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Improvement of diffusion models for outdoor condition

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Introduction

Wood material is a construction material highly influenced by surrounding climatic conditions. Therefore, predict water distribution in a timber structural element is essential to describe drying process, mechanical behaviour or also fungal damage. For that reason, numerous studies have been performed to established hygrothermal models of mass transfer [1-2]. However, most of them are based on isothermal conditions to identify water diffusion properties. This simplification is too restrictive to describe timber pieces in real environment. In this paper, we propose to identify various water diffusion properties influenced by temperature through a multivariable optimization method. This approach is more representative of a timber structure in outdoor conditions.

Objectives and Methodology

Identification of diffusion properties of an element is achieved through an optimization algorithm, where experimental results are compared with model predictions. The influence of environment on model parameters is established. Besides the determination of surface exchange coefficients, the parameters describing the hygroscopic equilibrium and the bound water transfer (described as sorption isotherms), and coefficients of material permeability are considered.

• In literature phenomenological [1,3] or thermodynamic [2] formulations are given to determine the equilibrium moisture content for a given temperature and humidity. The latter proposes a logarithmic relationship between moisture content w and relative humidity Rh :

$$\ln\left(\frac{w}{w_s}\right) = \varphi \cdot \ln(Rh) \cdot \exp(\alpha \cdot Rh) \quad (1)$$

where w_s is the saturation moisture content, φ and α two setting coefficients depending on the sorption cycle (adsorption or desorption). Temperature influence on moisture content is widely documented. Perré [6] proposes a correction of isotherm as a temperature-dependent phenomenological linear law. We propose to explain this phenomenon by presenting thermodynamic exchanges where temperature represents a catalyst according to the Le Chatelier principle. Thus, considering energetic equilibrium between variation of energy during a fluctuation of temperature, and energy induced by sorption heat the following relation is proposed:

$$w_s(T) = \left(w_s^0 + \frac{C_{anh}}{C_w} \right) \cdot \exp\left(-\frac{C_w}{L} \cdot T \right) - \frac{C_{anh}}{C_w} \quad (2)$$

where w_s^0 represents the saturation moisture content at temperature $T=0^\circ\text{C}$. The heat capacities of anhydrous wood C_{anh} and water C_w , as well as the latent heat of vaporization of water L are non-dependent temperature properties, and supposed constant in the considered range of moisture content and temperature.

• The second temperature-sensitive parameter is the permeability. Several references in literature deal with moisture content influence on permeability coefficients. By analogy to the non-linearity of diffusive behavior, several authors have proposed the following mathematical form of the apparent permeability in isothermal condition (Eq. 3):

$$\delta^* = \delta_v \cdot \exp(k \cdot w) \quad (3)$$

The influence of temperature on apparent permeability has been described by an Arrhenius law [3]. Thus, from the definition of activation energy [7] and a semi empirical law of Merakeb [2], we propose to represent the influence of temperature and moisture content on permeability as:

$$\delta^* = \delta_0 \cdot \exp\left(\frac{(C_{pv} \cdot T) + \Delta H_s}{R \cdot T}\right) \quad (4)$$

where ΔH_s is the sorption heat, C_{pv} the specific heat capacity, R the perfect-gas constant, T the temperature in °K and δ_0 a calibration coefficient.

• A model involving all these physical phenomena, dependent on temperature and water content, would have 12 physical or empirical parameters. An optimization algorithm cannot fit precisely and fairly so many parameters. However, because of the variety of wood species, several physical phenomena differentiate the sorption isotherms: the saturation moisture content w_s , then the hysteresis area, and finally the shape of isotherm as described by Skaar [5]. Wood is a hygroscopic material with low hysteresis compared to other plants [4] or clays. Saturation moisture content varies from 22% to 34% depending on species, but these data are widely documented in literature [8]. Thus, we propose to simplify different isotherms of wood species from bibliography to propose only two relative curves, one for hardwoods and one for softwoods. Thus, only saturation moisture content will distinguish species. Then, only three parameters remain to determine for permeability.

Results and analysis

With the simplification of hygroscopic equilibrium parameters gained by defining two types of sorption isotherms, species are differentiated with thermohydric diffusion. Sorption in wood in an outdoor environment is then available, considering the influence of temperature on two physical properties (Fig.1)

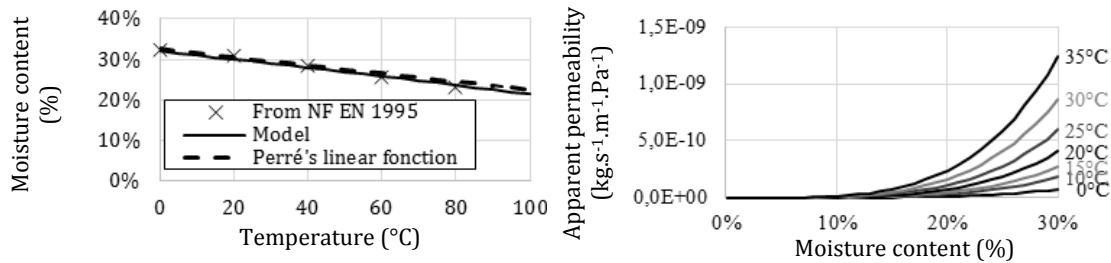


Fig1 : Temperature influence on diffusion properties: saturation moisture content (left) and apparent permeability (right)

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