INTERNAL HEAT SOURCE PULSED SUPPLY FOR OIL CROPS DRYING

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Abstract: The paper considers the possibility of vegetable oil crops' drying with the use of internal heat source in a pulsed mode. There was obtained the mathematical dependence of the duration of heating and duration of relaxation from the operational parameters of the drying process. It also shows the possibility of vegetable oil crops' drying with the use of internal heat source in a pulsed mode. There was obtained the mathematical dependence of the duration of heating and duration of the relaxation from the operational parameters of the drying process.

Introduction

It is well known that one of the main driving forces of the drying process is the value and direction of the temperature gradient $\nabla\vec{T}$. In turn, at wet products heating, temperature gradient involves the apparition of humidity $\nabla\vec{U}$ and pressure $\nabla\vec{P}$ gradients, which, as a rule have a positive influence on wet products drying process. The direction of these vectors depends largely on the type of heat source and its input method.

In case of convective heating $\nabla\vec{T}$ and $\nabla\vec{P}$ are directed from the superficial products layers to the inner layers, and $\nabla\vec{U}$ counter flow, from center to periphery. [1, 2, 3, 4]. This counter-targeting of mass and energy flows „brakes" drying process, leading to an increased energy consumption, drying period and consequently, reduces the quality indices od the dried product.

In case of heating using electromagnetic field, UHF and SHF, all three mentioned gradients are equally directed from the inner layers of the product to the surface. In this case, heat and pressure flows accelerate mass (moisture) transfer, and hence the drying process.

Materials and methods

In order to make experimental study and theoretical arguments of optimal parameters of internal heat source implementing during oil crops drying, were used sunflower seeds, variety "Luceafărul", grown in Ungheni, Republic of Moldova.

Samples were heated using high frequency electromagnetic field over a period of time of 1750 s. Fields intensity was 25.6, 31.8, 38.0 and 44.0 kV/m. Product layer height was accepted 0.04 m.

During drying, under online (measurement frequency of 0.5 s) was recorded product temperature in the center and periphery layers.

Statistical processing of the results was performed using the program Mathcad 14.

The mathematical model developed to determine the optimal parameters for implementing the regime of internal heat source in the drying process is based on solving differential equations of Academician A. V. Likov [5]. Mentioned differential equations were solved using the same computer program Mathcad 14.

Results and discussions

Due to thermal conductivity of the product, the application of internal heat source transmits heat superficial inner layers. While heat accumulated in the superficial layers and internal layers is transmitted from the environment.

Thus, at first stage of heating, when the heat flow rate is higher in product than into the environment, the temperature gradient increases (fig. 1 and 2). At the time, the speed of these flows equals the temperature gradient achieve maximum and begins to decrease until a minimum constant speed dependent on heat transfer rate into the environment.

Analysis of graphs in fig. 1 and 2 allows us to conclude that for volume heating is optimal to keep the thermal regime in the transition from one stage to the second, when $\nabla\vec{T}$ get maximum "positive" value. Further warming of product is unreasonable because temperature increase diminishes the quality of the finished product and reduces $\nabla\vec{T}$ which is one of the driving forces of the process.

In practice this system of drying may be achieved by boosting intake of internal heat source heating – relaxation – heating.

