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WHEAT GRAIN FLATTENING ON THE ROLLER DEVICE

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INTRODUCTION

These days, the share of baked goods and cereal products in the diet of various population groups in the country reaches up to 40 %. In world practice, of late, the production of flattened cereal flakes, convenient in the preparation of various meals, has become widespread.

This is achieved by the fact that because of additional hydrothermal treatment and especially in the process of flaking the product acquires increased consumer and nutritional value compared to traditional cereal products.

The process of flattening partially destroys the structure of the core of the grain, reducing its density and increasing the surface of the particles, which facilitates water access.

One of the reasons constraining the production of wheat flakes is the complexity of the technological process and the lack of equipment.

Production analysis of cereal products showed that the main and most energy-intensive stage in the technological process of grain processing into groats is flattening. The equipment used for this process is characterized by high-energy intensity and productivity.

Equipment and technology imperfection of cereal raw material processing leads to high-energy consumption, reducing the yield of the finished product, which has a high nutritional value and is in great demand.

Herewith, of great importance are the physical and mechanical properties of the processed grain, depending on which depends on the choice of technological equipment and milling modes.

For a reasonable technological process evaluation and calculation of milling equipment it is necessary to know the rheological properties of wheat grain. Until now such information on the development and modernization of existing technological equipment is insufficient.

From the foregoing it follows that the improvement of technological process of wheat grain milling, providing the maximum yield of the finished product with high quality indicators, is an urgent task.

1. The basis for the development of the topic

One of the main and energy-consuming processes in the production of flaked grain is flattening. This process is insufficiently covered in literature.

In this regard, the research on the study of technological process for milling of cereal crops is necessary.

Initial data for the development of the topic. Elastic-viscoplastic properties of grain raw materials are predetermined under various deformation conditions.

Justification for the necessity of the research work. The stress-strain state of grain during its flattening is studied incompletely. So their definition will allow to develop equipment scientifically groundedly and control the technological process of milling grains.

Information about planned scientific and technical level of development. As a result of theoretical and experimental research based on the created data bank on the rheological properties of wheat grains, a comparative analysis for other crops could be conducted, which will be used for practical calculations of technological equipment for milling.

About the patent research and conclusions from them. The conducted patent research over the past 20 years has shown that scientific research on the milling of grain raw materials was carried out mainly without taking into account their rheological properties.

The validity and reliability of the results obtained are confirmed by the consistency of the results of experimental studies carried out in laboratory, pilot plants using modern measurement means and methods, with similar findings of other authors.

The work was carried out in accordance with the State Program of the Republic of Kazakhstan 042 “Applied scientific research in the field of agro-industrial complex K” “Development of technology for processing of grain crops into products of high degree of readiness”, “Development and production of prototypes of machinery and equipment for harvesting, deep processing and storage of products”.

The purpose of the work. Developing a highly efficient method of wheat grain flattening process for small enterprises, which provides the intensification of optimal modes of technological process in conditions of uniaxial compression and the maximum yield of finished products with predetermined quality indices.

Scientific novelty. Scientific and engineering bases of the process of wheat grain milling, allowing to increase the efficiency as well as to improve the process of production of the finished product, have been developed.

Rheological model of wheat grain was offered and on its basis a mathematical description of the process of conditioning the grain material under compression was developed.

Selection of a rational way of intensive milling of wheat grain under uniaxial compression was theoretically and experimentally substantiated, enabling to control quantitative and qualitative indices of the finished product.

Reliability of scientific research is confirmed by the results of experimental tests of experimental-industrial sample under production conditions.

Research objectives. The quality and net cost of finished products, productivity and specific power consumption depend on the proper organization of the process of wheat grain flaking with the choice of parameters of technological equipment.

The analysis of technical literature showed that despite numerous studies of the process of treatment of various materials by mechanical pressure, the wheat grain flattening was not studied enough.

Creating highly effective technological equipment for grain milling should be based on taking into account the complex interaction of the influence of physical and

mechanical properties of the processed product, geometrical, kinematic and dynamic parameters of the equipment.

