PL ISSN 0033-2097, e-ISSN 2449-9544

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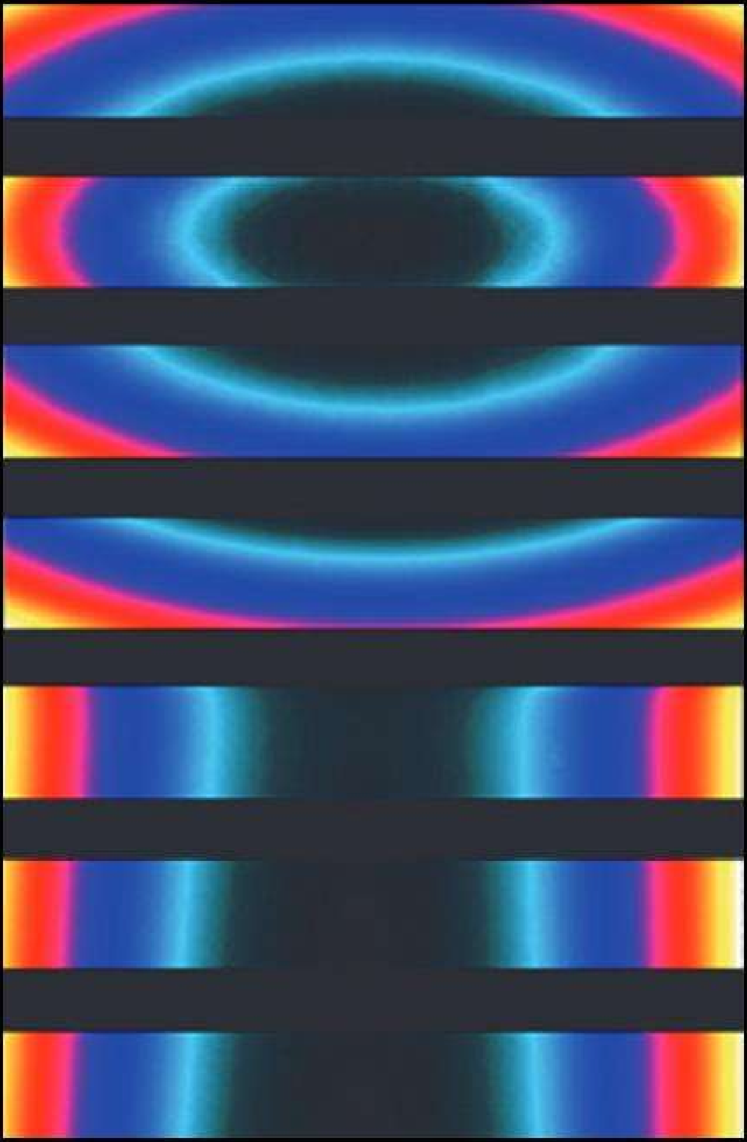

Analysis of the geometrical structure of the surface of the Shaped deformation area in the process of electrodynamic forming of metal - pager 200

PRZEGLĄD ELEKTROTECHNICZNY Vol 2022, No 12

Spis treści

PRZEGLĄD ELEKTROTECHNICZNY Vol 2022, Nr 12

Spis treści

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doi:10.15199/48.2022.12.76

Research of the process of vibroozone drying of grain

Abstract. *The process of post-harvest processing of grain, especially drying, is one of the most important in the technology of agricultural production. This processing contributes to obtaining high-quality products, their long-term and effective preservation until the harvest. Various methods of drying intensification are used to obtain grain raw materials of conditioned humidity and reduce energy consumption in agricultural production: vibration drying, recirculation drying, preheating, vacuum drying, drying with the use of infrared radiation, drying of grain under the influence of an electric field and many others. Promising in terms of energy consumption and quality of raw materials is the use of vibrating dryers in combination with ozonation technology, which is an additional factor in intensifying the drying process. The article is devoted to solving the urgent problem of intensifying the process of drying grain raw materials and the development of a new vibration-ozonating complex that implements a comprehensive technological impact on the processed raw materials.*

