Palamarchuk, Vladyslav; Gyrych, Sergi; Vasilishina, Olga et al.

Article

Intensification of the flow process of grain drying using two-sided infrared irradiation

Technology audit and production reserves

ISSN 2664-9969

UDC 664.8.036; 664.8.036.002.5
DOI: 10.15587/2706-5448.2021.225528
Article type «Original research»

Vladyslav Palamarchuk,
Sergii Gyrych,
Olga Vasilishina,
Olena Pahomska

INTENSIFICATION OF THE FLOW PROCESS OF GRAIN DRYING USING TWO-SIDED INFRARED IRRADIATION

The object of research is the process of infrared drying of grain of agricultural crops. In the process of processing seeds of cereals and oilseeds is a fairly large number of technological operations, among which one of the most important is drying. Maintaining the required grain moisture is a major factor influencing its shelf life and quality. Therefore, an urgent and important problem is the intensification of the process of drying seeds of cereals and oilseeds at low energy consumption.

The process of infrared drying of grain has significant advantages over the most common convective drying due to the fact that no organic fuel is used. Infrared rays are characterized by high thermal action of products, so the demand for the use of infrared radiation in agricultural, food and processing industries for drying grain, bulk ingredients, thermal disinfection, etc. is growing. The principle of operation of the infrared method is that the moisture inside the grain absorbs infrared rays, due to which it is heated. In other words, energy is directly supplied to moisture, which is why we managed to achieve not only high efficiency but also high efficiency.

To increase the efficiency of removing moisture from the grain by infrared irradiation, it is necessary to increase the area of contact of grains with infrared rays. Given the permeability of infrared rays and the layer of grain on the working body of the conveyor, it is possible to use several ways to increase the area of irradiation. The first method is to apply the vibration of the working body to mix the layers of grain, which contributes to a more uniform processing of products. The second method described in this paper is to use a larger number of emitters, which are located not only above the tray of the conveyor, but also below it. The tray must be made of infrared-permeable material.

Keywords: *infrared grain drying, vibration transportation, tray conveyor, vibration mixing, fluidized bed.*

Received date: 01.10.2020
Accepted date: 03.12.2020
Published date: 26.02.2021

1. Introduction

The problem of fast and high-quality drying of seeds is always relevant in agriculture, because it directly affects the reduction of seed losses during storage, its shelf life and the quality of the seeds themselves, which are sent for further processing. Use of infrared dryers gives the chance of fast and qualitative moisture removal from seeds of various cultures at the small sizes and metal capacity of designs of dryers.

The method of infrared (IR) irradiation is one of the promising physical methods of food processing. Due to its advantages over traditional methods of heat treatment, it is increasingly used in various sectors of the food industry and restaurant industry.

Thanks to infrared radiation, it is possible to transfer energy when there is no contact between the grain and the radiation source, as the air does not interfere with the passage of infrared rays.

The short-term intense effect of the infrared field on the surface layer of raw materials creates both problems of overheating and uneven layer-by-layer processing. Therefore, it is important when transporting products in the processing area to use vibrating conveyor and wave technologies that allow:

– to create favorable conditions for the intensification of the production process and the application of effective methods of action on its object;
– to implement technological movement in a continuous mode;
– to reduce and eliminate the use of unproductive labor in general, in particular in the implementation of ancillary operations;
– to create the general management of a dynamic condition of system in which there is a technological action;
– to minimize mechanical damage to the object.

2. The object of research and its technological audit

The object of research is the process of infrared drying of grain of agricultural crops. During infrared irradiation, the temperature rise is quite fast, but not to a great depth, i. e. only the seed coat is heated. This phenomenon is advantageous when processing sunflower seeds before further processing. After all, when irradiated with infrared rays is a rapid heating of the shell of sunflower seeds, with minimal risk of overheating of the grain kernels. Drying of the seed coat significantly affects the quality of its processing and the percentage of the husk after processing. This indicator is especially important in the production of sunflower seed kernels for confectionery purposes [1]. Dosed effect of infrared radiation on crop seeds provides a positive effect on its sowing qualities. Infrared rays are also used instead of air-heat or solar heating to reduce hardness in pre-sowing seed treatment. Infrared radiation activates the enzymes of the embryo, which increases the energy of seed germination and grain yield. Also, infrared drying at a temperature of 40–60 °C leads to the destruction of harmful microflora present on the grain surface [2, 3].

