

Sergey I. Pastushenko, Oleg V. Goldshmidt*, Stanisław Sosnowski**

THE THEORETICAL ANALYSIS OF SEEDS DEHYDRATION OF VEGETABLE CULTURES ON CENTRIFUGAL DEVICES

Summary. In the article the results of the theoretical analysis of work of a centrifuge of continuous action are given which has allowed proving the basic design parameters and kinematics modes. The ways for the further continuation of researches are planned.

Keywords: theoretical, analysis, dehydration, centrifugal devices

STATEMENT OF THE PROBLE

The complexes of the production equipment for getting seeds of vegetable cultures of nightshade group consist of small independent subsystems (functional modules). The basic operations, to which the gathered fruits are exposed, are the following: reception, accumulation and supply of the heap to the finishing; sorting of fruits according to the degree of ripeness; recycling processing products. These functional modules should be coordinated among themselves by technical facilities, which should provide the transportation of production to the technological zone of the complex or by systems, providing the auxiliary functions. All this will allow to form the standalone lines, executing various functions and allowing to receive the final production of the various nomenclature. All this becomes possible if to assume a principle of a continuity of processed fruits flow as a basis of work organization of processing production. The continuity of line processing will allow to increase the productivity of technological equipment and, as the consequence of it, will cheapen the cost price of the production. For example, in a line LST-10 this principle is broken because of presence of the device for seeds fermentation. One of tripper reservoir (and there are 7 of them) is daily filled, and the detachment of seeds integumentary shell happens in the rest of five [1]. A dehydration of seeds is also real-

* Dr Sergey I. Pastushenko candidate of technical science, senior lecturer, dr Oleg V. Goldshmidt candidate of technical science, senior lecturer, Nikolaev State Agrarian University, Ukraine

** D.Sc. Eng. Stanisław Sosnowski, Ropczyce School of Engineering and Management

ized with infringement of the principle of continuity. Seeds dehydration occurs in centrifuge of rotary type, thus seeds are packaged in linen bags after washing machine MOS-300. At the same time in chemical and the food-processing industries centrifuges of continuous action are already used. For increase of productivity of lines for getting seeds it is expedient to carry out the theoretical analysis of work of these centrifuges at finishing seeds of vegetable cultures.

THE ANALYSIS OF THE LATEST RESEARCHES AND PUBLICATIONS

The theoretical analysis of seeds dehydration in centrifuges of continuous action is impossible without definition of dimension-mass parameters of seeds of vegetable cultures of nightshade of group. The tomatoes, eggplants, sweet and bitter pepper concern to them. The basic dimension-mass characteristics of seeds are given in table. [2-4].

The dimension-mass characteristics of nightshades of cultures seeds

The name of culture	Length L , mm	Width b , mm	Thickness δ , mm	Density γ , t/m ³	Absolute mass m , g
Tomatoes	2.3–4.6	1.6–3.8	0.7–1.3	1.27–1.54	3.79–4.32
Eggplants	2.1–3.3	2.8–3.8	0.7–1.5	1.32–1.65	6.4–9.8
Pepper sweet	3.9–5.3	3.8–4.6	1.4–1.9	1.31–1.49	9.1–13.4
Pepper bitter	4.0–5.1	4.0–4.4	0.7–1.4	1.27–1.50	7.8–11.2

The density of seeds was determined as the ratio of the weight of 1000 seeds to the volume of the superseded water. As researches have shown, the seed density correlates with its individual weight and thickness. Let's assume that for average seed its length is equal to width. Then the volume of the seeds of nightshades cultures can be defined as volume of oblate ellipsoid of rotation:

$$V = \frac{4}{3} \cdot \pi \cdot \left(\frac{L}{2}\right)^2 \cdot \frac{\delta}{2} = \frac{\pi \cdot L^2 \cdot \delta}{6} \quad (1)$$

