Active substrate as a tool to improve the efficiency of green technology for seeds production

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Abstract. The most common and important method of agricultural products processing is drying. The quality of finished product, energy intensity and material intensity of the entire processing depend on the drying process. Drying the seeds of different crops is influenced by many factors: the structure, size, properties and condition. We studied the process of drying oil-bearing small-seeded crops taking rapeseeds as samples. Rapeseed is covered with a hard shell that prevents the release of moisture; in this case the seeds should be dried at low temperatures. High temperature causes rapeseeds to have low quality indicators. Analysis of the existing equipment has shown that nowadays there are no special systems for drying small-seeded crops, and the drying process is carried out on grain dryers which are characterized by large seed losses, considerable energy costs and high temperatures. The main advantages of the developed infrared dryer of conveyor cascade type are the lack of hot zones, the uniform heating and the minimum percentage of seeds losses because of their blowing out and removal. In addition, the heat carriers used in the dryer of conveyor cascade type help to perform the drying process at the required wavelength, that can affect only the moisture in the seeds.

1. Introduction
At present in the Russian Federation there is an acute problem of increasing the efficiency of agricultural production, which should be carried out under the condition of rational use of material and energy costs. Therefore, the issue of resource- and energy saving is of great interest now, since its solution helps to find the most effective ways to improve energy efficiency.

Post-harvest processing of seed stock is an integral part of agricultural production. Consequently, the preservation of seed material and the problem of reducing the energy intensity of the process related to drying small-seeded crops are considered to be urgent tasks. It is rather difficult to ensure effective drying of seeds that have hard shells and at the same time to minimize energy consumption [6, 15, 18, 20]. The process of drying small-seeded crops by infrared radiation (IR) depends on many parameters:
- heat treatment mode [5];
- state and properties of small-seeded crops [1, 9];
- design parameters of drying equipment [7, 16, 17].
The developed infrared dryer of conveyor cascade type [14] using the electric film heaters EFH [10] completely meets all the requirements for the technology related to the drying process of small-seeded oil-bearing crops.

2. Theoretical studies

The desire to minimize energy costs and to make profit and super-profit from production often leads to a negligent attitude to the quality of the finished product; therefore, it is recommendable not to forget about the post-harvest preparation of small-seeded crops for storage, sale or hydration.

Relatively easy destruction of organic matter is a characteristic of small-seeded crops; hence, the moisture removal by IR drying depends on the correct choice of the limiting temperature, which depends on the energy irradiation and the absorptive capacity of the irradiated material surface (with the growth of these values the temperature also increases; Tiller and Garber’s formula) [3].

\[ T_{max} = \frac{AE}{as} + T_0, \]  

where \( T_{max} \) is the limiting temperature; \( T_0 \) is the ambient temperature; \( A \) is the absorption capacity of the irradiated surface; \( E \) is the energy irradiation of the surface; \( a \) is the convection heat transfer coefficient; \( S \) is the surface area involved in heat exchange between the material and air.

It is also necessary to take into account the irradiation field uniformity depended on the density of the incident radiation flux which has a significant impact on the quality indicators of small-seeded crops [4, 13]. During the research it has been found that the flux density and the irradiation uniformity depend not only on the distance between the electric heater and rapeseeds, but also the substrate under the seeds significantly affects these indicators [12, 19].

The design parameters of a dryer are considered as the important factors related to high-quality drying of small-seeded crops. In addition to the length, width, height of the emitter suspension, the speed of the conveyor belt and other basic quantities [11], the following factors should also be included:

- the distance between the substrate and the crop being dried;
- the substrate and the material from which it is made;
- the material of a conveyor belt.

The effect of the distance between the substrate used in the design of the dryer and a small-seeded crop was studied earlier [15].

The description of the heat generation scheme shows that the temperature distribution in the product irradiated by infrared rays will depend on its thickness, reflectivity and absorption, as well as on the optical properties of the substrate on which it is placed (Fig. 1, a-d).

