UHF DRYERS WITH LONGITUDINAL INTERACTION

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Abstract: Basing on the analysis of differential equations system using partial derivatives proposed by A. V. Lykov, one proposes the calculation of soft regime dryers, using temperatures lower than boiling one. For a rational take place of drying or heating process one should constantly heat the air to exclude water vapors condensation on the waveguide's surface and provide proper moisture elimination from evaporation zone. The calculation is based on specific thermo-physical properties of the processed product. The obtained correlations show the repartition of temperature and moisture content along the dryer length. Basing on the analysis of the common solution for the temperature repartition and specifying the values of the admissible temperature (using technological conditions or others), one can calculate the level of used UHF power.

Key words: dryer, UHF energy input, waveguide, thin layer product, temperature.

Introduction:

When processing products with UHF-moving energy input one notices a productivity augmentation. Often used rectangular energy waveguide, for thin materials thermal processing, could be inputted from both product incoming and outgoing ways.

In paperwork [1] was shown the correlations for microwave dryers calculus without environment convective heat transfer, which isn't showing the always truth. As usual we have combined convective and microwave heat input. For a rational take place of drying or heating process one should constantly heat the air to exclude water vapors condensation on the waveguide's surface and provide proper moisture elimination from evaporation zone.

Materials and methods

To solve the assigned task, dryer calculus, we could use A.V. Lykov equations system solution, considering that our product is processed in a quasi-stationary regime, i.e. replacing the correlation with a partial derivative with respect to time:

$$\frac{\partial}{\partial\tau} = V\nabla T : \left| \frac{\partial T}{\partial\tau} = V\nabla T \right.$$

Then the equations system of A.V. Lykov will have the form:

$$\begin{cases} \pm V\nabla T = a\nabla^2 T + \dfrac{Q_v}{c\rho} \pm \dfrac{r?\varepsilon\nabla u}{c} & (1) \\ \pm V(1-\varepsilon)\nabla u = a_m\nabla^2 u + a_m\delta\nabla^2 T & (2) \\ \pm V\dfrac{\varepsilon}{c\rho}\nabla u \pm V\nabla\rho = a_p\nabla^2 p & (3) \end{cases}$$

Where:

V – product movement velocity in waveguide-applicator, [m/s];

T – temperature, [°K];

a – thermal diffusivity (conductivity) coefficient, [m^2/s];
Q_v – inside source power, [m^3/h];
Q_0 – inputted power, [m^3];
c – specific heat capacity, [J/(kg·K)];
ρ – density, [kg/m^3];
u – moisture content, [kg/kg];
ε – evaporated moisture ratio without phase-transfer;
a_m – mass-conductivity coefficient,;
δ – thermal-moisture-conductivity coefficient, [1/K];
p – vapor phase pressure, [Pa];
a_p – convective diffusivity coefficient, [m^2/s];
r – latent heat of phase-transfer, [J/kg].

Considering product's propagation velocity higher than heat's one, because of heat conductivity, we'll have the next result for equation (1):

$$\frac{\partial T}{\partial z} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{Q}{c\rho} + \frac{Vr}{c}\frac{\partial u}{\partial z} \tag{4}$$

The boundary conditions in our case could be written in the next form:

$$T(x, y, z)\big|_{z=0} = 0 \text{ for forward flow} \tag{5}$$

and

$$T(x, y, z)\big|_{z=4} = 0$$

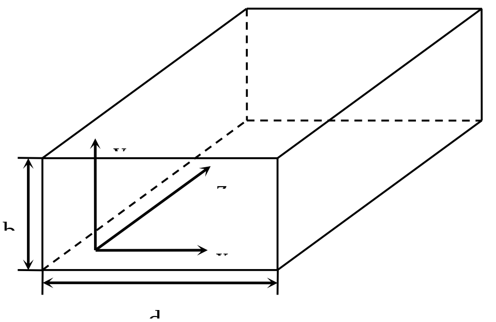

Fig. 1. *3D spacing of a longitudinal dryer*

Latent power

$$Q_v = \frac{2\beta Q_0 l^{-2\beta z}}{b \cdot d}$$

$$\begin{aligned} \frac{\partial T}{\partial x} &= (x, y, z)\Big|_{x=d} = \pm\frac{\alpha}{\lambda}\left(T_п - T_c\right) \\ \frac{\partial T}{\partial y} &= (x, y, z)\Big|_{x=b} = \pm\frac{\alpha}{\lambda}\left(T_п - T_c\right) \end{aligned} \tag{6}$$