The diameter d of a sphere which is equal to oblate ellipsoid with half-axes $\frac{L}{2} = \frac{b}{2}$ and $\frac{\delta}{2}$ will be determined from the equation

$$\frac{\pi \cdot d}{6} = \frac{4}{3} \cdot \pi \cdot \left(\frac{L}{2}\right)^2 \cdot \frac{\delta}{2} \quad (2)$$

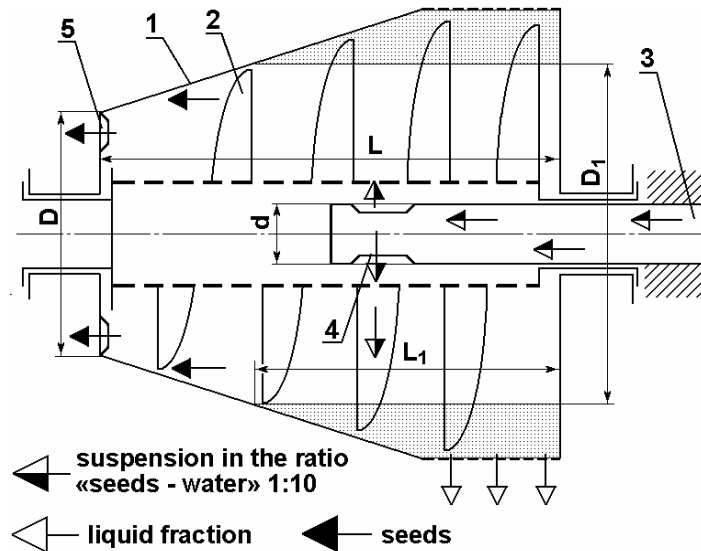
DEFINITION OF THE UNSOLVED PROBLEMS

Precipitating and the filtering centrifuges differs from each other not only by design of a drum, but also by processes, occurring in them. Sediment, formed on the wall of a drum consists of a skeleton, formed by firm particles, supporting each other, and of liquid filling emptiness between particles. The structure of sediment changes under the influence of pressure during the centrifugation, the sediment is packs, and the liquid is superseded from emptiness. In drums with apertures the liquid leaves through apertures outside and carries away the smallest particles. In case of the entire drum the superseded liquid passes into liquid, stuffing the drum.

In settling centrifuges it fails to remove in-band the liquid from the sediment, it turns out damp. In filtering centrifuges the sediment turns out drier. The larger particles are, the drier sediment is in filtering centrifuges. The filtering centrifuges are applied mainly for suspension, with a diameter of firm particles more than 100 microns and when it is required to receive probably drier sediment [5].

It is preferable to apply the rotor with apertures for desiccation of suspension of seeds with the sizes of particles from one up to four millimeters a. It will allow to receive the product with smaller humidity on exit. Thus it is necessary to take into account properties of particles: under influence of high pressure the particles can collapse, the splinters will block interstices of the filter, slowing down the process of water removal. When the comminuting of particles is inadmissible, it is necessary to be limited to smaller speeds or to use the settling centrifuge with large dryness, on an output. Besides at manufacturing a rotor with apertures about 1,5 mm there will inevitably be technological difficulties.

On the basis of stated it is possible to make a conclusion, that for desiccation of seeds of vegetable cultures of nightshade group the filtering centrifuge of continuous action with gravitational or auger by unloading suits. However several imperfections are inherent in both designs of centrifuges. In case of a gravitational unloading it is necessary to speed up and to brake rotation of a drum periodically, that is involves the additional power expenses. Auger unloading is connected to complication of a design, because of necessity of mounting of a planetary reducer, which provides relative rotation of screw and rotor with rotational speed of about 20...50 rev. Besides at the high pressure in a layer of sediment me damage of seeds by screw is quite possible at unloading. The structurally technological scheme of a centrifuge is given in Figure.



