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Modeling of energy saving methods of soybean drying for oil production

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Summary. The drying process of agricultural products processing is highly energy consuming. This problem determines to find new energy-efficient drying methods. One of the methods of the soybean drying process is the increase of the contact surface of the drying agent with the material being dried. It enables to intensify moisture removal as a result of broken bean surface. Device of preparation of soybean to drying is designed. This device executes proposed method of drying.

The device of material preparation is placed in download mechanism of the dryer. The soybean is cut there. Then the seed is fed into the drying zone. This leads to reduction in drying time and energy saving. Dry soybeans can be used to produce oil.

In order to investigate the effect from the soybean cutting on its drying, the experimental unit was developed and tested.

For the analysis of the drying process it is necessary to study the theoretical foundations of intensification of the process of the proposed method. It is necessary to model the heat and mass transfer process.

Key words: preconditioning unit, drying soy bean effective radius, moisture ratio, evaporation rate, moisture removal.

INTRODUCTION

Rational drying methods of the grain crops and their technical implementation are determined by the combination of thermal, hydrodynamic and mechanical influences providing the best (rational) process modes for the output material. The existing provisions of the thermal and mass exchange theory [1-4] in disperse medium enable to detect and evaluate the efficiency of the new methods and directions for drying process intensification as well as thermophysical effects from using the mechanical impact (crushing, fragmentation, surface damaging etc.) on the material.

One of the methods of the soybean drying process is the increase of the contact surface of the drying agent with the material being dried, which in its turn enables to intensify moisture removal as a result of broken bean surface [5]. This result is achieved by using of the preconditioning unit (Useful Model Patent No.87184, Ukraine) [6].

In order to investigate the effect from the soybean cutting on drying, the experimental unit was developed and tested. [7].

When developing and implementation of units for preconditioning of agricultural materials before drying, it is necessary to study the theoretical background of the process intensification with the suggested method and consider typical aspects of modelling of thermal and mass exchange aspects.

Performed trials have to be supported by theoretical dependences and the influence of the mass exchange factors at the bean cutting on kinetics of the drying process as well as physical mechanical and thermophysical aspects of the drying process intensification by the mechanical damage of the soybean body.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The drying process of the agricultural plant material was investigated by S.Ptitsyn, M.Lurie, A.Ginsburg, G.Okun, O.Krisher, P.Lebedev, A.Golubkovych, B.Kotov, V.Kovaliov, V.Zelenko, V.Petrushiavichus, V.Goriachkin [8, 9] and many other researchers. They established the mechanisms of drying processes, temperature influence, speed of drying agent and other important factors as well as the acceptable values of the drying process duration.

The general ideas of the thermal and mass exchange theory were developed by the following scientists: A.Lykov, A.Ginsburg, N.Grynchyk and G.Shubin. The analysis of physical and technological processes of thermal exchange during drying process of the various agricultural materials can be found on the works of P.Lebedev, G.Filonenko, B.Kotov, I.Kopiev and other researchers [10-12].

The mechanisms used for drying of the agricultural materials, preconditioning and devices to reduce energy consumption during drying were investigated by R.Rogatynsky, V.Melegov, V.Zelenko, V.Kovaliov, M.Boiarchuk, V.Sharshunov, V.Didukh, I.Dudarev and others [13-20]. The mentioned scientists investigated the preparation of the agricultural material for drying, mechanisms for moisture removal, developed new drying methods to ensure the intensive removal of extra moisture at the lowest energy consumption.

PURPOSE

The purpose of the investigation is the quantitative evaluation of the possibility to intensify soybean drying though surface deformation.

MAJOR INVESTIGATION RESULTS

Mechanical soybean deformation by cutting of the surface leads to creation of the new surface with the value ΔS .

$$S_H = \frac{V}{S} = \frac{V}{S + \Delta S}. \qquad (1)$$

Availability of the "new" additional surface increases the total surface of the bean: $S_H = S + \Delta S$ and accordingly leads to reduction of the determinative size of the body - hydraulic radius:

Taking the soybean body as a spherical body – ball, we will get: ball surface: $S = \pi \cdot D^2$; ball volume: $V = \frac{\pi D^3}{6}$; hydraulic radius: $R_V = \frac{R_K}{3}$.

