Drying Kinetics of Sunflower Seeds using Pulsed UHF Energy Intake

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Abstract **– In this paper the drying kinetics of sunflower seeds using pulsed UHF energy intake are given.It is shown and argued that the application of pulsed internal heat source made possible the reduction of heat treatment period by 17%, and of specific energy consumption by 21.8%.**

Keywords **– drying, sun flower seeds, UHF field, heat and mass transfer, pulse.**

1. Introduction

Sunflower (Helianthus annulus L.) ranks third among herbaceous oil plants. Fruits (achene) contain about 50% oil, with exceptional food quality and high degree of conservation; are used in human food (refined) and food (margarine, canned food, soap, lecithin, phosphatides, etc.) [1].

As a rule, the sunflower oil is obtained by pressing (hot or cold). Whatever the method, the product undergoes preventive drying process, which takes a lot of time and is usually accompanied by increased energy consumption. Process intensification with concomitant reduction of energy consumption is easily achieved by increasing temperature of the heating agent (during convection drying) or of the product (during drying using electromagnetic fields) [2, 3]. Given the fact that sunflower is characterized by a big content of fatty acid of high nutritional value, which is sensitive to temperatures advanced, this method of process intensification is not desired.

The study of heat and mass transfer demonstrated the possibility of drying time and energy consumption reduction, by applying a pulsed electromagnetic field. This permits to increase the one of the driving transfer phenomena forces, namely the temperature gradient (∇T) at relatively low product temperatures.

2. Materials and methods

In the paper is presented a study of sunflower seeds drying kinetics, by applying internal heat source – the ultra-high frequency electromagnetic field (UHF). Energy intake was studied continuously and periodically – pulses containing of active heating period and passive period of relaxation (lack of energy source).

For the study were used sunflower seeds of variety “Victoria”, with initial moisture of 26.9%.

Drying process was performed in a laboratory that allows the energy intake in various ways: convection, UFH and combined (convection + UHF). Mass decrease was registered online during drying process, using electronic scales SC-132, temperature drying agent – with thermocouples, temperature at product’s center and surface – with resistance thermometer NcW-1617.

According to the obtained parameters there were obtained drying curves, drying speed curves, average temperature dependence and variation of temperature gradient as a function of time.

3. Results and discussion

In order to study the effectiveness of the electromagnetic field applying during sunflower seeds drying process, there was investigated drying kinetics with UHF energy intake in both continuous and impulse regimes.

To ensure the pulsed regime there were determined formulas to calculate the duration of active (energy intake) and passive (resting) periods of a pulse as a function of drying parameters: field strength, temperature of product and its electro- and thermo-physical properties [4].

$$\tau_A = \frac{\alpha}{\lambda} \cdot \frac{c\rho x}{Q_V} \Delta T = \frac{\alpha}{\lambda} \cdot \frac{c\rho d}{2Q_V} \left(T_S - T_M\right), \qquad (1)$$

$$\tau_P = \frac{x^2}{2a_p} = \frac{d^2}{8a_p}, \qquad (2)$$

where τ_a represents the active pulse’s period, s;
α – heat transfer coefficient, W/m^2K;
λ – thermal conductibility coefficient, W/mK;
d – characteristic product’s dimension, m;
Q_V – internal heat source’s strength, W/m^3;
T_S – product’s surface temperature, K;
T_M – environment temperature, K;
τ_p – passive pulse’s period, s;
d – product layer’s thickness, m;

a_p – molar diffusion coefficient, m2/s.

Pulsed UHF energy input with pulse's parameters obtained by formulas (1) and (2) serves to maintain the maximum values of the temperature gradient through the drying period.

The drying kinetics was studied for the case of drying agent temperature of 20 ^{O}C, at which in case of continuously UHF energy intake was found minimum energy consumption compared to higher temperatures.

Field strength was calculated using formula (3) [5].

$$E = \sqrt{\frac{\alpha(T_C - T_M)}{0.555 \cdot 10^{-6} \cdot f \cdot k \cdot R\left(1 + \frac{\alpha}{\lambda} R\right)}} \qquad (3)$$

where $\boldsymbol{T_C}$ represents the temperature of the product's center, ^{O}C;

$\boldsymbol{T_M}$ – environment's temperature, ^{O}C;

$\boldsymbol{R}$ – product layer's thickness, m.

