International Communications in Heat and Mass Transfer 38 (2011) 717–722

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

3d-Transient modeling of heat and mass transfer during heat treatment of wood ☆

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ARTICLE INFO

Available online 9 April 2011

Keywords:
Heat and mass transfer
High-temperature wood treatment
Mathematical modeling
Luikov's model
Conjugate problem

ABSTRACT

In the current work, three-dimensional Navier–Stokes equations along with the energy and concentration equations for the fluid coupled with the energy and mass conservation equations for the solid (wood) are solved to study the transient heat and mass transfer during high thermal treatment of wood. The model for wood is based on Luikov's approach and solves a set of coupled heat and mass transfer equations. The model equations are solved numerically by the commercial package FEMLAB for the temperature and moisture content histories under different treatment conditions. The simulation of the proposed conjugate problem allows the assessment of the effect of the heat and mass transfer within wood on the transfer in the adjacent gas, providing good insight on the complexity of the transfer mechanisms.

1. Introduction

Heat treatment of wood is a complex industrial operation involving coupled heat and mass transfer, so it is very essential to utilize a mathematical model based on the mechanisms of heat and mass transfer for predicting the time of process and the distribution of temperature and moisture within wood, and realize the optimal control of the entire heat treatment process. Heat treatment of wood at relatively high temperatures (in the range of 150–250 °C) is an effective method to improve biological durability of wood [1–6]. The main objective is to reduce the hydrophilic behaviour of wood by the tridimensional modification of the chemical structure of some of its components through heat treatment in controlled atmosphere as a soft pyrolysis reaction. The process consists in starting from wood previously dried around 10%–15% in humidity and to heat slowly in a specific chamber up to 210–240 °C in a nitrogen atmosphere with less than 2% in oxygen. Currently thermal modification of wood has become well established procedure, and there are a growing number of industrial treatment centers in various countries [7].

Several physical mechanisms contribute to moisture migration during the process. For a porous solid matrix, with free water, bound water, vapour, and air, moisture transport through the matrix can be in the form of either diffusion or capillary flow driven by individual or combined effects of moisture, temperature and pressure gradients. The predominant mechanisms that control moisture transfer depend on the hygroscopic nature and properties of the materials, as well as the heating conditions and the way heat is supplied.

Most of previous works used a standard correlation to compute the heat and mass transfer coefficients at the interface of wood. Also, these coefficients were assumed to be constant throughout the wood surfaces. However, in reality, high thermal treatment of wood is a transient conjugate problem. Leading edge heats up faster when compared to other surfaces. So, this thermal treatment has to be studied along with the flow field as a conjugate problem. Hence it is necessary to solve Navier–Stokes equations in the surroundings of the wood sample in order to get information about the boundary conditions for the transport equations in the medium and solve the complete thermal problem.

From the mathematical point of view, the high thermal treatment of wood can be treated as a simultaneous heat and mass transfer through a porous medium. The theory of transport phenomena in porous materials has been summarized by Luikov [8,9], Bories [10], Whitaker [11], Ahiua and Yi [12] and Zhang [13]. The analysis of high thermal treatment of wood has been considered recently. Younsi et al. [14,15] analyzed the conjugate problem of heat and moisture transport in wood sample both experimentally and numerically. The classical Luikov model was used for the numerical formulation of the problem in wood only. A parametric study was presented. Kocaefe et al. [16,17] compared to the different models (diffusion, Luikov and Multiphase) for the high thermal treatment of wood. The authors showed that the diffusion model is very useful for industrial applications. Younsi et al. [18] considered heat treatment of wood by solving diffusion equation in wood and turbulent Navier–Stokes equation in the fluid field for Thermowood technology. The experimental results and the model predictions were found to be in good agreement. The full description of the moist air and superheated

☆ Communicated by W. J. Minkowycz.

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0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.03.026