Thus, equivalent bean radius (half of equivalent diameter) will be defined with the relation:

$$R_e = 3 \cdot R_V = \frac{3 \cdot V}{S + \Delta S}. \qquad (2)$$

Thus, equivalent ball radius as characteristic dimension will be reduced by soybean splitting.

As known from the theory of drying, [1,2], the speed of material drying increases at reduction of initial radius (since the distance of moisture transportation from the center to the surface is reduced).

Let us evaluate the possibility of soybean drying intensification by its surface deformation.

The degree of damage and the value of the bean size change are evaluated with the damage coefficient k, defined with the relation:

$$k = \frac{S_0 + \Delta S}{S_0}, \qquad (3)$$

where: S_0 – initial surface , m^2; ΔS – surface of the cut area (surface surplus), m^2.

Equivalent (effective) bean radius will be defined by the relation :

$$R_e = 3\frac{V}{kS_0}. \qquad (4)$$

Fig.1. shows graphical dependence of the effective dimension of the bean R_e from the cut depth.

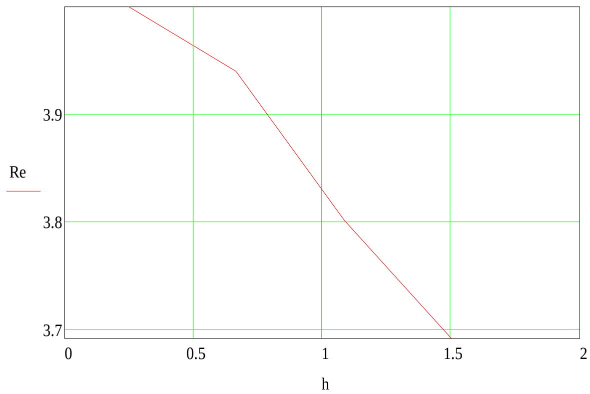

Fig. 1. Graphical dependence of the effective size of the bean R_e from the cut depth h

As known, the drying kinetics of the equation depends heavily from the criteria Bi_m and Fo_m [3]. Approximate value of the first radical μ_1 can be defined from the characteristic equation:

$$ctg\,\mu_1 = -\frac{Bi_m - 1}{\mu_1} = \frac{1}{\mu_1} - \frac{\mu_1}{3} - \frac{\mu_1^2}{3^2 \cdot 5} - \ldots$$

by breaking down $ctg\,\mu_1$ confining to the first two elements: $\mu_1^2 = 3Bi_m$.

Plugging the obtained values in the drying speed equation we get [3]:

$$-\frac{\partial u}{\partial \tau} = \frac{3\beta}{R_e}\left(1 - 0,025\frac{\beta \cdot R}{a_m}\right)\left(u_0 - u_p\right)e^{-\frac{3\beta}{R_e}\tau}, \qquad (5)$$

where: β – mass exchange coefficient, 1/s; a_m – mass transfer coefficient, m^2/s; u_0 – initial moisture content, kg/kg; u_p – equilibrium bean humidity, kg/kg.

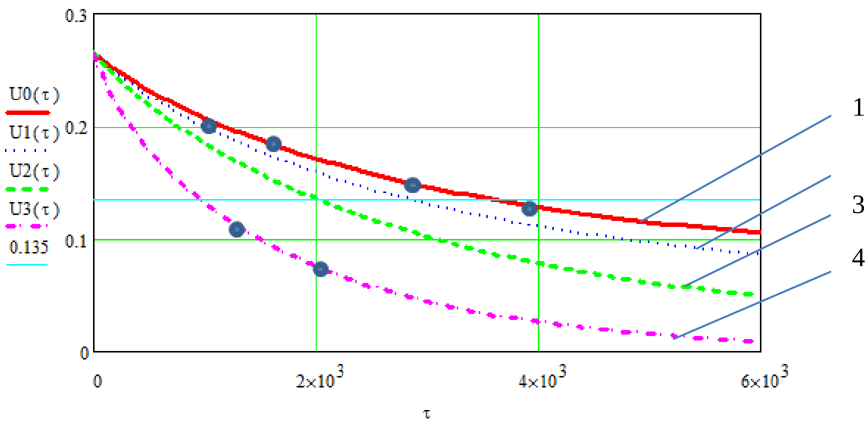

Fig. 2. Soybean drying curve at different degree of damage and the undamaged bean: 1 – undamaged beans; 2 – damage depth – 0,5 mm; 3 –1 mm; 4 – 1,5mm

Having analyzed the equation (5), reduction of the soybean effective dimension leads to increase of the drying speed, i.e. deformation of the soybean body (Fig. 2) intensifies the drying process.

