NON-STATIONARY HEAT AND LIQUID TRANSPORT IN CAPILLARY-POROUS MATERIALS DURING INTENSIVE MICROWAVE HEATING

Nikolay N. Grinchik[*], Alexander L. Adamovich[**], Semen P. Kundas[***], Yury G. Grozberg[**]
[*]*A.V.Luikov Heat and Mass Transfer Institute, P.Brovki 15, Minsk, Belarus*
[**]*Polotsk State University, Blockhina 29, Novopolotsk, Belarus.*
[***]*Belarusian State University of Informatics and Radioelectronics, P.Brovki 6, Minsk, Belarus*

Summary The differential equations system for non-stationary moisture transport in capillary-porous materials during intensive microwave heating based on multiphase filtration law, Kelvin, Clapeyron-Clausius formulas, desorption isotherms of wet materials, Debye relaxation model is offered. The results of numerical computer simulation are submitted to show the time evolution of temperature, moisture content, vapor pressure and strength of microwave in sample.

INTRODUCTION

Microwave energy is effectively used for heating and drying a number of materials [1]. Mechanism of heating and moisture transport during microwave processing of materials differs from specified mechanisms of conventional methods of heating. Theoretical description of non-isothermal heat and moisture transfer processes in porous materials in view of interaction of an electromagnetic field with dissipated media allows to simulate and to study processes of intensive microwave drying.
Heat occurrence in media under action of electromagnetic fields should be calculated proceeding from interaction of electromagnetic and thermal fields as systems with the continuously distributed parameters on basis of field and energy equations.

MATHEMATICAL MODEL

For description of moisture transport in a porous material the system of differential equations of non-stationary heat and mass transfer in porous media formulated earlier by Grinchik [2] is used. Given system consist from:
1) Equation of energy conservation

$$\left(\rho C_p\right)_{eff}\frac{\partial T}{\partial t}=\nabla\left(\lambda\nabla T\right)+L\cdot I+Q \tag{1}$$

где, $\left(\rho C_p\right)_{eff}$ и λ – effective heat capacity and thermal conductivity of materials – functions of moisture and temperature, Q – volumetric power density;
2) Transport equations of water and vapor

$$\frac{\partial W_l}{\partial t}=\nabla\rho_l\left(\frac{kk_{rl}}{\eta_l}\nabla P_l\right)-I \tag{2}$$

$$\phi\frac{\partial\left(\rho_v\Theta_v\right)}{\partial t}=\nabla\rho_v\left(\frac{kk_{rv}}{\eta_v}\nabla P_v\right)+I \tag{3}$$

As coupled equations is used:
1) Desorption isotherm of materials and expression of vapor pressure through inverse function

$$u_e=f\left(\varphi,T\right),\ P_v=f\left(u_l,T\right) \tag{4}$$

2) Dependence of saturated vapor pressure of liquid from temperature

$$P_{sat}=f\left(T\right) \tag{5}$$

3) Dependence of moisture pressure from liquid content and temperature

$$P_l=P_{sat}\left(T\right)+\frac{RT}{v_l'}\ln\frac{P_v}{P_{sat}} \tag{6}$$

4) Expressions of latent heat of vaporization and intensity of mass exchange between phases

$$L=\frac{RT^2}{v_l''}\left(\frac{\partial\ln P_v}{\partial T}\right)_{u_e},\qquad I=\rho_s\frac{\partial u_l}{\partial t}=\rho_s\left[\left(\frac{\partial u_e}{\partial P_v}\right)_T\frac{\partial P_v}{\partial t}+\left(\frac{\partial u_e}{\partial T}\right)_{P_v}\frac{\partial T}{\partial t}\right] \tag{7}$$

5) Equation of ideal gas (vapor)

$$\rho_v=\frac{v_vP_v}{RT} \tag{8}$$

The coupled expressions (4) – (8) are constructed on knowledge of sorption (desorption) isotherm of capillary-porous media, therefore they reflect characteristics of specific wet material: there is no necessity to determine Leverett

function, influence of internal heat generation on criterion of phase transition and thermal moisture conductance factor as in case of classical approach.
Besides heat generation term Q in the energy equation is offered to determine on model of Debye, outgoing from dipole relaxation time of substance, that on our sight is exacter as against traditional definition through the loss dielectric factor requiring some restrictions [3].
For modeling of distribution of microwave electromagnetic wave it is offered to use Helmgoltz homogeneous equation for strength vector of an electrical field, where dielectric properties of substance also are characterized by dipole relaxation time of Debye

$$-\nabla^2\mathbf{E}+k^2\mathbf{E}=0\,,\; k^2=-\omega^2\varepsilon_0\left(1+\frac{\varepsilon-1}{1+i\omega\tau_e}\right) \qquad (9)$$

SIMULATION AND ANALYSIS

The system of equation (1) – (3) and (9) with corresponding boundary and initial conditions were solved simultaneously using finite element method for one space dimension. Numerical modeling was carried out for wood sample with desorption isotherm as below:

$$u_e=10.6^{\varphi}\left(3.27-0.015\left(T-273\right)\right)/100 \qquad (10)$$

At the first stage the process of moisture transfer in wet wooden plate with isolated borders without account of influence of microwave field, and then with source of microwave was simulated. At the second stage the drying process of plate by powerful microwave field was considered. In all cases the electromagnetic wave of industrial frequency $2.45\Gamma\Gamma ц$ are assumed to arrive at the left side of sample (Fig.1.), and it was supposed, that component of field is tangential to wood surface, that in real conditions can correspond rectangular waveguide or horn resonator heating. Moreover boundary condition for (9) take into account reflected wave from sample. As a result of modeling the fields of temperature, moisture content, vapor pressure, distribution of microwave field strength in a sample are received.

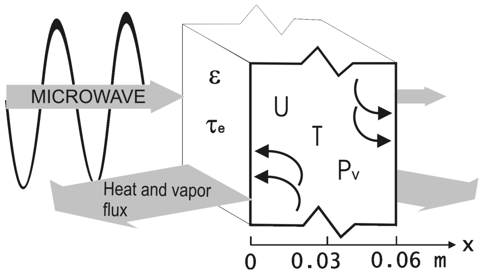

Fig.1. Schematic diagram of the microwave drying process

The analysis of simulation shows significant difference of character heat and liquid transport during microwave heating of wet capillary-porous materials from conventional heating. The penetrating electromagnetic field causes localization of heat generation in a sample, formation of area with increased temperature and vapor pressure, intensive movement of liquid to sites with lower temperature and pressure. Internal evaporation is a dominant effect of strong filtration flow during microwave heating.

CONCLUSION

In work the attempt from united positions is undertaken to describe processes of filtration and drying in correlation with the electrodynamics phenomena in dissipated media at action of microwave electromagnetic fields. The approach, submitted in work, of modeling not isothermal moisture transport, account of fields, and considered system of equations are useful for applications of high intensity microwave processing of materials, drying, for an estimation and optimization of technological regimes, theoretical study of the specified processes.

References

[1] Morozov G.A. Microwave technologies in an industry and agriculture: modern achievement and new approaches // J. Antenny. – 1998. – No.1(40)
[2] Grinchik N.N. Transfer processes in porous media, electrolytes and membranes. – Minsk, 1991
[3] Turov E.A. The material equations of electrodynamics. – M.: "Nauka", 1983