Streszczenie. *Proces pożniwnej obróbki ziarna, a zwłaszcza suszenia, jest jednym z najważniejszych w technologii produkcji rolniczej. Przetwarzanie to przyczynia się do uzyskania wysokiej jakości produktów, ich długotrwałej i skutecznej konserwacji aż do zbioru. W celu uzyskania surowców zbożowych o uwarunkowanej wilgotności i zmniejszeniu energochłonności produkcji rolniczej stosuje się różne metody intensyfikacji suszenia: suszenie wibracyjne, suszenie recyrkulacyjne, podgrzewanie wstępne, suszenie próżniowe, suszenie z wykorzystaniem promieniowania podczerwonego, suszenie ziarna pod wpływem pole elektryczne i wiele innych. Obiecujące pod względem energochłonności i jakości surowców jest zastosowanie suszarek wibracyjnych w połączeniu z technologią ozonowania, która jest dodatkowym czynnikiem intensyfikującym proces suszenia. Artykuł poświęcony jest rozwiązaniu palącego problemu intensyfikacji procesu suszenia surowców zbożowych oraz opracowaniu nowego kompleksu wibrująco-ozonującego, realizującego kompleksowy wpływ technologiczny na przetwarzane surowce.* (***Badania procesu suszenia wibroozonowego ziarna***)

Keywords: grain raw materials, drying, vibration, ozone, vibration-ozonating complex, quality indicators, grain moisture.
Słowa kluczowe: suszenie I segregacja ziarna, separator wibracyjny.

Introduction

Drying is one of the most important stages in the preparation of grain for storage in agricultural production. Currently, the convective drying method has found a fairly wide distribution for this technological process. But along with its advantages, this method has a number of significant disadvantages, one of which is significant energy consumption. In this regard, scientific research is being carried out quite intensively to develop ways and methods to reduce the energy intensity of the convective processing method [1].

An effective method of intensifying the drying of grain raw materials is the introduction of ozonation technology in combination with a vibrational effect on the processed raw materials.

Ozone intensifies the drying rate of cereals due to the direct chemical and biochemical effects on agricultural raw materials, improves the movement of moisture from the inner layers and heat and mass transfer during the drying process as a whole.

When using ozone, the savings are about 89 kg of standard fuel per ton of raw material obtained.

Drying with the use of ozone causes an antibacterial effect and improves grain quality, makes self-heating processes impossible, causes the necessary state of rest during storage, and preserves the volume of the processed material. There is no need for grain dressing and it is possible to minimize energy consumption for the drying process.

The peculiarity of the use of ozone is that it does not lead to the formation of harmful by-products, as ozone decomposes into atomic oxygen [2].

The vibration effect on the grain during its drying ensures uniform processing of the material with the exception of the occurrence of local overheating zones due to the constant movement of raw materials.

Analysis of literary sources and problem statement

The usefulness and relevance of the use of vibration technologies in the drying process are presented in the works [3, 4]. Theoretical and experimental research of the drying process of specific agricultural raw materials are devoted to the works [5, 6]. The results of the application of physical effects to intensify the drying process and subsequent storage of agricultural products are given in the works [7, 8]. A detailed review and classification of vibration and drying equipment was made in the works [9, 10]. In the works [11-14], the peculiarities of the effect of the ozone-air mixture on the characteristics of grain raw materials during drying are given in detail, depending on the ozone concentration, drying time, etc.

Purpose and tasks of research

After analyzing the works [3-14] we can establish that:

- existing grain dryers operate inefficiently, they are bulky, metal- and energy-intensive, difficult to maintain and repair, and are expensive;
- the process of drying grain raw materials can be significantly intensified by using vibration technologies and equipment in combination with the introduction of ozone into the composition of the drying agent.

Therefore, the purpose of the research is to increase the efficiency and rate of the process of drying grain raw materials with a simultaneous decrease in energy consumption for its implementation by developing a vibroozone complex.

Presentation of the main material of theoretical research

Seed germination is one of the most important indicators of seed productivity and quality. Therefore, an important task is to determine the effect of the ozone-air mixture on seed germination. The germination of seeds can predict future yields. It can be assumed that the internal energy of seeds is a function of the energy balance of seeds:

(1) $$Y = f(E),$$

where Y – germination of seeds of the studied species; E – seed energy balance.

