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STUDY OF VIBROZONATING PROCESS OF GRAIN DRYING AND ENERGY PARAMETERS OF THE INSTALLATION FOR THE REALIZATION OF THIS PROCESS

Drying is one of the most important stages of grain preparation for storage in agricultural production. Today the convective drying method is widely used in this technological process. But along with the advantages this method also has a number of disadvantages, one of them is great energy consumption. As a consequence, intensive scientific search is carried out to develop means and methods, aimed at the reduction of energy consumption of the convective method of drying.

Process of the post-harvest treatment of grain, especially, drying is one of the most important processes in the technology of agricultural production. This treatment promotes the obtaining of high-quality products, their long-term and efficient storage till the new harvest.

For obtaining grain raw material of the normal moisture and reduce the energy consumption various methods of drying process intensification are used in the sphere of agricultural production: vibration drying, recirculation drying, preliminary heating, vacuum drying, drying, using IR-radiation, drying by the high frequency currents, grain drying under the impact of the electric field and other methods. From the point of view of energy consumption and quality of the obtained primary products is the usage of the vibrating driers, combined with ozonizing technology, which is the additional factor, contributing to the drying process intensification.

The given paper is devoted to the solution of the urgent problem of the intensification of grain raw material drying and development of new vibro ozonizing complex, which realizes the complex technological impact on the handled medium.

Energy parameters of the developed vibroozonizing complex were experimentally investigated, depending on the mode parameters of the investigated process of grain raw material drying.

Key words: *grain raw material, drying, vibration, ozone, vibroozonizing complex, quality indices, grain moisture, germination index, ozone concentration, vibratory acceleration, processing time, energy parameters.*

Introduction

Drying is one of the most important stages of grain preparation for storage in agricultural production. Today the convective drying method is widely used in this technological process. But along with the advantages this method also has a number of disadvantages, one of them is great energy consumption. As a consequence, intensive scientific search is carried out to develop means and methods, aimed at the reduction of energy consumption of the convective method of drying.

Effective methods of grain raw material drying is the implementation of the ozonizing technology, combined with the vibrating impact on the handled raw material.

Ozone intensifies the rate of grain drying as a result of the direct chemical and biochemical impact on the agricultural raw materials, improves the displacement of moisture from the internal layers and heatmass exchange in the process of drying on the whole.

As a result of using ozone approximately 89 kg of the conventional fuel is saved per ton of the obtained raw material.

Drying, using ozone causes antibacterial impact and improves the quality indices of grain, makes impossible the processes of selfheating, stipulates the necessary dormant state in the period of storage, saves the volume of the handled material. The need of grain treatment disappears and there exists the possibility to minimize energy consumption of the drying process.

Characteristic feature of ozone usage is that it does not lead to the formation of the harmful accessory substances, as the ozone is decomposed to atomic state.

Oscillating impact on the grain in the process of drying, in its turn, provides the uniformity of the material treatment and makes impossible the formation of the zones of local overheating due to constant motion of the raw material.

Analysis of the recent research

Utility and importance of vibrotechnologies application in the drying process are described in the studies [1, 2]. The publications [3, 4] are devoted to theoretical and experimental research of the drying process of the specific agricultural raw materials. The results of the application of physical effects, aimed at the intensificatioin of the drying process and further storage of agricultural products are presented in the studies [5, 6]. Detail survey and classification of the vibration and drying equipment are carried out in the research [7]. In the papers [5 – 7] characteristic features of the impact of the ozone-air mixture on the characteristics of grain raw materials in the process of drying depending on the ozone concentration, drying time, etc., are presented.

Problems of the improvement the energy efficiency of grain drying process and study of the energy parameters of the drying installations are investigated in the works [4 – 8].

Objective of the research

Having performed the analysis of the studies [1 – 8] it could be established that:

– available grain driers operate ineffectively, they are bulky, metal and energy-consuming, complicated for maintenance and repair, their cost is high;

– it is possible to intensify the drying process of the grain raw material by means of using vibration technologies and equipment, adding ozone to the composition of the drying agent;

– improvement of energy efficiency of the drying process does not decreases but on the contrary, increases, as a result of sharp growth of energy carriers cost;

– study of the energy parameters of the drying units, using vibration impact on the handled material with the simultaneous treatment by ozone, present in the composition of the drying agent for the grain raw material drying, are understudies.

Thus, the **objective of the research** is the improvement of the efficiency and rate of the grain raw material drying and simultaneous decrease of energy expenses for drying realization by means of development of vibroozonizing complex and determination of energy parameters of this complex, intended for grain raw material drying, that is an important scientific-engineering task.

Results of the theoretical research

Germination index is one of the most important indices of the seed efficiency and its quality. Germination index predicts the future crop productivity. That is why, the determination of the impact of the ozone-air mixture on the germination of the seed grains is an important task. It is conceivable that the internal energy of the seed is a function from the balance of the seed:

$$Y = f(E), \tag{1}$$

where Y – is germination of the studied kind of seeds; E – is the energy balance of the seeds.

Among basic criteria for the assessment of the grain raw material drying final moirsture of the grain raw material W, %, and energy expenses for the drive of vibro ozonating complex N, kWh·, were chosen, these criteria are characterized by the impact of four most important factors, which determine the kinetics of this treatment : vibro accelerartion a, m/s^2 as a complex parameter of the dynamic state of the system; temperature of the drying agent T_{DA}, ^{o}C; ozone concentration N_{OZ}, mg/m^3, time of treatment t, sec:

$$W = f(a,\ T_{DA},\ N_{OZ},\ t), \tag{2}$$

$$W = f(a,\ T_{DA},\ N_{OZ},\ t), \tag{3}$$

As it is known, ozone impact in the process of agricultural crops seeds treatment depends on the character of the distribution and absorption of ozone in the whole volume of the material, being treated.

In the process of passage of the ozone-air mixture across the layer of the grain raw material part of ozone will be absorbed, as a result, the content of ozone changes. Correspondingly, part of the grain may be untreated at the set ozone concentration.

That is why, for reliable determination of the ozone-air mixture impact on grain treatment it is necessary to determine the regularities of the ozone absorption by the grain.

Rate of ozone absorption by the grain raw material from ozone-air mixture is determined by absorbing activity of grain and the value of the ozone concentration.

This dependence can be described by the following equation:

$$\frac{dC}{dt} = -K_c \cdot C \cdot S_з , \tag{4}$$

where C – is the ozone concentration , mg/m^3; K_c – is the coefficient, which shows the rate of the ozone concentration propagation in the layer of grain in the depth, $1/\text{m}^2 \cdot$ sec; S_g – is the area of the grain mass, m^2.

For the determination of the constant rate of the ozone absorbtion, the ozone-air mixture with the determined parameters (V_{DA}, V, S_g, C), was passed through the the grain layer and ozone concentration was measured at the input and outpt of the grain layer in certain intervals of time.

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

$$\frac{dC}{dt} = \frac{S_з}{V}\left[V_{CA}\left(C_0 - C\right) - K_c CV\right], \tag{5}$$

where V_{DA} – is the speed of drying agent supply, saturated with ozone, m/sec; V – is the volume of the treated grain, m^3; C_0 – is the concentration of ozone at the input, mg/m^3; C – is the concentration of ozone at the output, mg/m^3.

Solution of the equation (5) is the following:

$$C = \frac{C_0 \cdot V_{CA}}{V_{CA} + K_c \cdot S_з \cdot V}\left[1 - \exp\left(-\frac{V_{CA} + K_c \cdot S_з \cdot V}{V}\right) \cdot t\right]. \tag{6}$$

From the equation (6) at the known parameters V_{DA}, V, $S_з$, C the value of the constant of the rate of ozone absorbtion by the grain can be determined. As the equation (5) is transcendental relatively K_c and its solution in elementary functions can not be obtained, the K_c can be found from the equation (6), applying the iteration method.

During blowing off the layer of grain of certain thickness by means of ozon-air mixture, the absoption of the ozone takes place.

Mathematical description of the ozone propagation in the depth of the grain layer can be based on the example of the ozone-air flow motion in the form of the plane front. Ozone propagation equation will have the form:

$$\frac{dC}{dX} = \frac{K_c \cdot S\left(a\right) \cdot C}{V_{CA}}, \tag{7}$$

where C – is ozone concentration, mg/m^3; K_c – is the coefficient, which shows the rate of ozone concentration propagation in the grain layer in the depth, $1/\text{m}^2 \cdot$ sec.