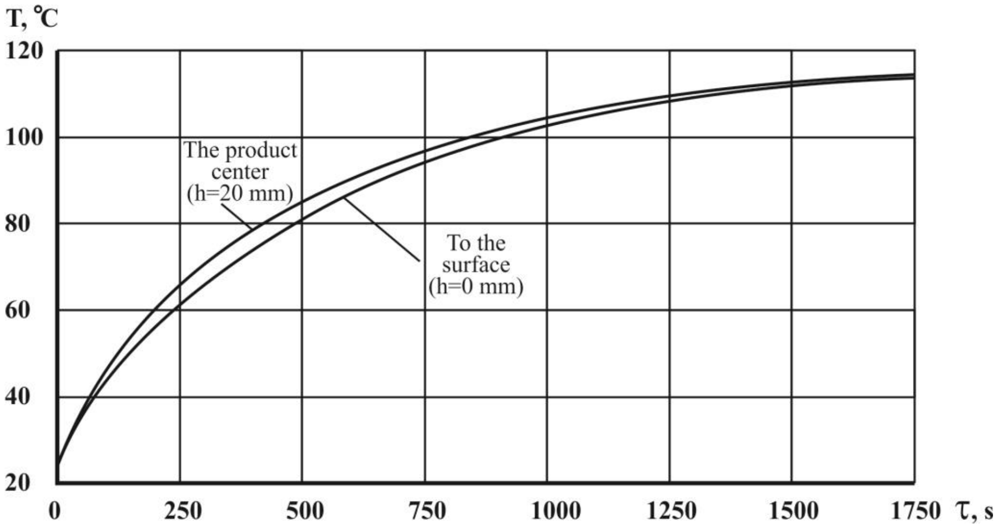
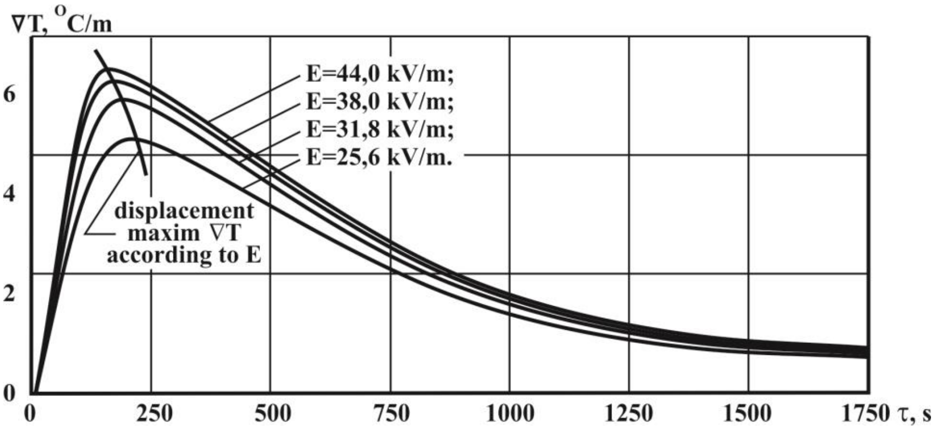


Fig. 1. Temperature variation curves of sunflower respect to time at heating using electromagnetic field f = 27,0 MHz; E = 44,0 kV/m; ambient temperature 20,0 ^{O}C; air speed 0,1 m/s; product layers thickness 0,04 m.



b)

Fig. 2. Curves of temperature gradient variation, for sunflower seeds, respect to time, heating using electromagnetic field f = 27.0 MHz, ambient temperature 20.0 ^{O}C, average speed 0.1 m/s, product layers thickness 0.04 m.

Maintaining maximum values of temperature gradient throughout the drying process is possible only after calculation of the length of detention energy intake depending on product properties and source power parameters.

Heating and relaxation periods can be determined for any single point in the drying process after solving the system of differential equations of Likov A. V. for internal heat source [5]:

$$\frac{\partial T}{\partial \tau} = a_T \frac{\partial^2 T}{\partial x^2} + \frac{\varepsilon \cdot r}{c} \cdot \frac{\partial u}{\partial \tau} + \frac{Q_V}{c \cdot \rho} \tag{1}$$

$$\frac{\partial u}{\partial \tau} = a_m \left(\frac{\partial^2 u}{\partial x^2} + \delta \frac{\partial^2 t}{\partial x^2} \right) + \varepsilon \frac{\partial u}{\partial \tau} \tag{2}$$

$$\frac{\partial p}{\partial \tau} = a_p \frac{\partial^2 p}{\partial x^2} + \frac{\varepsilon}{c_b} \cdot \frac{\partial u}{\partial \tau} \tag{3}$$

where a represents the diffusion coefficient of temperature, m^2/s;