Among the main criteria for evaluating the process of drying grain raw materials was chosen the final moisture content of the last raw material W, %, and energy consumption to drive the vibroozonating complex N, kWh, which are characterized by the influence of the four most significant factors that determine the kinetics of this treatment: vibration acceleration a, m/s^2 as a complex parameter of the dynamic state of the system; the temperature of the drying agent T_{DA}, °C; ozone concentration N_{Oz}, mg/m^3, time of processing t_p, s:

(2) $$W = f(a, T_{DA}, N_{Oz}, t_p),$$

(3) $$N = f(a, T_{DA}, N_{Oz}, t_p),$$

where a – vibration acceleration, m/s^2; T_{DA} – temperature of the drying agent, ^{o}C; N_{Oz} – ozone concentration, mg/m^3; t_p – time of processing, s.

As is known, the effect of ozone in the treatment of seeds of agricultural crops depends on the nature of the distribution and absorption of ozone throughout the volume of material being processed.

When an ozone-air mixture passes through a layer of grain raw materials, part of the ozone will be absorbed, and therefore the ozone content will decrease, respectively, part of the grain can be untreated at a given ozone concentration.

Therefore, in order to reliably determine the effect of the ozone-air mixture on grain processing, it is necessary to identify patterns of ozone absorption by grain.

The rate of absorption of ozone by grain raw materials from the ozone-air mixture is determined by the sorbing activity of the grain and the value of the ozone concentration.

This dependence can be described by the equation of the form:

(4) $$\frac{dC}{dt} = -K_r \cdot C \cdot S_g,$$

where C – ozone concentration, mg/m^3; K_r – coefficient showing the rate of propagation of the ozone concentration in the grain layer in depth, 1/m^2·s; S_g – area of grain mass, m^2.

To determine the ozone absorption rate constant, an ozone-air mixture with certain parameters was passed through the seed layer (V_{DA}, V, S_g, C), and at certain intervals the ozone concentration at the inlet and outlet of the grain layer was measured.

Under the initial conditions: $t = 0, C = C_0$ change in ozone concentration in ozone-air mixture can be described by the equation:

(5) $$\frac{dC}{dt} = \frac{S_g}{V}\left[V_{DA}(C_0 - C) - K_r C V\right],$$

where V_{DA} – feed rate of the drying agent saturated with ozone, m/s; V – volume of processed grain, m^3; C_0 – inlet ozone concentration, mg/m^3; C – outlet ozone concentration, mg/m^3.

The solution of equation (5) has the form:

(6) $$C = \frac{C_0 \cdot V_{DA}}{V_{DA} + K_r \cdot S_g \cdot V}\left[1 - \exp\left(-\frac{V_{DA} + K_r \cdot S_g \cdot V}{V}\right) \cdot t\right].$$

From equation (6) with known parameters V_{DA}, V, S_g, C it is possible to determine the value of the constant of ozone absorption rate by grain. Since equation (5) is transcendent to K_r and its solution in elementary functions cannot be obtained, therefore the magnitude K_r can be found by equation (6) by the iteration method.

When a layer of grain of a some thickness is blown with an ozone-air mixture, ozone is absorbed.

The mathematical description of the spread of ozone along the depth of the grain layer can be based on the example of the movement of an ozone-air flow in the form of a flat front. The ozone propagation equation will look like:

(7) $$\frac{dC}{dX} = \frac{K_r \cdot S(a) \cdot C}{V_{DA}}.$$

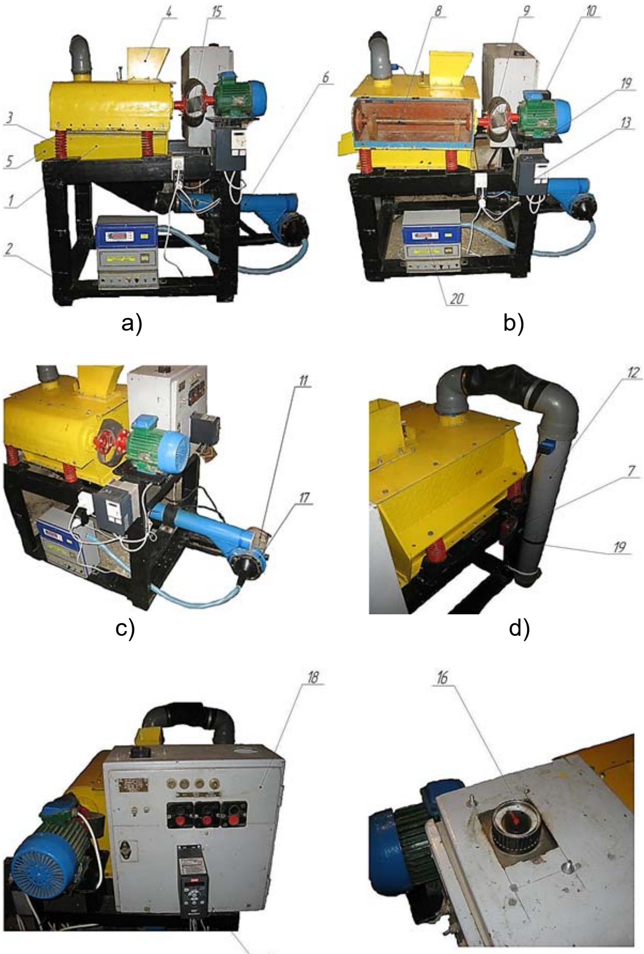
Coefficient $S(a)$ the area of interaction of the surface of seeds with ozone can be increased as a result of loosening the layer of grain through the use of vibrational effects on the processed raw materials. The state of loosening of the layer of grain raw materials, in turn, will depend on the intensity of the oscillation of the drying chamber, namely, on its vibrational acceleration a.

Coefficient $S(a)$ the area of interaction of the surface of seeds with ozone:

(8) $$S(a) = n \exp\left(-\frac{m}{a}\right),$$

where n, m – empirical coefficients that depend on process parameters.

The dependences presented make it possible to determine the intensity of the distribution of the ozone concentration over the depth of the layer under the influence of vibration impact, depending on the vibration acceleration of the drying chamber and the speed of the drying agent.



a) b)

c) d)

e) f)

Fig. 1. Experimental model of vibroozonating complex: a, b – front view; c, d, e – side view; f – view from above; 1 – U-similar chamber; 2 – rack; 3 – springs; 4, 5 – loading and unloading trays; 6, 12 – respectively inlet and outlet ducts; 7 – thermal anemometer; 8 – unbalance shaft; 9 – elastic coupling; 10 – unbalance shaft drive electric motor; 11 – fan drive electric motor; 13, 14 – frequency converters; 15 – thermostat; 16 – time relay; 17 – fan; 18 – control block; 19 – moisture meters; 20 – electronic ozone synthesis device.

Table 1. Technical characteristics of the experimental model of the vibroozone complex

Index	Value
Installed total electrical power, kW: – power of the unbalance shaft drive electric motor, kW – power of the fan drive electric motor, kW – power of the heating electric elements, kW – power of electronic ozone synthesis device, kW	5 2.2 0.75 2 0.25
Unbalance shaft drive electric motor rotation frequency, rpm.	to 1500
Fan electric motor rotation frequency, rpm.	to 3000
Drying agent temperature, °C	to 75
Ozone concentration in the ozone-air mixture, mg/m^3	to 18
Drying agent rate, m/s	to 5
Oscillation amplitude of the drying chamber, mm	0.5… 7.5
Productivity of the vibroozonating complex for dry grain raw materials, kg/hr.	to 25
The mass of vibroozone complex, kg	265
The mass of drying chamber, kg	95
Vibroozone complex dimensions (length × width × height), mm	1700× 970× 1300
Drying chamber volume, m^3	0.06

Experimental equipment

For the implementation of high-quality drying of grain raw materials, an experimental model of the vibro-ozonating complex was designed and manufactured (Fig. 1), in which the material being processed is subjected to vibration, which increases and renews the heat exchange surface [15]. As a result, there is an intensive removal of moisture, increasing the drying rate. The drying process takes place evenly throughout the layer, without causing local overheating of the material. The technical characteristics of the experimental model of the vibroozone complex are presented in Table 1.

