THE CALCULATION OF THE TEMPERATURE DISTRIBUTION IN PRODUCT FOR THERMAL PROCESSING USING THE TRAVELING WAVES OF MICROWAVE FIELD

Ivanov Leonid, Bernic Mircea, *Ciobanu Eugeniu

Technical University of Moldova – Chişinău, Moldova

***Ciobanu Eugeniu, 4eugeniu.ciobanu@gmail.com**

Abstract: The paper describes the equation of heat and mass transfer during wet products dehydration process, using SHF field moving with equal speed through a rectangular waveguide.
Key words: heating, drying, electromagnetic field, SHF

Abbreviations

T – temperature, K;
u – moisture content, $\frac{kg}{kg}$;
Q_v – volumetric power of the internal heat source, $\frac{W}{m^3}$;
a, a_m – coefficients of heat and mass transfer, $\frac{m^2}{s}$;
ε – coefficient of phasic transition;
P – pressure of steam and gas mixture, Pa;
c_v – volumetric mass;
V – product motion speed, $\frac{m}{s}$;
$\acute{\varepsilon}$ – dielectric permeability;
$tg\delta$ – tangent of dissipation angle

The process of heating and dehydration in the electromagnetic fields are well described by the Maxwell equations together with Likov heat and mass transfer equations.

For rational design of heating and drying devices, it is necessary to consider the impact of this environment on the electrical parameters of the transmission line (applicator).

It is known that a real microwave device is an irregular waveguide with linearly varying narrow wall, namely the parameter *b*.

The narrow wall thickness change has little effect on the propagation constant k_2 through the wave H_{10}, and the greater the value of $\sqrt{\acute{\varepsilon}\sqrt{1+tg^2\delta_2}}$, the less deviation from its value for wave H_{10} in the perfect waveguide (filled only with airenvironment).

For the case of a coaxial waveguide, in order to obtain uniform energy propagation (for corners), it is necessary to satisfy the condition:

$$\lambda > \pi(r_1 + r_2)$$

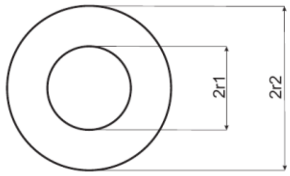

Fig. 1. Coaxial circular waveguide

The optimal working length for a rectangular waveguide is $\lambda \approx \sqrt{2}a$. In this case it is achieved uniform absorption of the electromagnetic field in the treated product, in section perpendicular to product movement.

Let`s describe the dehydration process using a regular waveguide with a rectangular section.

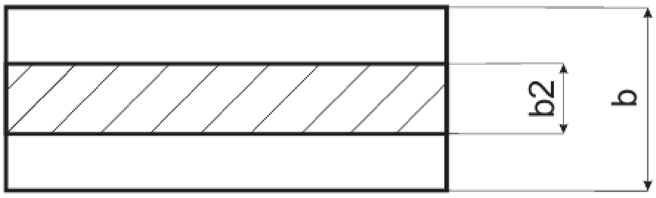

Fig. 2. Regular waveguide with a rectangular section

The system of equations which describe heat and mass transfer for internal heat source is the following [2]:

$$\begin{cases} \frac{\partial T}{\partial \tau} = a\nabla^2 T + \frac{\varepsilon r}{c}\frac{\partial U}{\partial \tau} + \frac{Q_v}{c\rho} & (1) \\ \frac{\partial U}{\partial \tau} = a_m(\nabla^2 U + \delta \nabla^2 T) + \varepsilon \frac{\partial U}{\partial \tau} & (2) \\ \frac{\partial P}{\partial \tau} = a_p \nabla^2 P + \frac{\varepsilon}{c_v}\frac{\partial U}{\partial \tau} & (3) \end{cases}$$

Now we will consider the case when the product moves by z axis with the speed *v*, and thermal and physical parameters on the plane x-y are constant, the process is stationary. In this case, relations (1) and (2) will take the following form:

$$v\frac{dT}{dz} = a\frac{d^2T}{dz^2} + \frac{\varepsilon r}{c}\frac{\partial U}{\partial \tau} + \frac{Q}{c\rho} \quad (4)$$

$$v\frac{dU}{dz} = a_m\frac{d^2U}{dz^2} + \varepsilon\frac{\partial U}{\partial \tau} \quad (5)$$

