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Paper presented at 3rd IUFRO International Wood Drying Conference, Vienna, August 18–21, 1992

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INSTITUTET FÖR TRÄTEKNISK FORSKNING

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DETERMINATION OF THE SURFACE EMISSION FACTORS IN WOOD SORPTION EXPERIMENTS

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ABSTRACT

The transport of moisture in wood can be mathematically described with a good approximation as a simple diffusion process, at least when the temperature is clearly below the boiling point of water. The surface emission factor is an important factor to take into account, when sorption experiments are analysed. In this paper some previously published data and results from new direct measurements of the surface emission factors are discussed and compared with values obtained from the boundary layer theory.

1 INTRODUCTION

In a wood sorption experiment, a piece of wood is exposed to a stream of air with a given humidity. As wood is a hygroscopic material, the piece tends to reach an equilibrium state with the air. There are two resistances for the approach to equilibrium. In the hygroscopic range, the moisture is bound to the cell wall. The moisture transport is here controlled by diffusion and the internal conductance is given by the diffusion coefficient. The external conductance is due to the fact that the surface moisture content is not in equilibrium with the ambient air stream. When the surface moisture content goes below the fiber saturation point, the surface layer starts to shrink and so high tensions can appear that surface checks can be created. These checks are strongly responsible for the degrade of dried lumber. Therefore, it is important in high quality wood drying to have a good information of the surface moisture content. One component of the external conductance is the moisture transport through the boundary layer close to the wood surface. This part of the external conductance increases with the air velocity. However, in wood drying the energy costs to achieve a high air velocity are considerable and, therefore, it is important to find a method to separate the internal and external conductances in order to minimize the the energy costs. An unobjectionable method has been presented earlier (Choong and Skaar 1969, 1972). Another method, which is questionable for mathematical reasons, has been used by others (Rosen 1978; Avramidis and Siau 1987).

2 THEORY

The moisture transport in wood is described by the diffusion equation:

$$\frac{\partial u}{\partial t}=\frac{\partial}{\partial x}\left(D\frac{\partial u}{\partial x}\right) \qquad (1)$$

where u is the moisture content of wood as mass of water/dry mass of wood, t the time, x the space coordinate and D the diffusion coefficient. The latter is here assumed to vary with temperature like an Arrhenius curve with an activation energy dependent on the local moisture content of the wood piece. Eq. 1 is one-dimensional and the wood piece is also assumed to be homogeneous, isotropic and symmetric. The initial condition is that the moisture content is constant u_0. The boundary condition is given by:

$$-D\left(\frac{\partial u}{\partial x}\right)_a=S\left(u_a-u_{eq}\right) \qquad (2)$$

where a is half the thickness of the wood piece, S the surface emission factor and u_{eq} the equilibrium moisture content for wood in the ambient air.

The solution of Eq. 1 with the initial and boundary conditions above is expressed by the relative moisture content change defined as:

$$F=\frac{u_0-\bar{u}}{u_0-u_{eq}} \tag{3}$$

where $\bar{u}$ is the mean moisture content. The behaviour of F as a function of t is discussed elsewhere (Söderström and Salin 1992).

The interaction between the wood surface and the ambient air is described by the equations for simultaneous heat and mass transfer. The heat flux is the product of the heat transfer coefficient α and the temperature difference between the ambient air and the wood surface. The mass flux of moisture is correspondingly the product of the mass transfer coefficient β and the difference in vapour concentration between the air close to the wood surface and the ambient air. This moist air close to the wood surface is in equilibrium with the wood and the relation between the vapour concentration and the wood moisture content is given by the sorption curve. For a turbulent flow the boundary layer theory gives a relation between α and β. By combination of these facts, the following expression is obtained (Söderström and Salin 1992):

$$S=\frac{\alpha v_{sT}}{c_p\rho_{air}\rho_{wood}\left(\frac{du}{dh}\right)_T} \tag{4}$$

where v_{sT} is the saturation moisture concentration in the moist air in the boundary layer, c_p the specific heat of the moist air, ρ_{air} the density of the moist air, ρ_{wood} the density of wood as dry mass/raw volume, h the relative humidity of air and $(du/dh)_T$ the derivative of the sorption curve at temperature T. The value of S from Eq. 4 is referred to as the classical value.