The Fig.2. shows kinetic curves (drying curves) of the soybean at different damage degree and the undamaged bean. The dots show experimental findings. The matching of experimental and theoretical data for the undamaged and maximal damaged bean is satisfactory.

Let us investigate the influence of the mass exchange factors at the bean cut on the kinetics of the drying process. After (deformation) cutting of the soybean, as mentioned above, the new open area is created. The moisture is removed from such area faster than from the rest of the surface. The evaporation intensity is so high, that the heat energy is taken not only from the surface, but also from the bean body, cooling it down. From the point of view of drying mechanisms, the creation of the "new" surface can be considered as availability in the bean body being dried the additional mass (moisture) removal point or source of moisture removal with the intensity determined by the mass transfer law. The intensity of the evaporation source is described with the Dalton equation [3]:

$$\frac{dG_w}{d\tau} = S\beta_p (P_n - P_c)\,, \qquad (6)$$

where: β_p – mass exchange equation referred to variety of partial pressure, kg/s·m^2·Pa; P_n, P_c – partial pressure of the vapour on the humid surface and in the area accordingly, Pa.

Partial pressure on the humid surface is equal to the pressure of the saturated vapour at the surface temperature $P_n = P(\theta_n)$.

According to the equation of ideal gas condition (vapour), partial pressure is defined with the equation:

$$P = R_n \cdot T \cdot C_n\,, \qquad (7)$$

where: R_n – universal gas constant (for vapour); T – temperature; C_n - moisture concentration in the air, kg/m^3.

Substituting the value (7) into (6) we obtain:

$$\frac{dG_w}{Sd\tau} = \beta (C_n - C_c)\,, \qquad (8)$$

The value of moisture concentration C is connected with the moisture content of the bean: $C = \rho_0 \cdot u$ (ρ_0 – density of the absolutely dry material, kg/m^3. Considering the last equation (8) and (6), we will obtain the following boundary condition:

$$-a_m \rho_0 \left(\frac{du}{dr}\right)_S + \left(u_n - u_p\right)\beta_p \cdot r_0 = 0\,, \qquad (9)$$

$$\frac{du(r,\tau)}{dr} = 0\,, \qquad (10)$$

where: u_p – equilibrium humidity of the bean, kg/kg, the value of which determines:

$u_p = f(\varphi, t)$. At the same time, in the ball center $(\frac{du}{dr})_{r=0} = 0$ (symmetry condition).

Equation (9) is the analogue of the boundary condition of the III-d type for convective heat exchange and defines planeness of the moisture flow from the body towards its surface and from the surface to the environment, since the moisture is not accumulated on the surface.

The availability of the additional moisture removal source leads to more non uniformity of distribution of the moisture in the bean. It causes tension in the surface resulting in body deformation, i.e. "opening" of the cut area and change of the effective bean dimension as well as increase of effective mass exchange area.

Since, according to the existing drying theory [2], the shrinkage value is proportional to moisture content of the material, the deformation value can be defined as:

$$l = l_0 \cdot \beta_e \cdot u\,, \qquad (11)$$

where: l_0 – initial cut size; β_e – linear shrinkage coefficient (for grain crops $\beta_e = 1{,}1 - 1{,}4$; u – moisture content of the bean, kg/kg).

Since the moisture content reduces, the surface area will reduce as well. Reduction of the bean surface leads to opening of the cut area. Thus, for fast "opening" of the cut area and intensification of the additional source of the moisture removal, it is appropriate to speed up the drying process at the initial stage.

Intensity of the moisture removal from the open surface leads to the surface drying up and deepening of the evaporation area. Thus, intensity of the additional source of moisture removal will be reduced with time. $m=m(\tau)$.

The impact of the additional surface source of moisture removal can be considered as follows.

Into the boundary condition we (9) we add additional element, which includes the additional source of the moisture removal:

$$-a_m \rho_0 \left(\frac{du}{dr}\right)_S + \frac{\rho_0 \cdot \beta}{a_m}\left[u - u_p - \frac{m_0}{\rho_0 \cdot \beta}\right] = 0\,, \qquad (12)$$

where: m_0 – maximal intensity of the moisture removal.