- ε – phase transformation criterion;
- r – latent heat of vaporization, J/kg;
- c – specific heat capacity, J/(kgK);
- ρ –dried part density of wet body, kg/m^3;
- u – moisture, %;
- a_m – mass diffusion coefficient, m^2/s;
- δ – Sore coefficient for wet body, K^{-1};
- a_P – molar diffusion coefficient, m^2/s;
- c_P – specific mass capacity, J/(kgM);
- Q_V – internal heat source, W/m3;

Boundary conditions for this case are as follows:

$$\frac{dT}{dx}(0,\tau)= f(\tau); \quad T(x,0)=\psi(x) \tag{4}$$

$$\frac{du}{dx}(0,\tau)= f_u(\tau); \quad u(x,0)=\psi_u(x) \tag{5}$$

$$\frac{dp}{dx}(0,\tau)= f_p(\tau); \quad p(x,0)=\psi_p(x) \tag{6}$$

At present there are many methods to solve partial derivatives, but in our opinion, for the case of pulsed heating with internal heat sources, the optimum is the source method.

According to the source method, action of internal basic heat source action in the body, one-dimensional heat flow is described by a straight infinite source function $G(x,\xi,\tau'-\tau)$ [6, 7]:

$$G(x,\xi,\tau'-\tau)=\frac{1}{2\sqrt{\pi a(\tau'-\tau)}}\left[e^{-\frac{(x-\xi)^2}{4a(\tau'-\tau)}}-e^{-\frac{(x+\xi)^2}{4a(\tau'-\tau)}}\right]. \tag{7}$$

After solving the differential equations (1-3) through the function (7) and taking into account the boundary conditions (4-6) over the duration of heating pulse τ_A:

$$\tau_A=\frac{\alpha}{\lambda}\cdot\frac{c\rho x}{Q_V}\Delta T=\frac{\alpha}{\lambda}\cdot\frac{c\rho d}{2Q_V}(T_S-T_M). \tag{8}$$

So, in order to obtain a maximal temperature gradient in the thermal treatment in an active electromagnetic field during heating of the product can be determined by the formula (8).

According to the table of Student criterion values for degree of freedom 3 (n-1), math function (8) describes the proper heating time until the maximum temperature gradient with an accuracy of up to 20% ($p \le 0{,}1$; $t_C = 1{,}21$; $t_T = 1{,}63$).

Variation of heating period until achieving the maximum temperature gradient versus E, obtained by experimental data and theoretical calculus is presented in figure 3.

Though graphs from figure 3 show a deviation of heating curve period, obtained by formula (8), from experimental obtained curve, they have the same character. The mentioned deviation can be minimized due to application of some correlation coefficients, characteristic for each product.