The following research tasks were defined to achieve this goal:

– to develop a rheological model of the wheat grain flattening process;

– to study the process of wheat grain flattening under uniaxial loading;

– to study physical and mechanical properties of wheat groats under the conditions of compression in a confined volume;

– to create a scientifically justified method of engineering calculation of the flattener;

– to develop a technological scheme for obtaining flattened wheat groats with predetermined quality indicators.

Practical significance of the work. On the basis of theoretical and experimental research simulation of the wheat grain flattening process was carried out and calculation dependence for determining the productivity of the flattening machine was proposed.

A database of experimental data on the process of wheat grain flattening taking into account physical and mechanical properties of the processed material was obtained.

An original unit was developed and created, allowing to research the process of wheat grain flattening.

A unified technological scheme for obtaining milled wheat groats has been developed.

2. Achievement results

The first section shows the choice of research direction by analyzing the current state of the production of wheat flakes, technological equipment for the implementation of plurification and various mechanical models of real materials.

The main technological processes of cereal flakes production are deep hydrothermal treatment of grain and mechanical impact on it.

Grain is flattened as a result of mechanical impact of the working bodies of technological equipment on it. The impact of external forces in the grain creates stress and strain state, depending on the physical and mechanical properties of the material.

Mechanical pressure processing of materials includes forming, pelletizing, briquetting, pelletizing, rolling, flattening, etc.

Models of large numbers of elastic and viscous elements are used to describe the viscoelastic properties of grains.

The use of various models allows us to describe the viscoelastic properties of wheat grain during conditioning. The coefficients included in these equations are determined from experimental data on grain deformation under constant stress (creep) or in the relaxation regime.

The mechanical effect achieved by plowing wheat grain dried to a certain moisture content changes the structural and mechanical properties of the product tissue, which contributes to its better assimilation by the body.

The second section gives a description and experimental facilities of the research object, as well as the methods of research.

An experimental installation of lever-type for testing the creep of bulk grain raw materials under volumetric compression has been designed and created.

The installation for the study of wheat grain under uniaxial compression was developed and made in metal. The signal obtained by measuring the force of compression with the help of amplifier TOPAZ-3-01 is fed to the high-speed self-recording device H327-1.

The third section presents the results of experimental and theoretical research on modeling of deformation properties of wheat grain.

The main task is to clarify the conditions of grain deformation, which will make it possible to scientifically justify the choice of technological equipment.

For mathematical description of the processes of solid bodies deformation, it is generally accepted to use the basic equations of the theory of elasticity in displacements or in stresses.

Knowledge of the nature of changes in the rheological parameters of the product makes it possible to conduct the technological process of conditioning under optimal conditions[1].

Real bodies have simultaneously elasticity, viscosity and plasticity in various forms and ratios. By combining, it is possible to input complex media corresponding to the behavior of those or other real materials. Models of large numbers of elastic and viscous elements are used to describe the viscoelastic properties of grains[2].

Consequently, a model that can be used to describe the behavior of wheat grain during flattening is a model consisting of a sequential combination of the two-element Maxwell and Kelvin-Voigt models (Figure 1,a).

The development of strain in time for real materials under constant stress is called creep, and the graphs of the dependence of strain on time are called creep curves.

The instantaneous application of τ stress at $t = 0$ results in an instantaneous elastic deformation $\gamma_1 = \tau/G$ (Figure 1, b segment *OA*). Further development of the deformation follows the curve *AB*. In this section, the delayed elastic deformation $\gamma_2 = \frac{\tau}{G_2}\left(1 - e^{-\frac{G_2}{\eta_2}t}\right)$ and the viscous flow deformation $\gamma_3 = \tau/\eta_1 \cdot t$ develop simultaneously.

After a certain time, a rectilinear dependence is established (Fig. 1, b section *BC*) corresponding to the established stationary process of irreversible viscous flow at a constant value of the elastic strain.

In the *BC* section, the strain increases with a constant velocity, which is characterized by the tangent of the angle of inclination of the line *BC* to the abscissa axis.

The rate of flow is proportional to the stress τ and inversely proportional to the viscosity η. At $t = t_H$, the stress is removed, and the instantaneous elastic strain γ_1 disappears (segment *СД=OA* and then the lagged elastic strain γ_2 decreases monotonically.

