



UDC [664.69:621.1:536.7]

DOI <https://doi.org/10.15673/gpmf.v25i3.3205>

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MECHANISMS AND DRIVING FORCES OF SAFE AND TECHNOLOGICAL PROCESSING OF GRAIN PRODUCTS USING VARIOUS ENERGY SOURCES

Abstract

The article discusses modern technological approaches to ensuring grain quality preservation and increasing yield in grain processing, particularly in wartime conditions. Particular attention is paid to energy-intensive post-harvest grain processing and the use of the latest methods of influencing raw materials, such as thermal irradiation, microwave and acoustic treatment. The article examines modern mechanisms and driving forces that determine the efficiency, safety and technological feasibility of grain processing using various energy sources. The theoretical principles underlying the transformation, distribution, mixing and dehydration of grain products are presented. The importance of complying with the basic principles of thermodynamics for the qualitative assessment and optimisation of technological processes is demonstrated. Particular attention is paid to post-harvest processing, which is a key link in preserving quality and increasing yield in conditions of high energy intensity of production processes. An analysis of the latest technological approaches to thermal and moisture-thermal processing of grain, such as microwave, infrared, and ultrasonic heating, as well as methods of drying, irradiation, grinding, and mixing, is presented. It is noted that the main processes of grain conversion, mixing and distribution are based on the fundamental principles of thermodynamics, in particular the equations of material and energy balance, kinetics and equilibrium. The influence of the dielectric and magnetic properties of grain products on the efficiency of electromagnetic heating is also described. Approaches to energy calculations for microwave processing are proposed, which take into account the peculiarities of the physical and chemical properties of grain. The advantages and limitations of high-frequency processing methods compared to traditional ones are noted, taking into account technical, environmental and economic aspects. A conclusion is made about the need to adapt equipment to the conditions of grain procurement enterprises and the advisability of further research to ensure the efficiency and safety of technological processes. The advantages of microwave treatment as an inertia-free, controllable and energy-efficient technology capable of destroying pests, increasing seed germination and preserving the biological value of the product are highlighted. At the same time, the difficulties regarding energy consumption, high equipment costs and the need to comply with environmental standards are emphasised. The work is based on the results of research by scientists at Odessa National Technological University and has practical significance for the agro-industrial complex.

Key words: grain processing, post-harvest grain processing, quality preservation, drying, microwave treatment, thermal processes, electromagnetic radiation, dielectric heating, thermodynamics, heat and mass transfer, energy consumption, technological processes, bacterial treatment, vibrating channel, ultrasonic treatment, energy efficiency

Introduction

The main goal in any grain processing production is to increase yield and ensure quality preservation. These processes are very energy-intensive. At the same time, quality assurance is considered one of the main and final stages.

Previously, aviation technologies were used to increase yield, which had certain advantages over ground technologies, but now there are certain restrictions [1]. However, post-harvest grain processing is becoming increasingly relevant, especially in wartime conditions. Therefore, various types of energy supply are used to process grain (seeds) at any stage to achieve increased yield and bacterial treatment, but evidence of their effectiveness is not always provided. Scientists at ONTU have laid out the theoretical foundations and proven the practicality of using the latest grain processing methods, namely heating with rays, drying, and other methods of moisture-heat treatment.

The objects of grain storage and processing technology should be considered to be grain, the grain environment, and the processes of transformation, distribution, and mixing that occur during its storage and processing.

The subject may be our understanding (theoretical patterns) of the main processes of transformation, distribution, and mixing during storage and processing, i.e., the theoretical foundations of these processes.

To preserve the quality of grain (seeds) and prepare it for long-term storage, excess moisture must be removed. The drying process is the most common method, but it is characterised by a high degree of technological complexity due to the simultaneous occurrence of interrelated thermophysical, physicochemical and biochemical processes. At the same time, the possibilities for increasing the drying temperature are limited by factors such as loss of germination, changes in individual components of the grain, disruption of the biological structure, and changes in quality indicators.



