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Movement of borates in a range of timber species at various moisture contents

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Abstract

Borate-based wood preservatives are used in industrial pre-treatment as well as remedial treatment of timbers *in situ*. In both of these areas, understanding the mobile nature of these compounds is important in optimizing the main benefits of borates. Considerable work has been conducted on movement of borates in dip-diffusion treatment of freshly felled wood, as well as focusing on subsequent diffusion following remedial application to dry timber. This paper sets out to review the existing body of data of borate movement in wood, in the context of more recent research findings.

Data are presented which show that the movement of borates, up to 6 months after dip treatment of a range of commercially important softwoods, is highly dependent on wood moisture content. Moisture content is of such over-riding importance that the identity of a particular timber species has an insignificant effect on borate movement, provided a minimum moisture content is attained. This observation is despite the fact that species as diverse as Douglas fir, Hem-fir, Southern Yellow Pine, Scots Pine and Norway Spruce were used in this study.

It has been suggested that there must be free water in the wood cell wall voids for significant diffusion of borate to occur. However, the precise influence of decreasing moisture content on the rate of borate diffusion is unclear. The data presented in this paper contribute to a more comprehensive understanding of borate movement at moisture contents representative of those seen in timber post-treatment and in-service. In addition, the importance of backing up results from colorimetric spot tests with detailed measurement by analysis is illustrated.

Keywords: Borates, Diffusion, Douglas fir, Hem-Fir, Norway Spruce, Scots Pine, Wood moisture content

Introduction

During their early years as wood preservatives, stand-alone borates were almost exclusively applied as dip-treatments of green timber. As the use of borate wood preservatives has widened, other application methods have been adopted, including pressure impregnation, of dry timber in particular. This latter application technique is of increasing commercial interest and data in this area is emerging (Lebow & Morrell, 1989; Morrell & Lebow, 1991). However there is still a bias in perception towards the movement of borates in the 'dip-diffusion/green timber' scenario, i.e. with wood moisture contents at or above 50% w/w (Warren *et al.*, 1968; Smith & Williams, 1969; Puettmann & Schmidt, 1997). Thus, barring studies which have looked at borates applied as remedial timber treatments (Morrell *et al.*, 1992; Morrell *et al.*, 1994; Highley *et al.*, 1994; Robinson & Barlow, 1993), relatively little is known about the behaviour of diffusible salts at low wood moisture contents (10-30% moisture content). This paper presents data on diffusion of borates in five 'dry treated' softwood timbers under various moisture regimes and investigates the practical implications of these findings. In particular, the potential effects of diffusion on sampling are discussed.

Materials and methods

Pieces of wood were prepared for the study by end-sealing 30 cm long (approx. cross-section 40 mm x 80 mm) portions of timber of the following species:

Douglas fir (*Pseudotsuga menziesii*)	Heartwood
Western Hemlock (*Tsuga heterophylla*)	Heart/Sapwood
Southern Yellow Pine (*Pinus ellotii* and related species)	Sapwood
Scots pine (*Pinus sylvestris*)	Sapwood
Norway spruce (*Picea abies*)	Heart/Sapwood

The timbers were chosen as representative of construction material in North America and Europe. Generally, the samples were comprised of predominantly sapwood, except in the case of Douglas fir which is typically a heartwood species, i.e. most of the commercially utilised cross-section is comprised of heartwood.

The pieces were each dipped in a 5% w/v aqueous solution of disodium octaborate tetrahydrate (DOT, commercially available as *Tim-bor*) and uptake was recorded as change in sample weight. Following dipping, the specimens were left overnight at 22°C and then left under one of the following conditions:
- Wrapped in polythene and stored indoors at 22°C;
- Placed in a sealed container, over water to achieve 100% relative humidity (22°C);
- Placed outdoors under cover and above ground (Guildford, UK ambient conditions).

Each wood species/exposure combination was replicated with five specimens.

