Discoloration of wood in the living tree and during processing

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ABSTRACT

The various kinds of discolorations in freshly felled and kiln-dried wood are classified according to the different physiological, biochemical, and chemical reactions involved. In freshly felled and stored round wood discolorations are initiated predominantly through physiological reactions of living parenchyma cells. Typical reactions are the formation of phenolic compounds and tyloses triggered by oxygen penetrating the tissues. Discolorations can also be caused by microorganisms, for instance blue stain fungi, mould fungi, and bacteria which affect the wood surface of inadequately stored and kiln-dried wood. The discolorations during kiln-drying and steaming are based mainly on chemical reactions of the accessory compounds and cell wall components in the woody tissue. The reaction mechanisms are dependent on the process parameters and chemical composition of the wood which have to be determined in individual cases.

INTRODUCTION

The discoloration of stored round wood after felling and in sawn timber during steaming and drying is a considerable economic problem due to the high demand on light and uniformly coloured wood in Europe. In order to provide practical procedures and techniques for its prevention, it is necessary to identify these discolorations as either physiological processes already initiated in the living or freshly felled tree or as secondary chemical reactions during steaming or kiln-drying (Tabel 1).

Table 1: Classification of discolorations on the basis of the different types of reactions (according to Bauch 1984)

Cause	Example and Description
(1) Fungi	Blue-stain as in sapwood of *Pinus* due to the chromophoric pigments in the hyphae
(2) Physiological reaction in living cells	Formation of tyloses and accessory compounds as in *Fagus* due to the reaction of living parenchyma cells
(3) Biochemical reactions	Orange discoloration as in *Alnus* due to the enzymatic reaction of polyphenoloxidases inducing the production of oregonin
(4) Chemical reactions	Metal-tannin reactions as in *Quercus*
(5) Combination of reactions	Yellow discoloration of *Quercus* and *Castanea* due to a fungal infection and reaction of hydrolysable tannins

The presentation is focussed on the characterization of discolorations in freshly felled and kiln-dried wood of sensitive timbers, e.g. beech, cherry, maple, and oak (Fig. 1). Furthermore, the increasing problems of discolorations and formation of cracks during processing of new imported tropical timbers, e.g. massaranduba, itaúba, and garapa are introduced. On the basis of this information, it may be possible to better understand basic patterns of discolorations and the different reaction mechanisms involved.

Gums in Black cherry (Discolouration in the living tree) | **Staining of Hard maple (Discolouration during storage)** | **Oxidative staining of Framiré (Discolouration during kiln-drying)** | **Iron-tannin stain of Oak (Chemical reaction)**

Figure 1: Examples of discoloration in hardwoods

DISCOLORATION OF WOOD DURING STORAGE

In freshly felled and stored round wood discolorations are initiated predominantly through physiological reactions of living parenchyma cells for at least for several weeks after felling. Typical reactions are the formation of phenolic compounds and tyloses, e.g., in beech wood and maple (Fig. 2), triggered by oxygen penetrating the tissues (e.g. Koch *et al.* 2003, Koch 2004).

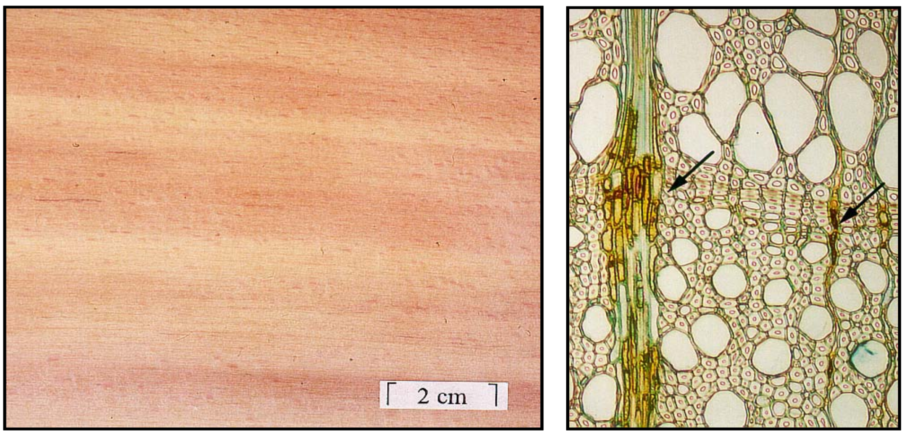

Figure 2: Striped discolorations due to an inadequate storage of beech round wood. The discolorations are caused by physiological reactions of living parenchyma cells