The transformation of grain properties is carried out by processes of various natures: chemical and biochemical.

Grinding can be viewed, on the one hand, as a process of transformation and, on the other hand, as a process of distribution depending on its purpose.

Distribution (sorting, separation) is carried out by precipitation, filtration in a gravitational field and in fields of centrifugal, electric and other forces. Sorting into fractions is carried out according to differences in size, shape, electromagnetic properties, density, etc. When distributing substances, combined methods are mostly used, which carry out distribution according to a set of characteristics, ensuring the removal of most of the distribution components.

Regardless of the purpose of the main processes, any processing and reprocessing of products is based on three principles of thermodynamics and can be generalised at a qualitative level. The basic provisions of thermodynamics are specifically defined by equations of material and energy balance, kinetics and equilibrium, which are used for the quantitative assessment of technological processes. The theoretical basis, i.e. the basic provisions, of these processes is the kinetics of chemical and biochemical transformations, heat and mass transfer, dissolution, compression, etc. That is, their implementation is based on the general principles of thermodynamics, according to which a qualitative assessment of specific processes can be made. This specific manifestation of the principles of thermodynamics is described by the equations of material and energy balance, kinetics and equilibrium, according to which a quantitative assessment is made, provided that the so-called transfer coefficients are determined.

For example: when processing grain into flour, it is moistened and ground into particles, i.e. components, with properties that allow the most valuable substance (endosperm) to be extracted; cereal crops are steamed and moistened in order to change the physical properties of the husks and kernels to increase their distribution characteristics; cereals are also steamed to improve their nutritional properties; primary feed products are heated, steamed, roasted and extruded to obtain better nutritional properties. Chemical (biochemical) transformations take place here.

Irradiation in a broad sense is considered one of the methods of influencing grain products, which includes thermal radiation treatment with infrared (IR) and ultraviolet (UV) fields, high-frequency (HF) and ultra-high-frequency (UHF) radiation, and sometimes with frequencies in the X-ray range at different oscillation frequencies, as one of the possible means of energy transfer (heating) and is carried out in the volume of the raw material mass. In accordance with international agreements, frequencies of 915, 2450, 5800, 22500 MHz are used for industrial and scientific work. For example, in microwave treatment, the frequency is (2450 ± 50) MHz with a generator efficiency of 55...60% and a power of 2.5...100 kW, and in the low-frequency field, the frequency is 915 MHz, with an efficiency of 80...86% at a power of 25...30 kW.

The purpose of grain treatment with energy drive is deep heating as a prerequisite for further dehy-

dration, destruction of pests, increasing the biological value of products, increasing the germination energy and germination of seeds, etc. due to the propagation of electromagnetic waves and their absorption by the product (grain) [3]. Obviously, it is necessary to adapt generators in accordance with technical capabilities, technological indicators of processing quality in accordance with the operating conditions of grain procurement enterprises, as well as to ensure compliance with environmental requirements and the economic attractiveness of this method compared to traditional ones. The use of chemical potential for the practical determination of energy costs requires the determination of the characteristics of the working agent and the object of transformation in a given or defined range of property changes. Since the characteristics of the technological process are probabilistic in nature, probability theory, which is the mathematical basis of the general principles of thermodynamics, is used along with the above methods to determine the characteristics.

Results and discussion

The efficiency of the heat treatment process in a microwave field [3] is characterised by the field energy absorption coefficient, the speed of propagation of the electromagnetic wave, which depends on the properties of the medium in which it propagates.