3 EXPERIMENTS

The results from three different experiments are presented. Some of them are preliminary and will be published more extensively later.

3.1 Sorption in a thin lamella

The specimens were sawn out from green Scots pine (*Pinus silvestris*) and green Norway spruce (*Picea abies*). The lamellae were free from visible defects, such as knots and compression wood, and had never been dried below the fiber saturation point before. The thicknesses of the lamellae were 3 mm and they were edge coated with silicone on the axial surfaces. The specimens were exposed to an air stream with a velocity of about 5 m/s, range of temperature from 26°C to 48°C and relative humidity from 25% to 45%. The main purpose of the experiment was to study the mechano-sorptive creep during drying, and further details about it is found elsewhere (Morén 1990). The moisture flux was measured continuously and, by using an iterative procedure the surface emission factor for several temperatures was determined as a function of the mean moisture content of the lamella. This result is shown in Fig. 1. The measured value is in the range of $1\text{-}5{*}10^{-7}$ m/s. The classical value, calculated with Eq. 4 above, is in the range of $50\text{-}200{*}10^{-7}$ m/s. The variation of this latter value is mainly due to the temperature dependence of the saturation moisture concentration of the air.

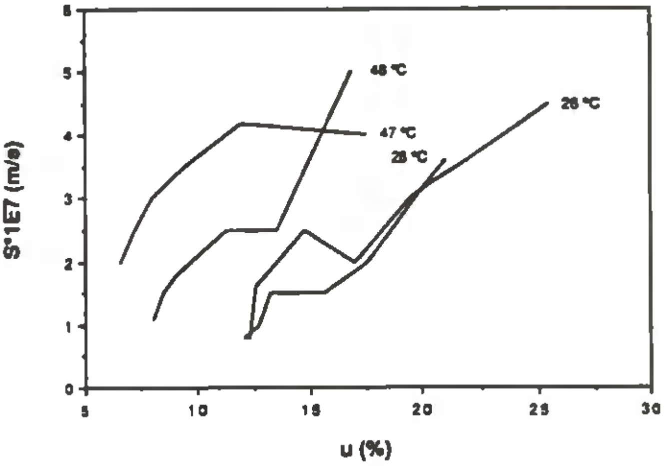

Figure 1: The surface emission factor for various temperatures as a function of the mean moisture content.

3.2 Evaporation from wooden surfaces

The evaporation from wooden surfaces of Scots pine has been studied with a method described in an earlier publication (Laurila 1992). The results for 40°C are presented in Fig. 2, where the ratio of measured and classical mass transfer coefficients is given as a function of the wood moisture content in the surface layer of the piece for four different drying conditions.

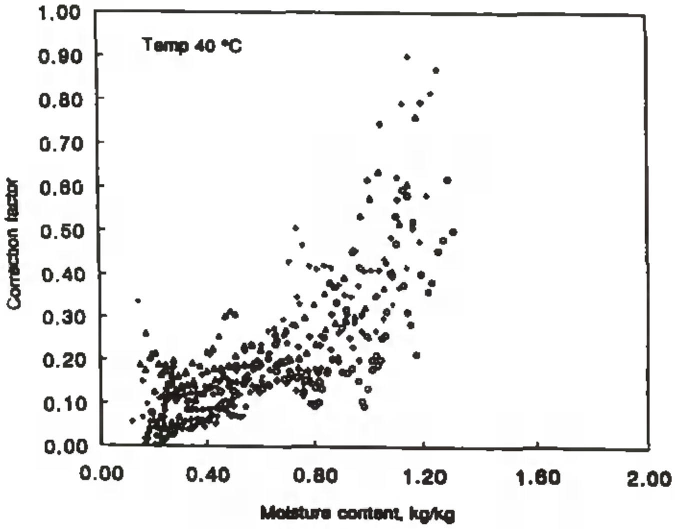

Figure 2: The ratio of measured and classical mass transfer coefficients for various drying conditions as a function of the moisture content in the surface layer of wood.