As a drying agent, a mixture of heated air and ozone of a certain concentration, generated by a corona discharge in an electronic ozone synthesis device, is used (Fig. 2), the electrical circuit diagram of the power of which is built on the basis of a quasi-resonant converter (Fig. 3).

a) b)

Fig. 2. Electronic ozone synthesis device: a – general form; b – ozone synthesis working chamber.

Vibro-ozonizing complex (see Fig. 1) is a hermetic U-similar chamber mounted on the rack with the help of springs. The chamber contains a loading and unloading trays, as well as air duct for the withdrawal of the spent drying agent. On the side of the chamber there is a shaft with two unbalances, which is driven into rotation through an elastic coupling by means of a three-phase electric motor.

In the lower part of the chamber there is an air duct with electric heating elements, through which the heated air and ozone generated by the ozonator enter, and is supplied by a fan using an electric motor.

The principle of operation of the complex is that the drying agent, which consists of heated air and ozone of a certain concentration, is fed by a fan mounted on the rack into a U-similar hermetic chamber in which the grain raw material is located. At the same time, the electric drive of the unbalanced shaft is turned on. The drying agent, passing through the grain layer and removing a certain percentage of moisture, enters the outlet air duct, through which it is removed from the drying chamber.

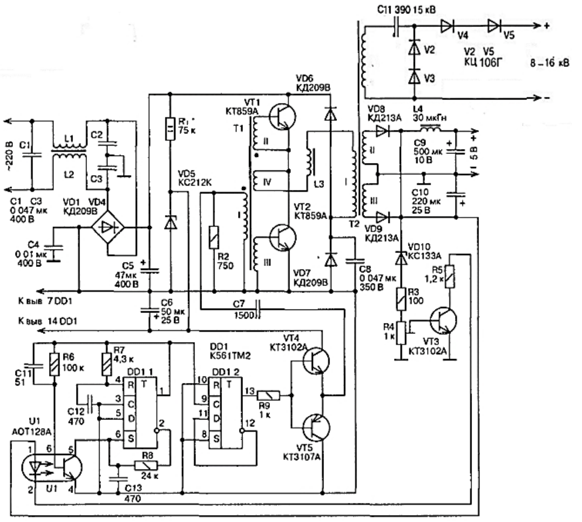


Fig. 3. Electrical circuit diagram of the power supply unit of the ozonizer based on a quasi-resonant converter.

The results of the experimental study

During experimental studies of the developed complex, an analysis was made of the influence of the comprehensive thermophysical action on the quality indicators of the processed raw materials, which were previously moistened and infected with spores of the fungi smut and Fusarium.

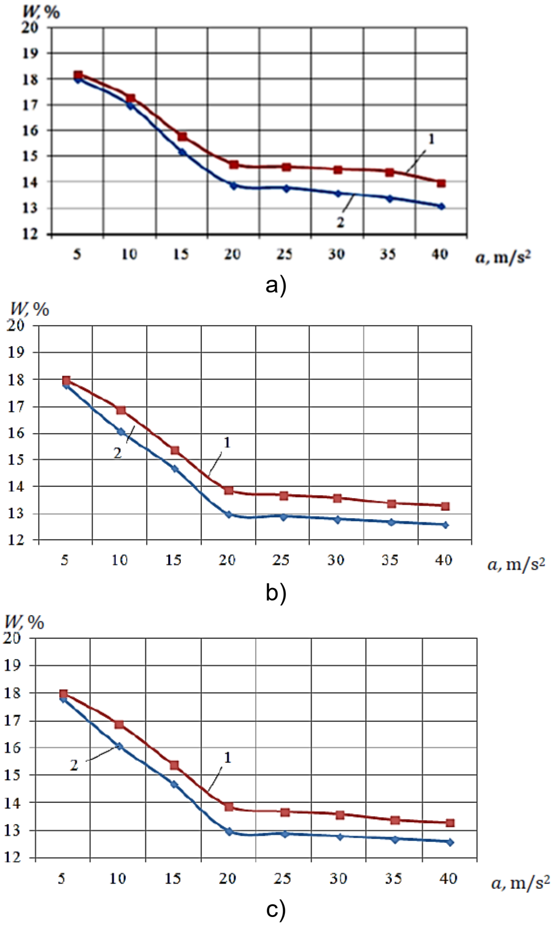
The obtained grain raw material was evaluated by such indicators as final moisture content, germination, the state of insemination by fungi smut and Fusarium, depending on the temperature of the drying agent ozone concentration in its composition and processing time.