The speed in a dielectric (\mathcal{V}) is less than in a vacuum (C) by a factor of $\sqrt{\epsilon}$ times, i.e. $\mathcal{V} = \frac{C}{\sqrt{\epsilon}}$. If the medium, in addition to the properties of a dielectric (ability to polarise electrically), also has the properties of a magnet (ability to polarise magnetically), then its magnetic permeability μ also affects the speed of propagation of the electromagnetic wave, as does the dielectric permeability, then $\mathcal{V} = \frac{C}{\sqrt{\epsilon\mu}}$. The energy entering the product layer is determined by the formula

$$Q = K_n \cdot E \cdot \delta \cdot \tau, \quad (1)$$

where K_n – is the absorption coefficient; E – is the energy component, which is determined experimentally.

The electromagnetic field is characterised by the wavelength (λ), which in turn depends on the field frequency (f), i.e. $\lambda = \frac{C}{f}$. It is known that electromagnetic waves with a wavelength of 0.1...0.01 m are used for dielectric heating, which corresponds to a frequency range of 300...3000 MHz. Thus, under certain conditions, the energy of an electromagnetic wave can be transformed into heat, resulting in volumetric heating of dielectrics, due to the ability of the electromagnetic field to penetrate them to a considerable depth.

When a material is exposed to an alternating electric field, there is a continuous shift of charges and associated molecules. Work is expended on the movement of charged particles, which is converted into heat due to the presence of 'intermolecular friction'. The higher the frequency of the electric field, the more heat is released in the dielectric per unit of time.

Solid particles of liquid and gas are mixed in order to obtain a uniform product composition (ice cream, margarine, compound feed, dough, etc.) using various machines or during transportation. The mixing process is



usually preceded by a dosing process. At the same time, transformation processes may also occur. The quality of the mixing process can be assessed by the increase in entropy.

In dielectric heating, the heat generated in the material per unit of time is calculated as [2]:

$$P_0 = 0,556 \varepsilon' \cdot \operatorname{tg} \delta \cdot f \cdot E^2 \cdot 10^{-12}, \text{ W/cm}^3, \quad (2)$$

where ε' – is the dielectric permeability of the material to be processed;

$\operatorname{tg} \delta$ – is the tangent of the dielectric loss angle;

f – is the frequency of the electric field oscillations, Hz;

E – is the field strength, V/cm

At the same time, the values of ε' and $\operatorname{tg} \delta$ depend on the properties of the material being processed and largely determine the choice of frequency and field intensity when calculating the dimensions of the processing equipment.

The process of heat treatment of products in an electric microwave field boils down to determining the heat consumption for heating the sample P_3 and evaporating a certain amount of moisture P_6 from it.

$$P_0 = P_3 + P_6. \quad (3)$$

The specific power for heating is determined as follows:

$$P_3 = \frac{\rho \cdot c}{\eta_i} \cdot \frac{\Delta t}{\Delta \tau}, \text{ Вт/см}^3, \quad (4)$$

where ρ – material density, kg/cm³;

c – specific heat capacity of the material, W/(kg•K);

η_i – is the thermal efficiency of the heating process, taking into account heat losses to the environment;

Δt – is the temperature increase over a period of time, s;

$\frac{\Delta t}{\Delta \tau}$ – is the heating rate (speed).

Specific power for evaporation

$$P_6 = \frac{r}{\eta_t} \cdot \frac{\Delta W}{\Delta \tau}, \text{ Вт/см}^3, \quad (5)$$

where r – latent heat of evaporation at a given temperature, cal/g;

ΔW – decrease in moisture per unit volume (g/cm³) over a period of time τ , s;

$\frac{\Delta W}{\Delta \tau}$ – evaporation rate (speed), g/(cm³•s).