When t increases, the *DE* curve asymptotically approaches the final value of strain, which is equal to the residual viscous flow strain γ_3.

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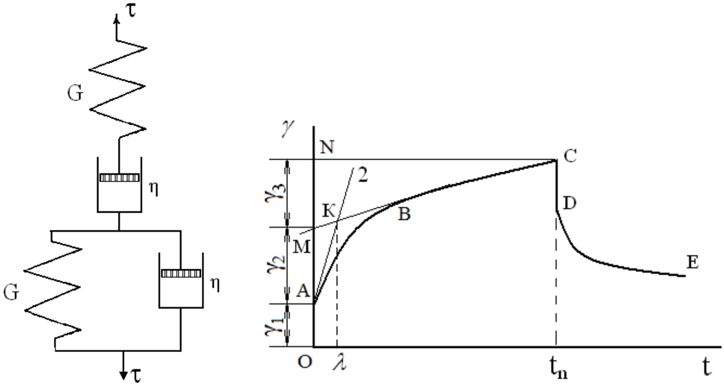
[1] Voicu G., Biris S., Stefan E., Constantin G.-A., Ungureanu N. (2013), Grinding characteristics of wheat in industrial mills. In: *Food Industry, IntechOpen*, pp. 323–354

[2] Yevgen Kharchenko, Andrii Sharan, Olena Yeremeeva. Effect of flattening wheat grain on grinding modes in roller mill. Ukrainian *Journal of Food Science*. 2021. Volume 9. Is. 2. pp.223–235.

In the period of constant stress τ at $0 \prec t \prec t_H$, therefore, the total strain is determined by the following expression, which includes four physical and mechanical characteristics

$$\gamma = \gamma_1 + \gamma_2 + \gamma_3 = \frac{\tau}{G_1} + \frac{\tau}{G_2}\left(1 - e^{-\frac{G_2}{\eta_2}t}\right) + \frac{\tau}{\eta_1}t, \qquad (1)$$

where G_1 – modulus of instantaneous elastic deformation, MPa; G_2 – modulus of delayed elastic deformation, MPa; η_1 – material viscosity, MPa-c; η_2 – viscosity of elastic aftereffects, MPa-c.



a) *b)*

Fig. 1. Mechanical model of wheat grain (a) and creep curve (b)

During the loading period $t = t_H$ the total deformation γ according to the figure 1, b corresponds to the segment *ON*, elastic deformation – to the segment *OA*, viscous deformation $\gamma_3 - MN$, where the point *M* is obtained by crossing the segment *BC* with the axis γ, deformation γ_2 to the segment *MA*.

Characteristics G_1 and η_1 were determined taking into account equality (1) by the following formulas

$$G_1 = \frac{\tau}{\gamma_1}; \;\; \eta_1 = \frac{\tau \cdot t_H}{\gamma_3} \qquad (2)$$

Keeping in mind that the lagged elastic deformation γ_2 is almost completely completed at point *B*, modulus G_2 can be determined by the formula

$$G_2 = \frac{\tau}{\gamma_2}. \qquad (3)$$

The elastic consequence viscosity η_2 is determined as follows. The ratio η_2 / G_2 has the physical meaning of the time during which the strain γ_2 reaches 63 % of the maximum value and is called the relaxation time λ.

The value λ is determined by the abscissa of the point of intersection of the tangent to the creep curve at point *A* with the line *MBC*.

$$\eta_2 = G_2 \cdot \lambda. \qquad (4)$$

Several creep curves at different stresses were obtained in order to improve the accuracy of determining the physical and mechanical characteristics.

As a result, firstly, the linearity of the dependences of instantaneous elastic strain, delayed elastic strain and viscous flow strain rate on shear stress was checked, and secondly, the material characteristics were determined graphically according to the results of several parallel tests.

The coefficients included in these equations were determined from experimental data on grain deformation under constant stress (creep).

For a reasonable choice of the rheological model, it was necessary to refer to the results of experimental studies on the study of the creep of wheat groats in a confined volume.

Figure 2 shows the creep of wheat groats under compression conditions in a closed volume. As can be seen, deformability of wheat groats with 12,1 % moisture content is the lowest. Therefore, obtaining data for further calculations will be made by this moisture content of the material.