3. The aim and objectives of the research

The aim of the research is to intensify infrared drying while reducing energy consumption and metal consumption in grain processing of crops. To achieve this goal, the following tasks were set:

1. Identify the basic patterns and methods of intensification of infrared drying of agricultural raw materials.
2. Substantiate the methods of intensification of moisture removal from crop seeds by means of infrared radiation.
3. Substantiate the technological and constructive scheme of the vibrating tray infrared dryer for flow processing of raw materials.

4. Research of existing solutions to the problem

Trends in the development of technologies for drying crop products, in particular when using infrared rays, fundamental theoretical and experimental results, experience and basics of designing equipment for their implementation are laid in the possession of scientific schools and works of many famous scientists [4, 5]. Thus, in [6] the scientific and applied problem of increasing the energy efficiency of drying seeds of cereals, oilseeds, vegetables and industrial crops was solved and experimentally substantiated the latest technical solutions in the development of technological lines and equipment. In [7] the importance of using the process of infrared drying of thermolabile materials is described. Thanks to the drying method described in the work, the quality of the product, the drying speed and the energy costs for the process increase. In [8], a method of drying grain by infrared (IR) rays using a pulsed mode is described. As a result, energy consumption is reduced and drying efficiency is increased, seed, grain taste, smell and color are improved. Irradiation of grain with IR rays has a positive effect on its preservation, as the use of IR rays leads to disinfection of grain. In [9], barley grain was dried in thin layers both by combined IR convection and only by convection. For convection drying, the highest temperature reached by the grain at the end of radiation drying with different intensity was used. Experimental results show that the use of infrared radiation improves the drying speed and significantly reduces energy consumption. The speed of air movement has shown a strong influence on energy consumption. Similarity and bulk density were used as quality parameters. The authors of the study [10] considered the drying of grains, including major cereals, corn, rice and wheat, as well as oilseeds, soybeans and canola. The basic physical and thermodynamic properties of grain and air are investigated and the theory of drying process is developed. The design of optimal operating conditions of dryers for farms is presented. In [11] the authors considered different ways of removing moisture from raw materials. When drying at high temperatures, harmful effects on grain quality can be avoided if the grain is not heated above the critical temperature. The investigated drying process combines high-temperature drying with low-temperature cooling and leads to better quality grain than high-temperature drying to remove the same amount of moisture. The authors of [12] studied the drying of rice by infrared radiation and showed a promising potential with improved quality and energy efficiency. However, due to the limited permeability of infrared radiation, only thin-layer drying can be effectively used in the design of an infrared dryer. The purpose of this study was to investigate the moisture characteristics of a thin layer of rice heated by infrared radiation and cooled by various methods, including natural cooling, forced air cooling and vacuum cooling. In [13] the model of the control system for dryers with transverse flow is presented. Simulation tests on a virtual dryer showed that the controller worked well in a wide range of drying conditions. It has been tested on a commercial cross-flow corn dryer and has shown excellent accuracy and stability. In [14], experimental and theoretical studies were performed on a convection dryer with pneumatic material transportation. Numerical values for optimal drying parameters and energy characteristics for the heat transfer model are given. Achieving heat transfer in these systems is based on the principle of direct contact between raw materials and warm air. The authors of [15] studied the conversion between different types of moisture-binding single wheat grains during isothermal treatment by drying at 60 °C. Moisture migration was examined by magnetic resonance imaging (MRI). During drying, moisture migrates from the endosperm to the epidermis. As the drying speed of wheat grains from the surface to the middle is significantly reduced, the drying conditions and parameters need to be adjusted to improve the drying speed, while ensuring the quality of wheat grains.

Based on the literature analysis, the authors of this research propose to combine infrared drying with ultra-high frequency drying, as ultra-high frequency drying absorbs moisture in the grain. When drying at very high frequencies, moisture from the middle of the grain is sent to the edge of the surface of the shell, and infrared drying takes it from the shell. Thus, the authors propose to speed up the drying process.