Solution of equation (5) can be written as follows:

$$u = c_1 + c_2 e^{\frac{(1-\varepsilon)v}{a_m}z} \quad (6)$$

Constants c_1 and c_2 can be found from the following boundary conditions:

$$u(z)|_{z=0} = u_0 \text{ and } u(z)|_{z=L} = u_K$$

In this case, taking into consideration $\frac{\partial U}{\partial \tau} = \frac{v du}{u_R}$, relation (6) will take the following form:

$$u(z) = u_0 - \frac{(u_0 - u_K)e^{\frac{(1-\varepsilon)v}{a_m}vL}}{1 - e^{\frac{(1-\varepsilon)v}{a_m}vL}} + \frac{(u_0 - u_K)}{1 - e^{\frac{(1-\varepsilon)v}{a_m}vL}} e^{\frac{(1-\varepsilon)v}{a_m}vz} \qquad (7)$$

If to insert (7) in (4) we will obtain a relation which describes temperature distribution along the applicator:

$$\frac{d^2T}{dz^2} - \frac{v}{a}\frac{dT}{dz} + \frac{(u_0 - u_K)\frac{(1-\varepsilon)v}{a_m}v^2}{\left(1 - e^{\frac{(1-\varepsilon)v}{a_m}vL}\right)a} e^{\frac{(1-\varepsilon)}{a_m}vz}\frac{\varepsilon r}{c} + \frac{Q}{c\rho u} \qquad (8)$$

Internal heat source power decrease along z axis will be allowed as exponential $Q = Q_0 e^{-K}$, where K is the coefficient of power absorption.
The homogeneous equation for (8) will have the following form:

$$\frac{d^2T}{dz^2} - \frac{v}{a}\frac{dT}{dz} = 0 \qquad (9)$$

Solution of equation (9) can be written as follows:

$$T = c_1 e^{\frac{v}{a}z} + c_2 \qquad (10)$$

Solution of the inhomogeneous equation (8) will be found varying constants of equation (10):

$$c_1^{`} e^{\frac{v}{a}z} + c_2^{`} = 0 \qquad (11)$$

$$c_1^{`}\frac{v}{a}e^{\frac{v}{a}z} = \frac{\varepsilon r v^2(u_0 - u_K)(1-\varepsilon)}{c\left(1 - e^{\frac{(1-\varepsilon)v}{a_m}vL}\right)a_m a} e^{\frac{(1-\varepsilon)v}{a_m}vz} + \frac{Q_0}{c\rho a}e^{-Kz} \qquad (12)$$

Integrating (12) takes the following form:

$$c_1 = \frac{\varepsilon r v^2 (u_0 - u_K)(1-\varepsilon) e^{\left[\frac{(1-\varepsilon)v}{a_m} vz\right]^2}}{c\left(1 - e^{\frac{(1-\varepsilon)v}{a_m} vL}\right) a_m a \left(\frac{1-\varepsilon}{am} - \frac{1}{a}\right) V} - \frac{Q v_0 e^{-\left(K + \frac{v}{a}\right)z}}{c\rho v \left(k + \frac{v}{a}\right)} + c_1^*$$

$$c_2 = -\frac{\varepsilon r (u_0 - u_K)}{c\left(1 - e^{\frac{1-\varepsilon}{a_m} vL}\right)} e^{\frac{(1-\varepsilon)v}{a_m} vz} + \frac{Q_0}{c\rho v k} e^{-kz} + c_2^*$$

In this case, solution of equation (8) will change in:

$$T = \frac{\varepsilon r v (u_0 - u_K)(1-\varepsilon) e^{\frac{(1-\varepsilon)vz}{am}}}{c\left(1 - e^{\frac{1-\varepsilon}{am} vL}\right) am \cdot a \left(\frac{1-\varepsilon}{am} - \frac{1}{a}\right)} - \frac{Q v_0 e^{-kz}}{c\rho v \left(k + \frac{v}{a}\right)} + $$
$$+ c_1^* e^{\frac{v}{a} z} - \frac{\varepsilon r (u_0 - u_K)}{c\left(1 - e^{\frac{1-\varepsilon}{a_m} vL}\right)} e^{\frac{(1-\varepsilon)vz}{am}} + \frac{Q_0}{c\rho v k} e^{-kz} + c_2^* \quad (13)$$

Constants of the integration can be determined from following boundary conditions:

$$T(0,\tau) = T_i \text{ and } T(L,\tau) = T_f \quad (14)$$

From (13) and (14), having the values of initial and final temperatures, and the length of the waveguide, it is possible to determine the power intake into the product, or knowing the initial and final temperatures and the power intake we can determine the optimal length of the waveguide.

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