Justification of the criterion for the washing process of fruits and vegetables

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Abstract. The article describes a calculation algorithm for modeling the process of washing the fruit, which allows you to change the parameters of the device in order to assess the quantitative change in the intensity of the mechanical interaction of the working body on the fruit surface. Parameters of the fruit washing machine, determined by the criterion the intensity of the mechanical interaction of the working bodies with the fruits When designing a machine, it is desirable to provide such process conditions under which the fetus makes 5 - 7 complete revolutions around its axis. This parameter is adjusted by changing the distance between brush cylinders, as well as the selection of parameters that provide the average value of the angular velocity of rotation of the fetus around its axis in within ωpl = 0.5 - 0.7 rad/s.

1 Introduction

When designing and operating technological equipment for processing fruits and vegetables, one of the main operations of primary processing is washing. Modern machines for washing fruits and vegetables consume more than 2 m3 for washing one ton of raw materials. For the conditions of Uzbekistan, this is wasteful. Therefore, in order to find the reserves of the process, the conditions for its implementation are analyzed.

From the analysis of machine designs, it was revealed that brush machines have the best characteristics, since they have the highest intensity of mechanical interaction, which makes it possible to design machines with low energy consumption, metal consumption and relatively low water consumption [1-5].

2 Materials and methods

Let us consider the phenomena that accompany the washing process (Figure 1) when using a brush device.

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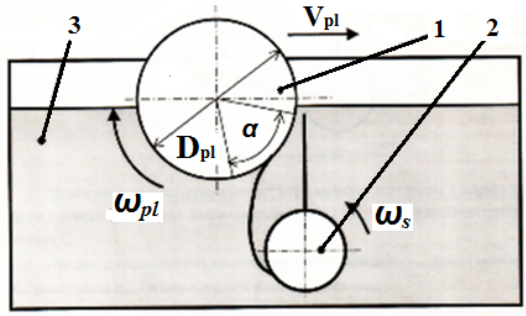

Fig. 1. Scheme of the process of interaction of the working body with fruit surface:1 - fruit; 2 - working body (brush bristles); 3 - washing liquid.

Fruit 1 is in washing liquid 3. On the surface of fruit 1 he brush elements act - bristles 2. The brush is a cylindrical drum that rotates at a certain angular velocity ω_s. The fetus moves at a speed V_{pl}. When interacting with the bristles, the fruit receives rotation with an angular velocity ω_{pl}. Consider the process of mechanical interaction of the working body with the surface of the fruit. We believe that there are contaminants on the fruit surface, the appearance of which corresponds to the design scheme (Figure 2).

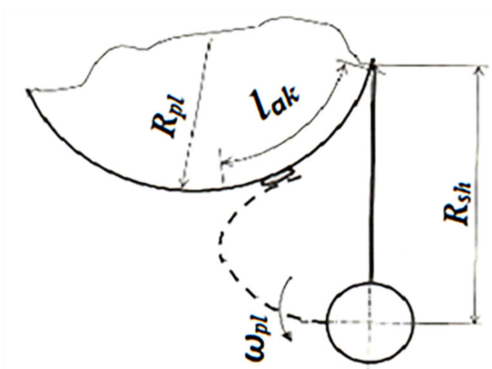

Fig. 2. Scheme of the interaction of the brush with pollution.

The individual bristles of the brush cylinder come into contact with the surface of the fruit as the shaft rotates. The interaction of the bristle with the surface is carried out along the path lak. We introduce: the angular speed of rotation of the brush cylinder - ωs, the radius bristles - Rsh, fruit radius Rpl, - angular velocity of fruit rotation - ωpl.

To assess the dynamics of the interaction of the working bodies with the surface, we introduce the concept of the intensity of the mechanical interaction, which evaluate the total effect of individual bristles on the surface fetus. The intensity of mechanical interaction can be estimated as the ratio of the actual acting forces to the cohesive forces between contamination and fruit surface. Cohesive forces estimated adhesive properties, are determined in a rather complex dependence on a number of operating factors:

- area of the contact surface between detached particles;
- viscosity of the liquid located in the space between the detached particles;
- conditions for detachment of particles - adhesive or cohesive adhesion (adhesive adhesion is characterized by the fact that particles detach from each other without violating their individual shapes, and cohesive detachment is characterized by the

fact that when particles detach from each other, there is a violation of the individual shape - detachment of individual elements from particles, destruction of the surface with the remains of parts of one element on the surface of another) [6-10];

– the direction of the forces of the mechanisms separating particles from each other – at in the presence of only normal forces, the values of the forces are usually greater than with the presence of tangential forces.