The instantaneous elastic strain γ_1, equilibrium strain γ_1, and viscous flow strain γ_3 were determined from creep curves by the graphical method.

The moduli of instantaneous elastic deformation G_1, lagged elastic deformation G_2, volume viscosity $\eta 1$, relaxation time λ and volume viscosity of elastic consequence $\eta 2$ were calculated by formulae 2, 3 and 4.

The relaxation time constant ($\lambda \approx 10\,\text{s}$) was also determined from the creep curves, given the insignificant variation G_1, G_2.

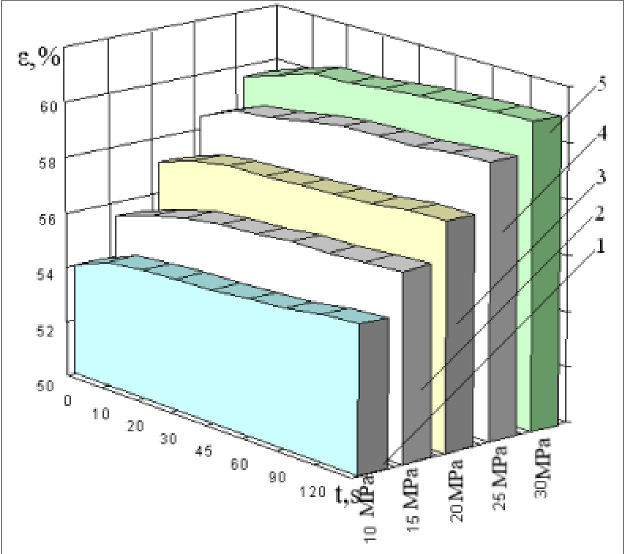


Fig. 2. Wheat groat creep curves:
1 – 12,1; 2 – 12,9; 3 – 13,2 and 4 – 14,0 %

Table 1 shows the calculated values of rheological characteristics of wheat grits with 12.1 % moisture content in the temperature range 320–360 K. As can be seen, the elastic moduli increase with increasing stress, that is, the resistance of the material to compression increases.

Table 1

Rheological characteristics of wheat groats
with a moisture content of 12.1 %

Temperature, К	**Rheological characteristics**	**Voltage, MPa**				
		10	**15**	**20**	**25**	**30**
1	2	3	4	5	6	7
320	G_1, MPa	0,192	0,283	0,371	0,456	0,539
	G_2, MPa	0,188	0,277	0,363	0,447	0,527
	η_1, MPa s	16,9	17,5	23,1	33,2	36,0
	η_2, MPa · s	20,2	29,7	39,0	47,9	56,6
330	G_1, MPa	0,185	0,270	0,358	0,443	0,522
	G_2, MPa	0,164	0,265	0,350	0,434	0,514
	η_1, MPa · s	17,5	18,1	25,4	36,0	36,4
	η_2, MPa · s	19,4	30,8	35,1	42,4	44,1

Table 1 (ending)

1	2	3	4	5	6	7
340	G_1, MPa	0,179	0,263	0,347	0,433	0,512
	G_2, MPa	0,174	0,258	0,343	0,425	0,507
	η_1, MPa · s	18,2	18,8	28,6	38,7	36,7
	η_2, MPa · s	18,8	27,6	36,4	45,5	53,8
350	G_1, MPa	0,175	0,261	0,346	0,428	0,511
	G_2, MPa	0,172	0,255	0,338	0,421	0,501
	η_1, MPa · s	17,0	20,83	37,5	50,0	50,01
	η_2, MPa · s	18,4	27,4	36,3	44,9	53,7
360	G_1, MPa	0,173	0,260	0,342	0,425	0,506
	G_2, MPa	0,170	0,253	0,338	0,417	0,498
	η_1, MPa ·s	16,7	21,43	33,33	43,10	42,86
	η_2, MPa · s	18,2	27,3	35,9	18,8	53,1

The same pattern occurs for the viscosity characteristics of wheat grain. This is explained by an increase in the density of the pressed product.