Furthermore, biochemical reactions are also responsible for the discoloration of round wood during storage. For instance the brown stain of lumber of pine species (Oldham and Wilcox 1981) and Douglas fir (Miller *et al.* 1983) is a serious problem that begins during storage in moist conditions. The stain is a result of an enzymatic reaction involving peroxidases on tannins and phlobaphenes. The orange discoloration of *Alnus* is an additional example for the enzymatic reaction of polyphenoloxidases inducing the production of oregonin (Hrutfiord and Luthi 1981). The intensity of the stain during storage of round wood is dependent on the moisture content of the wood, the length of time the wood is exposed to air, and the surrounding temperature (e.g. Liese 1958).
Discolorations can also be caused by microorganisms, for instance blue stain fungi, mould fungi, and bacteria which infect the wood surface of inadequately stored and kiln-dried wood (Fig. 3). While blue stain is based on the chromophoric pigments in the hyphae, mould fungi and bacteria can decompose the soluble carbohydrates and storage substances in the tissue. The staining is attributed to the metabolism of the microorganisms which decompose the soluble carbohydrates and storage substances (e.g. Bauch *et al.* 1985). Furthermore, bacterial wetwood, e.g., in sugar pine and fir, can predispose the wood to oxidative brown stain during drying.
The described discolorations during storage can be prevented, if the changes in moisture content and temperature that favour growth of microorganisms and the initiation of physiological and biochemical reactions are restricted. Quick harvesting, transport, and processing of round wood, especially during the growing season, is an important contribution to the conservation of wood quality (e.g. Koch *et al.* 2000, Koch 2004).

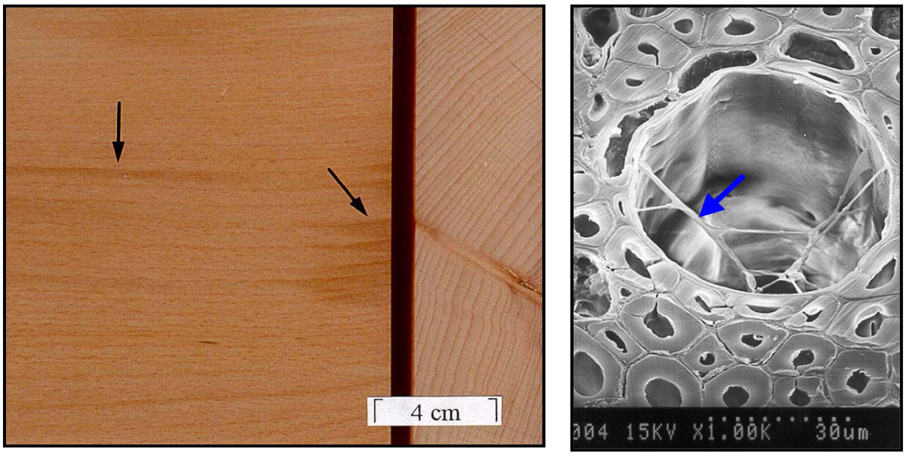

Figure 3: Fungal stain on the wooden surface of steamed and not sufficiently ventilated sawn beech wood (Fagus sylvatica)

DISCOLORATION OF WOOD DURING KILN-DRYING

The discolorations during kiln-drying are based essentially on chemical reactions of the accessory compounds and cell wall components (lignin and hemicelluloses) in the woody tissue (Fig. 4). It has been suggested that the main factors involved in chemical reactions are oxidation and condensation of phenolic compounds (Wengert 1990), although the reasons in many cases are unknown. For example, the phenols, including condensed tannins, are complex compounds, which can be converted in insoluble reddish compounds by oxidation and polymerisation in hot and acidic conditions (Hillis 1985). The discolorations can also be caused by hydrolysis of

hemicelluloses. The hemicelluloses are degraded gradually to monosaccharides which then react with nitrogen compounds in the wood.
These chemical reactions occur at temperatures above 40° C and a moisture content of 30% to 60%. A decrease in pH value during drying intensifies the hydrolysis (Ifju 1973). The reaction mechanisms are dependent on the process parameters and the chemical composition of wood (Koch *et al.* 2000).