The calculation was performed in recitals as ∇T_{max} to be obtained at the average temperature of 90 ^{O}C, temperature which assures the maximum extraction of essential oil without quality thermal damage.

To maintain maximum values of temperature gradient in this regime, according to formula (3) the electromagnetic field's strength was accepted - 44.0 kV/m.

Drying curves $W = f(\tau)$ of sunflower seeds for the case of pulsed energy intake (1) and continuous energy intake (2) are presented in figure 1.

Overall graphic character of drying curves for pulsed energy intake completely corresponds to drying curves for continuous one, except for a small deviation in time. This confirms once again the theory of such scientists as A.V. Lycov, A.S. Ginsburg, V.V. Krasnicov, M.A. Grishin etc. [2, 3] that the curves' character largely depends on the physic-mechanical structure of the product and on the related forms of moisture with the skeleton. However, on the drying curves are well highlighted periods of UHF energy intake (slope with an advanced inclination angle) and periods of relaxation (slope with a low inclination angle).

From graphs is observed that at pulsed energy intake compared to continuous energy intake, drying period decreased by 17.8% being 94.5 min.

On the drying curves for pulsed UHF energy intake are well highlighted some waves (curve enlarged in a circle) with the appearance of extremes. This indicates that when disconnecting power supply, occurs a redistribution of mass and heat transfer resistance forms, reducing them, which also favors the moisture transfer.

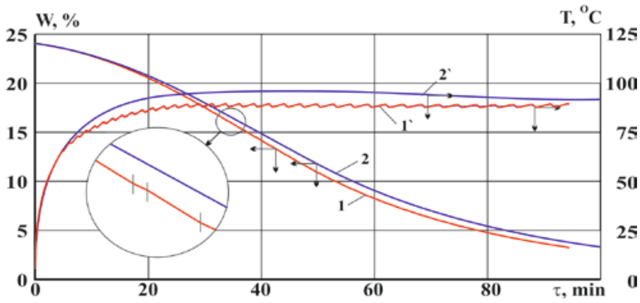

Figure 1. Drying and temperature curves of sunflower seeds drying process with pulsed (curves 1 and 1`) and continuous (curves 2 and 2`) UHF energy intake

The same figure 1 also shows the temperature variation character of sunflower seeds during the drying process (curves 1' and 2'). As shown in the graphs for both cases of energy intake (continuous and pulse), drying period increasing involves a temperature increase achieving some maximum value.

The value of maximum obtained temperature is a function dependent on field strength, electro- and thermo-physical properties of the product and energy application method. For the case of continuous UHF energy input at field intensity of 44.0 kV/m was obtained product's temperature of 96.0 ^{O}C (curve 2'). For the case of pulsed UHF field intake maximum values of the temperature was 88.7 ^{O}C (curve 1').

Duration of product temperature increase up to the maximum was 34 min. Further, for both methods of energy input was maintained a relatively constant product temperature, all the energy being consumed for the vaporization of free moisture and overcoming its moving resistances from the center to the exterior layers. However, during continuous energy application, it can be observed a temperature decrease of about 5% (curve 2`). Product's temperature decrease, at continuous heating, is caused by energy consumption increasing at chemical and mechanical bonds breaking (between moisture and product's skeleton) and reducing the released in the product heat amount, as a consequence of polar water molecules number reducing, which is mentioned in literature [6]. The phenomenon of product's temperature decrease in the second drying period practically disappears if using pulsed heating. This is due to uniform moisture redistribution during relaxation.

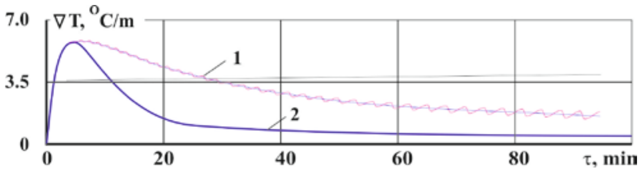

Figure 2. Temperature gradient variation during the drying process using pulsed (curve 1) and continuous (curve 2) UHF energy intake

One of the basic driving forces of the drying process is the temperature gradient. Figure 2 illustrates its variation during the drying process, using pulsed (curve 1) and continuous (curve 2) energy intake.