![Figure 1. Temperature distribution in the layer of irradiated rapeseeds (infrared radiation is directed from above).](image)

In a thin layer of irradiated side of the product, which weakly absorbs radiation, the temperature is slightly higher than on the opposite side, and besides it is lower in the cross section of the layer than at the boundaries (Figure 1, a). A completely different temperature distribution is observed on one side of highly absorbent rapeseeds irradiation. The outer irradiated side heats up quickly, whereas on the inner side the temperature does not rise (Figure 1, b). The substrate can significantly affect the temperature distribution in the layer of rapeseeds (Figure 1, c, d).
The optical properties of the substrate material can significantly affect the process of removing moisture, so using a blackened substrate gives better results than using a light substrate [9]. When analyzing the curves of mass loss we observed that higher final results were obtained using a blackened substrate, and the use of a light substrate was noticeably inferior in results. Thus, we use an electric film heater (EFH) as a substrate for the crops being dried, in which nichrome is applied as a resistive heating and radiating element [8]; that gives EFH blackness degree \( \varepsilon = 0.96 \) and brings it closer to the blackness degree of an absolutely black body.

The use of an electric film heater helps to achieve the effect of an active substrate, as it not only reflects infrared radiation, but also acts as a radiator while remaining within the temperature limits recommended when processing rapeseeds. Darkened substrate-reflector accelerates the drying process since it removes the shielding of dried rapeseeds, provides a high reflectance coefficient of radiant energy and makes the temperature distribution in the monolayer of seeds more uniform. The substrate-reflector doubles this effect, and as a result the difference in heating temperatures of rapeseeds in a conveyor cascade dryer decreases during the drying process; this indicates a more uniform distribution of irradiance.

The uniform temperature distribution helps not only to reduce the time of rapeseeds drying with infrared radiation in a conveyor-cascade dryer [2], but also to increase the thickness of the filled seed layer on the conveyor belt of the dryer, that is to increase the productivity.

3. Research methodology

The research was carried out on an experimental conveyor-cascade dryer made for small-seeded crops drying. It involved checking the curves of infrared drying of seeds with and without a substrate under continuous irradiation; the electric film heater (EFH) served as a substrate material. The initial moisture content of the material was 12% (Figure 2). Rapeseeds were transferred to the dryer in a dense layer.

Figure 2. System with the active substrate
1 - EFH, 2 - rapeseeds, 3 - conveyor belt, 4 - active substrate

Figure 3 illustrates the experimental curves for drying rapeseeds with and without a substrate. Analysis of the curves obtained reveals that at the beginning of the process, when the moisture content of the material decreases along a convex curve, there is a short-term stage of heating the material. Then, under all drying conditions studied, the process proceeds in the second period (the drying speed drops). The presence of a foil substrate speeds up the drying process, since it removes the shielding of dried seeds and provides a high reflection coefficient of radiant energy.
Figure 3. Curves of rapeseeds drying with the substrate and without it.

Figure 4. Turning on the radiator only (without substrate).

Distributing the temperature in a thin monolayer of rapeseeds provided only the EFH emitter is turned on, we can observe the following picture presented in Figure 4. The outer irradiated side of rapeseeds quickly heats up while on the inner side the temperature is slightly lower.

Figure 5. Turning on the radiator only (with substrate).

A different picture is observed when there is a substrate. When the radiation reaches the substrate, a greater amount of heat is emitted at the boundary of the material than in the substance layer, which leads to a uniform temperature distribution throughout the layer of material. The change in the temperature of rapeseeds can be observed in Figure 5.

However, this option in the system also does not dry the product effectively due to the temperature difference between the upper and lower layers of the material.
Changing the substrate into the active mode, i.e. turning on the substrate as another source of infrared radiation makes it possible to equalize the temperature between the outer layers of the material, thereby intensifying the drying process without increasing the temperature (Figure 6).

It should be noted that when using foil as a substrate for rapeseeds, no changes in colour or appearance of the seeds were observed which makes this drying option acceptable for practice.

