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MICROWAVE MODIFICATION OF THE PEELER CORES FOR PRESERVATIVE TREATMENT

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Abstract

The low permeability Radiata pine (*Pinus radiate D. Don*) heartwood often mitigates against its use in high decay hazards. Microwave (MW) wood modification increases heartwood permeability and improves preservative distribution and uptake. The experimental study of MW log modification and impregnation allows the rational determination of MW processing parameters to achieve high standards of treatment with an estimate of the effect of MW treatment on timber quality, such as strength and check formation. The costs of MW heartwood round timber processing are acceptable to industry and provide good opportunities for conveyor belt treatment options.

1. Introduction

The use of the softwood round timber in Australia (primarily Radiata pine), is limited by low durability and must be impregnated with preservatives to have high durability. The peeler cores (central part of the log left after veneer manufacturing) consists of heartwood, which is practically impermeable and preservative solutions do not adequately

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penetrate this timber. Microwave modification of wood structure can increase wood permeability and open new opportunities for increasing timber durability by impregnation with preservatives.

Green Radiata pine peeler cores have moisture contents ranging from 35 to 45% and readily absorbs microwave energy. Intense MW power applied to the wood generates steam pressure within the wood cells. Under high internal pressure, the weak ray cells are ruptured to form pathways for easy transportation of liquids and vapours in the radial direction (Vinden et al. [6]). Increase intensity of the MW energy applied to the wood increases the internal pressure, resulting in the formation of narrow voids in the radial-longitudinal planes and a several thousand-fold increase in wood permeability in the radial and longitudinal directions can be achieved in species previously found to be impermeable to liquids and gases (Torgovnikov and Vinden [4]).

The study of MW timber processing of softwood species for preservative impregnation showed that Radiata pine, Douglas fir, and Sitka spruce heartwood sawn timber can be MW modified and preservative treated according standard requirements (Torgovnikov and Vinden [5]). New MW technology for wood modification required the establishment of new techniques and MW equipment to provide the required degree of wood modification and satisfy the special demands of the timber industry. To achieve the required quality of wood modification for different applications, the MW equipment must have the ability to control the following operating parameters: frequency, MW intensity (flux), energy absorbed by wood, mode of energy application to wood (pulse or continuous), vector electric field strength "E" orientation relative to wood grain, energy distribution in timber cross section, MW applicator configuration, speed of timber through applicator, air flow parameters (temperature and speed), and MW leakage protection (Torgovnikov and Vinden [4]).

The aim of research described in this paper was to develop rational process parameters for achieving the required preservative distribution and uptake in round timber cross sections.

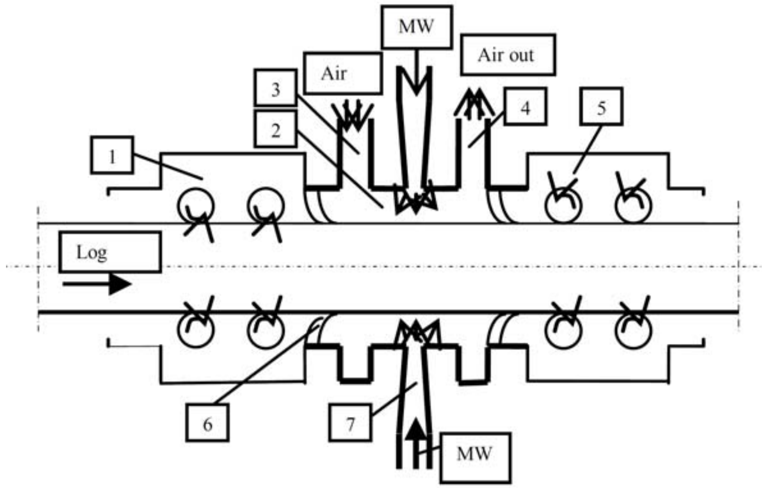
The research objectives included:

- An experimental study of MW interaction with logs using a three port MW applicator.
- A study of the effect of MW modification on preservative distribution and uptake in logs and determination of the rational process parameters of modification.
- Determination of the effect of MW modification on the peeler core strength properties.
- Economic assessment and recommendations for MW technology commercial application.