The results showed that with increasing temperature, the lagged elastic strain G_2 and the volumetric viscosity of the elastic aftereffect $\eta 2$ decrease (Table 1). For example, changing the temperature of wheat grit from 320 to 360 K led to a decrease in the values of G_1, $\eta 2$ (during the first 10 s) by a factor of 1.1.

This is explained by the fact that as the intramolecular and intermolecular interaction of the particles decreases under the influence of temperature, the values of the instantaneous elastic deformation γ_1 decrease, which leads to a decrease in the volumetric viscosity $\eta 1$.

Furthermore, the product is plasticized under the influence of temperature, and the starch contained in the product is pasteurized.

The change in the values of the above rheological parameters is also explained by a decrease in the free space and an increase in the forces of intermolecular interaction of particles, as the applied pressure of pressing leads to the formation of a compact body with simultaneous elastic and plastic deformation of the material.

Statistical evaluation of the stress effect on the rheological constants showed that in all cases R>0.9. Consequently, there is a close relationship between stress and rheological constants of the pressed material.

These rheological characteristics of wheat groats were further used in calculating the technological process of grain milling.

As an example, experimental and theoretical creep curves of wheat groats at 350 K at 10 MPa are shown (figure 3).

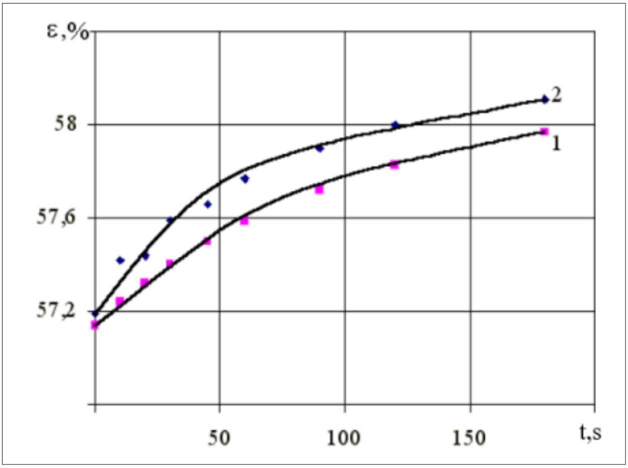


Fig. 3. Creep of wheat groats:
1 – theoretical; 2 – experimental

Experimental data comparison with calculated according to theoretical equation (1) of selected mechanical model showed that in time interval from 0 to 180 s divergence between them does not exceed 5 %.

To calculate the volumetric deformation during creep, taking into account the rheological parameters of wheat grits, a program was developed in the Python programming language.

In the fourth section the basic rheological and nutritional characteristics of wheat grain flakes are obtained on the basis of the experimental studies.

As shown above, the most important operation in the production of wheat grain flakes is flattening. In this process, the product in the wedge-shaped gap between the rotating rolls of the flattener undergoes compression deformation.

It is known that hydrothermal treatment changes the structural and mechanical properties of grain and affects the power indicators of technological equipment. For this reason, we tested homogeneous wheat grains of type 4 (row) under conditions of uniaxial compression under different modes of hydrothermal treatment.

Preparation of wheat grain was carried out as follows:

– wheat grain was moistened to 16 %, dehumidified for 16 h, dried, removing 2–3 % moisture;

– wheat grain was moistened and dehumidified as in the first method and steamed at steam pressure of 0.1 MPa for 3 minutes, dried, 2–3 % moisture was removed.

Figure 4 shows the dependence of the absolute deformation of wheat grain on the compression force. This dependence can be conditionally divided into three sections (I, II, and III) for a clearer presentation of the physical picture of flattening.

As can be seen from Figure 4, steamed wheat grain deforms at lower values of compression force (curve 2) than non-steamed grain (curve 1). For example, at a compression force of 4.72 kN, the difference in absolute deformation was 0.004 m.

This can be explained by the fact that steaming increases the plastic properties and decreases the elastic properties of the grain. Consequently, flattening of grain should be made after appropriate hydrothermal treatment of the material, which in turn increases the consumer and marketable qualities of the finished products.