5. Research methods

One of the disadvantages of infrared drying is that the moisture inside is stored for a long time, and heat absorption occurs due to the outer surface of the grain. The proposed design (Fig. 1) makes it possible to minimize this shortcoming due to the uniform irradiation of the grain surface on both sides simultaneously. The developed vibrating conveyor dryer with bilateral infrared irradiation of products is a combination of an IR dryer with a vibrating tray conveyor with a combined kinematic method of oscillation generation.

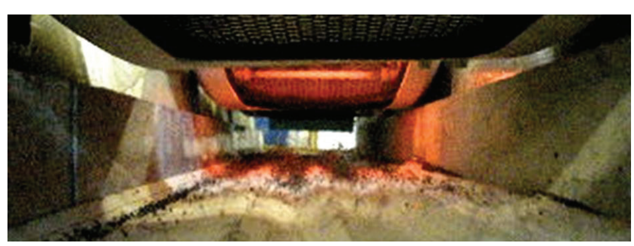

Fig. 1. Working chamber of the conveyor infrared dryer

Fig. 2 shows graphs of increasing the rate of moisture output from increasing the power of infrared radiation.

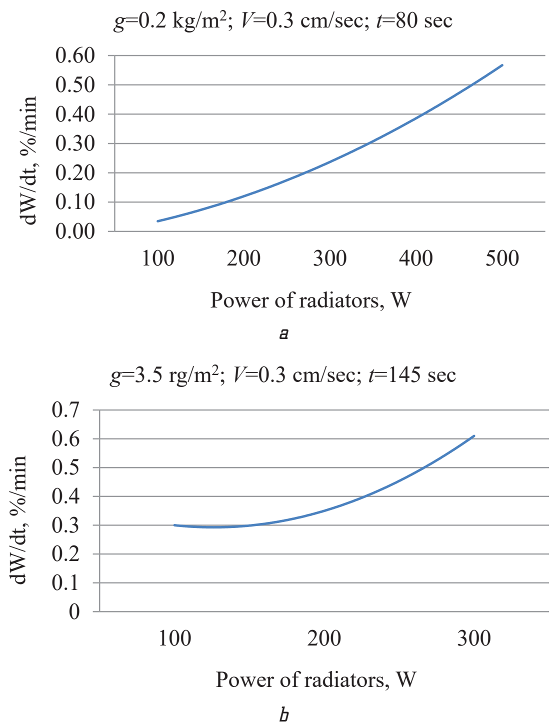

Fig. 2. Graphs of changes in the rate of moisture removal from increasing the power of the emitters during infrared drying of grain: *a* – rapeseed; *b* – soybeans

The experiments were performed on a belt conveyor with infrared emitters located above the belt with the products (Fig. 1).

When drying rapeseed with an emitter with a power of 500 W (Fig. 2, *a*) after 80 s, it is possible to achieve a moisture removal rate of 0.56 %/min [16].

The grain surface was heated to 40 °C. With prolonged drying at this power, the grain surface will overheat, which is undesirable to maintain the quality of the product. Therefore, the best option is to use several emitters of lower power for more uniform heating of the grain. The intensifying factor in this case will be to increase the area of processing of products by irradiation from different sides, as well as the connection of vibration to create a vibration-weighted layer of products [17].

6. Research results

The influence of vibration action on the mass of the product leads both to a significant renewal of the heat and mass transfer surfaces during the oscillation of the support tray, and to ensure uniform heat treatment of bulk products [18, 19]. It also prevents overheating of the surface layer, reducing internal friction and viscosity in the process environment. Irradiation of the product layer on two sides allows the simultaneous processing of grain over the entire surface, due to which there is an intensification of the process of heating the product and moisture removal. It also makes it possible to use a lower amplitude of oscillations of the working body of the dryer in comparison with designs where infrared emitters are located only above the layer of products (Fig. 1). In such designs, when vibrating mixing of the grain layer to achieve a significant increase in the processing area, it is necessary to use a large amplitude of oscillations of the working body, which leads to increased power consumption of the electric drive and significant scattering of small grain products. Reducing the amplitude of oscillations reduces energy consumption per drive and increases the durability of the support units of the machine, allows better control of the speed of movement of products in the working area [20].

To solve these problems, the design of a conveyor tray infrared dryer was developed (Fig. 3).