Of course, it is quite a difficult task to take into account the totality of acting factors in the process of detachment of particles from the surface of fruits, but as the practice of washing fruits shows, an approximate solution of the task maybe.

On Figure 3 shows the design diagram of the process of interaction of pollution with the brush element. The brush element strikes the surface (its shape in the transverse section plane is assumed to be elliptical). Impact strength decomposes into components Px and Py, the component Px tends to displace the seed from its place, which is prevented by the friction force Pm, determined by adhesive properties.

The Py component forms a moment that tends to tear off the contamination from the surface, which is prevented by the force Ps. The process of mechanical interaction of the brush element on the surface of the contamination continues in for a certain time τ-, which depends on the angular velocity brush cylinder rotation ωs and bristle radius Rsh, as well as linear dimensions of pollution (we believe that it is quite solid and has longitudinal section plane elliptical shape).

$$\tau = \frac{\omega r}{2a}, \tag{1}$$

where a is the length of the long semi-axis of the ellipse in the cross section of the contamination.

If in the initial period of interaction, the moment formed by the force Py is directed counterclockwise, then at the end of the interaction it directed clockwise. A similar process repeated many times leads to a gradual disruption of the connection between the seed and the surface contact. In the theory of destruction [11-14], the dependence of the critical conditions for the destruction of structures, which has an exponential form

$$P_{kp} = \alpha \cdot e^{-\frac{nP}{\beta}}, \tag{2}$$

where α, β - coefficients determined by the structural features destructible structure;

n - the number of periodic loaded;

P- is a periodically acting load.

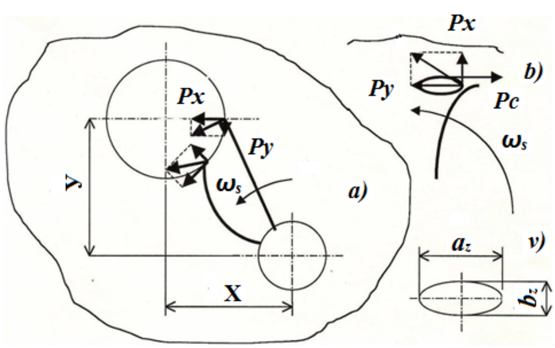

Fig. 3. Scheme of the forces acting during the interaction of the bristles and the fetus: a - general scheme; b - interaction with pollution; v - pollution parameters.

With an increase in n or P, as well as with their joint increase, the value of the critical fracture force decreases, there comes a moment at which Pkr becomes disproportionately small compared to the actual load, and there is a destruction of the structure, and in our case - a violation of the links between pollution and the material.

Based on the above as the intensity of the mechanical interaction, we take the ratio of the product of the acting force bristle impact on pollution P by the number of impacts n to the value critical breakout force Pkp

$$I_{\mathrm{M}} = \frac{n\mathrm{P}}{P_{kp}} \tag{3}$$

Assuming that the force of separation of one pollution [15-17] is within Pkp = 4 - 6 N, it is possible to determine the dependence of the intensity of mechanical interaction of the working body with the surface of the fetus in the contact zone in the form

$$I_{\mathrm{M}} = \frac{\mathrm{P}N_f n}{P_{kp}} \tag{4}$$

where Nf is the number of cycles of periodic impact of the brush cylinder on the fetus (the fetus rotates in the flow with an angular velocity ωpl).

The question of the angular velocity of fruit rotation ωpl, which depends on the conditions of interaction between the bristle and the surface, remains unclear. In general terms, the angular rotation of the fetus around its axis is created due to tangential forces acting on the surface.

The tangential force of the bristles is the sum of the forces acting on the bristles of the brush cylinder, which at a certain point in time are in contact with the surface of the fetus:

$$F_{sh} = \sum_{i=1}^{i=n} F_i \cos\beta_i \tag{5}$$

where n is the number of bristles in contact with the fruit surface;

Fi - the force of action of a separate bristle on the surface, N;

βi- angle of impact of the bristles on the fetus (between the radius and the force vector Fi), rad.