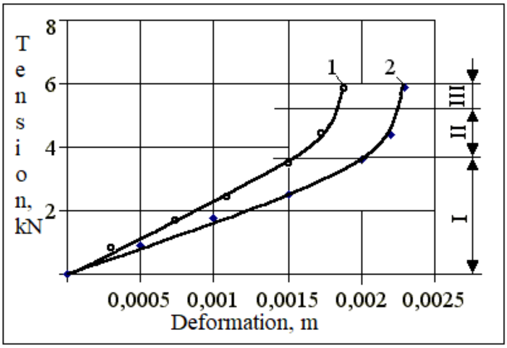


Fig. 4. Dependence of absolute deformation of wheat grain on compression force:
1 – moistened grain; 2 – steamed grain

The definitive stage of the technological cycle for the production of flattened wheat grain is the pressing operation, characterized by compaction of the initial material from the initial density to the final one.

Obviously, at the initial stage the deformation is proportional to the applied load. Hence, in this section elastic deformation predominates, obeying Hooke’s law, to which corresponds a rectilinear part with an inclination relative to the abscissa axis at a certain angle.

The second section is characterized by the predominance of residual deformations, the occurrence and development of which depends on the plastic properties of the grain.

The third section, the last one, is characterized by a significant increase in the compression force with relatively small values of the absolute deformation of the grain. At this stage, the final flattening of the grain and the formation of compact material takes place.

Press flattening, i.e. compacting under the action of external mechanical forces, is based on the formation of a dense product structure which is caused by cohesive ties between the particles during their compression.

Compaction of the material structure in the process of plumping is characterized by the dependence of density on pressing pressure[3].

As is well known, wheat grain has a complex geometric shape, which causes significant difficulties in determining its compression characteristics. It is therefore, in the first approximation, we chose coarse wheat grit № 1 with humidity of 12,1 % as an object of research.

Typical curves of wheatgrass density dependence on compression pressure, shown in Figure 6, have the form of exponents, and we can see that as the pressure of compression increases, the density of the material increases[4].

The physical picture of pressing is that with increasing pressure each particle is loaded more evenly and tends to take the most stable position, which is accompanied by contact crushing and shifting of particles relative to each other.

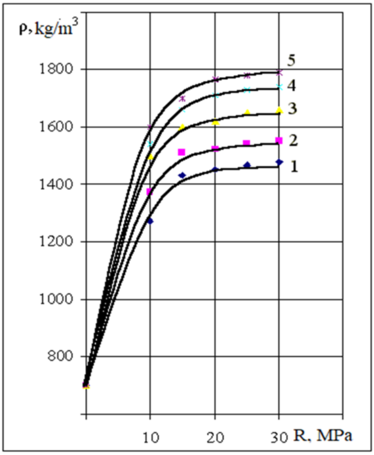


Fig. 5. Dependence of wheat groat density on pressing pressure:
Temperature K: 1-320; 2-330; 3-340; 4-350 и 5-360

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[3] Voicu G., Tudosie E., Ungureanu N., Constantin G.-A. (2013), Some mechanical characteristics of wheat seeds obtained by uniaxial compression tests. *U.P.B., Sci. Bull.*, Series D, 75 (4), pp. 265–278.

[4] Nurzhan Muslimov, Askhat Dalabaev, Abdymanap Ospanov, Abilkhan Sadibaev, Almaz Moldakarimov. Changes in the carbohydrate-amylase complex germination of cereal crops. *Journal of Hygienic Engineering and Design*, Vol. 40, pp. 114–118.

Processing of experimental data allowed to propose the dependence of wheatgrass density on pressing pressure to describe by the equation of the form.

$$\rho = ALnP + B, \tag{5}$$

where A and B are empirical coefficients depending on the product temperature.

The obtained values of correlation coefficients R indicate a strong degree of relationship between the studied parameters[5, 6].

Equation (6) is valid in the interval of practical pressures from 15 to 30 MPa.

To make engineering calculations for machines it is necessary to know load value, at which deformation of the product during its staying in the zone of action of working bodies of technological equipment reaches its limit value[7].

That is why creep tests of wheat groats were carried out at 320 K in a closed volume. It is seen from picture 6, above, that the character of creep curves is the same, which makes it possible to look for their common law[8].

