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Modeling of coupled heat and mass transfer during drying of tropical woods

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ABSTRACT

We have developed a model on drying of two tropical woods of ayous (*Triplochiton Scleroxylon*) and frake (*Terminalia Superba*) coming from Cameroon forests. Some thermophysical parameters used in the model were experimentally obtained in this work while the remaining properties were from literature. A comparison is doing between numerical results of our model, these given by the Luikov's model and experimental data. Numerical simulation results from the developed model give close agreement with experimental results. We note that Luikov's model not gives a satisfaction results in the non-hygroscopic domain in the case of frake. The present model can be used to explain the drying phenomenon of these two tropical species and can be applied to others species when necessary thermophysical parameters of these species are known. In a future work, it is important to integrate the influence of anatomical direction on our numerical and experimental results.

1. Introduction

Tropical countries have vast forests that contain many species of wood [1–3]. These varieties enable the European and Asian to import enough woods to meet their needs. Unfortunately, the majority of these woods are exported in wood logs from Africa. However, many African countries such as Cameroon and Gabon require that the primary processing of these woods must be done locally [4]. This primary wood processing will create local job and promote employments. Moreover the transformed wood is a value added when it is sold abroad. However, due to the recent world-wide financial crisis, the economies of tropical countries do not depend mainly on the foreign markets. For high quality timber, it is very important to develop thermal drying technologies for tropical countries. This could be an issue for the immediate needs of wood preservation. Also, the utilization of the forest resource is optimized with ecological advantages such as carbon fixation and preservation of biodiversity.

The first works on the drying have started since 1921 with W.K.Lewis's works [5]. W.K.Lewis describes the drying as a conjugation of the evaporation of humidity at the surface of porous material and the diffusion of the humidity from inside to outside of the product. Since 1929, many researches were dedicated on the drying with the objective to explain this physical phenomenon. The molecular diffusion is used by T.K.Sherwood to explain the internal migration of the water since 1929. Sherwood used the constant mass diffusion coefficients. In 1937, Ceaglske and Hougen have done many experiments on some materials and they demonstrate that the Sherwood's hypothesis is not always true [6]. In 1935, E.A.Fisher presented three phases on the drying curve: (1) a constant rate drying period, (2) a linear falling rate drying period and (3) a nonlinear falling rate drying period. Each phase was represented by an equation. In 1957, Philip and De Vries showed that the drying is a conjugation of heat and mass transfer. In 1962, Krisher is the first to use Fisher's ideas to determine the sorption isotherms and equivalent conductivity of many products.

Today, it is known that the diffusion and the movement of the internal wood water are the consequence of many mechanisms

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such as gravity, external pressure, capillarity, temperature gradient and water concentration. Each influence is varied in function of the material type, the drying conditions and the drying type. For example, in 1940, Hougen showed that the capillary strengths influence the most the migration of water in the porous media which have an interconnected system of pores such as the wood [7]. From this date, many drying models are established to explain the drying of specific material and product in function of the process and drying type. Some parameters are integrated without enough physical explanations. The analytical drying models can be classified in two groups: diffusion models and multiphase models. Multiphase models such as Philip and De Vries's model, Whitaker's model, Perré's model (adaptation of Whitaker's model), Duforestel's model and Nicolas's model in which the various phases are considered and the describe the motion of the liquid and the vapor through the rigid porous media. The transport phenomena are described by the principled of conservation of each phase separately. Such equations are often highly coupled. The models based on Luikov's approach are used with success in the literature to explain the drying of wood. D.Kocaefe et al. [8] use it to explain the thermal drying of the wood at higher temperatures. The Luikov's hypothesis is verified only when the gas pressure is uniform within the temperature range of 0 °C–100 °C [5]. In addition, the ratio between the vapor diffusion coefficient and the total moisture diffusion coefficient of Luikov's model is a parameter difficult to obtain by a physical law [5]. According to Issiaka Traoré [9], the value of the potential of moisture transport is arbitrary. Thus, to adapt on industrial process, Messaoud Nabhani [10] specified that a correction of convective mass flux of Luikov's model is necessary in order to describe the experimental data. Then, it is important to use a model including parameters which can be easily obtained through the drying test.

