian Forest Research 13:** 151–64.

——— 1983b: A process for reducing pulpwood transport costs. **CSIRO Division of Forest Research, Technical Paper No. 1:** 4–11.

WINGATE-HILL, R.; CUNNINGHAM, R. B. 1984a: Removal of moisture from green sapwood by compression. **Journal of the Institute of Wood Science 10(2):** 66–75.

——— 1984b: Compression drying of sapwood. **Wood Fiber Science 18(2):** 315-26.

——— 1984c: Preparation of wood specimens for compression tests parallel to the grain. **Journal of the Institute of Wood Science 10(2):** 91–3.