The structurally technological scheme of the centrifuge of continuous action with a mesh rotor

SUBSTANTIATION OF THE RECEIVED RESULTS

The required productivity of a centrifuge is defined from general productivity of a line for getting seeds of vegetable cultures. At the productivity of line on initial heap up to 20 t/hour and output of seeds in 1.5, the productivity of the line on crude seeds will amount to 300 kg/hour. For convenience of seeds submission to centrifuge they are diluted with water; suspension, which is formed in result, has the ratio of weight of seeds and waters about 1:10. In this case mass charge of suspension will make about $M_s = 3300$ kg/hour. Accepting the density of suspension $M_s = 1000$ kg/m³, we shall determine the volumetric charge of suspension:

$$Q_v = \frac{M_s}{\rho_s} = 9,17 \cdot 10^{-4} \text{ m}^3/\text{sec} \quad (3)$$

Taking into account the safety factor it is finally possible to accept volumetric productivity of a centrifuge equal $Q_v = 0,001$ m³/second.

Diameter of the pipe, leading suspension to the rotor of a centrifuge, we find from a condition of indissolubility of a flow of supplied mass:

$$d = \sqrt{\frac{4 \cdot f_p}{\pi}} = \sqrt{\frac{4 \cdot Q}{\pi \cdot v_p}} \quad (4)$$

where: f_p – the area of cross section of a pipe;

v_p – is the speed of movement of suspension in a pipe.

At the next stage of the theoretical analysis for obtaining the concepts about the qualitative aspect of the centrifugation process, it is necessary to know speeds and acceleration of particles, moving in a liquid under the influence of centrifugal force to the walls of a rotor. In practice of calculations use two laws of environment resistance to movement of a particle are used. If the particle has the considerable sizes and moves at the high speed in low-viscosity environment ($Re > 1000$), it is considered that the head resistance is proportional to the square of speed:

$$P = C_w \cdot \rho \cdot \frac{v^2}{2} \cdot F \quad (5)$$

where: C_w – the drag coefficient, which depends on Reynolds number and form of a particle; at the given stage of the theoretical analysis; it can be accepted as equal to unit.

If the sizes of a body and speed are insignificant, the main role is played by viscous resistance of environment, which obey the Stokes law (Stokes law is applicable for Reynolds numbers about $Re < 1 \dots 2$ [4]):

$$P = 3 \cdot \pi \cdot \mu \cdot v \cdot d \quad (6)$$

where: μ – the dynamic viscosity of environment,
 d – the diameter of a particle.

Except the centrifugal force and force of resistance of environment the Archimedeian carrying capacity also acts on the particle. Therefore above all it is necessary to investigate the process of sedimentation of particles in the assumption that the resistance to movement obeys the square law. In this case the equation of the movement of a particle will look like:

$$m \cdot \frac{dv}{dt} = m \cdot v^2 \cdot r - m \cdot v^2 \cdot r - C_w \cdot \rho_l \cdot \frac{v^2}{2} \cdot F \quad (7)$$

Here index l concerns to the liquid, in which production is located. Having divided the both parts of the equation by m and having rearranged me members, we receive:

$$\frac{dv}{dt} + A \cdot v^2 = B \cdot v^2 \cdot r \quad (8)$$

$$\text{where: } A = \frac{C_w \cdot \rho_l \cdot F}{2m} = \frac{3 \cdot C_w \cdot \rho_l}{4 \cdot d \cdot \rho_s}; \quad B = \frac{\rho_s - \rho_l}{\rho_s}.$$