The force of hydraulic resistance to the rotation of the fruit in the liquid according to the recommendations can be defined as an inhibitory the effect of a continuous medium on a spherical body according to the formula:

$$F_j = \xi R_{pl} \frac{v}{2} \rho, \tag{6}$$

where v is the speed of rotation on the peripheral surface of the body, m/s;

p - liquid density, kg/m3

Denote

$$k = \frac{\xi R_{pl} \rho}{4\pi^2 R_{pl}^2} = \frac{\xi \rho}{4\pi^2 R_{pl}^2} \tag{7}$$

then, equation (5) is transformed to the form

$$F_j = k\varphi \tag{8}$$

The moment of inertia of a rotating spherical body is defined as:

$$J = 0{,}4 m_{pl} R_{pl}^2 \tag{9}$$

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– taking into account the accepted notation, we write the equation of the relative rotation of the fetus in the fluid flow

$$\varphi'' J + k\varphi' - F_{sh} = 0 \tag{10}$$

This is a second order differential equation with variables coefficients. Such equations in general form are solved only by numerical methods, for example, the Runge-Kutta method.

You can simplify the solution of the equation and bring it to a homogeneous if we assume that the first term of the equation is equal to zero, in this form, the quasi-stationary equation of motion is solved. Another solution method is to accept the conditions that the coefficients are constant and do not change over time. Let us assume that the coefficients remain constant. Then, after appropriate transformations, we obtain

$$\omega = \frac{M_b}{k}(1 - e^{-n\tau}) \tag{11}$$

$$n = \frac{k}{a_{pl}};$$

$$M_b = F_{sh} R_{pl}$$

The resulting equation establishes the dependence of the angular velocity fruit rotation ω on the duration of brush bristle contact surface cylinder.

When the fetus moves in the zone of contact with the brush cylinder, a different number of bristles interact in different areas, and the angle between the bristle force vector and the fruit radius also changes. It leads to the fact that the magnitude of the force Fsh changes according to a rather complicated law. Therefore, the general solution of equation (11) is a particular case for the entire process.

To simulate the process of washing the fetus, a calculation algorithm has been developed, which allows you to change the parameters of the device to evaluate the quantitative change in the intensity of the mechanical interaction of the working body on the surface of the fruit.

In the simulation, it was assumed that the washing machine fruits can have 1 or more brush cylinders, so the parameter is the number of working bodies of the machine. The number of bristles along the periphery of the cylinder is assumed to be 100 pcs.

To implement the program, the Excel-2019 software package was used, on on the basis of which, according to the recommendations [18-22], a dynamic calculation program was compiled that allows you to change the parameters and obtain a result that characterizes the change in the intensity of the mechanical interaction of the working bodies with the fruit surface.

3 Results and discussion

As a result of the calculations, graphic dependences were obtained, characterizing the change in the intensity of mechanical interaction working bodies with fruits (Figure 4-7).

As can be seen from the presented dependencies, the intensity mechanical interaction varies over a fairly wide range from lm lm= 30 - 35 to lm = 180 - 200. For comparison, the analysis of the operation of the brush machine KUM-III showed that under standard loading the intensity of mechanical interaction in it does not exceed lm = 35 - 40. This determines quite high specific consumption of washing liquid. Therefore, using proposed method of analysis, we can count on the creation of a device with higher rates of mechanical interaction intensity working bodies with the surface of the fruit.

As a result of the analysis of the results, analytical equations have been derived that make it possible to quantify the effect of the device parameters on the intensity of the mechanical interaction of the brush cylinder bristles with the fruit surface lm, as well as to determine the angular velocity of the fruit rotation relative to its axis ωs.

$$I_{м} = 20,44\, R_{pl}^{0.32} R_{sh}^{0.44} \omega_{s}^{0,13} X^{0,00012} У^{-0,23} v^{-0.41} i_{sh}^{0.78}; \quad (12)$$

$$\omega = 0,34\, R_{pl}^{0.12} R_{sh}^{0.27} \omega_{s}^{0,78} X^{0,015} Y^{0.036} v^{-0.14} i_{sh}^{0.74},\ rad/s \quad (13)$$

To obtain the intensity of mechanical interaction between the working bodies and fruits Im > 100, the fruit washing machine must be performed with the parameters shown in Table 1.

