WOOD PRESERVATION RESEARCH:A BRITISH PERSPECTIVE

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Mr. Chairman, Ladies and Gentlemen,

Thank you, Mr. Chairman, for your kind introduction. May I begin by expressing my thanks to the Association for your kind invitation to come to this fine city and give the Keynote Address. You have done honour, not only to me, but to the members of the research team in London to which I belong.

First, I bring you greetings from the President, Council and Members of the British Wood Preserving Association, who have asked me to express to you their wishes for the continued success of your Association.

When I was seeking advice as to the subject of this Address it was suggested that I might give some account of the work we are doing at Imperial College. So, with a short introduction to outline some of the important background considerations we have to keep in mind, I will attempt to give you some idea of our areas of interest and such progress as we have managed to make within them. Therefore, like Montaigne in Lord Wavell's translation,

"I have gathered a posy of other men's flowers
And nothing but the string that binds them is mine own".

Britain, as you well know, has been for centuries a wood importing country. Wood and wood products are our second biggest national import, of which, in 1982, solid wood constituted 37.5%, board materials and panel products 28% and newsprint, paper and wood pulp 34.5%. For many years, over 90% of our requirements have come from overseas. This was mainly due to historical developments, including the advent of the days of Empire; the land clearance to support the population expansion following the industrial revolution; and the increased demands of agriculture in the relatively small land area of the British Isles. Two world Wars amply and horrifically illustrated the vulnerability of these overseas supplies and has led, during the last sixty years, to a re-afforestation programmme, which, although still small with respect to our overall requirements, has begun to be an increasing source of softwood lumber.
Traditionally Scots pine or European redwood has been the major softwood species used in the U.K. However, spruce, particularly Sitka spruce, has been found to be one of the best species for fast growth under British conditions and consequently, today Sitka spruce constitutes 40% of the standing softwood with Norway (or European) spruce providing a further 9%. Spruce, as you will well know, is not an easy wood to treat effectively with wood preservatives and has a reputation for doubtful durability. However, James Brown writing in The Forester in 1861 has this to say about this matter:

> "I must make an observation here which I have often found verified by my own experience - namely, the spruce fir, when young and immatured, yields a far more durable timber than the Scots pine at the same age. In erecting paling-fences, I find that, taking the two trees for rails at thirty years old, the spruce will last two or three years longer than the other; and even as a gate-post or common paling post, the same observation holds good. Notwithstanding this superiority of the wood over that of the Scots pine, country carpenters are always ready to recommend the Scots pine in preference to the spruce, even for such purposes as those mentioned above; and I make this observation in order that proprietors may be aware of the true state of the case".

James Brown was a Wood Manager to the Earl of Seafield and Surveyor of Woods in General.

Britain is thus faced for almost the first time in its history with having to utilise to the full its own increasing forest resource of a wood species that will require marketing. The build-up or integration with existing systems, of a forest products industry will be needed with an appreciation of the potential resource and capable of developing the technology required to utilise that resource to the full. At the same time misuse and wastage of the imported material has to be reduced to a minimum in order to assist the national balance of imports and exports. The export of British expertise and technology in wood preservation will have to include the ability to treat effectively short rotation plantation grown hardwoods and hardwoods from the tropics and sub-tropics. The effective treatment of the ever increasing volume and variety of panel products to render them durable in a variety of situations will be another important research priority.

This, therefore, is the background to our research in wood protection at Imperial College. We are concerned primarily with the fungal decay of wood and wood products and over the last 30 years have made fundamental studies in each of the four main areas into which the subject can be divided: -

1. **The Anatomy of Wood.** This has been described as appearing to a wood inhabiting fungus as a series of conveniently orientated holes surrounded by food. The holes are the pathways for both fluids and organisms to move through wood, whilst the food is the wood cell wall material which provides the mechanical strength required in the utilisation of wood, supplemented in the sapwood by the accumulated food

reserves of the standing tree. The pathways will vary with the differences in anatomical structure and access to the main structural elements may be relatively easy as in pine or difficult as in some hardwoods. Both decay and its control will be a function of the cellular anatomy of a particular wood.