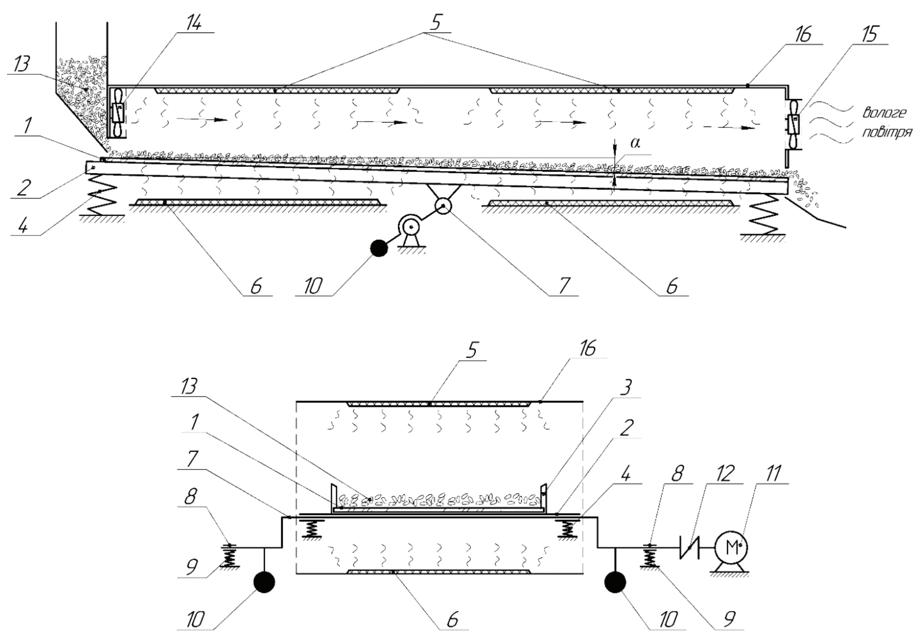

Fig. 3. Scheme of the conveyor tray infrared dryer: 1 – tray; 2 – spring-loaded platform; 3 – flanges; 4, 9 – elastic elements; 5, 6 – infrared emitters; 7 – eccentric shaft; 8 – support units of the vibrator; 10 – counterweights; 11 – electric motor; 12 – elastic coupling; 13 – grain products; 14, 15 – fans; 16 – working chamber of the dryer; α – angle of the vibrating tray

A feature of the proposed design of the vibrating infrared dryer is the use in the form of a working body of the tray 1 of transparent sheet glass mounted on a steel platform 2 with flanges 3, which rests on elastic elements 4. Above and below the tray are infrared emitters 5 and 6. Eccentric shaft 7 rests on the support unit 8 of the vibrating exciter, which through elastic elements 9 is connected to the frame of the installation, which rests on the vibrating support, which allows to eliminate parasitic oscillations that are transmitted to the frame of the installation. Counterweights 10 balance the inertial forces in the kinematic vibrator. The drive of the vibrator is carried out by the motor 11 through the elastic coupling 12. Products 13 are fed to the tray of the conveyor 1. Turn on the motor 11 and radiators 5 and 6. Torque from the motor 11 through the flexible coupling 12 is transmitted to the eccentric drive shaft 7, creating oscillations of the tray 1, until the occurrence of the fluidized state of the processing material 13 and its translational movement due to the inclination of the tray at a certain angle α. The kinematic vibrating exciter allows to reduce the oscillating mass of the drive and provides leveling of parasitic oscillations by means of elastic elements 9.

Due to the fact that in a short time there is an active supply of energy to each grain, the release of moisture from the seeds is intense, causing condensation inside the drying chamber 16. To solve this problem in the design of the dryer provides active air circulation with fans 14 and 15. Adjusting the speed of rotation of the fan blades allows to set the optimal air flow rate inside the drying chamber depending on the intensity of the IR irradiation of the product and the size and weight of the individual grains being processed. Blowing the fluidized bed of grain with a horizontal stream of air makes it possible to more effectively remove the evaporated moisture and prevent the formation of condensate inside the drying chamber.

7. SWOT-analysis of research results

Strengths. In comparison with analogues, the positive effect of the developed design of the dryer makes it possible to dry the seeds more intensively during its movement on the tray, as well as to effectively remove the removed moisture from the working chamber. The quality of dried seeds also increases due to a significant increase in the area of irradiation, which allows for more uniform processing of products.