Coefficient S (a) of the area of the interaction of the grain surface with ozone can be increased as a result of loosening the grain layer, applying the vibration impact on the handled raw material. State of the loosened grail raw material layer in its turn will depend on the intensity of the drying chamber oscillations, namely, on its vibratory acceleration a.

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

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

where n, m – are the empirical coefficients, which depend on the process parameters.

The given dependences enable to determine the intensity of the ozone concentration distribution in the depth of the layer under the action of the vibration impact, depending on vibratory acceleration of the drying chamber and rate of the drying agent motion.

Electric power, spent for the heating of the drying agent by means of electric elements (TEHs) N_1; power spent by the electric motor of the drive of the unbalance axle N_2; power, spent by the electric motor of the blower drive N_3 and electronic device for ozone synthesis N_4 are referred to the energy parameters of vibro ozonating complex.

Electric power, spent for heating of the drying agent, by means of electric elements (TENs) N_1 (kW) is determined by the formula:

$$N_1 = k\cdot\left(\frac{Q}{t_p} + P_{вт}\right)\cdot 10^{-3}, \tag{9}$$

where k – is the coefficient for the assessment of the margin of power (it can be assumed $k = 1.2\ldots1.3$); Q – is the total value of heat, needed to provide heating process, J; t_p – is the duration of the heating process, sec; P_{hl} – is total power of heat losses, W.

Power, spent by the electric motor of the unbalance shaft drive N_2 (kW) is determined by the formula:

$$N_2 = \frac{M\cdot n}{9550}, \tag{10}$$

where M – is the torgue, H·m; n – is rotation frequence of electric motor shaft , rpm.

Power, spent by the electric motor of the blower drive N_3 (kW) is determined by the formular:

$$N_3 = \frac{9.81\cdot L_в\cdot H}{3600\cdot\eta_в\cdot\eta_n}, \tag{11}$$

where $L_в$ – is the efficiency of the blower, m^3/h; H – is full pressure, Pa; $\eta_в$ – is blower efficiency (could be taken $\eta_в = 0.4\ldots0.6$); η_n – is the transfer efficiency (could be taken $\eta_n = 0.85\ldots0.99$).

Power, spent by the electronic device for the ozone synthesis N_4 (kW) is determined by the formula:

$$N_4 = 4fC_d e_0\left(e_{\max} - \frac{C_a}{C}e_0\right)\cdot 10^{-3}, \tag{12}$$

where f – is current frequency, Hz; C_d – is dielectric capacitance, Ф; C_a – is capacitance of the discharge gap, Ф; C – is average capacitance of the installation, Ф; e_0 – is the discharge potential across the gap, Ф; $e_{\max}$ – is maximal voltage of the current, flouring across the electrodes, V.

Main criterion for the energy characteristics of vibro-ozoninzing complex is energy consumption of the vibro-ozonizing complex drive N, kW·hrs, energy consumption is characterized by the impact of four most important factors, determining kinetics of this treatment: vibratory acceleration a, m/sec^2 as a complex parameter of the dynamic state of the system; temperature of the drying agent T_{da}, ^{o}C; ozone concentration N_{OZ}, mg/m^3, treatment time t, sec:

$$N = f\,(a,\ T_{DA},\ N_{OZ},\ t). \tag{13}$$

Experimental equipment

To perform high quality drying of grain raw material experimental model of vibro ozonizing complex (Fig. 1), was designed and manufactured, in the given complex the material, being treated is undergone vibration impact, which enlarges and renovate the heat-exchange surface [9]. As a result of this process, intensive moisture removing occurs, drying rate increases. Drying process is uniform acrss the whole layer, without causing local overheating of the material. Technical characteristic of the experimental model of vibro-ozoning complex is presented in Table 1.

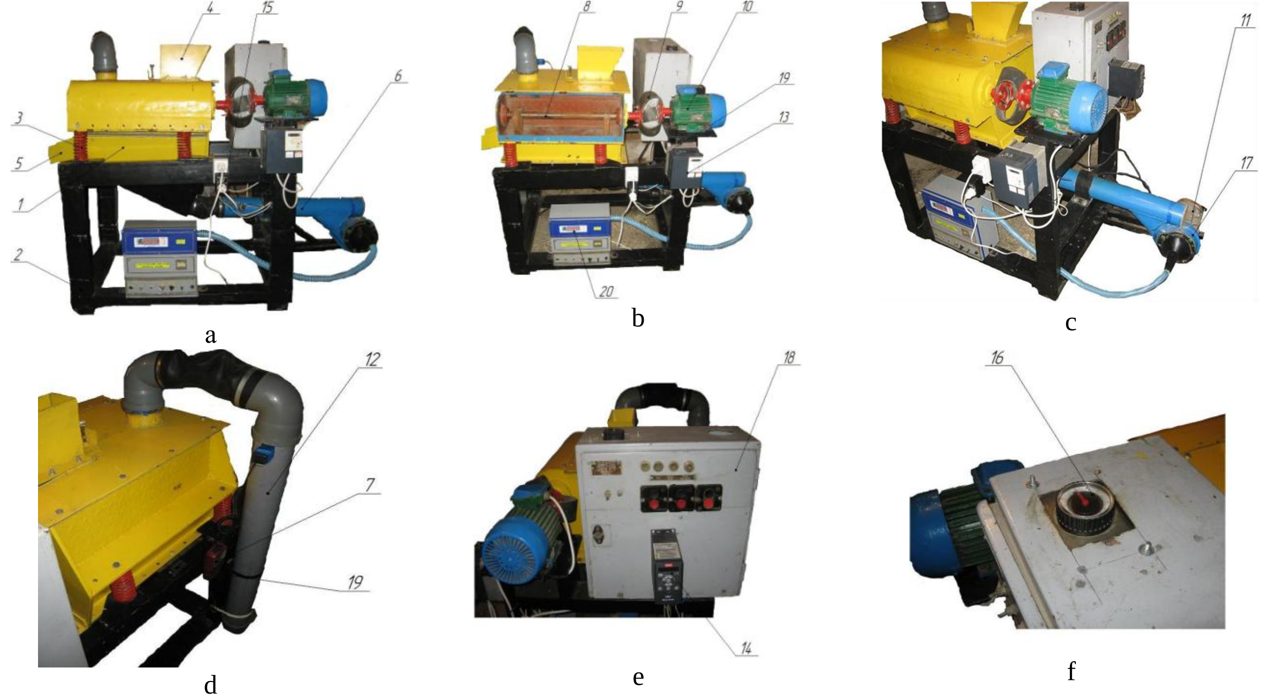


Fig. 1. Experimental model of vibro-ozoning complex:
a, b – front view; c, d, e – side view; f – top view; 1 – U-shaped chamber; 2 – frame; 3 – spring; 4, 5 – loading, unloading trays; 6, 12 – air inlet, air outlet, correspondingly; 7 – heat-loss anemometer; 8 – unbalanced shaft ; 9 – elastical coupling; 10 – electric motor of the unbalanced shft drive; 11 – electric motor of the blower; 13, 14 – frequency inverters; 15 – thermoregulator; 16 – time relay; 17 – blower; 18 – control unit; 19 – moisture meters; 20 – electronic device for ozone synthesis

Mixture of the heated air and ozone of certain concentration, generated by means of the corona discharge in the electronic device for the ozone synthesis (Fig. 2) , electric circuit diagram of power supply unit of which is built on the base of guasi-resonant transducer, is used as a drying agent.

Vibro-ozonising complex (Fig. 1) is leak proof U-shaped chamber, installed on the frame by means of the springs. Chamber contains loading and unloading trays as well as the air duct for the evacuation of the used drying agent.

At the side of the chamber the shaft with two unbalances is located, this shaft across the elastic coupling, by means of the three-phase electric motor is set into the rotation mode.

A the bottom of the chamber there is an air duct with electric heating elements , the heated air and ozone , generated by the ozonizer is supplied across the duct by the blower by means of the electric motor .