The value $u_p - \frac{m_0}{\rho_0 \cdot \beta} = u_м$ will be considered the moisture content of the "humid" surface as analogues to the temperature of the "wet" bulb: $t_м = t_c - \frac{r \cdot m}{\alpha}$ [3].

Thus, replacing in the equation (9) the value u_p with: $u_p - \frac{m_0}{\rho_0 \cdot \beta} = u_М$, the known solutions can be used [3] (Eq. 13).

$$u(r,\tau)=u_{M}+(u_0-u_{M})\sum_{n=1}^{\infty}\frac{2\left(\sin\mu_n-\mu_n\cos\mu_n\right)\cdot\sin(\mu_n\frac{r}{R})}{\left(\mu_n-\sin\mu_n\cdot\cos\mu_n\right)\cdot\mu_n\cdot\frac{r}{R}}\cdot e^{-\mu_n^2\cdot Fo_m},\tag{13}$$

where: $u_{M}=u_p-\dfrac{m_0}{\rho_0\cdot\beta}$.

The known equation of drying kinetics [3]:

$$-\frac{du(\tau)}{d\tau}=K(u(\tau)-u_p(t,\varphi)),\tag{14}$$

where: K – drying coefficient.

Equation (14) , where $u_p\to u_p-\dfrac{m_0}{\rho_0\cdot\beta}$:

$$-\frac{du(\tau)}{d\tau}=K(\theta)u(\tau)-u_{M}(\tau)).\tag{15}$$

Equation of drying kinetics (15), as against the known one, considers evaporating intensity from the open surface (evaporation intensity is time-constant).

When evaporation intensity from the open (new) surface changes with time, it is possible to set, by analogy with the change of the general drying speed, the exponential law of evaporation intensity change, namely:

$$m(\tau)=m_0\cdot e^{-k\tau},\tag{16}$$

where: m_0 – evaporation intensity at the beginning of the process, kg/m^2·c (maximal) intensity.

Then, the boarder condition (9) we put in the following way (Eq. 17).

The solution of the differential equation of the mass transfer with the input condition [3] and boarder condition (17), is analogous with the solution of the equation of the ball thermal conductivity with available negative heat energy source (heat energy for surface evaporation) is in the form of the equation (Eq. 18).

The variation of the average moisture content in time can be defined by integrating the functional relationship $u(R,\tau)$ (Eq. 19).

Fig. 3. shows the curve of relation of moisture content variation depending on bean radius and in time.

$$-a_m\rho_0\frac{du(R,\tau)}{dr}+\beta\cdot\rho_0\left[u-u_p\right]+m_0e^{-k\tau}=0\tag{17}$$

$$\frac{u(r,\tau)-u_p}{u_0-u_p}=\frac{R\cdot\bar{\theta}_{м}\cdot Bi_m\cdot\sin\sqrt{Pd_m}\cdot\frac{r}{R}}{r\cdot\left[(Bi_m-1)\cdot\sin\sqrt{Pd_m}+\sqrt{Pd_m}\cos\sqrt{Pd_m}\right]}\cdot e^{-Pd_m\cdot Fo_m}+\sum_{n=1}^{6}\left[1-\frac{\bar{\theta}_{м}}{(1-\frac{Pd_m}{\mu_n^2})}\right]\cdot A_n\frac{R\cdot\sin\mu_n\frac{r}{R}}{r\cdot\mu_n}\cdot e^{-\mu_n^2\cdot Fo_m},\tag{18}$$

where: $A_n=\dfrac{2(\sin\mu_n-\mu_n\cos\mu_n)}{\mu_n-\sin\mu_n\cos\mu_n}$; $Pd_m=\dfrac{k}{a_m}R^2$ – mass exchange analogue of Predvoditelev criterion; $\bar{\theta}_{M}=\dfrac{m_0}{\beta(u_0-u_p)}$ – dimensionless complex (criterion) of the mass exchange.