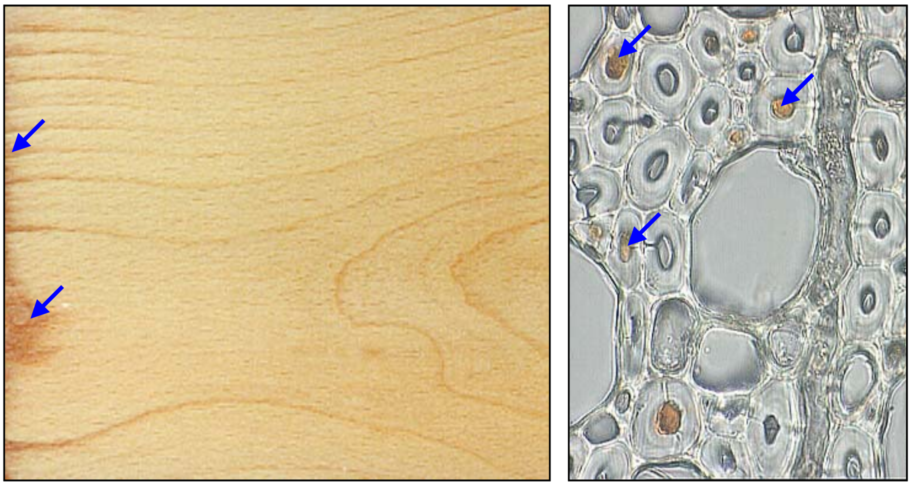

Figure 4: Discolouration due to an accumulation of accessory compounds on the wooden surface of beech during the drying process

One of the most important problems in conventional drying of hardwoods are discolorations of oak, which cause major financial losses for the industrial dryers. According to Wegener and Fengel (1987) the discolorations can be classified into two groups: brown and yellow.
The brown discoloration is induced by hydrolysis and oxidative transformation of ellagtannins. Particularly, vescalagin and castalagin are involved in the hydrolytic mechanisms influenced by temperature and oxygen during conventional kiln-drying (Charrier *et al.* 1995). Wassipaul and Fellner (1987), Fortuin *et al.* (1988a, 1988b), and v. Hundt (1990) have characterised the specific conditions favouring such discolorations, e.g., wood moisture content between 30 and 60% combined with a kiln-temperature above 30°C and a relative humidity at about 70% (Fig. 5). The same authors showed that the brown discoloration penetrates from the surface to the centre of the wood. Stich and Eberman (1984) found enzymatic activities by peroxidases and polyphenoloxidases in oak heartwood, which could be also responsible for the discoloration in moist conditions.
The discoloration is probably independent of wood origin and can be prevented by quick kiln-drying without oxygen (Charrier *et al.* 1992). According to Wassipaul and Fellner (1992) and Fortuin *et al.* (1988a) air drying or low temperature predrying from the green to approximately 25 percent moisture content before kiln-drying are the most efficient ways of protecting the wood from discolorations. Other techniques like drying in a nitrogen atmosphere would be a good preventive method (Wassipaul and Fellner 1992), but such laboratory scale systems preventing oxidative reactions have not yet found an industrial application. In recent years, kiln-drying under vacuum and super heated steam vacuum drying have been proven as effective methods preventing the brown discoloration (Welling and Wöstheinrich 1995, Brunner 1999). These methods combine two advantages: quick drying and a low oxygen concentration inside the kiln (Welling and Wöstheinrich 1995).