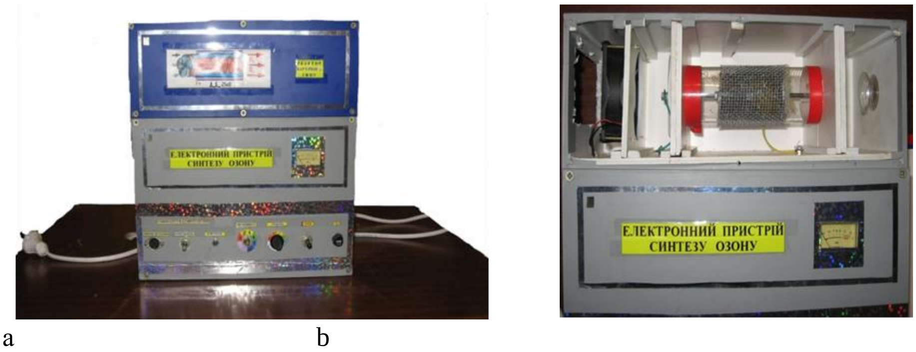


Fig. 2. Electronic device for ozone synthesis:
a – general view; b – operating c hamber for the ozone synthesis

Table 1

Technical characteristic of the experimental model of vibro-ozonising complex

Index	Value
Installed general electric power, kW – power of electric motor of unbalanced shaft drive, kW – power of electric motor of blower drive, kW – power of heating electric elements, kW – power of electronic device for ozone synthesis, kW	5 2.2 0.75 2 0.25
Rotation frequency of the electronic motor of unbalanced shaft drive, min^{-1}.	up to 1500
Rotation frequency of the electric motor of the blower drive, min^{-1}.	up to 3000
Temperature of the drying agent, °C	up to 75
Ozone concentration in ozone-air mixture, mg/m^3	up to 18
Speed of drying agent motion, m/sec	up to 5
Oscillation amplitude of the drying chamber, mm	0.5 – 7.5
Efficiency of vibro-ozonizing complex of dry grain raw material, kg/hrs.	up to 25
Weight of vibro-ozonizing complex, kg	265
Weigth of drying chamber, kg	95
Dimensions of vibro ozonizing complex, mm (length x width x height)	1700×970×1300
Volume of the drying chamber, m^3	0.06

Operation principle is that the drying agent, consisting of the heated air and ozone of certain concentration, is supplied by means of the blower, fixed on the frame, into U-shaped, sealed chamber, where grain raw material is located. Simultaneously electric drive of unbalanced shaft is switched on. Drying agent, passing across the layer of grain and removing certain percent of moisture, enters the outlet air duct and is evacuated from the drying chamber.

Results of the experimental studies

In the process of experimental studies of the developed complex the analysis of the impact of complex thermal-physical action on the indices of the treated raw material quality, which was pre-moisted and infected with the spores of smut and fusarium fungi, was performed.

The obtained grain raw material was assessed according to such indices as final moisture, germination, state of fecundation with fungi of smut and fusarium, depending on the temperature of the drying agent, ozone concentration in its composition and treatment time.

Final moisture of grain at technological loading of the drying chamber of 50 % and 75 % from the total volume was determined in the process of its treatment by the drying agent at the temperature of 45 ^{o}C, 55 ^{o}C and 65 ^{o}C, the agent contained ozone of N_{OZ} = 10 mg/m^3 concentration according to the recommendation of the study [10] (Fig. 3). Duration of the treatment was 9600 sec at the rate of the drying agent V_{DA} = 1.5 m/sec.

Equations, obtained on the base of the regression analysis of the experimental data of the grain raw material moisture change depending on vibratory acceleration of the drying chamber have the form:

– at the temperature of drying agent 45 ^{o}C and loading 75 % of the full volume of the chamber (Fig. 3, 1 a)

$$W = 17.905357 + 0.19775433 \cdot a - 0.042132576 \cdot a^2 + 0.001625757 \cdot a^3 - 1.8939394 \cdot 10^{-5} \cdot a^4; \quad (14)$$

– at the temperature of the drying agent 45 ^{o}C and loading 50 % of the full volume of the chamber (Fig. 3, 2 a)

$$W = 18.210714 + 0.1659127 \cdot a - 0.047886364 \cdot a^2 + 0.001920202 \cdot a^3 - 2.2727273 \cdot 10^{-5} \cdot a^4; \quad (15)$$

– at the temperature of the drying agent 55 ^{o}C and loading 75 % of the full volume of the chamber (Fig. 3, 1 b)

$$W = 17.994643 + 0.22007395 \cdot a - 0.050746212 \cdot a^2 + 0.001945959 \cdot a^3 - 2.2272727 \cdot 10^{-5} \cdot a^4; \quad (16)$$

– at the temperature of the drying agent 55 ^{o}C and loading 50 % of the full volume of the chamber (Fig. 3, 2 b)

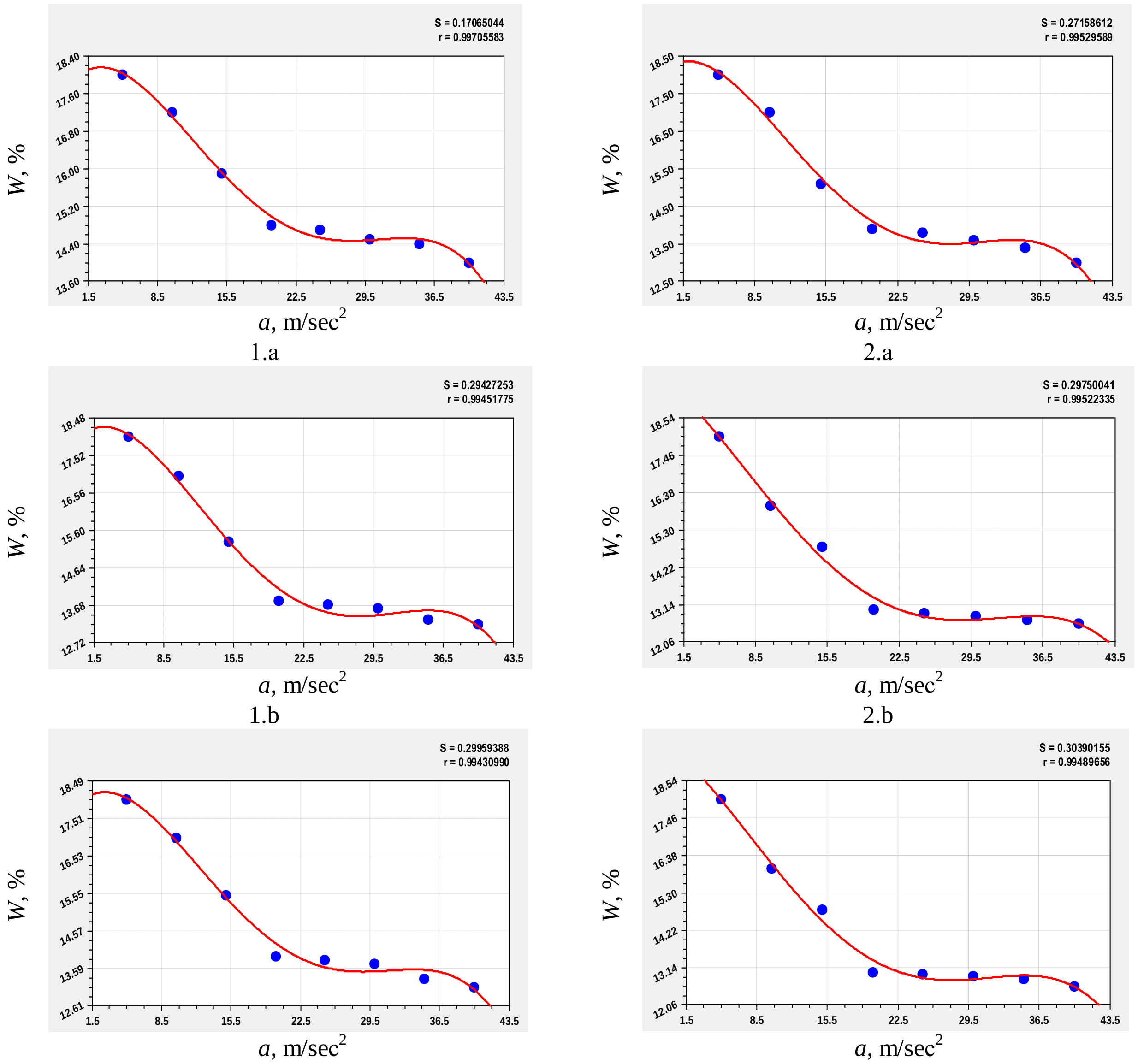
$$W = 19.560714 - 0.24747114 \cdot a - 0.018583333 \cdot a^2 + 0.0010313131 \cdot a^3 - 1.3030303 \cdot 10^{-5} \cdot a^4; \quad (17)$$