Periodically, slices were taken from randomly selected pieces in each group. These slices were then assessed for boron penetration by spraying the freshly-cut cross-section with curcumin indicator (Smith & Williams, 1969). Penetration was visually assessed 20 minutes after adding the spot-test reagents and involved recording the extent of boron penetration at six points (evenly spaced around the circumference of the cross-section) into the timber piece. Approximate moisture contents were obtained by using a moisture meter.

Results

Figures 1 to 5 show movement of boron into the timbers with time. Average moisture contents for the 60-day duration of the study are also given. Generally, the wrapped and outdoor pieces were at 10% moisture content (MC, percentage weight basis) and the specimens stored in the humidity chamber attained 25% MC.

In all cases, movement of boron into timbers stored at 100% RH was much more rapid than those kept outside or polythene-wrapped in the laboratory. However, this difference tended only to become pronounced after 30 days and was most marked in the two European softwoods (Scots pine and spruce) and, to a lesser extent, the hem-fir. In all cases, but most obviously in the European timbers, there was a rapid rate of movement initially, followed by reduction or even 'leveling off' in penetration rate.

Fig. 1 - Penetration of DOT into Douglas Fir

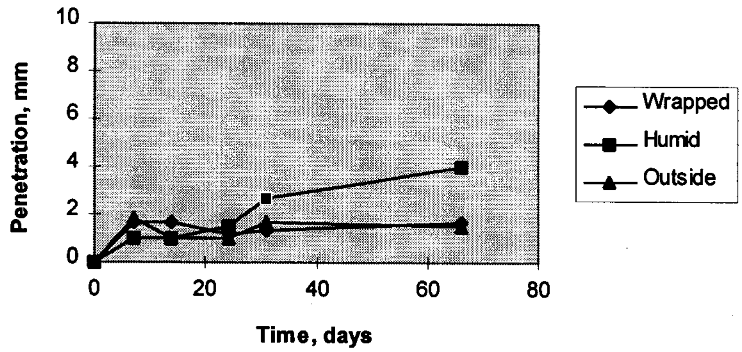


Fig. 2 - Penetration of DOT into Hem Fir

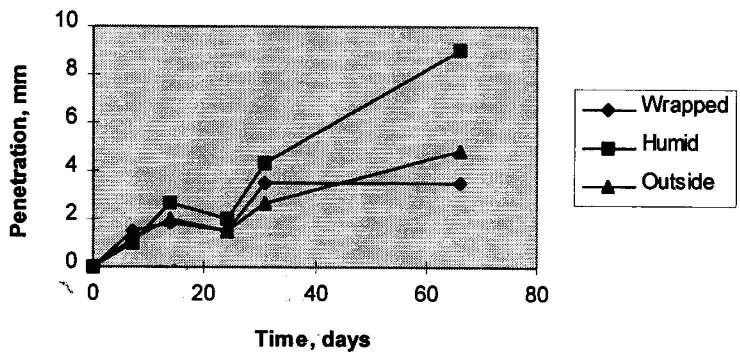


Fig. 3 - Penetration of DOT into Southern Yellow Pine

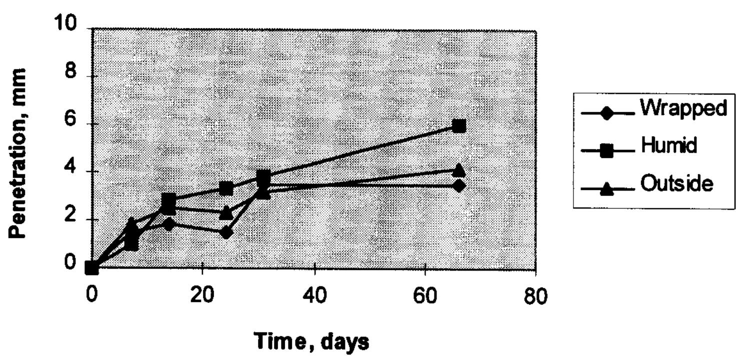


Fig. 4 - Penetration of DOT into Scots Pine

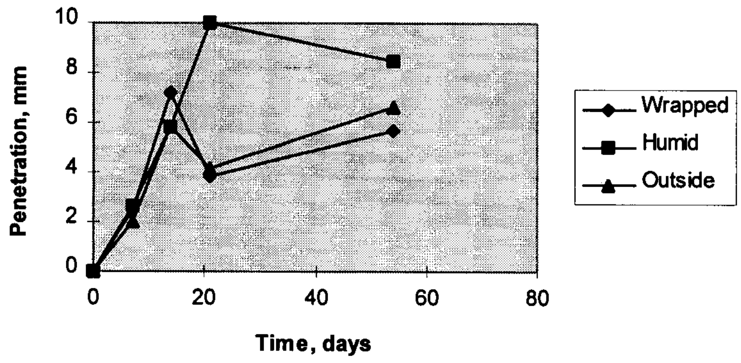
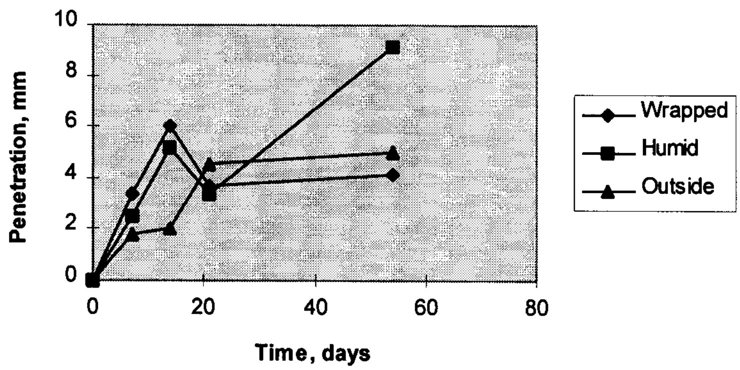