Generally, the creep process can be divided into two stages: the first is unsteady with gradually decreasing strain rate, the second is steady with constant strain rate[9].

The first stage is of practical interest for ploughing of wheat grain, because during this time there is the greatest deformation.

After processing of experimental data, a generalized equation for the first stage of creep is proposed

$$\varepsilon = \varepsilon_0 \left[1 + 10^{-4} \left(56{,}1 - 0{,}69 \varepsilon_0 \right) \sqrt{t} \right] \tag{6}$$

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[5] Nurzhan Muslimov, Askhat Dalabaev, Aigul Timurbekova, Abilkhan Sadibaev, Almaz Moldakarimov, Yerman Spandiyarov. Changes in the protein-protease complex of germinated grains of leguminous crops. *Journal of Hygienic Engineering and Design*, Vol. 40, pp. 132–138.

[6] Dziki D., Cacak-Pietrzak G., Mis A., Jonczyk K., Gawlik-Dziki U. (2012), Influence of Wheat Kernel Physical Properties on the Pulverizing Process, *Journal Food Science and Technology*, 51 (10), pp. 2648–2655.

[7] Deineko V. A., Pryshchiepova Y. M. (2012), Mathematical modeling of power of roller crusher of grain, *Ukrainian Food Journal*, 1 (3), pp. 4049.

[8] Galindez-Najera S. P., Campbell G. M. (2014), Modeling First break Milling of Debranned Wheat Using the Bouble Normalized Kumaraswamy Breakage Function, *Cereal Chemistry*, 91 (6), pp. 533–541.

[9] Afanasj'ev V. A., Ostrykov A. N., Manujlov V. V. (2018), Yssledovanye processa plbshhenyja zerna jachmenja. In: *VII international scientific and practical conference*, Voronezh, RF, pp. 234–238.

The deviation between the experimental and calculated values does not exceed 5 %.

To evaluate the quality indicators of the finished product were selected two samples from each type of flattened grain, and each sample was subjected to a certain regime of hydrothermal treatment[10].

The quality of porridge was evaluated by the following indicators: color, taste, consistency of porridge, coefficient of digestibility, cooking time.

Taken for the analysis of 4 portions of 30 g, after determining the volume of groats before cooking in a measuring cylinder and double washing, placed in the crockery for cooking and poured water heated to 370 K.

For fullness of taste, 2.5 g of salt was added during tasting. Total boiling time was 15 min. Readiness of porridge was determined organoleptically.

The study of the effect of hydrothermal processing modes on culinary properties of steamed groats by a method of test cooking of porridge showed that as a result of steaming of moistened cereals coefficient of digestibility of groats increases, and cooking time is reduced in case of steamed wheat by 4 min, as well as the consistency of porridge is improved.

Steaming of moistened grains decreases the scrap and flours content in the mashed groats compared to the mashed groats made of unsteamed grains. This is due to dextrinization and pasting of starch granules, due to which the structure of the kernel is strengthened and the crumbliness of mashed groats is reduced.

The fifth section presents practical application of the theoretical and experimental research results.

We developed a method for engineering calculation of the flattener productivity taking into account the rheological properties of the processed material.

Grain flattening capacity was calculated by the formula

$$Q = \frac{m}{t}, \qquad (7)$$

where m – grain weight; t – time.

$$m = \rho V,$$

where ρ – grain density; V – the volume of grain flowing between the rolls for t time was determined by the formula

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[10] Fang C., Campbell G. M. (2003), On predicting roller milling performance IV: Effect of roll disposition on the particle size distribution from first break milling of whea, *Journal of Cereal Science*, 37, pp. 21–29.

$$V = Sv_{\text{в}}t, \qquad (8)$$

where $S = h_1 L$ – roller gap area; $v_{\text{г}}$ - horizontal velocity.

The theoretical capacity of the conditioner can be determined by the following expression

$$Q = \rho h_1 v_{\text{в}} L\psi, \qquad (9)$$

where L – roller length, m; ψ – volumetric fill factor of the flattening zone (ψ=0,7 – 0,8).