2. Material and Methods

Radiata pine peeler cores from plantation grown timber measuring 126-130mm in diameter by 2600mm long (280 logs) and 138mm in diameter by 2600mm long (29 logs) were used in experiments. Every log contained heartwood with different densities and moisture contents. Moisture content ranged from 18 to 36%. Oven dry density ranged from 373-468kg/m^3 with an average of 426kg/m^3.

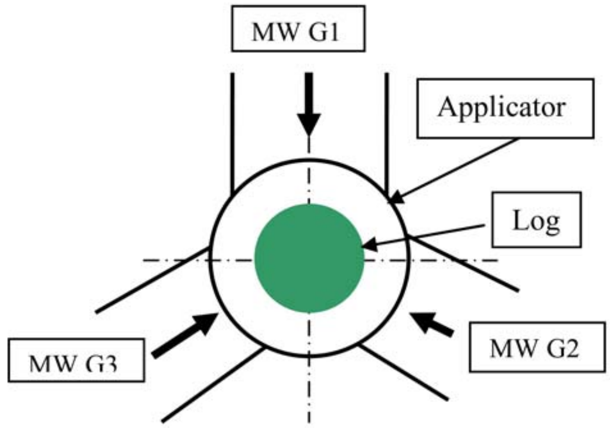
A 300kW MW plant (frequency 0.922GHz) was used for experiments (Figure 1). The plant was designed to handl round timber with diameters up to 300mm and 4700mm in length; output - 0.5-2.5m^3/h; MW power - 30-300kW; and feed speed - up to 8.5m/min. The key part of every MW plant is the applicator which must provide the required energy distribution within the timber. A three port MW applicator (350A) was used for log processing (Figure 2). It has an aluminium round body with a diameter of 350mm, a length 600mm, and three radiator inlets (waveguides with open ends 60 × 200mm) through which MW energy was supplied to the applicator from three generators (G1, G2, and G3) each with a maximum power output of 100kW. The MW applicator provided an electric field strength vector E orientation parallel to wood grain.



(a)

(b)

Figure 1. 300kW MW plant diagram (a) and, photo (b). (1) In-feed mechanism; (2) MW applicator; (3) air supply inlet; (4) air outlet; (5) out-feed mechanism; (6) MW suppressor; and (7) MW radiator for energy supply to the applicator.



(a)

(b)

Figure 2. MW applicator (350A) for round timber with power supply to the applicator via three ports (radiators). (a) diagram, (b) MW applicator photo.

During experiments, timber was held rigidly in the applicator and could be transported through the applicator at controllable speeds. Energy distribution within the timber was determined by measuring the temperature at different points across the timber cross section and along the log by means of thermocouples after MW heating the wood up to 80-100^{o}C. Temperature distribution in logs diameter 128-130mm along the radius (from the centre to the surface) measured in the vertical plane of the radiators middle in the log centre, at the half radius (R/2) and at 10mm distance from the log surface. Temperature increase along the log was measured in timber cross sections along the log up to 1000mm in both directions from the centre of the radiator.

MW power applied to the logs ranged from 66 to 130kW measured by power meters during timber processing. MW energy applied to the logs ranged from 79 to 126kWh/m^3. The average MW intensity (flux) in the radiator cross section 60 × 200mm ranged from 1830-3600kW/m^2. Specific MW power released in the log modification zone ranged from 9000 to 12600kW/m^3. The required log speed was provided through a variable speed drive ranging from 14 to 30mm/sec. Vapours and water released from the wood during the modification were removed from the applicator by using 90-110^{o}C air flow with a velocity 16m/s.