The objectives of the present work are: (1) to establish a drying model applied to dry tropical woods, (2) to compare the experimental and simulated results, (3) to validate the results obtained by such model to those obtained by Luikov's model, (4) to use our model to simulate the drying of some woods according to the drying schedules.

This work is applied on ayous (*Triplochiton Scleroxylon*) and frake (*Terminalia Superba*), two tropical wood species from the Central Africa region. These two woods have an important potential market locality in Cameroon and export [11].

2. Materials and methods

2.1. Methods

Modeling of wood drying can be done in three scales [12]:

- Scale of physics processes which influences drying process;
- Scale of the product when this one is expose to a drying process well determined;
- Scale of the dryer to the industrial level.

In the following, our objective is to modeling the tropical woods drying with application of the two firsts scales.

An example of wood porous media is given in Fig. 1:

Porous media is composed by anhydrous mass, bound water mass, vapor mass and free water mass. Thus, mass of porous media when volume is equal to one is given by:

$$\rho_S H = \left(\alpha S \rho_l + X_b \rho_S + \alpha(1-S)\rho_g c_g\right) \tag{1}$$

with: ρ_s,ρ_l et ρ_g are densities respectively of the anhydrous, free water and vapor. H and X_b are respectively humidity of porous media and bound water content (on dry basis). α is the wood voluminal porosity. S is the voluminal fraction of free water. c_g is the vapor mass fraction of the water in the pore.

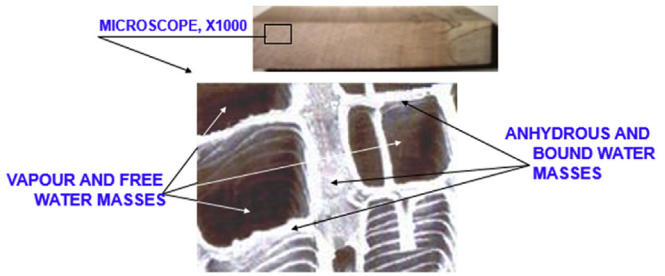

Fig. 1. Representation of porous media (Wood cells visible under the microscope (×1000)).

2.1.1. Mass transfer

It is given by following general equation [6,13]:

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot \overrightarrow{W} + K = 0 \tag{2}$$

where K is the voluminal mass rate and $\overrightarrow{W}$ is the flux vector, all in considered phase. Thus, previous equation must be applied in each phase presents in the wood.

2.1.1.1. Liquid water. In the drying, water is not evacuated to the wood in the liquid state. Contribution of this phase in the flux expression is neglected and we have:

$$\frac{\partial(\alpha S \rho_l)}{\partial t} + \vec{\nabla} \cdot \vec{J_l} = -K_l \tag{3a}$$

with K_l the voluminal mass rate of the passage of free water phase to vapor and $\vec{J}_l$ the flux vector of the liquid phase.

2.1.1.2. Bound water. The kinetic term in the flux contribution is equal to zero because, bound water is fixed during the drying.

$$\frac{\partial(X_b \rho_S)}{\partial t} + \vec{\nabla} . \overrightarrow{J_{as}} = -K_{as} \tag{3b}$$

with $\vec{J}_{as}$ and K_{as} are respectively the flux vector of the bound water phase and the voluminal mass rate to the passage of bound water to free water.

2.1.1.3. Vapor phase. Vapor phase receives the contributions of bound water and free water during the phase change. We obtained:

$$\frac{\partial\left(\alpha(1-S)\rho_g c_g\right)}{\partial t} + \vec{\nabla} . \left(\rho_g \overrightarrow{V_g} + \overrightarrow{J_g}\right) = K_{as} + K_l \tag{3c}$$

The term $\rho_g \overrightarrow{V_g}$ is the flux characteristic of the movement of the vapor phase.

The sum of Eq. (3-a), Eq.(3-b) and Eq.(3-c) gives Eq. (4) with consideration of Eq. (1):

$$\frac{\partial(\rho_S H)}{\partial t} + \vec{\nabla} . \left(\rho_g \overrightarrow{V_g} + \vec{J_l} + \overrightarrow{J_{as}} + \overrightarrow{J_g}\right) = 0 \tag{4}$$