Considering $\frac{\partial u}{\partial z} = 0$, while heating the row material, the equation (4) could be written using the method of variables separation [2]:

$$T(x,y,z) = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} A_{nm}(z)\left[\cos K_{ym} + \frac{\alpha}{\lambda K_{ym}} \sin K_{ym} y\right] \cdot \cos K_{xn} x \tag{7}$$

where:

$$A_{nm}(z) = \frac{1}{V} e^{\pm\frac{aK_{nm}^2 dz}{V}} \int_0^z B_{nm}(z) e^{\pm\frac{aK_{nm}^2 z}{V}} \cdot dz$$

$$B_{nm} = \frac{8Q_0 \alpha(z) e^{-2\int_0^z \alpha(z)dz} \cdot \dfrac{\sin\left(K_{xn}\frac{d}{2}\right)}{K_{xn}\frac{d}{2}} \left[\dfrac{\sin(K_{ym} b)}{K_{ym} b} + \dfrac{\alpha b \sin^2 K_{yn}\frac{b}{2}}{\alpha\lambda K_{yn}\frac{b}{2}}\right]}{bdc\rho\left[1 + \dfrac{\sin(K_{xn} d)}{K_{xn} d}\right]\left[1 + \left(\dfrac{\alpha}{\lambda K_{ym}}\right)^2 + 2\dfrac{\alpha}{\lambda b K_{ym}^2}\right]} \tag{8}$$

and the transcendental equation to determine K_{xn} and K_{ym}:

$$-\frac{K_{xn} d}{2} tg\left(\frac{K_{xn} d}{2}\right) = \frac{\alpha d}{\alpha\lambda} : tg(K_{ym} l) = \frac{\dfrac{2\alpha}{\lambda K_{ym}}}{1 - \left(\dfrac{2\alpha}{\lambda K_{ym}}\right)^2} \tag{9}$$

if one ignores the heat losses from the both ends of the product, than temperature repartition can be written in next form:

$$T = T_0 + \frac{2Q_0}{b \cdot dc\rho V} e^{\pm\int_0^z \frac{2\alpha dz}{c\rho V d}} \cdot \int_0^z \beta(z) e^{\pm\int_0^z \left[\frac{2\alpha}{c\rho V d} - 2\beta\right] dz} \cdot dz \tag{10}$$

Moisture content repartition value, along the length of the co-current thin materials dryer (axe Z) (2) can be written in the form:

$$u = u_0 e^{-\frac{2\alpha_n Z}{c_m \rho b V}} \tag{11}$$

and for countercurrent

$$u = u_0 e^{-\frac{\alpha_n (L_1 - Z)}{c_m \rho b V}} \tag{12}$$

The obtained correlations show the repartition of temperature and moisture content along the dryer length.

Conclusion

Basing on the analysis of the common solution for the temperature repartition and specifying the values of the admissible temperature (using technological conditions or others), one can calculate the level of used UHF power.

As a result the resolution of equation (4) in adiabatic conditions can be written as:

$$T = T_0 + \frac{Q_0}{2\beta c\rho Vb\cdot d}\left(e^{-2\beta z} - 1\right) + \frac{r}{c}\left(u_c - u_0\right) \quad (13)$$

References

1. Okress E., „UHF energetika T2”, M; Mir. 1971.

2. Tihonov A.N., Samarskij A.A., „Urovnenija matematicheskoj fiziki”, M; Nauka, 1982.