Two types of the preservatives were used in these experiments: CCA (copper-chrome-arsenic) and creosote. For CCA treatment, the following schedule was used: initial vacuum – 85kPa for 20 min, pressure 1300kPa for 20 min, final vacuum – 85kPa for 20 min. Preservative uptake was used as an indicator of the wood permeability for liquids (peeler cores were weighted before and after impregnation). After treatment, the preservative distribution was determined by copper spot test reagent Chrome Azurol-S (CAS). The presence of copper was identified as a black or blue colouration on the cross section of peeler cores.

Creosote (density 1.08kg/l) treatment of the sleepers was done using a commercial schedule at a treatment plant at Carter Holt Harvey's Mt Gambier mill. Treatment was afforded using a schedule that consisted of an initial air pressure of 350kPa (6 min), an impregnation pressure of 1400kPa (12 min) and a final vacuum of – 75kPa (35 min).

The following MW process variables were used for MW log processing: MW power and intensity, MW energy consumption, speed of the timber in the applicator. Electric field strength vector E orientation was parallel to the wood grain. Peeler core modification quality was determined by examining preservative distribution in the cross section; preservative uptake; check distribution in cross section and along the length; log shape changes and strength properties.

Peeler core bending strength and stiffness were tested by the Salisbury Research Centre (Queensland, Australia) according to the methods specified in Australian Standard AS/NZS 4063 [1]. Testing details were as follows: load was applied and measured with a Shimadzu 30 tonne universal testing machine; deflection was measured at centre span with a Type MLT displacement transducer; bending test span – 2070mm with load applied at third points: specimens were loaded at random orientation; localised crushing was avoided by supporting the specimens in semi-circular cradles mounted on each loading support.

3. Results and Discussion

3.1. MW processing

Experiments with the 350A applicator allowed an estimate the energy distribution in the log cross sections and along the log. After MW heating of the logs, the maximum temperature occured in the centre of the log (Figure 3) opposite the centre of the radiators. And a zone of the temperature increase spreads along the log up to 800mm in both directions from the centre of the radiator.

Temperature distribution in logs along the radius (from the centre to the surface) measured in the vertical plane of the radiators middle in the log centre, at the half radius (R/2) and at 10mm distance from the log surface showed that temperature in the area centre (0)-R/2 has almost same values and in the area R/2-R (surface) temperature reduces.

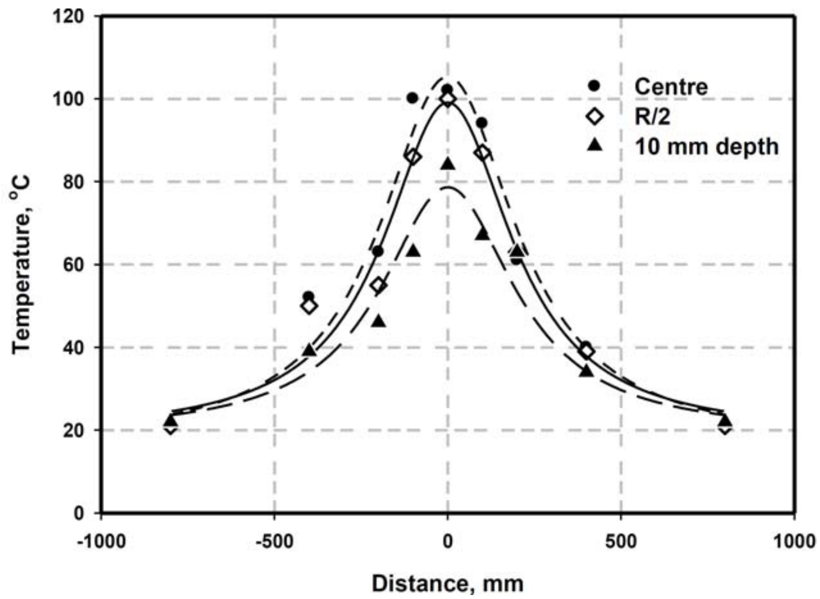


Figure 3. Temperature distribution along the log (diameter 128mm, moisture content 28%, oven dry density $401 kg/m^3$) after heating during 20 second in applicator (350A). MW power was supplied via 3 radiators each with 10kW of power, vector E orientation is parallel to the wood grain in all ports. 0 – plane of the radiator centre.