As $\frac{dv}{dt} = \frac{dv}{dr} \times \frac{dr}{dt}$, after multiplication to 2 equations (8) will assume the form:

$$2v \frac{dv}{dt} + 2A \cdot v^2 = 2B \cdot v^2 \cdot r \quad (9)$$

Having made the replacement of the variable $v^2=z$ we shall finally receive the equation

$$\begin{aligned}\frac{dz}{dr} + 2A \cdot z &= 2B \cdot r \cdot z \\ \frac{dz}{dr} + 2A \cdot z &= 2B \cdot r \cdot z,\end{aligned}\quad (10)$$

which is easily integrated with the help of Laplacian transformation:

$$\mathfrak{Z}\left(\frac{dz}{dr}\right) + 2A \mathfrak{Z}(z) = 2B \cdot v^2 \cdot \mathfrak{Z}(r) \quad \text{or} \quad s \cdot z - z(0) + 2A \cdot z = 2 \cdot \frac{I}{s^2} \cdot B \cdot v^2 \quad (11)$$

After the solution and simple transformations is received:

$$z = \frac{z(0) + 2 \cdot \frac{I}{s^2} \cdot B \cdot v^2}{s + 2A} \quad (12)$$

where: $z(0) = v_0^2$ – the square of initial speed, which can have the particle on radius r_i in the beginning of the movement in the field of centrifugal forces.

The inverse transformation allows to receive the expression:

$$\begin{aligned}v^2 &= v_0^2 \cdot e^{-2Ar} + \frac{2B \cdot v^2}{4A^2} (e^{-2Ar} - 1 + 2a \cdot R) = \\ &= \left(v_0^2 + \frac{2B \cdot v^2}{4A^2} \right) e^{-2Ar} + \frac{2B \cdot v^2}{4A^2} \cdot (2A - I)\end{aligned}\quad (13)$$

If the particle begins movement without initial speed $v = v_0 = 0$ on radius r_0 , then the speed on radius $R = \frac{D_I}{2}$ will be defined as:

$$v = \frac{I}{A} \cdot \sqrt{\frac{B}{2}} \cdot \sqrt{e^{-2Ar} + 2A \cdot r - I} \quad (14)$$

The average speed of a particle between r_0 and R , which is named the average speed of sedimentation V_{0s} and, in essence, is the average speed of all particles on ring cross-sectional of the liquid in a rotor, is equal:

$$v_{0s} = \frac{I}{R - r_0} \cdot \int_{r_0}^R v dr \quad (15)$$

The sedimentation time τ_{0s} can be found from expression:

$$\tau_{0s} = \int_{r_0}^R \frac{dr}{v} \text{ or approximately } \tau_{0s} = \frac{R - r_0}{v_{0s}} \quad (16)$$

It is easier to calculate v_{0s} by one of numerical methods, for example having replaced integral by the sum and having broken the range of integration on the n of parts, when $\Delta r = \frac{R - r_0}{n}$, then the value of sedimentation speed v_{0s} can be determined under the formula:

$$v_{0s} = \frac{w_0 \cdot \sqrt{B}}{A \cdot \sqrt{2}} \cdot \frac{1}{R - r_0} \cdot \sum_{i=1}^n \sqrt{e^{-2B \cdot r} + 2B \cdot r - \Delta r} \quad (17)$$

Simultaneously with movement under the influence of centrifugal force on rotor radius the particle, carried away by a flow of liquid, proceeding through the rotor, moves also along the axis of the rotor. In the assumption, that the flow is laminar [6], we receive the dependence of required minimal length of the rotor:

$$L = \frac{9i \cdot g}{\omega^2 \cdot d_s^2} \cdot \frac{\rho_l}{\rho_s - \rho_l} \cdot \left[\frac{R^2}{2} \cdot \ln\left(\frac{R}{2}\right) - 0,5r^2 \cdot \ln^2\left(\frac{R}{2}\right) - \frac{R^2 - r^2}{4} \right] \quad (18)$$

Here, the multiplier before the bracket is defined by value of angular velocity w , diameter of particles d_s and hydraulic slope of the flow in the rotor i . In fact the length of the rotor should be accepted twice as much from the condition of screw location. Besides, the length of the rotor is defined by an opportunity of the occupancy of the necessary quantity of apertures for the passing of fugait.

