Method of oat grain peeling using vacuum

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Abstract. The paper presents the results of a study regarding the processing of cereal crops, specifically peeling of oat grain with an air-water stream in a vacuum. This method allows reducing the operation of oat grain processing due to the exclusion of hydrothermal processing (HTP) operations. The paper presents studies concerning the design of the main structural elements, as well as mathematical calculations that allows assessing the main parameters of the technological process of grain processing and establishing its relationship with the design parameters of the equipment.

1. Introduction
The development of a fundamentally new method of processing cereal crops, specifically oat grain peeling with an air-water stream in a vacuum, is relevant in connection with the technical modernization and re-equipment of agricultural organizations [1].

The hydrothermobarometric treatment preceding the oat grain peeling, according to traditional technology, includes hydrothermal processing of grain (HTP) to achieve its moisture content W=14-15% and to provide fragility of shells with this humidity [2] for subsequent peeling with an air stream. Guaranteed provision of such a moisture level requires control of the initial grain moisture and moisture during the HTP process, which is unattainable at the current level of technological development in production conditions.

The proposed method will allow to reduce the operation of oat grain processing by eliminating the HTP processes and implementing in a single set of vacuum processes to achieve fragility of shells and peeling.

It is known [3] that during preliminary evacuation of grain up to 0.03-0.05 MPa, the capillaries (pores) of the shell are released from the air, which subsequently contributes to the almost instantaneous penetration of moisture to the core, providing the required parameters for its moistening. During preliminary evacuation of the grain below 0.03 MPa, an “explosion” of the shells occurs - aerodynamic peeling, affecting the core of the grain, on which micro- and macrocracks appear, up to destruction. Such a process requires the selection of an optimal processing method for it, which, in our opinion, consists in ensuring the fragility of grain during evacuation. This will allow us to consider grain as a completely fragile body for constructing physico-statistical models that are adequate to the real process of fragile fracture of the capillary-porous structure of the shells of the studied crops.
2. Materials and methods

The developed device (Figure 1) contains a sealed chamber 1, divided into lower 2 and upper zones 3 by a fixed perforated partition 4, a hermetically closed side door 5, a vacuum pump 9, an air accumulator 10, a vacuum tank 11, an automatic control system 12. Automatic control system 12 includes a valve 13 for supplying air to the nozzles 14 from the air accumulator 10, a valve 15 for cutting off the lower zone 2 from the vacuum pump 9, a valve 16 for letting air into the lower zone 2, a valve 17 for cutting off the upper zone 3 from vacuum vessel 11, valve 18 for cutting off lower zone 2 from the vacuum vessel 11, the valve 19 for cutting off a vacuum container 11 from the vacuum pump 9.

In the initial position, the sealed chamber 1 is closed, the lower zone 2 is separated by a fixed perforated partition 4 from the upper zone 3, the side door 5 is closed. The vacuum pump 9 is connected through a valve 19 to a vacuum tank 11, the valve 15 for cutting off the lower zone 2 from the vacuum pump 9 and the valves 17 and 18 for cutting off the zones 1 and 2 from the vacuum tank 11 are closed. The air inlet valve 13 from the air accumulator 10 to the nozzles 14 is closed, the air inlet valve 16 into the lower zone 2 is closed.

The device operates as follows: through an open side door 5, they place oat grain 7, which is located in a perforated container 6 with a hole diameter not exceeding the diameter of the oat grain, on a fixed perforated partition 4, and then cover it with an airtight film 8, the edges of which are fixed on the base of the perforated partition 4. After that, the chamber 1 is sealed with a side door 5. They close the valve 19 and the vacuum pump 9 through the valve 15, and the vacuum tank 11 through the valve 18, create a vacuum in the lower zones 2, and the compressed air pumped out from the lower zone 2 enters the air accumulator 10. When the degree of rarefaction in the lower zone 2 is 0.02 MPa, which ensures “fragility” of the oat grain shells [3], the compressed air from the air accumulator 10 enters through the valve 13, into nozzles 14 under a pressure equal to 1.2 MPa, acting on a perforated container 6 with oat grain 7 located on a fixed perforated partition 4. Then, at the end of the cycle, air is let into the lower zone 2 through valve 16 until atmospheric pressure is reached in it and unload processed shelled grain through the side door 5, after its separation produced using appropriate technologies.