Table 1. Parameters of the fruit washing machine.

Parameter name	Dimension	Featured values
Brush cylinder radius Rsh	m	0,05 ... 0,07
Angular speed brush cylinder ωs	rad/s	1,25 ... 1,50
The distance between the fruit and the brush cylinder along the axis У	m	0,03 ... 0,04
Fetal movement speed v	m/s	0,10 ... 0,15
Number of brush cylinders ish	pcs	4 ... 5

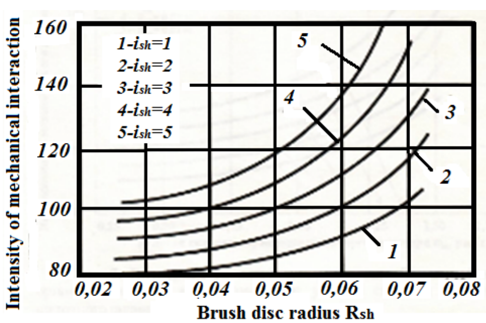

Fig. 4. The intensity of the mechanical interaction of the working bodies with the fruits, depending on the radius of the brush cylinder and the number of brush cylinders at ωs = 1,0 rad/s; X = 0,06m; Y= 0,05 m; v = 0,20 m/s; Rpl = 0,03 m.

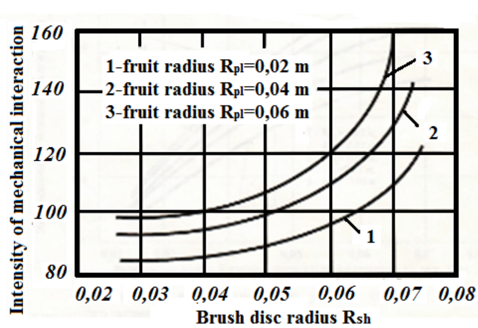

Fig. 5. The intensity of the mechanical interaction of the working bodies with the fruits, depending on the radius of the brush cylinder and the radius of the fruits at: ωs = 1,0 rad/s; X = 0,06m; Y= 0,05 m; v = 0,20 m/s; ish = 3.

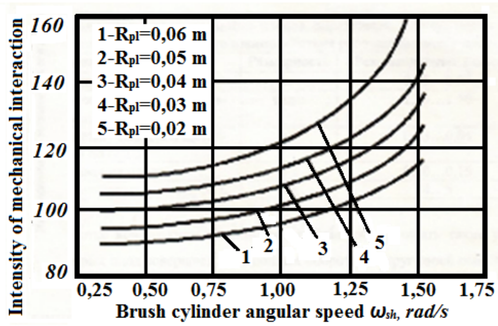

Fig. 6. The intensity of the mechanical interaction of the working bodies with the fruits, depending on the angular speed of rotation of the brush cylinder and the radius of the fruit at: Rsh = 0,35m; X = 0,116 m; Y= 0,05 m; v = 0,20 m/s; ish = 3.

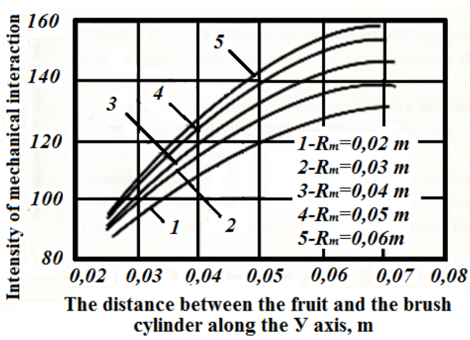

Fig. 7. The intensity of the mechanical interaction of the working bodies with the fruits, depending on the distance between the fruit and the brush cylinder along the Y axis, as well as the radius of the brush cylinder at: Rsh = 0,35m; X = 0,06m; ωsh = 1,0 rad/s; v = 0,20 m/s; ish = 3.

4 Conclusions

Parameters of the fruit washing machine, determined by the criterion the intensity of the mechanical interaction of the working bodies with the fruits When designing a machine, it is desirable to provide such process conditions under which the fetus makes 5 - 7 complete revolutions around its axis. This parameter is adjusted by changing the distance between brush cylinders, as well as the selection of parameters that provide the average value of the angular velocity of rotation of the fetus around its axis in within ωpl = 0.5 - 0.7 rad/s.

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