4. Conclusions

1. Technical means that work on the principle of convective heat exchange, using heat obtained from burning liquid, solid, or gaseous fuels are widely used for drying various crops. The mode of operation is characterized by high temperatures, high energy intensity and is considered environmentally unsafe.

2. Technological regulations of infrared drying in a conveyor cascade driers using an active substrate can be shorter in time; this results in energy and cost savings, reduces working time without loss of the final product quality.

3. Among all IR heaters the electric film heaters (EFH) with sputtering having body blackness of 0.96 are best suited for drying small-seeded oil-bearing crops according to the optical characteristics and the magnitude of the radiation flux.

4. The experiments have proved that low-temperature electric film heaters can effectively dry crops with a layer thickness of 1 or 0.8 cm.

5. The results of the experiment carried out on the installation of conveyor cascade type show that by changing the thickness of seed layer and technological parameters of drying, it is possible to change the temperature distribution in rapeseeds (since the initial seed moisture is different).

6. The conducted studies suggest that during the continuous mode of drying rapeseeds in a dense layer, the use of the substrate will lead to a significant intensification of the process.

References

[1]  Altukhov I V and Ochirov V D 2009 Irkutsk, Journal of IrSAA 37 43-9
[2]  Afanasyev, V A 2002 Theory and practice of special processing of grain components and compound feed technology. (Voronezh: Voronezh State University) p 296
[3]  Borkhert, R and Yubits 1963 V Technique of infrared heating (Moscow: Gosenergoizdat) p 278
[4]  Volonchuk S K, Sapozhnikov A N and Shornikova L P 2011 Novosibirsk - Barnaul, Polzunovskiy Journal 2/1 167-171
[5]  Ginzburg A S 1973 Fundamentals of the theory and technology of drying food (Moscow: Food industry) p 528
[6]  Malin N A 2004 Energy-saving drying (Moscow: KoloSS) p 240
[7] Machkashi A and Banhidi L 1985 Radiant heating (Moscow: Stroiizdat) p 464
[8] Polevoy B G and Popov V M 2010 Patent 100353
[9] Popov V M, Afonkina V A and Shukshina E I 2012 Science and education: experience, problems, development prospects 2 144-6
[10] Popov V M, Afonkina V A and Shukshina E I 2012 News of St. Petersburg State Agrarian University 26 387-91
[11] Popov V M, Afonkina V A and Shukshina E I 2014 LIII International scientific and technical conference Achievements of science to agricultural production III 357-63
[12] Popov V M, Afonkina V A, Shukshina E I and Levinskiy V N 2014 LIII International scientific and technical conference Achievements of science to agricultural production III 363-7
[13] Popov V. M, Afonkina V A, Shukshina E I and Mayorov V I 2017 Patent 2638690
[14] Popov V. M, Afonkina V A, Shukshina E I and Mayorov V I 2016 In: International scientific-practical conference in the framework of the XXVI international specialized exhibition "Agrocomplex-2016" III 45-9
[15] Popov V. M, Afonkina V A, Shukshina E I, Mayorov V I and Levinskiy V N 2015 International research journal 9 (40) 109-12
[16] Popov V. M, Afonkina V A, Shukshina E I and Khatmullin Sh A 2014 X International scientific and practical conference "Věda a vznik". Prague: Publishing House "Education and Science" 32 30-3
[17] Romanenko G A 1987 Oil-bearing crops 4 2-5
[18] Sekanov Yu P 1985 Moisture measurement of agricultural materials. All-Union Academy of Agricultural Sciences named after V. I. Lenin (Moscow: Agropromizdat) p 160
[19] Tsuglenok N V and Manasyan S K 2003 Resource-saving mechanization technology. Krasnoyarsk. Appendix to the “Bulletin of KrasGAU” 1 pp 122-5
[20] Skvortsov A A, Pshonkin D E, Luk‘yanov M N and Rybakova M R 2017 Solid State Phenomena. 269 31-6
[21] Goroshko D L, Shevlyagin A V, Chusovitin E A, Galkin K N, Chernev I M and Galkin N G 2016 Solid State Phenomena 247 61-5