2. **The Moisture Relationships of Wood.** Dry wood will not be subject to fungal decay and an understanding of the moisture content of wood, its relationship to the moisture content of its surroundings and the movement of water through the wood in service are all key factors in the decay of wood and may also be in its control.

3. **The Wood Inhabiting Organisms. It is important to know** the biology and interactions of the organisms colonising wood; what they do to the wood and particularly wood cell walls; the "pecking order" of the microorganisms and the consequences of this factor in the process of wood decay in many varied exposures service is information vital to the effective economic control of decay.

4. **The Wood Preservatives. In spite of the long usage of** chemicals in wood preservation and their wider use in agriculture in combatting plant diseases, very little is known of the mechanism of how they work. In wood preservation there is some evidence to suggest that in some cases they interfere with the metabolism of the organism in some way, whilst in others it appears that the presence of the preservative may block a site in the molecular structure of the wood which prevents the enzyme system of the micro-organism from breaking down the structural polymers of the wood cell wall. It is, therefore, necessary to know where the toxic ingredient has to be deposited in relation to the anatomical structure of the wood to be most effective and having found that out, the larger problem is how to get it there.

The philosophy behind our work at Imperial College is, therefore, to increase our basic knowledge of the wood, water, micro-organisms and wood preservatives and their interactions and utilise this knowledge to find effective and economic means of treating wood. Our first concern is with spruce and other refractory softwoods, whilst not forgetting that hardwoods, with their different anatomical structure are not always easy to treat effectively. With the increasing production of fast growing, short rotation hardwoods in plantation forestry throughout the world, as well as the increasing use of secondary hardwoods from natural forests, the myth that hardwoods are naturally more durable than softwoods is being swept away. The difficulties encountered in treating certain hardwoods are being more clearly understood, so that means to overcome them can be devised. In addition, the durability of panel products and sheet material made from wood has also to be studied, understood and measures worked out to ensure its long-term effectiveness.

So far as anatomy is concerned it is important to remember that softwoods are constituted predominantly of tracheids, which form the water conducting system in the earlywood and, when thicker walled and with a narrower radial diameter, they provide the mechanical strength in the late wood of each growth ring. These cells are totally enclosed by a cell wall and access from the centre of one tracheid to the centre of the adjacent cell has to be through the cell wall or through the pits where the membrane is usually much thinner than the rest of the wall. This means that any liquid, be it water or wood preservative is likely to make contact with the cell walls of the majority of tracheids in penetrating the wood. In the case of the hardwoods, however, liquid movement will be through the vessels which are open-ended and in the absence of tyloses, form a relatively easy pathway. The main mechanical tissue is formed by specialised cells, the fibres, which are often thick-walled with a very small void space (the lumen) and sparsely pitted. The fibres may not even be adjacent to the vessels and access to them for wood preservative solutions may not be easy. In addition, if the wood is partly dried before treatment the fibre walls have to become filled with treating solution, a process that can be easily prevented by air embolism in the pit or cell lumina. Variation in the arrangement of vessels, fibres and parenchyma is very considerable and their configurations will have a major part to play in the effectiveness of a treatment. Gross uptake may appear to be good, but if this is confined to filling the vessels only, it will leave the fibres untreated and liable to be destroyed by wood rotting fungi.

In the living tree, the wood cells are filled with water and even in the heartwood where little active water conduction takes place, the cell walls are usually saturated. The nature of the free water in the cell lumina and the bound water in the cell wall are well known and have been studied by many people over the years, especially Stamm (1964), who has published extensively on the subject. The relationship between the moisture content of wood and that of its surroundings and the concept of the equilibrium moisture content, (EMC), are the basis of methods of drying wood.