In a case of cylindrical-conic rotor of centrifuge its productivity is found by incoming suspension, as the product of the area of sedimentation surface on average speed of particles settling.

$$Q_v = 2\pi \cdot R_{av} \cdot \left(D + \frac{b}{2}\right) \cdot v_{0s} \quad (19)$$

In that case, when the resistance to particles movement follows the Stokes law, the equation of movement will look like:

$$m \frac{dv}{dt} = m \cdot v^2 \cdot r - m_l \cdot v^2 - 3\pi \cdot \mu \cdot v \cdot D \quad (20)$$

$$\text{After transformation we receive } \frac{dv}{dt} + A_l \cdot v - B_l \cdot v^2 \cdot r = 0 \quad (21)$$

where: $A_I = \frac{\pi \cdot \mu \cdot D}{m} = \frac{18\mu}{D^2 \cdot \rho_s}$; $B_I = \frac{m_s - m_l}{m_l}$

As $r(t)$ is current value of radius $\frac{dr}{dt} = v$, and after differentiation on t we received the linear differential equation with constant coefficients:

$$\frac{d^2 v}{dt^2} + A_I \cdot \frac{dv}{dt} - B_I \cdot v^2 = 0 \quad (22)$$

Its characteristic equation looks like

$$z^2 + A_I \cdot z - B_I \cdot v^2 = 0 \quad (23)$$

And roots of the characteristic equation: $z_{1,2} = \frac{A_I}{2} \pm \sqrt{\left(\frac{A_I}{2}\right)^2 + B_I \cdot v^2}$ (24)

Integral of the equation

$$v = C_1 \cdot e^{z_1 t} + C_2 \cdot e^{z_2 t}; \quad \frac{dv}{dt} = z_1 \cdot C_1 \cdot e^{z_1 t} \quad (25)$$

For $t = 0$ we have $v = 0$, hence, $C_1 + C_2 = 0$ and $\frac{dv}{dt} = B_I \cdot v^2 \cdot r_0 = z_1 \cdot C_1 + z_2 \cdot C_2$

From these two conditions we find constants C_1 and C_2

$$\left| \begin{array}{l} C_1 + C_2 = 0 \\ z_1 \cdot C_1 + z_2 \cdot C_2 = B_I \cdot v^2 \cdot r \end{array} \right| \Rightarrow C_1 = -C_2 = \frac{B_I \cdot v^2 \cdot r}{z_1 - z_2}, \text{ and finally the expression for}$$

speed looks like

$$v = \frac{B_I \cdot v_0^2 \cdot r_0}{z_1 - z_2} \cdot (e^{z_1 t} - e^{z_2 t}) \quad (26)$$

However to define the value of average sedimentation speed is impossible, because the time of particle settling is unknown. The expression (26) can be simplified, having noticed, that the value z_2 is negative, and therefore it is possible to neglect the member $e^{z_2 t}$ and to consider:

$$\left\{ v = \frac{B_I \cdot v_0^2 \cdot r_0}{z_1 - z_2} \cdot e^{z_1 t}; \quad r(t) = \int v dt + C_I \right. \quad (27)$$

After integration and simple transformations we shall find time seeds settling in a conical-cylindrical centrifuge:

$$t = \frac{I}{z_1} \cdot \ln \frac{z_1(z_1 - z_2) \cdot R}{B_1 \cdot v \cdot r_0} \quad (28)$$

In the earlier carried out researches [7] the technique of definition of centrifuge volumetric productivity in the assumption of laminarity of the flow in the ring space of a rotor is given. At first there is an expression for speed of suspension flow along an axis of a rotor:

$$v = Z \left(\frac{R^2 - r^2}{2} + R_l^2 \cdot \ln \frac{r_i}{R} \right) \quad (29)$$

where: $Z = \frac{\rho_l \cdot i}{2\mu}$ – the constant, dependent from the value of hydraulic sloper of a flow

and viscosity;

r_i – the current value of radius; at walls of a rotor $r_i = R$, and on an internal surface of a layer of liquid $r_i = R_l$.

