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Multiphysics modeling of vacuum drying of wood

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ABSTRACT

Drying of porous media is characterized by the invasion of a gaseous phase replacing the evaporating liquid. Vacuum drying is an alternative method to alleviate discoloration for oakwood, so description of its underlying physics is important to understand this process. In this work, *a coupled* modeling is proposed to describe vacuum drying of oakwood at lab scale. This model describes the physics of wood-water relations and interactions with the vacuum dryer. Results provided important information about liquid and gas phase transport in wood. Water vapor and air dynamics in the chamber were simulated linking large scale (dryer) and macroscale (wood) changes during drying. We analyses results at 60–100 bar and 250–300 mbar both at 70 °C. The phenomenological one-dimensional drying model is solved by using the COMSOL's coefficient form and an unsymmetric-pattern multifrontal method. Good agreement was obtained for these drying conditions. The numerical results and experimental measures provide some confidence in the proposed model.

1. Introduction

Modeling of wood drying has been the topic of much research works over the years. Many publications cover a wide range of applications, including the derivation of the macroscopic equations, the development of analytical and numerical solutions, the determination of the physical and mechanical characterization of the medium being dried, and the experiments carried out on both laboratory and industrial scales. Nowadays, advances in software engineering results in ever-increasing computational power, and thus numerical simulation have fast become a very powerful tool to study and optimizes drying operation [1].

It is nowadays well accepted that vacuum drying of wood offers reduced drying times and higher end-product quality compared with others conventional drying operations [2]. The reduction of the boiling point of water at low pressure facilitates an important overpressure to enhance moisture migration. Is well know drying is a critical step in manufacturing timber products and is one of the most pressing issues in wood industry since there is a growing emphasis on high quality dried lumber because customers demand timber products which are defect free [3]. Then, the aim of industrial drying is to accelerate the natural drying process and to take advantage of dry wood's attributes, while minimizing some of the negative impacts [4].

Advantages of vacuum drying include the reduced drying times, recovery of water vapor, and a higher end-product quality [5]. Operating at low pressures the boiling point of water is reduced, which in turn enables an important overpressure that drives moisture efficiently [1,6,7]. For some wood species like oak that cannot be dried at high temperature conditions, vacuum drying offers the possibility to avoid collapse and discoloration [7–9]. As a consequence of these benefits, research in

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Nomenclature

A	total surface area of the board (m^2)
Atm	atmospheric
aw	water activity (–), 1 if $W > Wpsf$; $\exp(-AB^{100W})$ if $W < Wpsf$; $A = 2.51e-4T_2 - 0.1780T + 35.719$; $B = -9.475e-4T + 1.133$
$\overline{\rho Cp}$	specific heat of wood (J/kg K)
∇h_b	heat of desorption ($J\,kg^{-1}$)
k	intrinsic permeability (m^2) 1e−16
$\bar{C}$	vapor concentration (–)
ch	chamber
$cond$	condensation
Cp	specific heat (J/kg K)
D	diffusion coefficient (m^2/s)
eq	equilibrium
F_m	mass flux ($kg/m^2\,s$)
fsp	fiber saturation point
G	gravity force ($m\,s^{-1}$)
HR	relative humidity (%)
hv	latent heat of vapourisation at the reference temperature
J	bound water flux ($kg/m^2\,s$)
K	phase change rate of water
P	pressure (Pa)
Pc	capillary pressure (Pa)
R	ideal gas constant, 8.314 472 $J\,K^{-1}\,mol^{-1}$
S	saturation (–)
s	solid
$surf$	surface
T	temperature (K or °C)
t	time (s)
V	velocity ($m\,s^{-1}$)
W	moisture content (dry basis)

Greek Symbols

ρ	density (kg/m^3)
ε	porosity (–)
μ	dynamic viscosity (kg/m s)
∇	gradient operator
$\nabla\cdot$	divergente operator
λ	thermal conductivity ($Wm^{-1}\,K^{-1}$) $0.386\,W + 0.137$

Subscripts and Superscripts

v	vapor
f	fluid
w	water
Sat	saturation
b	bound water
l	liquid
i	species
g	gas
a	dry air
$\bar{}$	average
rl	relative to liquid

Input values for all model parameters

Parameter	Expression
ρ_a	1.2
ρ_l	1000