$$u(\tau)=u_p+(u_0-u_p)\cdot\left[\frac{3\cdot\bar{\theta}_{м}\cdot Bi_m(tg\sqrt{Pd_m}-\sqrt{Pd_m})}{Pd_m\left[\left(Bi_m-1\right)\cdot tg\sqrt{Pd_m}+\sqrt{Pd_m}\right]}\right]\cdot e^{-\mu_n^2\cdot Fo_m}+\sum_{n=1}^{\infty}B_n\left(1-\frac{\bar{\theta}_{м}}{(1-\frac{Pd_m}{\mu_n^2})}\right)\cdot e^{-\mu_n^2\cdot Fo_m},\tag{19}$$

where: $B_n=\dfrac{6Bi_m^2}{\mu_n^2\cdot\left(\mu_n^2+Bi_m^2-Bi_m\right)}$.

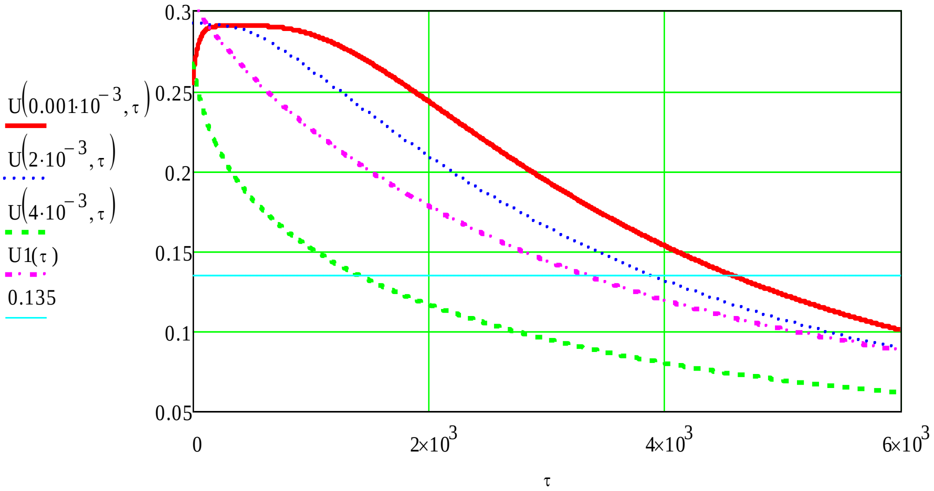

Fig. 3. The curve of relation of moisture content variation depending on bean radius and in time

Comparing the obtained curves, given that the additional evaporation surface is available, the upper layers of the bean dry out faster and the drying time (change in the mean on moisture content) reduces from 3600 to 300 sec.

CONCLUSIONS

1. Thus, by means of theoretical analysis and experimental trials, the possibility of intensification of the soybean drying process by cutting of the surface is proved.

2. However the obtained data characterize the heating and drying process provided the drying agent parameters are stable (under the experiment conditions).

In order to define the influence of the drying agent parameters on the nonstationary process of moisture removal, the additional analysis is necessary.

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МОДЕЛИРОВАНИЕ ЭНЕРГОСБЕРЕГАЮЩИХ МЕТОДОВ СУШКИ СОИ ДЛЯ ПРОИЗВОДСТВА МАСЛА

В. Дидух, Р. Кирчук, К. Цызь

Аннотация. Процессы сушки очень энергоемкие в первичной переработке сельскохозяйственной продукции. Это побуждает к поиску новых энергосберегающих методов сушки.

Одним из методов интенсификации процесса сушки семян сои является увеличение площади контакта сушильного агента с сушащимся материалом. Это позволяет более интенсивно выводить влагу вследствие потери целостности внешней оболочки семени. Для реализации данного метода разработано устройство предварительной подготовки сои к сушке.

Устройство размещается в механизме загрузки сушилки. Там происходит надрез плода сои и тогда семена подается в зону сушки. Это приводит к уменьшению времени сушки и экономии энергии. Полученная высушенная соя может быть использована для получения масла.

Для исследования влияния рассечение боба сои на последующую его сушку, была разработана экспериментальная установка и проведены ряд исследований с ее использованием.

Для анализа такого процесса сушки необходимо изучить теоретические основы интенсификации процесса предложенным методом и рассмотреть типичные аспекты моделирования тепло и массопереноса.

Ключевые слова: предварительная обработка, сушка сои, эффективный радиус, соотношение влаги, скорость испарения, удаление влаги.