3.3 Infra-red thermography

The surface of a drying wood piece has been studied with a camera equipment sensitive to infra-red radiation. The moisture flux is assumed to be proportional to the heat flux which, in its turn, is proportional to the temperature difference between the wood surface and the ambient air. Therefore, by studying the surface temperature, it is possible to qualitatively determine the moisture flux. An example of a photo is seen in Fig. 3. The air velocity was about 2.8 m/s, the wet-bulb temperature 11.2°C and the dry-bulb temperature 23.5°C. Further details about the measurements are found elsewhere (Morén 1992). The heartwood is exposed to the surface of the flatsawn piece. The diffusion coefficient for heartwood is lower than for sapwood. This is seen in Fig. 3 as the region with a higher temperature, i.e. a lower moisture evaporation from the heartwood. The growth rings are also seen in the heartwood in the beginning of the drying process.

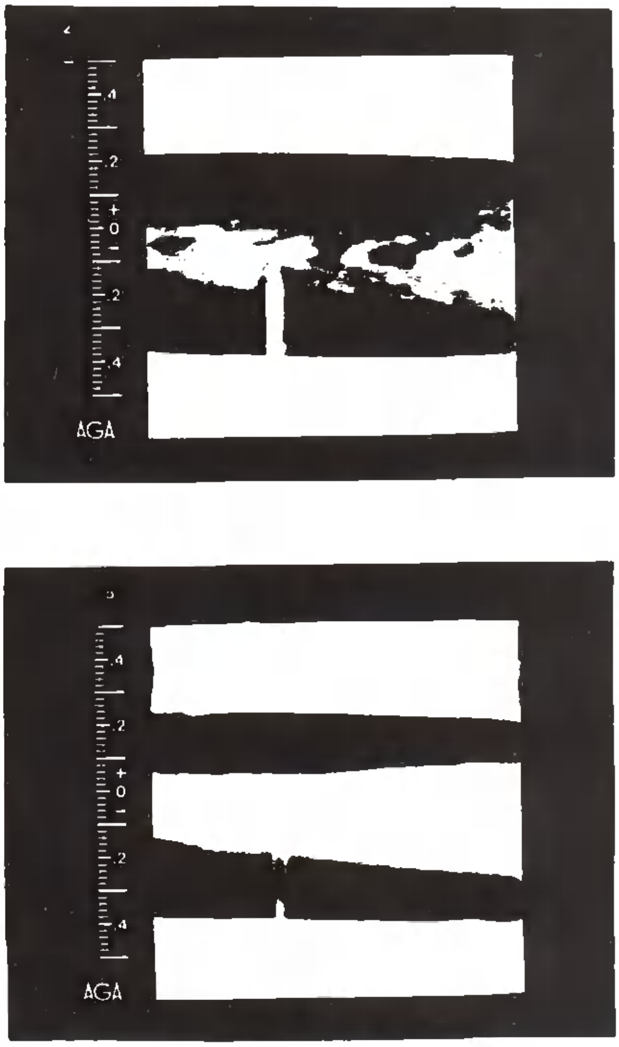

Figure 3: Thermography of wooden surfaces. Dark areas mean a lower temperature than light areas. Top: 7 minutes after start. In the heartwood the earlywood temperature is about 2°C lower than the temperature in the latewood.
Bottom: 62 minutes after start. The temperature of the sapwood is about 5°C lower than the heartwood temperature.