– at the temperature of the drying agent 65 ^{o}C and loading 75 % of the full volume of the chamber (Fig. 3, 1 c)

$$W = 17.898214 + 0.23610209 \cdot a - 0.050541667 \cdot a^2 + 0.001918686 \cdot a^3 - 2.1969697 \cdot 10^{-5} \cdot a^4; \quad (18)$$

– at the temperature of the drying agent 65 ^{o}C and loading 50 % of the full volume of the chamber (Fig. 3, 2 c)

$$W = 19.490179 - 0.22141324 \cdot a - 0.021585227 \cdot a^2 + 0.0011608586 \cdot a^3 - 1.4772727 \cdot 10^{-5} \cdot a^4. \quad (19)$$



1.a 2.a

1.b 2.b

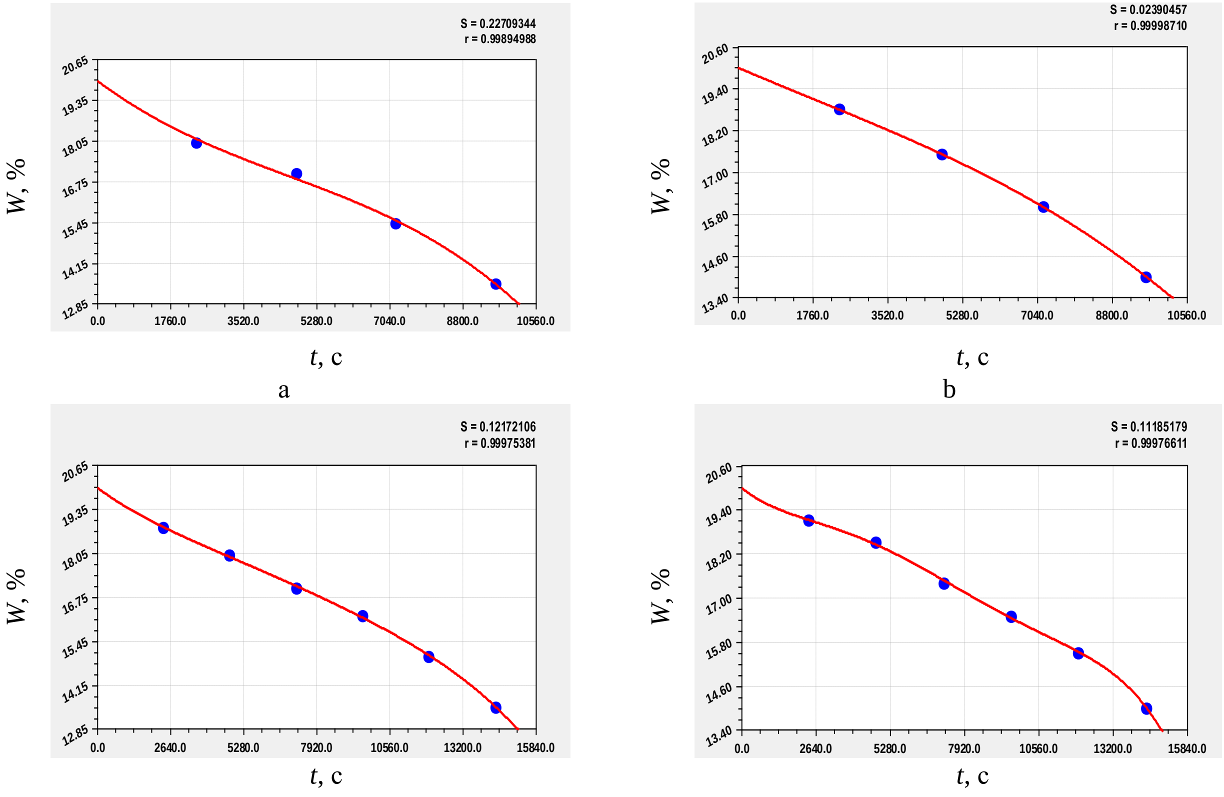
1.c 2.c

Fig. 3. Dependence of the grain raw material moisture change on the vibratory acceleration:
a – at the temperature of the drying agent 45 ^{o}C; b – at the temperature of the drying agent 55 ^{o}C;
c – at the temperature of the drying agent 65 ^{o}C;
1 – at technological loading of the drying chamber 75% of the full volume;
2 – at technological loading of the drying chamber 50% of the full volume

Based on the obtained data of the drying process kinetics of the grain raw material at the ozone concentration in the composition of the drying agent N_{OZ} =10 mg/m^3, it is obvious that the increase of its temperature up to 55 ^{o}C promotes the intensive exudation of moisture, the temperature above the indicated value does not give significant results and leads to the excessive power consumption.

Besides, the most intensive exudation of moisture from the grain raw material occurs at the vibratory acceleration a = 20…25 m/sec^2, after that it does not change greatly. It means that the increase of the vibratory acceleration of the drying chamber above the indicated value is not efficient, as it does not promote the substantial decrease of the moisture level and leads to the growth of energy consumption on the drive of the unbalanced shaft.

Comparing the curves of grain raw material drying on conditions of vibrational and vibroozonizing actions it becomes obvious that the duration of the treatment , using ozone as the component of the drying agent N_{O3} =10 mg/m^3 reduces the duration of the given process by 4800 sec, and reduces the energy consumption of this technological operation (Fig. 4).



a b

c d

Fig. 4. Kinetics of grain raw material drying:
a, b – using ozone as the component of the drying agent (technological loading of the drying chamber is 50 % and 75 % of the full volume, correspondingly); c, d – using vibration drying (technological loading of the drying chamber is 50 % and 75 % of the full volume, correspoindingly)

Equations, obtained on the base of the regression analysis of the experimental data of the kinetics of grain raw material drying are the following:

– using ozone as the component of the drying agent and 50 % loading of the full volume of the chamber (Fig. 4 a)

$$W = 19.972857 - 0.0009905754 \cdot t + 1.078869 \cdot 10^{-7} \cdot t^2 - 7.8366127 \cdot 10^{-12} \cdot t^3; \qquad (20)$$

– using ozone as the component of the drying agent and 75 % loading of the full volume of the chamber (Fig. 4 b)

$$W = 20.002857 - 0.0005218254 \cdot t + 1.2400794 \cdot 10^{-8} \cdot t^2 - 2.4112654 \cdot 10^{-12} \cdot t^3; \qquad (21)$$

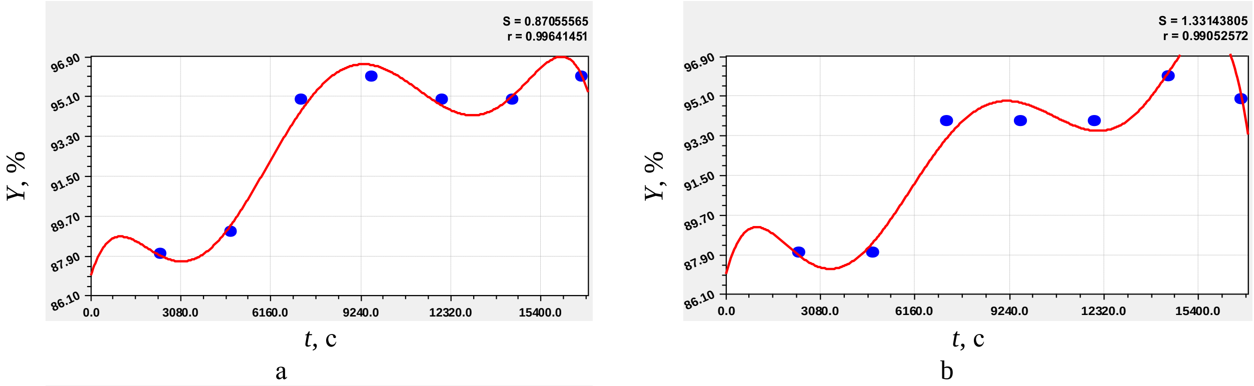
– using vibration drying and 50 % loading of the full volume of the chamber (Fig. 4 c)

$$W = 19.995996 - 0.00061398359 \cdot t + 7.1384417 \cdot 10^{-8} \cdot t^2 - 9.2203502 \cdot 10^{-12} \cdot t^3 + \\ + 5.7655731 \cdot 10^{-16} \cdot t^4 - 1.5698343 \cdot 10^{-20} \cdot t^5; \qquad (22)$$