The final moisture content of the grain at the technological loading of the drying chamber 50% and 75% from full volume was determined when it was treated with a drying agent at a temperature 45 °C, 55 °C and 65 °C, which included ozone concentration N_{Oz} = 10 mg/m^3 based on research recommendations [16] (Fig. 4). The processing time t_p = 9600 s at a rate of the drying agent V_{DA} =1.5 m/s.

Based on the obtained data on the kinetics of the process of drying grain raw materials at an ozone concentration in the composition of the drying agent N_{Oz} =10 mg/m^3, it is obvious that an increase in its temperature to 55 °C contributes to intensive moisture release, while a temperature above the specified value does not give significant results and leads to excessive energy consumption.

In addition, the most intense moisture from the grain material is released during vibration acceleration a = 20…25 m/s^2, after which it does not change significantly. It follows that increasing the vibration acceleration of the drying chamber above the specified value is inefficient, since it does not contribute to a significant decrease in the level of moisture, but only leads to an increase in energy consumption for the unbalance shaft drive.

Comparing the drying curves of grain raw materials under the condition of vibration and vibration-ozonizing conditions, it is obvious that the duration of treatment using ozone in the composition of the drying agent N_{Oz} = 10 mg/m^3 reduces the duration of this process by 4800 s, and therefore reduces the energy consumption of this technological operation (Fig. 5).



a)

b)

c)

Fig. 4. The dependence of the change in the moisture content of grain raw materials depending on the vibration acceleration: a – at drying agent temperature 45 °C; b – at drying agent temperature 55 °C; c – at drying agent temperature 65 °C; 1 – at the technological loading of the drying chamber 75% from total volume; 2 – at the technological loading of the drying chamber 50% from total volume.

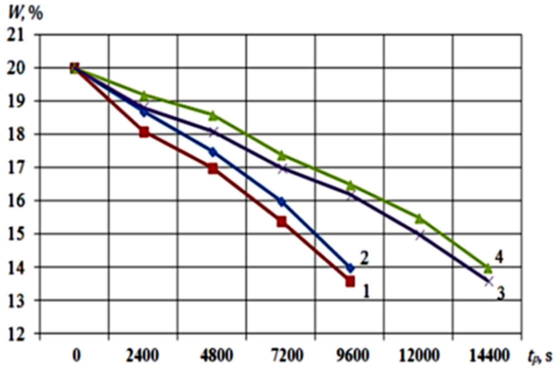


Fig. 5. Kinetics of drying grain raw materials: 1, 2 – with using ozone as a drying agent (with a technological loading of the drying chamber of 50% and 75% of the total volume respectively); 3, 4 – with use of vibration drying (with a technological loading of the drying chamber of 50% and 75% of the total volume respectively).

The dependence of the germination of wheat variety «Tsarivna» on the time of treatment and the concentration of ozone in the composition of the drying agent was determined (Fig. 6).

Experimentally obtained dependences show that ozone has a positive effect on the germination of the processed raw materials. Moreover, the germination increases by 8% compared to drying without ozonation. The rational concentration of ozone is 10 mg/m^3, since a higher concentration hasn't a significant effect on the germination of treated winter wheat and is within 0.5%.