Thus, the operation of oat grain processing is reduced due to the elimination of HTP processes aimed at increasing the fragility of the grain shells before peeling and the implementation in a single set of vacuum processes to ensure the fragility of the shell, which ultimately reduces the cost of cereals and energy costs in its production.
3. Assumptions
The following assumptions were made when developing a model for processing grain with an air-water stream:

1) Molecules transported in a stream by turbulent moles [4] are spheres of the same size (molecules intensively rotate around their center of gravity during movement; the geometric axis of a rotating molecule constantly and randomly changes its angle of inclination with respect to, for example, the axis of the stream, therefore, we can talk about some "spherical surfaces" formed by each point of the molecule; the radius Ra of the largest "spherical surface" described by the point farthest from the center of gravity will be called conditional radius).

2) A stream is a medium of orderly moving, non-interacting molecules, the coefficient of resistance to movement of which is constant in the first approximation [5].

3) The averaged local values of gas (air) velocity and water molecules are the same.

4) The rate of molecule pulsation (soaring), as a component of motion, is assumed to be zero due to the greater inertia of large molecules compared to small ones.

The accepted restrictions make it possible to involve a number of more general models of physical processes for constructing a stream model (provided, of course, that the above limitations are identical in them) [6]. With this in mind, it is possible to conditionally divide the entire set of physical processes occurring in a two-phase stream into separate model processes, perform their analysis and modeling, and the result - the general stream model - can be obtained as a superposition of models of individual processes.

Note that the stream model obtained by the indicated method is likely to be closed, since when creating it, any considerations that are beyond the scope of the above assumptions adopted when idealizing the stream expiration process are not involved.

When developing a general stream model, one should also establish the influence of each of the model processes on the main factors determining the efficiency - the velocity of the molecules in the stream and their concentration [7, 8].

In the framework of the task, the phenomena occurring in a real two-phase stream can, in our opinion, be described and explained from an analysis of the following processes:

- the process of moving molecules in a cylindrical nozzle (analysis of this process will determine the distribution of molecular velocity and concentration at the initial moment of formation of the stream at its exit from the nozzle);
- the process of expansion of the stream in the cross section after the exit of water molecules from the nozzle (an analysis of the process can show how and why the distribution of the velocity of the molecules and their concentration changes as the stream moves away from the nozzle);
- the process of moving molecules along the axis of the stream (when analyzing the process, one can establish the nature of the change in the velocity and concentration of molecules along the axis of the stream);
- the process of changing the distribution of velocity and concentration of molecules in the cross section of the stream (analysis of this process will reveal the reasons for the transformation of this distribution as the stream develops).

4. Conducting experiments
Sequentially consider these processes.

1) Since the movement of molecules to the exit from the nozzle takes place in a certain cylindrical volume bounded by the walls of the nozzle, the process of their movement up to the moment of crossing the plane of the initial section of the nozzle (nozzle exit) under the assumptions made can be compared with the known process of translational motion of a viscous liquid or gas in a cylindrical pipe with rigid walls [9]. In this case, the component of the averaged velocity of the stream molecules, directed parallel to the stream axis and at a distance r from this axis, at the initial moment of time at the exit from the nozzle can be specified by the formula
\[ V_r = A \left( R_n^2 - r^2 \right) \]  

(1)

where \( A \) - coefficient depending on the pressure drop and the properties of the liquid (gas);
\( R_n \) - nozzle radius;
\( r \) - distance from the central axis of the pipe.

Thus, at the moment the stream exits the nozzle, the averaged particle velocity has an axisymmetric
distribution, which, as the stream propagates further, is likely to change.

2) The process of expansion of the stream in the cross section with a constant velocity front of the
outer radius of the stream begins immediately after the molecules exit the nozzle (Figure 2).

\[ V_r = V_L \left[ 1 - \left( \frac{r}{R} \right)^{3/2} \right]^2 \]

(2)

where \( V_L \) - axial velocity of the molecules at a distance \( L \) from the nozzle exit;
\( R \) - radius of the expanding stream at time \( t_0 \), and the value of \( R \) can be expressed through the design
radius of the nozzle \( R_n \) from simple geometric considerations as
\[ R = R_n + L \tan \beta, \]

where \( \beta \) - spray angle of the stream (Figure 2).