– using vibration drying and 75 % loading of the full volume of the chamber (Fig. 4 d)

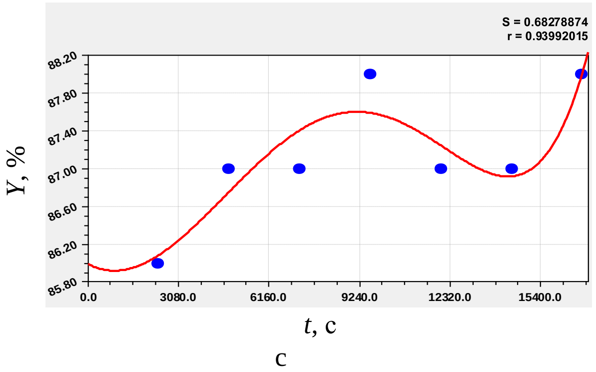
$$W = 19.99632 - 0.00061590909 \cdot t + 1.7545244 \cdot 10^{-7} \cdot t^2 - 3.5949776 \cdot 10^{-11} \cdot t^3 + \\ + 2.922746 \cdot 10^{-15} \cdot t^4 - 8.3724494 \cdot 10^{-20} \cdot t^5. \qquad (23)$$

Dependence of the wheet «Tsarivna» germination on the time of treatment and ozone concentration in the drying agent is determined (Fig. 5).



a

b



c

Fig. 5. Germination of the obtained grain raw material depending on the ozone concentration:
a – ozone concentration 10 mg/m^3;
b – ozone concentration 15 mg/m^3;
c – absence of ozone in the drying agent

Equations, obtained on the base of the regression analysis of the experimental data of the germination of the obtained grain raw material depending on the ozone concentration, are the following:

– ozone concentration 10 mg/m^3 (Fig. 5 a)

$$Y = 87.01486 + 0.0041830929 \cdot t - 3.2343306 \cdot 10^{-6} \cdot t^2 + 9.1419945 \cdot 10^{-10} \cdot t^3 - \\ - 1.0860033 \cdot 10^{-13} \cdot t^4 + 5.7540463 \cdot 10^{-18} \cdot t^5 - 1.1265014 \cdot 10^{-22} \cdot t^6; \qquad (24)$$

– ozone concentration 15 mg/m^3 (Fig. 5 b)

$$Y = 87.022727 + 0.005142361 \cdot t - 3.9975492 \cdot 10^{-6} \cdot t^2 + 1.1124702 \cdot 10^{-9} \cdot t^3 - \\ - 1.3333126 \cdot 10^{-13} \cdot t^4 + 7.2212376 \cdot 10^{-18} \cdot t^5 - 1.4535502 \cdot 10^{-22} \cdot t^6; \qquad (25)$$

– absence of ozone in the drying agent (Fig. 5 c)

$$Y = 85.988345 - 0.00016239316 \cdot t + 9.8136817 \cdot 10^{-8} \cdot t^2 - 5.1639863 \cdot 10^{-12} \cdot t^3 - \\ - 3.8642074 \cdot 10^{-16} \cdot t^4 + 2.4151296 \cdot 10^{-20} \cdot t^5 - 5.1553911 \cdot 10^{-34} \cdot t^6. \qquad (26)$$

Experimentally obtained dependences show that ozone has a positive impact on the germination of the treated raw material. Germination increases by 8 % as compared with drying without ozonizing. Rational concentration of ozone is 10 mg/m^3, as higher concentration does not influence greatly the germination of the treated winter wheet and is within the limit of 0.5 %.

Sanitation properties of ozone as the component of the drying agent acting on the germination of smut and fusarium fungi were investigated (Fig. 6, 7).

Exceedance ratio of the critical density of microorganisms to the unit of graim mass was determined by the expression [9]:

$$C_n = \Delta n / m_з \times 10^3,$$

where Δn – is exceedance of microorganisms density; $m_з$ – is a unit of the grain mass.

Equations, obtained on the base of regression analysis of the experimental data of the state of fungi contamination of the winter wheet by the spores of smut, are the following:

– duration of handling t =10800 sec (Fig. 6 a)

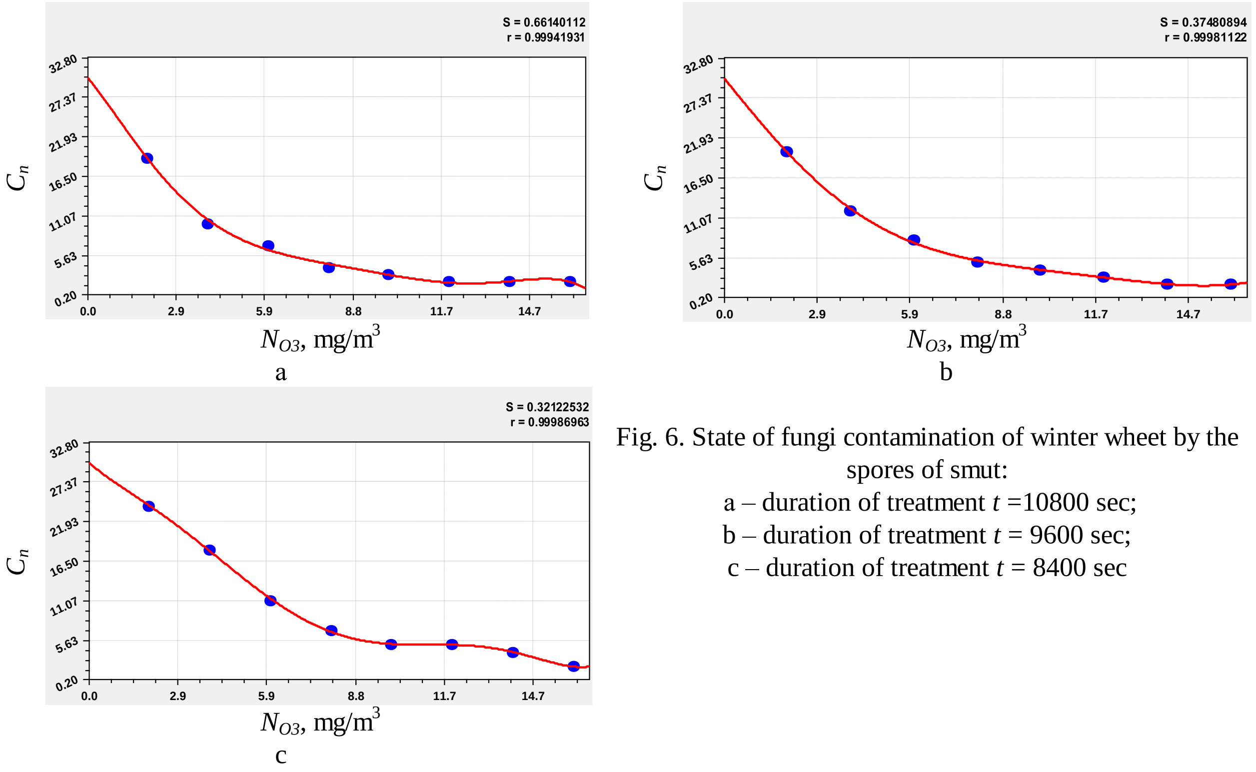
$$C_n = 30.027195 - 5.0753885 \cdot N_{OZ} - 0.83060088 \cdot N_{OZ}{}^2 + 0.36592487 \cdot N_{OZ}{}^3 - \\ - 0.045862268 \cdot N_{OZ}{}^4 + 0.0025006677 \cdot N_{OZ}{}^5 - 5.0636574 \cdot 10^{-5} \cdot N_{OZ}{}^6; \qquad (27)$$