Taking into account the rheological equation of state of the wheat grain, we got the following expression to determine the productivity of the machine

$$Q = \rho h_1 \frac{\sqrt{R^2 - \left\{ R - \frac{h}{2}\left[\varepsilon_h - \frac{\varepsilon_h - \varepsilon_y}{\exp\left(\frac{G_2 t}{G_1 \lambda}\right)} \right] \right\}^2}}{t} L\psi \qquad (10)$$

In order to verify expression (10) under production conditions, we tested an experimental-industrial unit for wheat grain flattening on the basis of small-sized technological equipment of BShR (БШР) brand.

Discrepancy between theoretical and actual productivity was 20 to 30 %. Tests in production conditions showed high efficiency of the proposed device.

The technological scheme for obtaining flaked wheat grain, which can be successfully used in farms, small and medium-sized enterprises, has been developed.

CONCLUSIONS

1. On the basis of the theoretical and experimental studies scientifically – justified methods of technological equipment calculation for wheat grain flattening with regard to rheological properties of the material have been developed.

2. Rheological model of wheat grain, which consists of a sequential connection of two-element models of Maxwell and Kelvin-Voigt, has been proposed for estimating the elastic-viscous properties. The discrepancy between the experimental data and those calculated by the theoretical equation of the selected mechanical model did not exceed 5 %.

3. Numerical values of instantaneous elastic deformation, equilibrium deformation, viscous flow deformation, instantaneous elastic deformation module, lagging elastic deformation module, volume viscosity $\eta 1$, relaxation time λ and volume viscosity of elastic aftereffect $\eta 2$ of wheat grain were determined experimentally.

4. Equation of dependence of volume change of wheat grits on pressing pressure is proposed, numerical values of coefficient of initial volume of pressed material and conditionally-limit volume of pressed material are determined.

5. A generalized rheological equation of relative deformation of wheat groats compression in a confined volume, which is valid in the range of pressing pressures from 10 to 30 MPa, has been obtained.

6. It has been established that as a result of steaming coefficient of digestibility of the obtained mashed groats increases, and duration of their cooking decreases by 4 min, consistency of groats also improves.

7. The method of engineering calculation of the productivity of the fflattener in view of the rheological properties of the processed material has been developed.

8. The technological scheme of obtaining flakes from husked whole kernel of wheat grain, which significantly increases the yield of the finished product in relation to the original raw material by reducing the losses during the processing of grain into groats, has been developed.

Completeness assessment of the research of the set tasks. Based on the set objectives of the research, the rheological model of wheat grain was developed; the behavior of wheat grain under uniaxial loading was studied, physical and mechanical properties of wheat groats under compression conditions in a confined volume were studied, a scientifically justified method of engineering calculation of the conditioner was developed, the technological scheme for obtaining conditioned wheat groats with predetermined quality indices was developed.

Obtained scientific results are quite consistent with the set objectives and fully cover their solutions.

Recommendations and baseline data on the specific use of the results of the work. The results and conclusions, as well as the proposed methods of determining the rheological properties of wheat grain can be used by teachers, bachelors, masters, doctoral students of higher and secondary educational institutions, scientific and engineering – technical personnel in the development and creation of highly efficient equipment for conditioning wheat grain and other crops.

Evaluation of the technical and economic level of the work performed in comparison with the best achievements in this area.

Previously, when calculating technological equipment for wheat grain flattening the rheological properties of wheat grain were not taken into account, which made it difficult to develop highly effective bases of technological process of wheat flattening.

The proposed approach taking into account rheological properties of the processed material gave the most effective method of obtaining milled wheat grain grits with high quality indicators.

SUMMARY

In this monograph scientific justified methods of technological equipment calculation for wheat grain flattening taking into account rheological properties were developed.

The choice of a rational method of intensive flattening of wheat grain under uniaxial compression was theoretically and experimentally substantiated, allowing to increase the quality of the finished product.

Rheological wheat grain model has been developed.

A generalized rheological equation for the relative deformation of wheat grain compression in a closed volume, which is valid in the range of pressing pressures from 10 to 30 MPa, has been derived.

Scientifically justified method of engineering calculation of flattener productivity with rheological properties of processed material taken into account has been developed.

Technological scheme for obtaining milled wheat groats with predetermined quality indicators has been developed.

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