Thus, the energy release in the log core (centre – R/2) was much higher compared to the shell areas and did not provide the required uniformity of the energy distribution. Therefore, more energy needs to heat up the shell area to the temperature of 120-127°C. This is the minimum required for increasing wood permeability.

Practically, all of the applied energy was absorbed in the log length 1600mm. The central zone (200mm) absorbs 35% and 400mm zone – 60% of supplied MW energy. MW modification takes place mainly in the zone length 200mm along the log. This means that for good modification of the heartwood in Radiata pine (with moisture content 25-40% and oven dry density $400\text{-}450 kg/m^3$) the minimum required specific energy release is $9000 kW/m^3$. The applicator (350A) can provide the required MW energy distribution and concentration needed for wood modification.

The effect of the log speed in the range 14 to 30mm/sec on the degree of wood modification at the same applied energy and specific MW power release in the range 9000 to $12600 kW/m^3$ was negligible. This can be explained by the high variability in log properties: different wood moisture contents and density in the timber cross sections and different wood dielectric properties.

During MW modification every log lost moisture by evaporation and by water removal in the form of liquid by internal pressure via log ends, surfaces and cracks and also in the form of small drops from small micro-steam explosions. At initial moisture content ranging from 22-30% and applied MW energy $90\text{-}110 kWh/m^3$, the MC losses after MW processing range from 12-19% MC.

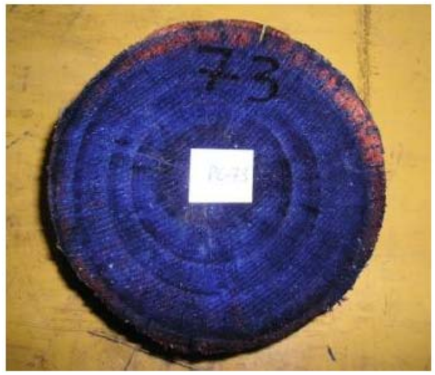
3.2. Log quality

MW modification does not produce significant changes in the size and shape of the logs. There are no end splits greater than 40mm long. About 90% of the MW modified logs have surface check widths no grater than 2mm. MW modification ruptures some elements of the wood structure and reduces the strength of the timber. Torgovnikov and Vinden [4] reported moderate levels of microwave modification resulting in strength losses of 4-26%. The difference in modulus of elasticity and modulus of rupture of MW treated and non MW treated peeler cores was not identified. Strength tests of 30 MW treated peeler cores with applied MW energy 111kWh/m^3 showed the average log modulus of elasticity at MC = 21.7% was 6.6GPa with a variation coefficient of 27.2%. The modulus of rupture was 31.9MPa with a variation coefficient of 23.5%. The Radiata pine peeler cores can be rated grade F7 according to Australian Standard AS1720 [2].

3.3. Preservative treatment

Spot-testing of preservative penetration following MW modification and pressure impregnation with CCA is summarised in Figure 4. From the point of the preservative distribution 90-95% of logs had full cross section preservative penetration. Preservative uptake was used as an indicator of the wood permeability for liquids.

CCA



(a)

(b)

(c)

Control

(d)

(e)

Creosote

(f)

(g)

Figure 4. Log cross section impregnated by preservatives after MW modification and controls.

Copper-chrome-arsenic (CCA): (a), (b), (c) MW treated - full cross section preservative penetration; (d), (e) control, only some areas are preservative treated. Creosote: (f) MW treated - full cross section preservative penetration; (g) control, only some areas preservative treated.