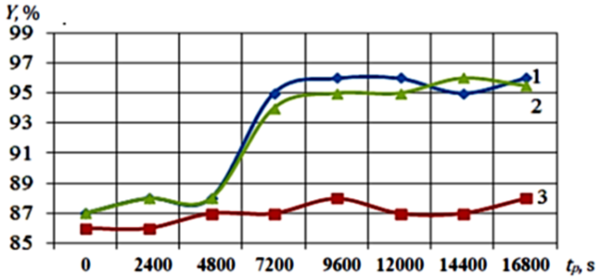


Fig. 6. Germination of the resulting grain raw material depending on the concentration of ozone: 1 – at ozone concentration 10 mg/m^3; 2 – at ozone concentration 15 mg/m^3; 3 – in the absence of ozone in the composition of the drying agent.

Also the disinfecting properties of ozone in the composition of the drying agent at action on insemination of fungi smut and Fusarium were investigated (Fig. 7, 8).

The ratio of exceeding the critical density of microorganisms to a unit mass of grain was determined by the expression:

$$C_n = \Delta n / m_g \cdot 10^3, \quad (9)$$

where Δn – excess density of microorganisms; m_g – grain mass unit.

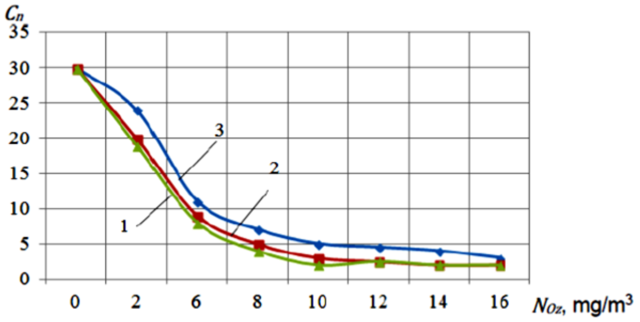


Fig. 7. State of fungal infection of winter wheat with Smut spores: 1 – at processing time t_p = 10800 s.; 2 – at processing time t_p = 9600 s.; 3 – at processing time t_p = 8400 s.

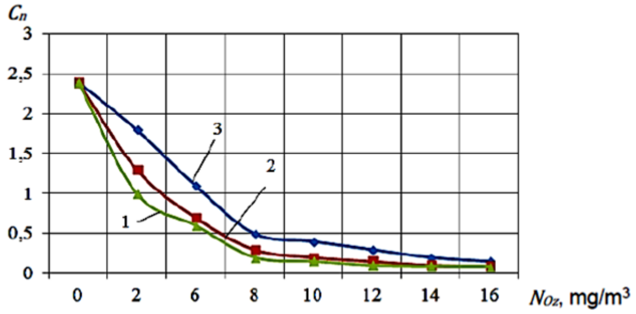


Fig. 8. State of fungal infection of winter wheat with Fusarium spores: 1 – at processing time t_p =10800 s.; 2 – at processing time t_p = 9600 s.; 3 – at processing time t_p = 8400 s.

Analyzing the dependences obtained, it can be concluded that ozone in the composition of the drying agent reduces the state of insemination with Smut spores and Fusarium spores most optimally at a concentration of N_{Oz} = 8 … 10 mg/m^3 with a processing time of t_p = 9600 s, as higher values of concentration and processing time do not lead to significant changes.

Conclusions

1. Existing technologies do not fully exhaust the possibility of using vibration and ozone, although they indicate the expediency of their use and combination not only in agricultural production but also in other industries in order to intensify processes and obtain high-quality products.

2. A mathematical model has been developed for the distribution of ozone concentration over the depth of the grain layer under the action of vibration exposure.

3. A vibroozonizing complex was proposed and developed for the implementation of the technological process of drying grain raw materials, in which the processed products are exposed to vibration with the simultaneous supply of a drying agent, which is a mixture of heated air and ozone of a certain concentration.

4. In the course of experimental studies, compromise technological parameters of the studied process of drying grain raw materials were obtained, which are: vibration acceleration a = 15…20 m/s^2, drying agent temperature T_{DA}= 50…55 ^{o}C, ozone concentration N_{Oz} = 8…10 mg/m^3, processing time t_p = 7800…9600 s. according to the rate of the drying agent V_{DA}=1.5 m/s.

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