– duration of treatment *t* = 9600 sec (Fig. 6 b)

$$C_n = 30.015229 - 5.3068726 \cdot N_{OZ} - 0.030542282 \cdot N_{OZ}^{\,2} + 0.096666181 \cdot N_{OZ}^{\,3} - 0.010260862 \cdot N_{OZ}^{\,4} + 0.00041800214 \cdot N_{OZ}^{\,5} - 5.787037 \cdot 10^{-5} \cdot N_{OZ}^{\,6}; \qquad (28)$$

– duration of treatment *t* = 8400 sec (Fig. 6 c)

$$C_n = 29.989433 - 3.6338034 \cdot N_{OZ} - 0.74179908 \cdot N_{OZ}^{\,2} - 0.27221979 \cdot N_{OZ}^{\,3} - 0.039440883 \cdot N_{OZ}^{\,4} - 0.0023410791 \cdot N_{OZ}^{\,5} + 4.9189815 \cdot 10^{-5} \cdot N_{OZ}^{\,6}. \qquad (29)$$

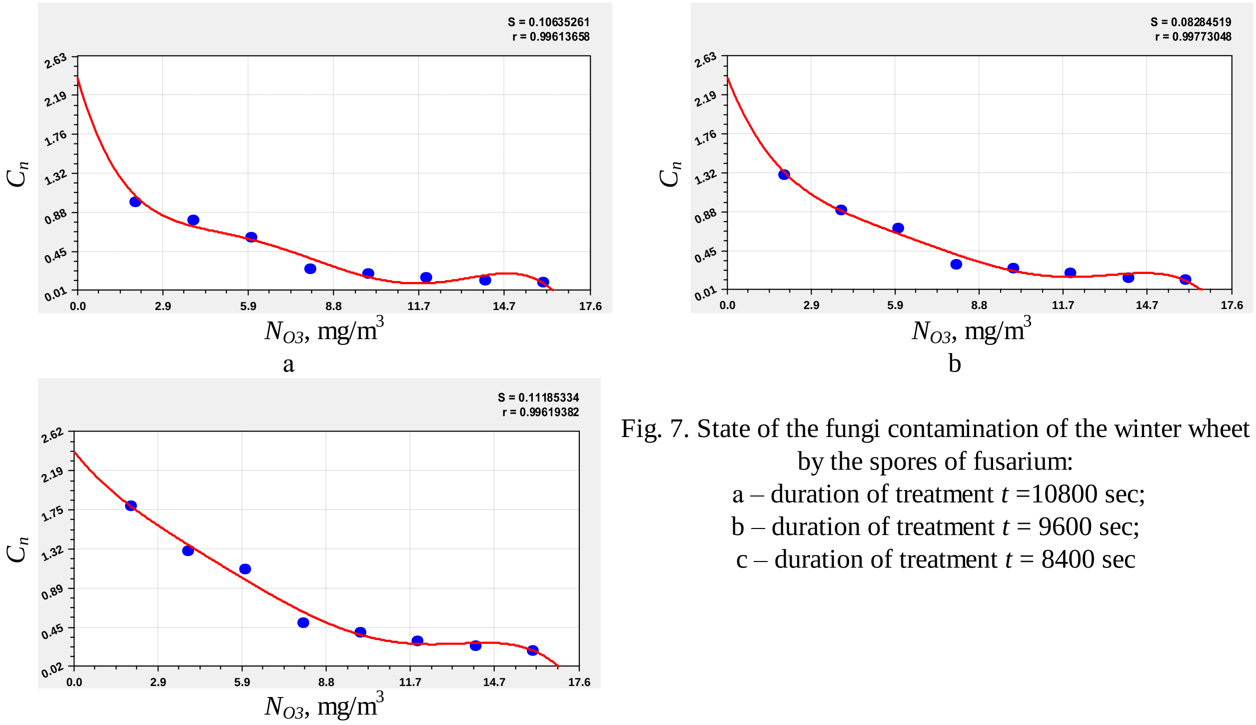


a

b

c

Fig. 6. State of fungi contamination of winter wheat by the spores of smut:
a – duration of treatment *t* =10800 sec;
b – duration of treatment *t* = 9600 sec;
c – duration of treatment *t* = 8400 sec



a

b

Fig. 7. State of the fungi contamination of the winter wheet by the spores of fusarium:
a – duration of treatment *t* =10800 sec;
b – duration of treatment *t* = 9600 sec;
c – duration of treatment *t* = 8400 sec

Equations, obtained on the base of the regression analysis of the experimental data regarding the state of fungi contamination of winter wheat with the spores of fusarium, are the following:

– duration of treatment t =10800 sec (Fig. 7 a)

$$C_n = 2.3844755 - 1.1223759 \cdot N_{OZ} + 0.30336466 \cdot N_{OZ}^{\,2} - 0.040846445 \cdot N_{OZ}^{\,3} + \\ + 0.0025234921 \cdot N_{OZ}^{\,4} - 5.7291667 \cdot 10^{-5} \cdot N_{OZ}^{\,5}; \qquad (30)$$

– duration of treatment t = 9600 sec (Fig. 7 b)

$$C_n = 2.3928671 - 0.81853263 \cdot N_{OZ} + 0.18388986 \cdot N_{OZ}^{\,2} - 0.023568619 \cdot N_{OZ}^{\,3} + \\ + 0.0014517774 \cdot N_{OZ}^{\,4} - 3.3253205 \cdot 10^{-5} \cdot N_{OZ}^{\,5}; \qquad (31)$$

– duration of treatment t = 8400 sec (Fig. 7 c)

$$C_n = 2.4002331 - 0.403412 \cdot N_{OZ} + 0.066619318 \cdot N_{OZ}^{\,2} - 0.010501348 \cdot N_{OZ}^{\,3} + \\ + 0.00078944493 \cdot N_{OZ}^{\,4} - 2.0532853 \cdot 10^{-5} \cdot N_{OZ}^{\,5}. \qquad (32)$$

Analyzing the obtained dependences, the conclusion can be made that ozone as the component of the drying agent decreases the state of the fecundation with the spores of smut and fusarium optimally if the concentration is $N_{OZ} = 8\ldots10$ mg/m^3 and treatment duration is t = 9600 sec, as the greater values of concentration and treatment time do not cause the substantial changes.

The following energy parameters of the developed vibro ozonizing complex were studies: electric power, used for heating of the drying agent by means of electric elements N_1; power, used by the electric motor of the unbalanced shaft drive N_2; power, used by the electric motor of the blower N_3 drive and electric device for the ozone synthesis N_4.

Fig. 8 shows the change of the power consumption of the electric heating elements, depending on the temperature of the drying agent at the rate of drying agent motion 1.5 m/sec.

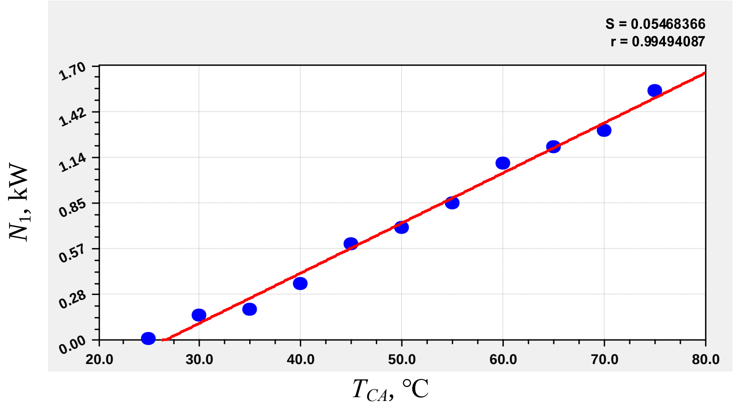


Fig. 8. Change of the consumed power of electric heating elements, depending on the temperature of the drying agent

Equation, obtained on the base of regression analysis of the experimental data of the consumed power change of electric heating elements depending on the drying agent temperature (Fig. 8), is the following:

$$N_1 = - 0.8209 + 0.0309 \cdot T_{DA}. \qquad (33)$$

It is seen from the above-mentioned dependence, that with the increase of the drying agent T_{DA} temperature, the power consumption N_1 of the heating electric elements increases practically proportionally.