3.4. Preservative uptake

Average CCA uptake of MW modified timber was $326 l/m^3$ with variation coefficient of 12.3%. For control logs, CCA uptake was $35 l/m^3$ with a variation coefficient of 31.8%. The log uptake increases 9.3 times after MW processing.

According to Australian Standard AS 1604.1 [3], Hazard class H6, retention requirements of timber needs a minimum of $160 kg/m^3$ of creosote. The retention of the samples was 150-$173 kg/m^3$ compared to controls that have uptakes of $51 kg/m^3$. MW modification provides creosote uptake increases about 3.2 times and close to the Hazard class H6 requirements. Thus, MW modification provides very significant heartwood permeability increases. MW processing allows for the required preservative uptake and full cross section preservative distribution.

Increases in MW energy supplied to the logs (from 90 to $110 kWh/m^3$) did not show significant increase in CCA solution uptake or improvement in preservative distribution. This can be explained by the significant variability in wood moisture content, density, and resin quantity in the wood. The minimum applied MW energy needed to provide full log cross section of water based preservative penetration is $90 kWh/m^3$ applied at a frequency 0.922GHz.

3.5. MW processing parameters

The main MW parameters need to achieve full cross section peeler core modification using a three port MW applicator are as follows: applied MW energy at frequency 0.922GHz - $90 kWh/m^3$, specific MW power release in the wood - in the range 9000 to $12600 kW/m^3$, electric field strength vector E orientation - parallel to wood grain, mode of energy application to wood - continuous. Temperature of the air flow in the applicator needs to be 90-100°C with a velocity between 10 to 20m/sec. These MW parameters for processing Radiata pine peeler cores can be used (from other research undertaken by authors) for other softwood species. These include Douglas fir (*Psevdotsuga taxiflolia),* Sitka spruce (*Picea sitchensis*), Hemlock (*Tsuga heterophylla*), and Yellow Pine (*Pinus ponderosa* Dougl.).

The power requirements of an MW plant is determined by the required commercial plant output. For example, if plant output is $4\text{m}^3/\text{hour}$ (or $24000\text{m}^3/\text{year}$ at 3 shifts per day) a required MW power of the plant will be $90(\text{kWh/m}^3) \times 4(\text{m}^3/\text{hour}) = 360\text{kW}$.

3.6. Costs of MW wood modification

A costing of MW wood modification is presented below. The assessment is based on technical data from experiments and tests and world-wide prices for the MW equipment.

Figure 5 provides a cost analysis for MW peeler core treatment under the following conditions:

(1) MW plant output: $24{,}000\text{m}^3/\text{y}$ at 6,000 working hours per year (3 shifts per day), 4m^3/hour; $16{,}000\text{m}^3/\text{y}$ at 4,000 working hours per year (2 shifts per day), $4\text{m}^3/\text{hour}$.

(2) MW power of the plant 360kW.

(3) MW plant at frequency 0.922GHz costs AU$1,428,000.

(4) Microwave plants work automatic (no operator) or with operator (one worker per shift).

(5) Electric energy consumption at frequency $0.922\text{GHz-}113\text{kWh/m}^3$.

(6) Electricity cost range AU$0.06/kWh to AU$0.12/kWh.

(7) Depreciation rate 17%.

The estimated specific costs include costs associated with capital, maintenance, magnetron replacement, labour, floor space cost, and electricity costs. These costs do not include costs of mechanical installation, electrical connections, on costs (overheads), and taxes.