Weaknesses. The weaknesses of the proposed method of drying include the difficulty of setting the operating modes of vibration transportation of products, as well as the power of infrared emitters, which directly depends on the type of product and the speed of its transportation.

Opportunities. The proposed technical solutions for the intensification of infrared drying provide opportunities for further technical improvement of industrial dryers and the development of new designs with increased productivity. Further research in this area will make it possible to determine the individual optimal operating modes of infrared radiation for seeds of different crops, which will maximize the efficiency of dryers, as well as improve their operating conditions.

Threats. The enterprise or operating organization will be required to make initial capital investments in the re-equipment of production and replacement of obsolete bulky drying units with new ones, as well as retraining of personnel for efficient operation of equipment.

8. Conclusions

1. The main ways to increase the efficiency of removing moisture from the grain by infrared irradiation are to increase the irradiation area of the grain, to ensure mixing of the grain layers during processing and effective removal of moisture from the working chamber.

2. Irradiation on both sides simultaneously to increase the area of heat and mass transfer and the ability to process a larger layer of products, which in turn makes it possible to enter the mode of moisture removal of 0.6 %/min for 60 s using two emitters with a capacity of 300 watts.

3. The use of the proposed design of the vibrating dryer will significantly intensify the process of removing free and physically bound moisture from the product due to:

– increasing the area of seed treatment;
– due to the created vibration-weighted layer of products, due to which there is a more uniform heat treatment and mixing of the layers with each other. This contributes to the intense thermal infrared action of high moisture yield from the grains into the air while ensuring a safe temperature on the grain surface – up to 60 °C;
– active blowing of the vibration-weighted layer of products accelerates the process of moisture removal and prevents condensation of moisture inside the working chamber;
– vibration action allows to mix products in the processing zone and at the same time to transport it at use of small power of the electric motor, namely to 500 W at maintenance of speed of moisture removal of 0.6 %/min.;
– such a scheme of the drive body together with the IR irradiation of the product can significantly increase the efficiency of the drying process.

References

1. Zhilinskii, Iu. M., Kumin, V. D. (1982). *Elektricheskoe osveschenie i obluchenie.* Moscow: Kolos, 272.
2. *Primenenie elektroenergii v selskom khoziaistve* (1974). Moscow: Kolos, 623.
3. Kozinskii, V. A. (1991). *Elektricheskoe osveschenie i obluchenie.* Moscow: Agroprom-izdat, 239.
4. Burdo, O. G. (2008). *Energeticheskii monitoring pischevykh proizvodstv.* Odessa: Poligraf, 244.
5. Snezhkin, Iu. F., Paziuk, V. M., Petrova, Zh. A., Mikhailik, T. A. (2010). Issledovaniia vliianiia parametrov sushki na kinetiku i vskhozhest semian rapsa. *Promyshlennaia teplotekhnika, 32 (3),* 37–42.
6. Paziuk, V. M. (2019). *Teplotekhnichni osnovy sushinnia nasinnievoho zerna.* Kyiv, 355.
7. Korinchuk, D. M., Demchuk, D. Yu. (2015). Fizychna model protsesu infrachervonoho sushinnia termolabilnykh materialiv. *Naukovi pratsi ONAKhT, 47 (2),* 98–100.
8. Bandura, V. M., Kiriienko, O. O. (2015). Rozvytok infrachervonoi tekhniky dlia obrobky zerna. *Tekhnika, enerhetyka, transport APK, 3 (92),* 53–57.
9. Afzal, T. M., Abe, T., Hikida, Y. (1999). Energy and quality aspects during combined FIR-convection drying of barley. *Journal of Food Engineering, 42 (4),* 177–182. doi: http://doi.org/10.1016/s0260-8774(99)00117-x
10. Brooker, D. B., Bakker-Arkema, F. W., Hall, C. W. (1992). *Drying and storage of grains and oilseeds.* New York: Van Nostrand Reinhold, 450.
11. Jayas, D. S., Ghosh, P. K. (2006). *Preserving quality during grain drying and techniques for measuring grain quality.* Department of Biosystems Engineering, E2-376 Engineering and Information Technology Complex. University of Manitoba, 969–980.
12. Khir, R., Pan, Z., Salim, A. (2006). Drying Rates of Thin Layer Rough Rice Drying Using Infrared Radiation. *ASABE Annual*