The graphs show that during continuous UHF energy intake, the temperature gradient for E = 44.0 kV/m increases to 5.8 ^{O}C/m and then decreases to approx. 0.6 ^{O}C/m (curve 2). Application of pulsed internal heat source from the moment the temperature gradient reaches maximum values, allowed the maintenance of advanced gradient's values throughout the drying process (curve 1). Thus, if at continuous UHF energy intake, the maximum speed of temperature gradient decrease was of 0.34 ^{O}C/(m·min), then at pulsed energy intake – only 0.07 ^{O}C/(m·min).

So the temperature gradient, during drying process, was maintained about 4.8 times higher.

Figure 3 presents the variation of active (energy intake) and passive (resting) period of one pulse of UHF energy intake, depending on drying process duration. From the graphs is observed that for the case of electromagnetic field's intensity maintaining (44.0 kV/m), both active period and the passive one are growing during drying. The duration of active period grows faster than the duration of the passive one.

The increasing of the active (energy intake) period of the pulse during drying process is a result of moisture content reducing, and therefore the amount of heat released in a unit of time under the action of the electromagnetic field. Passive period (relaxation) increases due to products thermal conductibility reduction at dehydration [7].

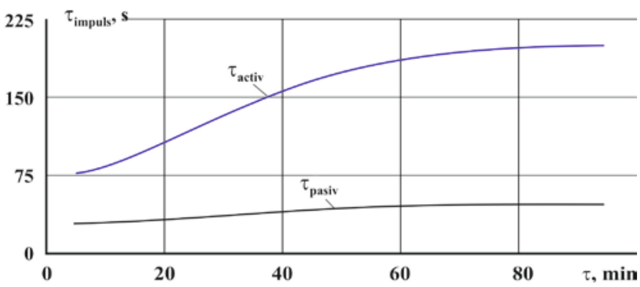

Figure 3. Variation of UHF energy intake period (τ_{activ}) and resting period (τ_{pasiv}) of a pulse during sunflower seeds drying using pulsed UHF energy supply

Application of pulsed electromagnetic energy fields have reduced the total duration of heat treatment of sunflower seeds using UHF field of 0.79 times, or 33.8 min (brief duration of all periods of rest during impulse drying). Figure 4 presents the curves of sunflower seeds drying speed using pulsed UHF energy intake (curve 1) and continuous (curve 3). Curve 2 is the regression of curve 1.

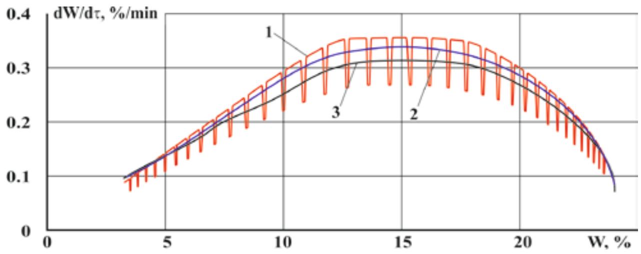

Figure 4. Drying rate curves of sunflower seeds: 1 – pulsed UHF energy intake, 2 – regression of function 1, 3 – Continuous UHF energy intake

From the figure is observed that the drying rate curve for the pulsed UHF energy intake (curve 1) draws the same shape as the drying rate curve for the continuous UHF field intake, but has an oscillating character. Maximum extremes of the oscillations (pulse) correspond to the period of active energy intake and minimum extremes - to the relaxation period. Thus, the maximum drying rate for the active periods of energy intake for sunflower seeds was 0.359%/min and passive ones – 0.268 %/min. Compared to maximum drying speed, at continuous energy intake was observed an increase of 14% in active periods and a decrease of 25% during passive ones.

Comparative analysis of specific energy consumption for oil products drying using pulsed UHF pulse energy intake comparative to continuous energy intake showed a decrease from 0.855kW/kg to 0.537kW/kg, which consists 37%.

These energy consumption reductions are caused by drying time decreasing at the same field strength, dehydration which takes place also in relaxation periods. However, energy consumption is reduced accordingly and the partial removal of moisture from product's surface, under the action of the air flow's kinetic energy.

4. Conclusion

The study of sunflower drying kinetics has confirmed the application of pulsed internal heat source. This made it possible to shorten the heat treatment product's duration by 20 min (17%) compared to continuous energy input. Reducing the duration of heat treatment duration allowed a significant reduction of specific energy consumption by 21.8%.

Application of pulsed UHF energy showed a reduction of 5% of product's average temperature at the same field strength 17.8 kV/m.

Reduction of product temperature duration of heat treatment will influence the quality indices of nutrients that are found in sunflower seeds, especially in fatty acids.

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