Fig. 5 - Penetration of DOT into Spruce

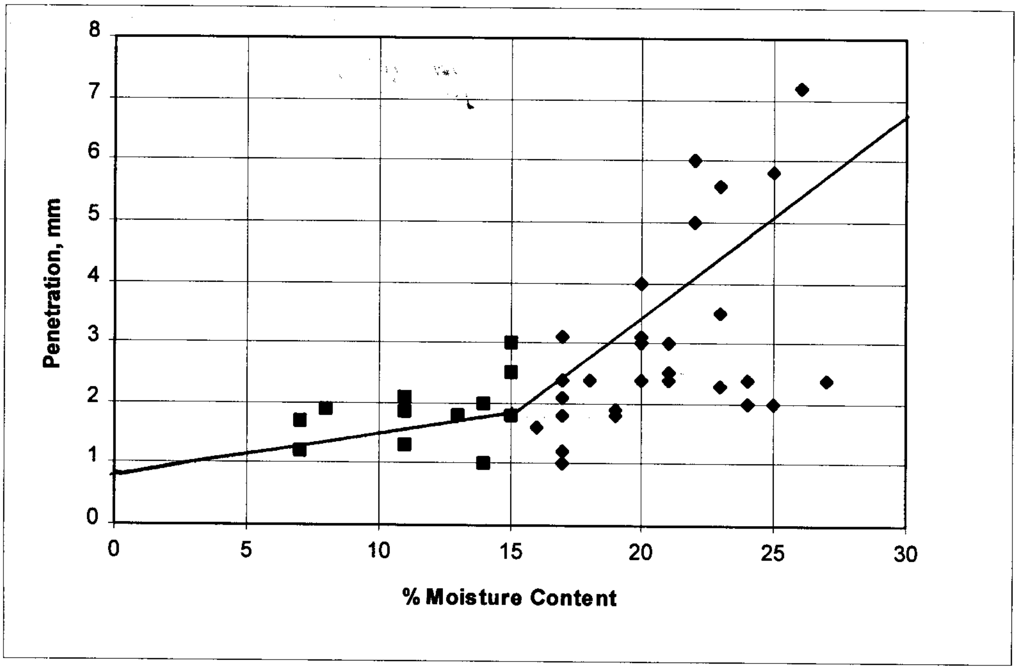


Discussion

In wood, diffusion of soluble species occur predominantly in liquid in interstitial cell wall voids and cell lumina (Eaton & Hale, 1993). Thus it is well established that diffusion will be significantly reduced at wood moisture contents below the fibre saturation point (26% MC). In the current study, diffusion was generally very slow in the wood pieces stored outside or in the laboratory (wrapped) and rapid in material stored at 100% RH and close to, or at, the fibre saturation point. Interestingly, over the first week of the study, all of the wood pieces exhibited the same initial rate of penetration. This is likely to be due to the water in the DOT solution increasing the moisture content of the outer 5 mm of the cross-section, and the potential effects of initial adsorption.

Plotting all of the data from this study on one graph of penetration against moisture content (Fig. 6) it is apparent that there is a clear point of inflection at a moisture content corresponding to 15%. This is probably the result of a rapid initial penetration of boron, largely irrespective of wood moisture content, followed by subsequent diffusion which is significant only at moisture contents above 15%.

Fig. 6 Penetration in all wood species after 6 months at various moisture contents. Lines of best fit plotted for <15% moisture content (■, $R^2 = 0.43$) and for >15% moisture content (◆, $R^2 = 0.52$).



Even when the wood moisture content is conducive to diffusion, with the retentions used in this investigation, the rate of penetration drops off after 4 weeks. This is because the second pre-requisite for diffusion, apart from the existence of pathways for transfer, is an adequate concentration gradient. As diffusion occurs from regions of high concentration to low, the concentration gradient is gradually run down, resulting in ever diminishing rates of diffusion (obeying Fick's first law: the rate of this diffusion is directly proportional to the concentration