ISSN 2664-9969

International Meeting. Available at: https://www.researchgate.net/profile/Zhongli_Pan/publication/43262362_Drying_Rates_of_Thin_Layer_Rough_Rice_Drying_Using_Infrared_Radiation/links/54b55c1c0cf28ebe92e50bd6/Drying-Rates-of-Thin-Layer-Rough-Rice-Drying-Using-Infrared-Radiation.pdf

13. Liu, Q., Bakker-Arkema, F. W. (2001). A model-predictive controller for grain drying. *Journal of Food Engineering, 49 (4),* 321–326. doi: http://doi.org/10.1016/s0260-8774(00)00229-6
14. Prvulovic, S., Tolmac, D., Lambic, M. (2007). Convection Drying in the Food Industry. *Agricultural Engineering International: the CIGR Ejournal, IX (9).* Available at: https://ecommons.cornell.edu/bitstream/handle/1813/10679/Invited%20Overview%20Tolmac%20final%2030June2007.pdf?sequence=1
15. Hu, X., Wu, P., Zhang, S., Chen, S., Wang, L. (2018). Moisture conversion and migration in single-wheat kernel during isothermal drying process by LF-NMR. *Drying Technology, 37 (7),* 803–812. doi: http://doi.org/10.1080/07373937.2018.1459681
16. Bandura, V. M., Palamarchuk, V. I. (2012). Eksperymentalni doslidzhennia kinetyky sushinnia ripaku ta soi v nerukhomomu shari v infrachervonomu poli. *Naukovi pratsi Odeskoi natsionalnoi akademii kharchovykh tekhnolohii, 41 (2),* 110–113.
17. Bandura, V. M., Tsurkan, O. V., Palamarchuk, V. I. (2015). Eksperimentalnoe issledovanie tekhnologicheskikh parametrov protsessa infrakrasnoi sushki dvizhuschegosia shara syria maslichnykh kultur. *MOTROL. Commission of Motorization and Energetics in Agriculture, 17 (4),* 211–214.
18. Palamarchuk, I. P., Bandura, V. M., Palamarchuk, V. I. (2012). Obgruntuvannia konstruktyvnoi ta tekhnolohichnoi skhemy konveiernoi vibratsiinoi susharky. *Vibratsii v tekhnitsi ta tekhnolohiiakh, 2 (66),* 116–125.
19. Palamarchuk, I. P. (2015). Justification of constructive-technological scheme of infrared vibrowave conveyor dryer for post-harvest processing of granular agricultural products. *Proceedings of VNAU. A series of technical science, 1 (1 (89)),* 117–123.
20. Palamarchuk, I. P., Palamarchuk, V. I., Drachyshyn, V. I. (2013). Grounding parameters of flexible element in drive mechanism with combined kinematic vibroexcitation. *Eastern-European Journal of Enterprise Technologies, 6 (7 (66)),* 25–30. Available at: http://journals.uran.ua/eejet/article/view/18826

Vladyslav Palamarchuk, *PhD, Associate Professor, Department of Commodity Science, Expertise and Commercial Business, Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics, Vinnytsia, Ukraine, e-mail: kupc1989@gmail.com, ORCID: http://orcid.org/0000-0002-7478-9521*

Sergii Gyrych, *PhD, Associate Professor, Department of Commodity Science, Expertise and Commercial Business, Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics, Vinnytsia, Ukraine, e-mail: c1902@ukr.net, ORCID: http://orcid.org/0000-0002-0342-092X*

Olga Vasilishina, *Assistant, Department of Commodity Science, Expertise and Commercial Business, Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics, Vinnytsia, Ukraine, e-mail: olga_vasilishina@ukr.net, ORCID: http://orcid.org/0000-0003-0955-511X*

Olena Pahomska, *Assistant, Department of Commodity Science, Expertise and Commercial Business, Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics, Vinnytsia, Ukraine, e-mail: olana1980@ukr.net, ORCID: http://orcid.org/0000-0002-0915-8811*