4 DISCUSSION

The relative change of the mean moisture content F from Eq. 4 is seen in Fig. 4. With the assumption of constant diffusion coefficient and surface emission factor a mathematical analysis shows that no information concerning the separation of the internal and external conductances can be obtained from the linear part of this curve. However, the half-drying time method, suggested earlier, is a useful method for this separation (Choong and Skaar 1969, 1972). This method has the disadvantage of the experiments having to be performed with several wood pieces of different thicknesses. Another method, where only one thickness is needed, has also been published (Liu 1989). However, both these methods are only empirical approximations. A rigorous analysis shows that the half-drying time function can be developed into a series in the inverse of Sa/D (Söderström and Salin 1992). A third alternative is to use numerical methods (Droin et al 1988; Droin-Josserand et al 1988, 1989).

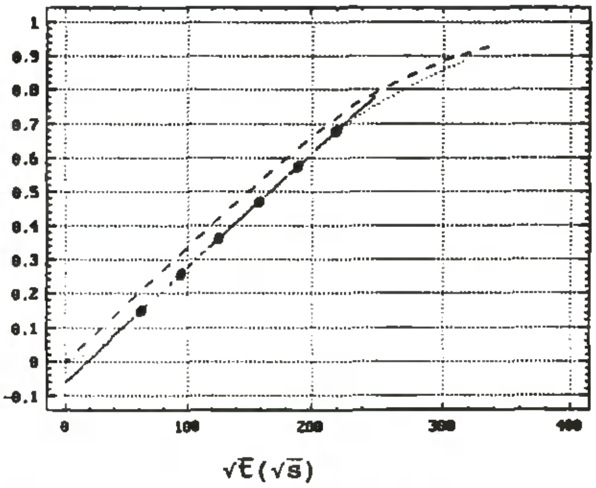

Figure 4: F vs. $\sqrt{t}$. The dots are "experimental points" and the full line their regession line. The dotted curve is a calculated curve with a surface emission factor included. The dashed curve is calculated with an effective diffusion coefficient and no explicit surface emission factor.

The classical approach of the mass transfer coefficient has recently been questioned. Probably the first quantitive results for wood were presented some years ago and showed that the presented values were one order of magnitude lower than the ones obtained from classical theory (Plumb et al 1985). This observation is confirmed by the two first experiments presented above. Both these latter experiments show a tendency of increasing surface emission factor with increasing wood moisture content. The reason for deviation from classical theory is not fully understood. Based on, for instance, results obtained for beds of glass beads, it can be concluded that this phenomenon is not unique for a hygroscopic material and also that the form of the relationship between correction factor and moisture content is different for different materials (Kaviany and Mittal 1987). On the other hand the thermography study showed that a wood surface dries in another way than a bed of glass beads. The observation made earlier, that the bed of glass beads dries nonuniformly is not seen for wood (Maneval et al 1990).

5 CONCLUSIONS

The surface emission factor is a very important parameter in wood drying as it influences the development of the surface moisture content. When that quantity goes below the fiber saturation point, the material starts to shrink and so severe tensions can occur that a surface check appears. Therefore, it is important to find a method that correctly separates the internal and external conductances for the moisture transport. There is a considerable difference between the measured and calculated mass transfer coefficients and this difference is strongly dependent on the material and the surface characteristics. Wood also seems to dry in a complete other way than a nonhygroscopic porous material. All these facts and observations imply that it is necessary to perform more extensive theoretical and experimental investigations of the interaction between a wood surface and an ambient air. Such studies are underway.

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SAMMANFATTNING

Fukttransporten i trä kan med god approximation beskrivas som en diffusionsprocess, åtminstone när temperaturen är under vattnets kokpunkt. Ytemissionsfaktorn anger hur långt ytfuktkvoten befinner sig från den omgivande luftens jämviktsfuktkvot och är mycket viktig att ta med i analysen av sorptionsförsök. I denna artikel diskuteras tidigare utförda mätningar och analyser av ytemissionsfaktorn och jämförs med de värden som fås från inverkan av luftgränsskiktet närmast virkesytan.

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