The coefficient of field energy absorption by the sample, which determines the efficiency of the heat treatment process:

$$K = \frac{7,6 \cdot 10^{12} (\rho c \Delta t + r \Delta W)}{\eta_t \Delta r f \cdot E^2}. \quad (6)$$

If is denoted $\frac{\Delta t}{\Delta \tau}$ as U_H (heating rate) and

$\frac{\Delta W}{\Delta \tau}$ – as U_6 (evaporation rate), then

$$K = \frac{7,6 \cdot 10^{12} (\rho c U_H + r \Delta U_6)}{\eta_t \Delta r f \cdot E^2}. \quad (7)$$

The technological requirements for the heat treatment process determine the specific power that must be supplied to the product being treated over a certain period of time. The field frequency that will allow the required heating intensity to be obtained at the permissible electric field strength is determined as

$$f = \frac{7,6 \cdot 10^{12} (\rho c U_H + r \Delta U_6)}{\eta_t K \cdot E_{\text{прип}}^2}. \quad (8)$$

Since the thermal conductivity of products does not affect the heating rate, the heat treatment process does not take much time. At the same time, the high-frequency method itself is inertial-free and easily subject to automatic regulation. However, it is necessary to distinguish between the types of energy loss in the generators themselves: electrical efficiency ($\eta_e = P_T / P_{\text{мер}} \approx 0,4 \dots 0,8$) and the efficiency of the heated system – the ratio of the energy theoretically required for heat treatment of a material sample Q_T to the energy transferred to the generator during heat treatment Q_r .

$$\eta_H = Q_m / Q_r = 0,2 \dots 0,5 \quad (9)$$

where $Q_T = G \cdot c \cdot (t_2 - t_1)$ – is the theoretically required energy for heat treatment of the material sample;

G – is the mass of the sample (productivity);

c – is the specific heat capacity;

t_1, t_2 – are the temperatures of the sample before and after treatment.

Considering the significant cost of microwave equipment, economic efficiency should be approached with caution.

Acoustic (ultrasonic) treatment of grain and food products is used at a frequency of $0,002 \dots 10^{-9}$ Hz.

The lengths (L) of the shortest ultrasonic waves are close to the wavelengths of light [4]. The intensity of sound I is measured in W/cm² or decibels ($I = 1 \text{ W/cm}^2$, which corresponds to 160 dB).

$$L = 10 \lg \left(\frac{I}{10^{-16}} \right). \quad (10)$$

The most intense heating occurs at a frequency of $500 \dots 600$ Hz with a sound intensity $L > 160$ dB. The processing time is calculated taking into account the thickness.

Conclusions

The listed types of processing are volumetric and are not suitable for moisture removal, since internal heat sources can create significant excess pressure in the product, which can lead to destruction.

Most scientific and technical publications focus on the advantages: high energy efficiency, intensification of heat and mass transfer, and reduction of the duration of technological processes. At the same time, important aspects related to increased energy consumption at the industrial level, the high cost of specialised equipment, as well as issues of technical regulation and electromagnetic safety, are generally not sufficiently covered.



REFERENCES

1. Serhii Khablak. Experience in the use of agricultural aviation in intensive winter wheat cultivation technologies / Agribusiness Ukraine, 2023. <https://agrobusiness.com.ua/dosvid-zastosuvannia-silskohospodarskoi-aviatsii>
2. Honcharuk H. Improvement of the grain processing process in combined washing machines [Text]: abstract of thesis... Candidate of Technical Sciences: 05.18.12 / Goncharuk Anna Anatoliivna; Odessa National Academy of Food Technologies. - O., 2007. - 18 p. - Ukrainian. NBUV Rubricator: L821.032.2.
3. Dissertation O-66 Orlova Svitlana Serhiivna. Microwave treatment of seeds during movement in a vibrating channel [Text]: dissertation for the degree of Candidate of Technical Sciences: specialisation 05.18.12 'Processes and apparatus of food, microbiological and pharmaceutical production' / S.S. Orlova; scientific supervisor L.G. Kalinin; Odesa National Academy of Food Technologies. - Odesa: ONAFT, 2006. - 150 p. + Appendix. - Bibliography: p. 114-126. NBU classification: P144.9.
4. Lepikh, Ya.I. Applied Acoustics in Medicine: Textbook. – Odesa: Astroprint, 2005. – 208 p.