Thus it is supposed, that the resistance to the movement of particles follows the Stokes law. The volumetric productivity is found from the ratio. The suspension quantity, which can pass through a centrifuge is defined as:

$$Q_v = 2\pi \cdot Z \cdot \int_{R_l}^R \left(\frac{R^2 - r_i^2}{2} + R^2 \cdot \ln \frac{R_i}{R} \right) \cdot r_i dr_i \quad (30)$$

After integration we receive:

$$Q_v = 2\pi \cdot Z \cdot \left(\frac{R^4 - 3R_l^4}{4} - R^2 \cdot R_l^2 - R_l^4 \cdot \ln \frac{R_l}{R} \right) \quad (31)$$

After realization of the estimation of productivity of a centrifuge under the formulas (19) and (31) it is visible that the numerical values differ more than in 20 times. Thus results of theoretical calculation can be only approximate, as deriving the ratios, they proceed from the assumptions, which actually are hardly carried out precisely. It is considered, that the flow of a liquid in a rotor is laminar, though it is continuous cuts by the seeds, moving across it, but influence of Coriolis acceleration left out of account; hydraulic slope is different for various designs. The received ratios require the check by experiment. The experiment will allow to insert the correction factors.

At suspension submission inside of a centrifuge rotor seeds experience the percussion, contacting with rotating details of a rotor. For a very short interval of time the seed speed changes from zero up to value of peripheral velocity on radius of a point of contact. From the theoretical mechanics it is known, that if the force F works during time t , beginning the action at the moment of time t , its pulse looks like:

$$S = \int_t^{t+\tau} F dt = F \cdot \tau \quad (32)$$

As the pulse of the force S is equal to change momentum

$$F \cdot \tau = m \cdot (u_2 - u_1) \quad (33)$$

where: u_1 the speed of a seed at the moment of impact;
 u_2 the speed of a seed after impact (speed of reflection).

In case of zero initial speed $u_1=0$, the shock efforts are equal to:

$$F = \frac{m \cdot u_2}{\tau} \quad (34)$$

The less is the radius of contact of seeds with a rotating detail; the less is the force of impact. The power, spent on overcoming of the forces of friction at transportation of the sediment inside a rotor of a centrifuge, will be defined as [6]:

$$N = N_1 + N_2 + N_3 \quad (35)$$

where: N_1 the power, spent on overcoming of component of centrifugal force, directed along generatrix of a drum;
 N_2 the power, spent on overcoming of friction between the sediment and walls of a drum;
 N_3 the power, spent on overcoming of forces of friction between a sediment and coils of screw.

$$N_1 = n^2 \cdot R_{av} \cdot L \cdot G \cdot \left(1 + \frac{b}{100}\right) \cdot \operatorname{tg} \beta \cdot 10^{-9} \quad (36)$$

$$N_2 = n^2 \cdot R_{av} \cdot L \cdot G \cdot \left(1 + \frac{b}{100}\right) \cdot f_1 \cdot 10^{-9} \quad (37)$$

$$N_3 = n^2 \cdot R_{av}^2 \cdot z \cdot G \cdot \left(1 + \frac{b}{100}\right) \cdot (\sin 2\beta + 2f_1 \cos \beta) \cdot f_2 \cdot 10^{-9} \quad (38)$$

In the formulas (36) - (38) the following denotations are assigned:

f_1 – the friction coefficient of a sediment on filtering a surface of screw coils;
 f_2 – the friction coefficient of a sediment on a surface of screw coils;
 z – the number of screw coils;
 n – the rotational speed of a rotor.

CONCLUSIONS

The carried out theoretical analysis of work of a centrifuge of continuous action has allowed proving the basic design parameters and kinematics modes. For the further research of the work it is necessary to investigate the physico-mechanical characteristics of production, which comes into treatment.

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Recenzent: Prof. dr hab. Janusz Nowak