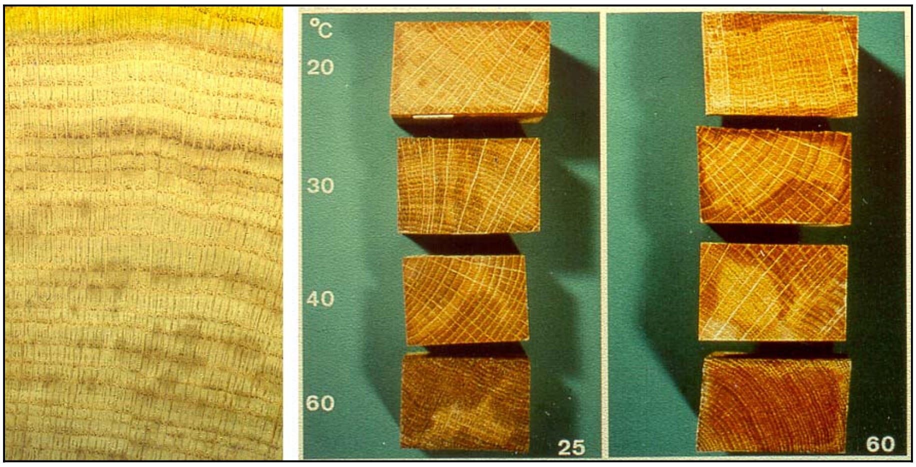

Figure 5: Brown staining of kiln-dried oak. The discolorations are dependent on increasing kiln- temperature and relative humidity

The yellow discoloration of oak which frequently occurred as sticker stain or as longitudinal yellow streaks were identified to be caused by an infection with the mould fungus *Paecilomyces variotii* (Bauch *et al.* 1991). The fungus colonises the vessels of the wood reacting with the hydrolysable tannins (lactone derivatives) likely to be responsible for the yellow discoloration. These specific heartwood compounds were found in *Quercus* species of the Section *Robur* (white oak) and also in *Castanea sativa*, but not in *Quercus* species of the Section *Rubrae* (red oak). Given the thermophilic adaptation of the fungus – tolerating an acidic medium of pH-3 as well as a temperature of up to 50°C (Husain and Zamir 1968) – the yellow discolorations can arise during the first stage of kiln-drying.

The prevention of mould growth can be achieved by good ventilation of sheltered stacks, or by faster drying schedules. In situations where these prophylaxes are not practicable, a pre-treatment of green lumber with 5% to 10% propionic acid can prevent mould growth during the critical phase of drying (Bauch *et al.* 1991).

Another severe problem during kiln-drying are yellow or grey discolorations of light coloured timbers like birch or maple, which normally occur in the inner parts of the boards, while the outer layer to a depth of 1-5 mm from the surface remains unaffected (Trübswetter 1995). In this case, visual sorting by colour is impossible before the boards are processed. The reason of the discoloration is described as oxidative reaction of water soluble low molecular compounds including carbohydrates, amino acids, and phenolics (Koch 2004). The intensity of the discoloration is mainly a function of the drying temperature, more severely under so warmer conditions. The relative humidity during the drying process has also been found to affect the final colour of wood. In sugar maple which behaves similar to birch during kiln-drying, the final colour is lighter if the relative humidity is lower (Mc Millen 1976). Contrary to e.g. oak, a low relative humidity could be used for drying of birch and maple timber because they do not check easily.

To reduce the discoloration, it has been recommended that timber be dried rapidly (low relative air humidity, high air velocity) at a low temperature (Koch and Skarvelis 2007). This recommendation is based on the experimental comparison of drying schedules. It has also been suggested that other factors may affect discolorations in wood, e.g., felling date, length and season of storage period, and climatic conditions before felling (Kreber and Byrne 1994, Luostarinen *et al.* 2002).

DISCOLORATION OF TROPICAL TIMBERS

The utilisation of tropical timbers, e.g., the high demand on terrace floorings, requires special information on the chemical composition and reactions of their extractives. An increasing problem is the staining of the wood surface of several tropical timbers, e.g., bangkirai, garapa tatajuba, caused by a contamination with iron ions (Fig. 6). The so-called "iron-tannin-stain" occurred already by reactions of tannins with very low concentrations of iron (10 to 15 ppm = mg/kg). The discoloration can nearly be removed by a treatment with oxalic acid. Another current problem is the leaching of phenolic extractives and resins, especially of species of the Dipterocarp family (Fig. 6).

Figure 6: Discoloration of bangkirai caused by a contamination with iron (left) and accumulation of resins on the wood surface of keruing (right)

CONCLUSIONS

In order to provide a better understanding of discoloration during storage and kiln-drying detailed studies on the physiological, biochemical, and chemical reactions of the extractives and cell wall components have to be carried out in individual cases. As soon as the reaction mechanisms and chromophoric compounds are identified, information on establishing comprehensive methods for preventing this economically important loss of wood quality can be provided.

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