УДК [664.69:621.1:536.7]

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МЕХАНІЗМИ ТА РУШІЙНІ СИЛИ БЕЗПЕЧНОЇ ТА ТЕХНОЛОГІЧНОЇ ПЕРЕРОБКИ ЗЕРНОВИРОБНИЦТВА З ВИКОРИСТАННЯМ РІЗНИХ ДЖЕРЕЛ ЕНЕРГІЇ

Анотація

У статті розглядаються сучасні технологічні підходи до забезпечення збереження якості зерна та підвищення врожайності при переробці зерна, зокрема в умовах воєнного часу. Особлива увага приділяється енергоємній післязбиральній обробці зерна та використанню новітніх методів впливу на сировину, таких як термічне опромінення, мікрохвильова та акустична обробка. У статті розглядаються сучасні механізми та рушійні сили, що визначають ефективність, безпеку та технологічну доцільність переробки зерна з використанням різних джерел енергії. Представлено теоретичні принципи, що лежать в основі трансформації, розподілу, змішування та зневоднення зернопродуктів. Показано важливість дотримання основних принципів термодинаміки для якісної оцінки та оптимізації технологічних процесів. Особлива увага приділяється післязбиральній обробці, яка є ключовою ланкою у збереженні якості та підвищенні врожайності в умовах високої енергоємності виробничих процесів. Представлено аналіз новітніх технологічних підходів до термічної та вологотермічної обробки зерна, таких як мікрохвильовий, інфрачервоний та ультразвуковий нагрів, а також методів сушіння, опромінення, подрібнення та змішування. Зазначається, що основні процеси перетворення, змішування та розподілу зерна базуються на фундаментальних принципах термодинаміки, зокрема рівняннях матеріального та енергетичного балансу, кінетики та рівноваги. Також описано вплив діелектричних та магнітних властивостей зернопродуктів на ефективність електромагнітного нагрівання. Запропоновано підходи до енергетичних розрахунків для мікрохвильової обробки, які враховують особливості фізичних та хімічних властивостей зерна. Зазначено переваги та обмеження високочастотних методів обробки порівняно з традиційними, враховуючи технічні, екологічні та економічні аспекти. Зроблено висновок про необхідність адаптації обладнання до умов зернозаготівельних підприємств та доцільність подальших досліджень для забезпечення ефективності та безпеки технологічних процесів. Виділено переваги мікрохвильової обробки як безінерційної, керованої та енергоефективної технології, здатної знижувати шкідників, підвищувати схожість насіння та зберігати біологічну цінність продукту. Водночас наголошується на труднощах щодо енергоспоживання, високої вартості обладнання та необхідності дотримання екологічних норм. Робота базується на результатах досліджень вчених Одеського національного технологічного університету та має практичне значення для агропромислового комплексу.

Ключові слова: обробка зерна, післязбиральна обробка зерна, збереження якості, сушіння, мікрохвильова обробка, термічні процеси, електромагнітне випромінювання, діелектричний нагрівання, термодинаміка, тепломасообмін, енергоспоживання, технологічні процеси, бактеріальна обробка, вібраційний канал, ультразвукова обробка, енергоефективність

Received 11.07.2025

Reviewed 17.07.2025

Revised 07.08.2025

Approved 02.09.2025



Cite as Vancouver Citation Style

Honcharuk H., Orlova S., Shoful I. Mechanisms and driving forces of safe and technological processing of grain products using various energy sources. Grain Products and Mixed Fodder's, 2025; 25 (3,99): 47-50. DOI <https://doi.org/10.15673/gpmf.v25i3.3205>

Cite as State Standard of Ukraine 8302:2015

Mechanisms and driving forces of safe and technological processing of grain products using various energy sources. / Honcharuk H. et al. // Grain Products and Mixed Fodder's. 2025. Vol.25, Issue 3 (99). P.47-50. DOI <https://doi.org/10.15673/gpmf.v25i3.3205>