Taking into account the last relation, dependence (2) takes the form

\[ V_r = V_L \left[ 1 - \left( \frac{r}{R} \right)^{3/2} \right]^2 \]

(3)

For the concentration of molecules \( \rho_r \), the distribution, similarly to [4], has the form

\[ \rho_r = \rho_L \left[ 1 - \left( \frac{r}{R_n + L \tan \beta} \right)^2 \right]^3 \]

(4)

where \( \rho_L \) - concentration of molecules on the stream axis at a distance \( L \) from the nozzle exit.
3) As moving away from the nozzle, the axial velocity of the molecules changes, since it takes a value from the initial $V_0$ to zero. The reason for the decrease in the speed of the molecules, obviously, is the air resistance exerted during their movement.

Assuming that the axial component of the velocity of the molecules prevails over all other components (as evidenced by the small spray angles of the stream, not exceeding, as a rule, $6^\circ$), the movement of the molecules along the axis under the action of the air resistance force can probably be represented as an equally slow motion of a rectilinearly moving body.

Using well-known equations to describe such a motion, the axial velocity of molecules $V_L$ can be found from the expression

$$V_L = V_0 \left(1 - \frac{3cp_aL}{4R_a\rho_w}\right)^{1/2},$$

where $V_0$ - initial axial velocity of the molecules at the exit of the nozzle;
$c$ - coefficient depending on the shape of the body;
$R_a$ - radius of a spherical particle;
$\rho_w$ - water density;
$\rho_a$ - air density.

Let us now consider how the concentration of molecules changes along the axis of the stream. If the change in the concentration of molecules in any section of the stream along its radius occurs in accordance with the laws provided by the model according to point 2, then, depending on the distance $L$ from the nozzle, this characteristic of the stream, apparently, changes differently.

In our opinion, the nature of the change in the concentration of particles along the axis of the stream is similar to the change in the concentration of air molecules in a certain cylindrical volume, extending above the earth to a height $h$, where the value of the concentration of molecules is zero (the Boltzmann barometric distribution). This assumption is supported by the coincidence of the initial conditions for the formation of a two-phase stream and an air column at the initial time $t = 0$.

Thus, the distribution of the particle concentration $\rho_L$ in the stream along its axis can take the form

$$\rho_L = \rho_0 \exp\left[-\frac{4}{3}\pi R_a^3 \frac{gL}{k'T}\right],$$

where $\rho_0$ - concentration of molecules on the axis when exit the nozzle;
$g$ - gravity acceleration;
$k'$ - empirical coefficient of the type of Boltzmann constant;
$T$ - absolute temperature.

4) According to studies [8, 9], at a certain point in time $t_0$, when the rarefaction wave reaches the stream axis, the process of transformation of unimodal profiles of the longitudinal (parallel to the stream axis) velocities of particles and its concentration into a profile that develops over time (and changes the distance $L$ from the nozzle) to the depression in the center of the stream (Figure 3).

The nature of the transformation process of the initial profiles of longitudinal velocities and concentrations of molecules suggests that such a change occurs similar to the process of propagation of sound waves in a gaseous medium described by the wave equation when solving the initial problem for it (the Cauchy problem) using the D'Alembert formula [8, 9],

$$f(r,t) = \frac{1}{2} [f_0(r-at) + f_0(r+at)],$$

where $f_0$ - initial distribution function of the velocity or concentration of particles;
$a$ - constant, depending on the properties of the medium in which the sound wave propagates;
$t$ - time.
5. Conclusions

Thus, for the mathematical description of the real process of propagation of a two-phase stream and obtaining the values of \( V \) and \( \rho \) at any point of the stream, the influence of each considered model process on the parameters \( V \) and \( \rho \) should be taken into account, i.e., it is necessary to know the general functional dependences of \( \rho = f(r, L) \) and \( V = f(r, L) \).

In view of expressions (1) - (6), the desired dependences will have the form

\[
V = V_0 \left(1 - \frac{3c\rho_w L}{4 R_n \rho_w} \right)^{1/2} \left[1 - \left( \frac{r}{R_n + L \tan \beta} \right)^{3/2} \right]^2. \tag{8}
\]

\[
\rho = \rho_0 \exp \left(-\frac{4}{3} \pi R_n^3 \rho_w g L / k T \right) \left[1 - \left( \frac{r}{R_n + L \tan \beta} \right)^2 \right]^{3/2}. \tag{9}
\]

Expressions (8) and (9) allow calculating the main parameters of the technological process of grain processing (\( V \) and \( \rho \)) and establishing their relationship with the design parameters of the equipment [10] \( (R_n, L, \beta, \text{etc.}) \) at their known initial values \( V_0 \) and \( \rho_0 \) at any point in the stream.

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