The fact that, in spite of an apparently stable EMC, the free water in wood in service may be in movement and the important implications arising from such movement, have not been so well understood. Baines and Levy (1979) showed that if the water potential (or the availability of water) at the two ends of a piece of wood were very different, then water would flow from a region of high water potential to that of low water potential. Such differences in water potential caused wood to act as a wick, with the flow of water along the grain through the water conducting, cellular, structural systems used for precisely that purpose in the living tree. Uju, Baines and Levy (1980) demonstrated that solutes could be carried through wooden stakes from the soil and deposited in the portion of the stake above the ground as water drawn up from the soil evaporated to the air and

left the dissolved material in the wood. Baines (1982) has discussed the important basic principles involved and has put forward the hypothesis that each wood species may have its own moisture characteristic. Morris, Dickinson and Levy (1984) have demonstrated the importance of water movement in creosoted poles in relation to the colonisation of the pole by fungi and the onset of a heartrot. Carey (1980), Mendes (1982) and le Poidevin (1985) have shown the importance of water movement in the decay of simulated window joinery and the effect of sealing the end grain.
Recent research has been aimed at establishing the facts of water movement in wood in service and then following-up the implications for increasing the decay potential of wood on the one hand (Vinden 1983, Vinden et al 1982, 1983) and utilising the movement to carry wood preservative chemicals to sites of potential decay within the wood, on the other (Dickinson 1980, Dicker et al 1983). One clear implication from this is the potential importance of the development of preservative treatments for wet (green) wood.

Morris (1983) described work to prevent internal decay of creosoted poles, using a biological control system. He inoculated such poles with spores of the fungi Scytalidium and Trichoderma which were known to be antagonistic to the main causal organisms Lentinus lepideus. Having established the moisture relationships in a standing pole he was able to determine the mode of infection and the development of decay by means of airborne spores deposited in surface checks. When suitable wet conditions occurred the spores germinated and the hyphae grew down the check following the water until the groundline was reached where the internal moisture content of the pole was suitable to support decay, (Morris, Dickinson and Levy, 1984). He was able to show that biological control would only be possible if the biological control fungi could become well established in the pole before the arrival of the L. lepideus. In the normal course of events both of the antagonistic fungi were secondary moulds which were only able to survive in wood after a wood-rotting fungus had begun to decay the cell walls and provide access for the cellulolytic enzymes to reach the cellulose which is normally inaccessible beneath the encrusting materials, e.g. lignin, (Morris and Dickinson, 1986). If they could be established in the wood first, they would be a useful preventative system, but if not they could not be considered as an eradicant. He was also able to determine the mode of infection and microbial ecology in relation to the moisture distribution in wooden railway sleepers (ties).

Mwangi (1986) investigated the importance of the water balance between soil, wood and the surrounding atmosphere. The objective of the work was the establishment of the requisite conditions where soil beds, often called fungal cellars, could be used to develop the most severe decay hazards for a laboratory decay test system for the evaluation of biocides in wood. He demonstrated that the water potential of a soil was very important and not to be confused with the water holding capacity of the soil. Soils exist where the available water at water holding capacity of that soil is too low for sufficient water to be taken up by wood

samples planted in it. He showed that in an atmosphere of high relative humidity the part of the wood sample above soil level could have a very high moisture content. Conversely at very low atmosphere relative humidity, the upper part of the sample would have a very low moisture content and wick action through the wood could cause the soil to dry out, given time.

Mwangi (1986) also demonstrated at low soil moisture contents that the relative humidity of the air in the soil could cause CCA treated stakes to wet up more quickly than untreated stakes, whereas at soil moisture contents near and above water holding capacity the reverse situation was true.

Woodward (1985) had shown a similar difference with chipboards made from three separate wood species. In the case of solid wood in contact with liquid water, pine, spruce and birch showed variation in the rate of sorption of moisture and in swelling behaviour. In the case of wood kept in an atmosphere of 100% RH, there were close similarities in their final moisture contents. Chipboard made from each of the three species showed similarities in moisture sorption from liquid water between birch and pine which were greater than spruce. There was no marked difference between untreated boards and those treated during manufacture in their relationships to liquid water. However, when stored in an atmosphere at 100% RH the treated boards achieved twice the moisture content of untreated boards. This suggests that boards so treated may show some degree of hygroscopicity.

Decay of wood in ground contact.