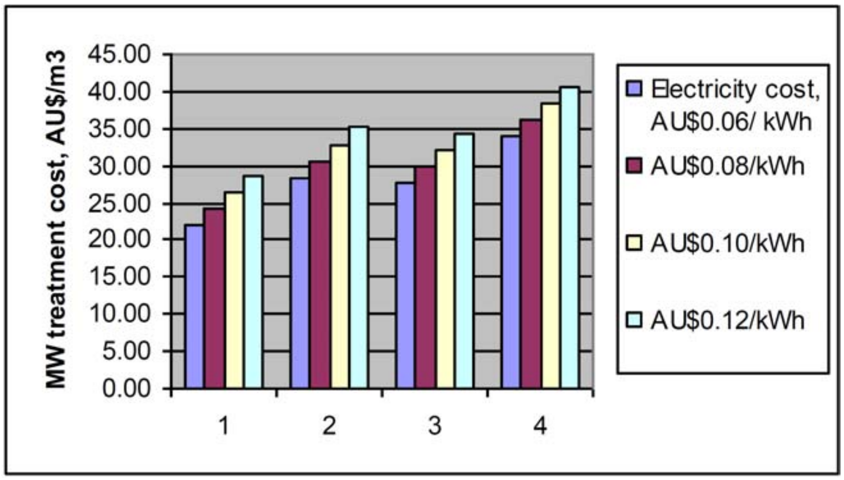


Figure 5. MW log processing costs depending on plant output and electricity costs (frequency 0.922GHz). (1) Automatic plant, three working shifts per day, output 24,000m^3/year; (2) automatic plant, two working shifts per day, output 16,000m^3/year; (3) one plant operator per shift, three working shifts per day, output 24,000m^3/year; and (4) one plant operator per shift, two working shifts per day, output 16,000m^3/year.

The calculations show that the MW processing costs for an automatic plant with a frequency of 0.922GHz and electricity costs of AU$0.06/kWh compared to AU$0.12/kWh increase from AU$22.0/m^3 to AU$28.8/m^3 (three working shifts per day) and from AU$28.3/m^3 to AU$35.1/m^3 (two working shifts per day). The increase in electricity costs (from AU$0.06/kWh to AU$0.12/kWh) leads to an increase in MW processing costs from 24 to 31%. For MW plant operated by a worker, MW processing costs increase from 16 to 26% compared to automatic plant. The MW processing costs for Radiata pine heartwood are reasonable and acceptable for industry.

4. Conclusion

MW peeler core modification increases heartwood permeability enabling the treater to achieve the required quality of preservative treatment with different preservatives. The MW treatment increases heartwood Radiate pine permeability (based on uptake increase) for creosote and water based preservatives by 3.2-9.3 times, and facilitates full cross- section preservative distribution.

Experimental study of the energy release in the log cross section after processing by a three port MW applicator showed acceptable uniformity of the temperature distribution for wood moisture content ranging from 22-36%. Practically, all of the applied energy was absorbed in the log length 1600mm. The central zone (200mm) absorbs 35% of supplied MW energy. MW modification takes place mainly in the zone length 200mm along the log. The study demonstrated the suitability of a three port MW applicator for peeler core processing and allowed rational MW process parameters to be determined, together with the effect that MW processing has on the quality of preservative impregnation.

MW modification ruptures some elements of wood structure and leading to some timber strength reduction. Strength tests of 30 MW treated peeler cores showed the average log modulus of elasticity (at MC = 21.7%) was 6.6GPa with a variation coefficient 27.2%. The modulus of rupture was 31.9MPa with a variation coefficient of 23.5%. The peeler core can be rated as grade F7 according to Australian Standard AS1720 [2].

The MW energy required for modification depends on wood density and wood moisture content. MW energy required at a frequency 0.922GHz for full cross section modification at timber moisture content 22-36% and oven dry density about 430kg/m^3 is 90kWh/m^3. The MC losses after MW processing are approximately 12-19% MC.

Economic calculations made on the basis of this research showed that the costs of Radiate pine peeler core modification are in the range AU$22-35/m^3 at electricity cost range AU$0.06 - 0.12/kWh. These costs of MW timber processing are acceptable for industry and provide good opportunities for commercialization of the new MW technology.

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