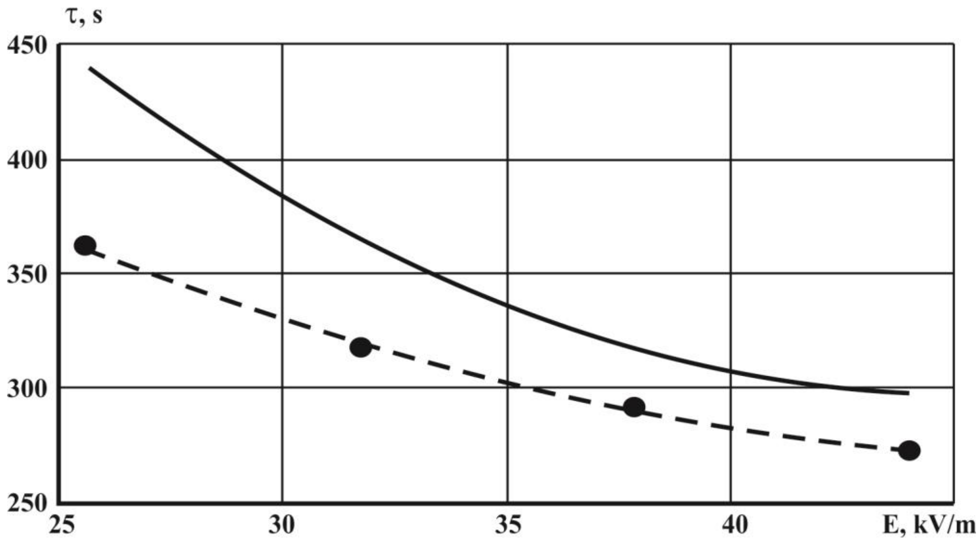


Fig. 3. Variation of heating period until achieving the maximal value of temperature gradient depending on E, obtained from experimental data (interrupted line) and from theoretical calculus (continuous line).

After interrupting the internal heat source, temperature gradient value minimizes continuous by a low dependent on thermo-physical properties of the product and neighbor. Numerical value of temperature gradient, in this period, goes to „zero" at an infinite period of time. That`s why the determination process of the rest period is very difficult.

If interrupting the heat source, the pressure relaxes rapidly by an exponential function. Rapid relaxation is also a consequence of water steam condensation in absence of heat source. In some cases, this can involve the apparition of vacuum.

So, the duration of relaxation (absence of internal heat source) is rational to be determined after analyzing the pressure field in product.

In order to determine the relaxation period it was solved the Likov A. V. differential equation (3) using the initial condition:

$$p(x,0) = p(x) \quad , \tag{9}$$

and boundary condition:

$$p(0,\tau) = 0 \quad . \tag{10}$$

After using the same "source" method, it was obtained the following relation:

$$\tau_P = \frac{x^2}{2a_p} = \frac{d^2}{8a_p} \quad . \tag{11}$$

According to relation (11) it can be determined the period from internal heat source interrupting till $\nabla\vec{P}$ reaches the value "zero". Namely this period between two pulses is recommended as the optimal one for temperature gradient maximal value maintaining.

Figure 4 shows graphic functions of dependence the period of internal heat source application (fig. 4a) and resting period (fig. 4.b) on sunflower seeds moisture.

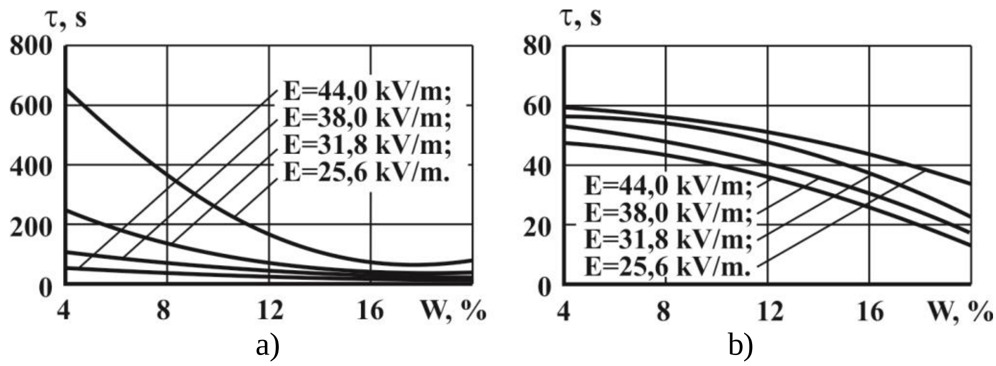


Fig. 4. Variation of heating period a) and resting period b) depending on product moisture, determined by formulas 8 and 11. f = 27,0 MHz; neighbor temperature 20,0 ^{O}C; air speed 0,1 m/s; product layers thickness 0,04 m.

From graphs we can observe that as internal heat source application period, so the period between pulses, obtain maximal values la relatively low product moistures, so, this method will obtain a major effect for advanced product moistures, when internal heat source application periods are relatively short.

Conclusion

From mentioned above, we can conclude that pulsed internal heat source application, at oil products (such as sunflower seeds) drying, allows temperature gradient values increasing, which also allows the intensification of mass transfer in product and energy consumption reduction.

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