During the analysis of energy characteristics of the studied vibro-ozonizing complex the increase of the power consumption by the electric motor of the unbalanced shaft drive was revealed, depending on the total volume of the drying chamber loading, at the working angular valosity w = 90 rad/sec it is: N_2 = 480 W at 75 % of loading (Fig. 9 a); N_2 = 450 W at 50 % of loading (Fig. 9 b).

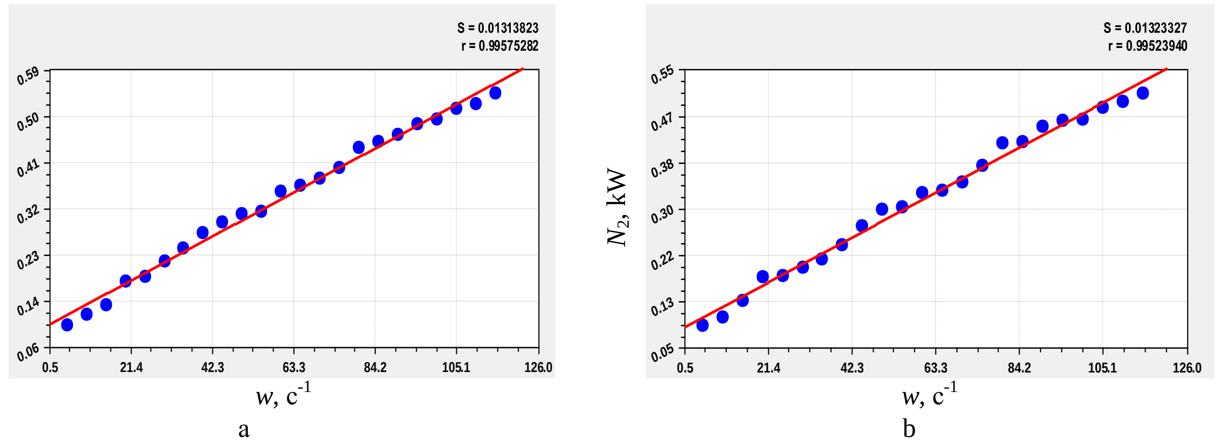
Equations, obtained on the base of the regressional analysis of the experimental data of the consumed power change of the electric motor of the unbalance shaft drive depending on the angular velocity and the degree of the technological loading of the drying chamber, are the following:

– loading is 75 % of the total volume of the chamber (Fig. 9 a)

$$N_2 = 0.0982 + 0.0040 \cdot w; \qquad (33)$$

– loading is 50 % of the total volume of the chamber (Fig. 9 b)

$$N_2 = 0.0838 + 0.0038 \cdot w. \quad (34)$$



a b

Fig. 9. Change of power consumption by the electric motor of the unbalanced shaft drive, depending on the angular velocity and degree of the technological loading of the drying chamber:
a – loading is 75 % of the total volume of the chamber;
b – loading is 50 % of the total volume of the chamber

While determining the energy characteristics of vibro-ozoning comlex the changes of the consumed power, depending on the rotation frequency of the electric motor of the blower drive were studied (Fig. 10).

From the experimentally obtained curve the conclusion can be made that with the increase of the rotation frequency of the electric motor its power consumption increases. Besides, at maximum rotation frequency of electric motor n = 3000 rpm power consumption is N_3 = 0.115 kW at the rate of the drying agent 3 m/sec and loading 50 % of the total volume of the drying chamber and at the rate of the drying agent 2.5 m/sec and loading 75 % of the total volume of the drying chamber.

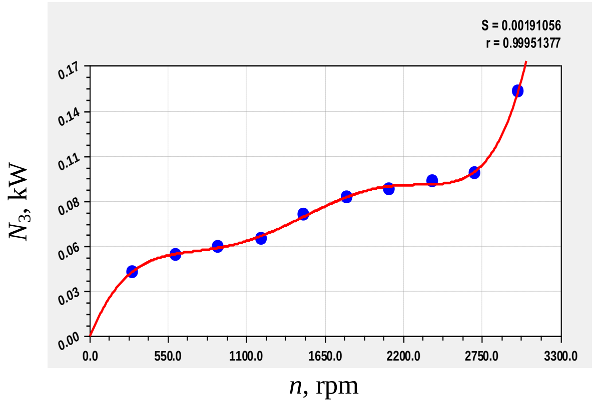


Fig. 10. Dependence of power consumption change of electric motor of the blower drive on the rotation frequency

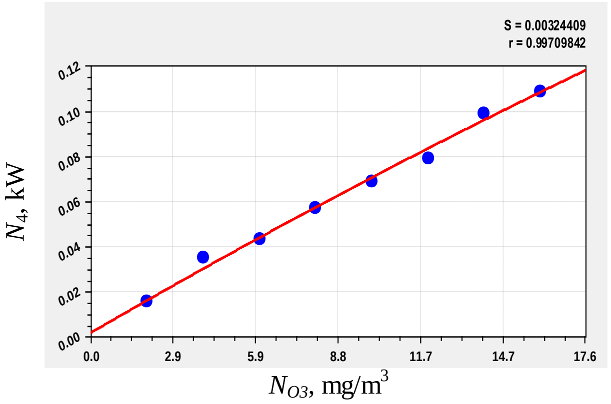


Fig. 11. Power consumption change of the electronic device for the ozone synthesis depending on the ozone concentration, generated by it

Equation, obtained on the base of regression analysis of the experimental data of the consumed power change of the electric motor of the blower drive on the rotation frequency (Fig. 10) is the following:

$$N_3 = 5.1419 \cdot 10^{-5} + 0.0002 \cdot n - 3.4807 \cdot 10^{-7} \cdot n^2 + 2.5394 \cdot 10^{-10} \cdot n^3 -$$

$$- 6.5128 \cdot 10^{-14} \cdot n^4 - 2.8901 \cdot 10^{-18} \cdot n^5 + 2.4095 \cdot 10^{-21} \cdot n^6. \quad (35)$$

Fig. 11 shows the change of the consumed power of the electronic device for the ozone synthesis N_4, depending on the ozone concentration N_{OZ}, generated by this device.

As it is seen from the experimentally obtained curve, with the increase of ozone concentration N_{OZ} consumed power N_4 increases, practically, proportionally.

Equation, obtained on the base of the regression analysis of the experimental data of the consumed power change by the electronic device for ozone synthesis, depending on the ozone concentration, generated by the device (Fig. 11), is the following:

$$N_4 = 0.0020 + 0.0072 \cdot N_{OZ} – 3.6255 \cdot N_{OZ}^2. \qquad (36)$$

On the base of the determined energy characteristics of the developed vibro-ozonizing complex, dependence of the general energy consumption N on the duration of the processing t without ozone in the drying agent (Fig. 12) and with ozone in the drying agent (Fig. 13) is obtained.

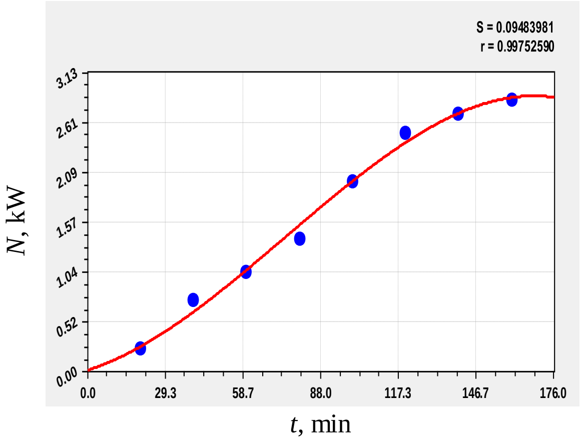


Fig. 12. Change of the total energy consumption by the developed unit without ozone in the composition of the drying agent

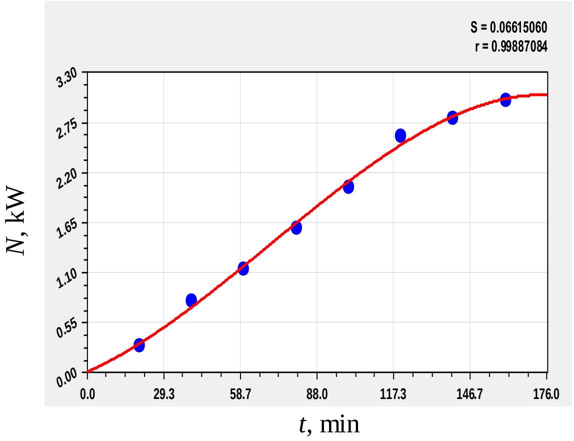


Fig. 13. Change of the total energy consumption by the developed unit with ozone in the composition of the drying agent