The decay of wood in ground contact is an interesting example of microbial ecology. A wide range of micro-organisms from many diverse taxonomic groups are readily available to colonise and destroy wood in contact with the ground. Some are specific to a particular wood under certain precise conditions of exposure. Others are more opportunist and may play a different role in the decay process under varying conditions. It is not possible to define or restrict each decay type within taxonomic frontiers, since the same organism (e.g. Phialophora fastigiata) may, given suitable environmental conditions, fill one or several ecological niches or 'physiological groups' (Clubbe, 1978).

Studies on the micro-organisms colonising wood and on the sequence of events leading to the onset of decay have shown the importance of reclassifying the species involved, irrespective of their taxonomic identity, into a small number of groups relevant to their effect on the wood. Clubbe (1980 a, b) recognised six such groupings. Based on his own observations and other studies published in the literature:-

Bacteria
Primary moulds
Sapstain fungi
Soft rot fungi
Wood-rotting basidiomycetes (White rot fungi)
(Brown rot fungi)
Secondary moulds.

Decay of wood not in ground contact.

The decay of wood in an exposed situation out of ground contact, such as external window joinery, has been shown to be remarkably similar to the ground contact situation. Carey (1980, 1983), Mendes (1982) and Le Poidevin (1986) have examined the microbiology involved in the colonisation and initiation of decay in simulated window joinery exposure trials using L-joints on racks out of ground contact. The unexpected initial result was the discovery by Carey of the similarity in the ecological succession of micro-organisms, where the same sequence of events took place, although at a shortened time scale. The interesting inference to be drawn from this was the appreciation that it must be the wood itself that "selects" the micro-organisms colonising it at any period of exposure. In the case of ground contact the colonisation could arise from mycelium and spores in the ground, whereas the L-joints out of ground contact must have been colonised only from air-borne spores deposited by chance on the timber. The anatomical features of the wood and their relationship to water form a constant characteristic of both habitats and provides consistency of substrate for the change of conditions which enable specific groups of organisms to develop and at a later stage to be replaced by others.

The ecological sequence of these groups of micro-organisms depends to a large extent on their effect on the wood structure and/or cell contents (Levy and Dickinson, 1982). Bacteria bring about a progressive breakdown of the pit membranes of the wood, thereby opening up the wood structure to allow gaseous diffusion to occur, to provide an open pathway for water from cell to cell and to give access to other colonising micro-organisms incapable of causing lysis of a wall or pit (Levy 1973, 1975). Foremost amongst the latter are the primary moulds scavenging for cell contents, particularly nitrogen. They are followed by the stainers which cause discolouration of the sapwood and are capable of penetrating through the wood cell walls by means of fine constricted hyphae. The first of the wood-rotting fungi to appear are usually the soft-rots which form characteristic chains of cavities in the middle layer of the secondary cell wall. The cavities form round a fungal hypha which has penetrated into the S2 layer of the cell wall and grows in a helix parallel to the orientation of the cellulose micro-fibrils. This type of decay was first recognised by Savory (1954 a and b, 1955) whilst Corbett (1963, 1965) was the first to describe the way in which the fungal hyphae penetrated the wood cell wall. More recently, Leightley and Eaton (1977) and Hale and Eaton (1985 a, b and c) have studied the development of the hyphae in the wall by time-lapse photography.

The soft rot fungi are one of the first of the wood-rotting fungi to colonise wood, but are usually followed by the wood-rotting Basidiomycetes which, normally, establish dominance and become the main causal organisms of wood decay. Where these other fungi have great difficulty in becoming established, e.g. at extremes of moisture content or in the presence of wood preservatives, the soft rot fungi have little competition and although they may take longer to do so, they can give rise to serious economic losses of timber.

The wood-rotting Basidiomycetes can be divided into two groups, the white rot fungi which can break down all the major cell wall constituents and the brown rot fungi which only destroy the cellulose and hemicellulose, leaving the lignin largely unaffected.