gradient). On a practical note, this also means that it is increasingly difficult to assess penetration by colorimetric methods such as curcumin. The curcumin reagent reveals the presence of boron at between 0.15 and 0.20% BAE (boric acid equivalent). At this threshold level, the cut off point in the positive (red) reaction is often blurred, especially in material in which the boron has been allowed to diffuse for some time.

Thus, in this study, it was actually the movement of a 0.15-0.20% BAE front which was being assessed rather than boron penetration *per se*. Comparison of curcumin and analytically-derived data suggest that absolute boron penetration is up to double that observed by curcumin reagent (Table 1). Note that levels of boron sufficient to control most wood destroying organisms (0.10%) are frequently recorded at depths beyond the limit of curcumin detection.

Table 1 Comparing penetration of boron by analysis and visual assessment with curcumin. Samples were assessed for penetration by curcumin spray of the cross-section and ICP (Inductively Coupled Plasma Atomic Emission spectroscopy) analysis of extracts taken from wood at 1.5mm intervals into the wood.

Wood species	Detection of boron	Region measured in (expressed as depth from surface, mm)				
		0-1.5 mm	1.5-3.0mm	3.0-4.5mm	4.5-6.0mm	6.0-7.5mm
Scots pine SW*	Curcumin					
	ICP (%BAE)	2.71	1.96	1.37	0.61	0.26
Spruce SW	Curcumin					
	ICP (%BAE)	4.25	1.35	0.54	0.19	not measured
Spruce HW	Curcumin					
	ICP (%BAE)	2.50	0.56	0.40	0.10	not measured

*sapwood = SW, heartwood = HW

Conclusion

From the data presented, it is confirmed that moisture content of the wood is of over-riding importance to borate movement in wood. Differences in wood species do occur but this is apparently related to the ease with which they equilibrate to wood moisture contents above 15%. In instances where the wood moisture content is maintained below this level, the impact of post-treatment redistribution after the first week is likely to be low.

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