Equations, obtained on the base of the regression analysis of the experimental data of the total energy consumption change by the developed unit are the following:

– without ozone in the composition of the drying agent (Fig. 12)

$$N = 0.0080 + 0.0127 \cdot t + 0.0001 \cdot t^2 – 7.3653 \cdot 10^{-7} \cdot t^3; \qquad (37)$$

– with ozone in the composition of the drying agent (Fig. 13)

$$N = 0.0196 + 0.0086 \cdot t + 0.0002 \cdot t^2 – 8.9962 \cdot 10^{-7} \cdot t^3. \qquad (38)$$

Analysis of the Figs. 12 and 13 showed that the specific energy consumption per unit of the finished product with the moisture of 14 % at the initial moisture of 20 % is: using the conventional technology with the supply of the heating agent of the temperature 50 °C and treatment duration 240 min. – 112.93 W·hr/kg or 18.82 W·hr/kg per 1 % of the evaporated moisture (406.54 kJ/kg or 67.75 kJ/kg per 1 % of the evaporated moisture); using complex thermal physical impact and duration of the treatment 160 min. – 91.01 W·hr/kg or 15.16 W·hr/kg per 1 % of the evaporated moisture (327.63 kJ/kg or 54.6 kJ/kg per 1 % of the evaporated moisture).

After the processing of the experimental data in the statistical environment «STATISTICA 10.0» the coefficients of complex equations of the multiple regression of the 2nd order were obtained and the following dependences were constructed:

– final misture of the grain raw material on vibratory acceleration of the chamber, temperature of the drying agent, ozone concentration and handling time:

$$W_к = 33.23 + 0.22 \cdot a – 0.134 \cdot T_{DA} – 0.627 \cdot N_{OZ} – 0.074 \cdot t – 0.001 \cdot a^2 – 0.001 \cdot T_{DA}^2 – 0.015 \cdot N_{OZ}^2 – – 0.011 \cdot a \cdot N_{OZ} + 0.01 \cdot T_{DA} \cdot N_{OZ} + 0.002 \cdot N_{OZ} \cdot t; \qquad (39)$$

– power consumption for vibro-ozonizing complex drive on vibratory acceleration of the chamber, temperature of the drying agent, ozone concentration and handling time:

$$N = 11.828 – 0.005 \cdot a – 0.303 \cdot T_{DA} – 0.335 \cdot N_{OZ} – 0.011 \cdot t + 0.001 \cdot a^2 + 0.003 \cdot T_{DA}^2 + + 0.01 \cdot N_{OZ}^2 + 0.001 \cdot N_{OZ} \cdot t. \qquad (40)$$

On the base of the obtained experimental data Pareto charts of the effects were constracted for the assessment of the impact of the factors on the final moisture of the grain raw material (Fig. 14) and power consumption of the developed vibratory ozonizing complex (Fig. 15).

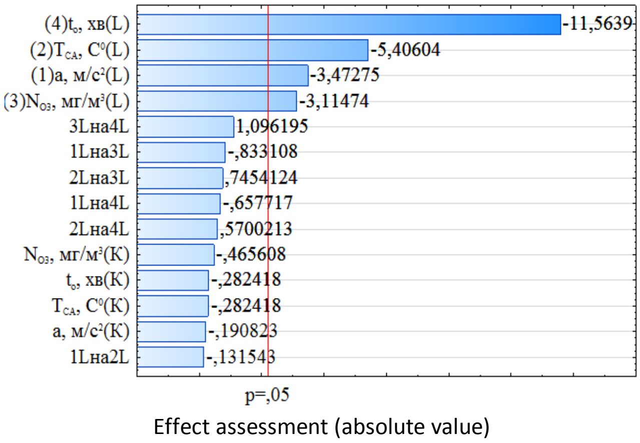


Fig. 14. Pareto chart of the effects for the assessment of the impact of the factors on final moisture of the grain raw material

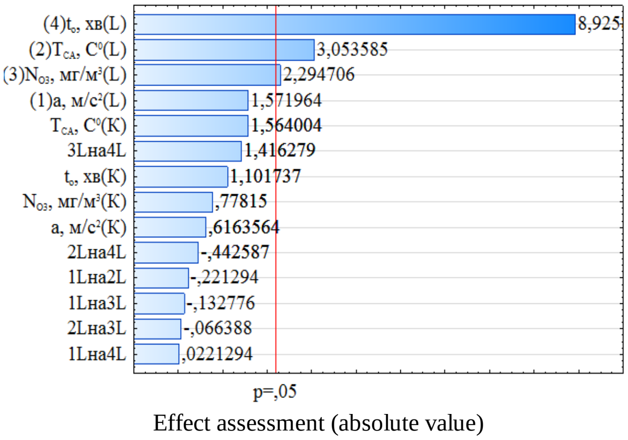


Fig.15. Pareto chart of the effects for the assessment of the impact of the factors on power consumption of the developed vibratory ozonizing complex

In accordance with the obtained charts, the time of treatment and temperature of the drying agent T_{DA} have the greatest impact on the final moisture of the grain raw material and power consumption of the vibro ozonizing complex the time of treatment t and temperature of the drying agent.

Thus, quality characteristics of the drying process obtain rational values at the final moisture of the grain raw material 13…14 % and energy consumption at the drive of vibro-ozonizing complex 3…3.2 kW.

Conclusions

1. Available technologies do not completely use the possibilities of vibration and ozone although they prove the expediency of their usage and combination not only in agrarian production but also in other branches in order to intensity processes and obtain quality products.
2. Mathematical model of ozone distribution in the depth of the grain layer under the impact of vibration has been developed.
3. Vibro-ozonizing complex for the realization of the technological process of grain raw material drying has been proposed and developed, in the given complex the treated production is undergone the vibration impact with simultaneous supply of the drying agent, which is the mixture of the heated air and ozone of certain concentration.
4. In the process of the experimental studies the comromizing technological parameters of the investigated process of grain raw material drying were obtained, these parameters are the following: vibratory acceleration a = 15…20 m/sec^2, temperature of the drying agent T_{DA} = 50…55 ^{o}C, ozone concentration N_{OZ} = 8…10 mg/m^3, time of treatment t = 7800…9600 sec at the rate of drying agent motion V_{DA} = 1.5 m/sec.
5. In the process of the realization of the experimental studies of vibro-ozonizing complex energy parameters it was established that:

– with the increase of the drying agent temperature T power consumption N_1 of heating electric elements increases practically proportionally;

– the increase of the power consumption by the electric motor of the unbalanced shaft drive depending on the total volume of the loaded drying chamber was revealed, at operating angular velocity ω = 90 rad/sec it is : N_2 = 480 W at 75 % of loading and N_2 = 450 W at 50 % of loading;

– the conclusion can be made that with the increase of rotating frequency of the electric motor power consumption increases. Besides, at maximum rotating frequency of the electric motor (n = 3000 rpm) power consumption is N_3 = 0.115 kW at the rate of the drying agent 3 m/sec and 50 % of loading of the total volume of the drying chamber and rate of drying agent 2.5 m/sec and loading 75 % of the total volume of the drying chamber;

– it was established that with the increase of ozone concentration N_{OZ} power consumption of the electronic device for ozone synthesis N_4 increases, practically, directly proportional.

6. On the base of the obtained data it was established that specific power consumption per unit of the end product with the moisture of 14 % at initial moisture of 20 % was:

– using the conventional technology with the supply of the drying agent of the temperature 50 ^{o}C and treatment duration 240 min – 112.93 W·hr/kg or 18.82 W·hr/kg per 1 % of the evaporated moisture (406.54 kJ/kg or 67.75 kJ/kg per 1 % of the evaporated moisture);

– using complex thermal physical impact and duration of treatment 160 min – 91.01 W·hr/kg or 15.16 W·hr/kg per 1 % of the evaporated moisture (327.63 kJ/kg or 54.6 kJ/kg per 1 % of the evaporated moisture).

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Editorial office received the paper 15.05.2023.
The paper was reviewed 27.05.2023.

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