Bravery (1971, 1972, 1975 and 1976) published an outstanding series of scanning electron photomicrographs, which illustrated another fundamental difference between the attack by white-rot and brown-rot fungi. His observations were confirmed by Nasroun (1971) with other Basidiomycetes. Bravery showed that the hypha of a white-rot fungus penetrated into the cell lumen and lay on the inner surface of the wood cell wall. Lysis of the wall occurred along the hyphal contact, forming a groove or trough with a central ridge on which the hypha rested. As the hypha branched, new troughs were formed and eventually the new troughs coalesced, eroding the wall of the wood cell. The hypha was able to penetrate through the S3 layer of the cell wall and well into the S2; if the trough was parallel to the microfibrils its edges were smooth, but if it cut across their orientation the edges were ragged and the ends of the cellulose microfibrils could be seen clearly. The formation by white-rot fungi of troughs in the cell wall suggests some restriction to the free diffusion of enzyme away from the hypha. Montgomery (1982), Green (1980) and Green et al (1980) give possible explanations for these characteristics.

The brown-rot fungi show a different micromorphology (Bravery, 1971; Nasroun, 1971). The hypha again penetrates the lumen and lies on the inner surface of the cell wall. The appearance of both the hypha and the S3 wall layer change very little, but the other layers are completely altered by breakdown of the holocellulose. The resulting friable residue, with its high lignin content, looks more like expanded polystyrene or foam rubber than the normal smooth texture of unattacked walls.

In this case, the active agent appears to be unrestricted and some component of the enzyme system seems to diffuse completely through the wall layers, although it does not penetrate through the primary wall-middle lamella complex into adjacent cells (Crossley 1979). The concept of the activation of a small radical, i.e. veratryl alcohol, capable of penetrating through the cell wall polymers and breaking them down at a distance from the enzyme source (Harvey et al 1986) provides a simple explanation to these observations.

An interesting development of the effect of free radicals has been the observations of Belford and Dickinson (1985) that some fungi can produce extracellular free radicals which can break down certain organic solvent type wood preservatives. Research is proceeding to determine the extent of this breakdown and its effect on the long term effectiveness of these preservatives.

To overcome the effects of these organisms a good deal of work has been carried out to determine how biocides prevent fungi from decaying wood. One major development has been an appreciation of the importance of establishing the toxic ingredient in depth in the cell wall to prevent soft rot attack, whereas white rots and brown rots may be eliminated by far less rigorous treatment. Gray and Dickinson (1982, 1983) have shown that the amount of adsorbed copper in the cell wall may determine the performance of hardwoods that are difficult to treat effectively, like birch. Double treatment of pine and birch with a copper-chrome-boron formulation followed by arsenic pentoxide gave comparable performances of the two woods against all three fungal types. Subsequent chemical analysis of the treated birch showed a lower retention of copper, chromium and arsenic in the wood than with comparable treatment with a copper-chrome-arsenic formulation alone, whilst the retention of boron was negligible. Work is now proceeding to establish the optimum position of copper within the cell wall structure for the most effective durability of the treated wood.

Once it is clear that the toxic ingredient has to be put in a particular part of the wood cell wall to establish effective protection for wood, the next obvious question is how to get it there. A major investigation is being undertaken to look into this problem, particularly in those timbers most difficult to treat, like spruce and birch. In the case of spruce, the wood structure is very impermeable, whilst birch is one of those hardwoods where the microdistribution of the wood preservatives into the wood fibres is the major problem. Several lines of development are under investigation. Amofa (1984) examined the possibility of using water miscible solvents. Murphy has concentrated on accelerated diffusion systems into green spruce wood (Murphy and Dickinson 1986) whilst Khan is investigating the treatment of green Eucalyptus camaldulensis. Both are producing very interesting results.

From these fragmentary remarks you will appreciate the range and variety of the problems under investigation. The interaction of wood with water, micro-organisms and wood preservatives is a very complicated process, involving a series of inter-disciplinary approaches in any attempt at investigation. Although this has been an attempt to give a British perspective of some of the wood research required to be done, I think you will see how much we have in common with you. The complex nature of the subject makes it essential for collaboration in research and in unpublished research results to be undertaken by all of us involved in such work.

Thank you for inviting me to speak at this meeting and for being such a good audience.

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