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SUBSTANTIATION OF THE ENERGY EFFICIENT SCHEDULES OF DRYING GRAIN SEEDS

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Abstract: *It is important to study the patterns of drying grain seeds in order to improve the energy efficiency of the process. Energy efficiency is one of the main parameters that define the choice of a drying schedule. Traditional drying technologies are based on low temperature schedules, which do not allow significantly intensifying the process by increasing the temperature of the heat agent because of substantial reductions in the quality of the material. To adequately assess the drying schedules, we conducted the study of drying grain seeds at low temperatures aimed to preserve the seed properties of the material. To increase the energy efficiency of the drying process, a step-by-step descending low-temperature drying schedule was suggested, which provides for the required quality of seed material. All the proposed technical solutions for the energy-efficient schedules of drying grain seeds were summarized in the recommendations for industrial drying in column type direct-flow grain dryers.*

Key words: *seeds, drying, drying stand, energy efficiency.*

1. Introduction

Many researchers at different times have been involved in drying cereals to preserve their nutritional properties, which is related to the biochemical properties of the materials [11], [16], [19]. The resulting technologies of drying grain crops with the recommendations provided involve high temperature drying (above 100°C) [2], [9]. However, higher standards for seed grain and high energy costs do not allow the efficient drying process because of significant increase in material costs as larger volumes of grain need to be dried [17].

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To compare the energy costs for drying food grains, more than 5000 kJ of heat is consumed per 1 kg of the moisture evaporated, and in modern and modernized dryers the heat consumption can be about 3500 - 4800 kJ per 1 kg of the evaporated moisture [14, 15], while costs increase by over 30 - 40% when drying seed grain (depending on the means of disposal and recycling of the spent heat agent, preparation of the heat agent in the heat generator, efforts to reduce heat loss in the grain dryer) [3], [5], [10], [12].

Understanding of the mechanism of internal heat and moisture transfer, as well as the efforts to develop the technology close enough to natural processes of seed drying by introducing energy-efficient methods, provide significant savings in energy resources. One of the factors influencing the viability of seed grain during the drying process is the maximum allowable heating temperature of seed grain. Information on the maximum allowable heating temperature for seed grain allows developing energy-efficient drying modes.

The recommendations of different researchers for drying grain seeds vary and largely depend on the drying plant on which the research was conducted, and the accuracy of control and measuring devices [6], [17], [19]. These studies did not always indicate the maximum allowable grain heating temperature

Therefore, the relevance of this work is about the need for research to determine the rational schedules of drying grain seeds, which is essential for high yield.

The aim of the work is to study the schedules of grain drying and substantiate the scheme of energy-efficient drying equipment based on the results obtained.

To achieve the goal, the following tasks were set:

- Conduct the study of low-temperature schedules for grain crops drying with the heat agent temperature of 50 - 80°C;
- Offer energy-efficient schedules for grain seeds drying;
- Analyze the specific heat consumption for the grain crops drying process;
- develop the scheme of the direct-flow drying installation for drying grain seeds.

2. Materials and Methods

Many researchers did not specify the maximum allowable heating temperature of grain seeds in their studies, which is important in determining rational drying schedules [2], [9, 10], [14], [19]. The suggested empirical formulas aim to determine the maximum allowable temperature of food grains while the error in the calculations of various authors is about 10% and above, which is quite high [2], [13], [17].

Multizone dryers currently use high-temperature drying technology for seed grain through ascending stages, followed by cooling, which dramatically increases the energy costs for drying and cooling, while the quality of seed material significantly drops.

The research methodology developed drastically differs from the established traditional approaches to grain drying and aims to reduce energy costs by reducing the duration of the drying process.

The developed technique for determining rational drying schedules provides for the following:

- Installation of a modern automated system for processing the results of experimental research [2], [5];
- Finding the maximum allowable heating temperature of grain seeds through installed chromel-copel thermoelectric converters (DSTU 2837

- 94) with a diameter of 0.2 mm, PC connected via an analog digital converter i-7018 with the converter-interface i- 7520 [8], [15];
- Installation of high-precision scales AD-500 with the accuracy of 0.02 g, PC connected via analog-to-digital converter i-7018 with the converter-interface i-7520 [5], [8, 9];
- Drying the material in the elementary layer (one grain) to obtain more accurate results of the process kinetics [18].

3. Results

To determine the rational drying schedules of seed grain, experimental studies were performed on a convective drying stand with an automated information reading and processing system of the process timing, the heat agent and the material temperature, the change in sample weight [3, 4],[7], [17].

Seed grain drying in the convective drying stand was carried out in an elementary layer at the following parameters: heat agent temperature t = 50 - 80°C; heat agent speed V = 0.5-1.5 m/s; initial humidity of the material $W_п$ = 16 - 24%; moisture content of air d = 10 - 12 g / kg of dry product. To study the seed grain drying schedules, grain crops of the following selection varieties were selected: soft winter wheat of the «Podolyanka» variety, spring barley of the “Barvystyi” variety and oat of the “Zoryanyi” variety (Figure 1).

Studies of the effect of initial humidity, speed and moisture content of the drying agent on the drying time of grain seeds have shown (Figure 1) that reducing the initial humidity from 24 to 16% reduces the duration by 3 - 3.5 times; the increase in drying speed from 0.5 to 1.5 m/s - 1.22 - 1.42 times; reducing the moisture content of the heat agent from 12 to 10 g/kg of dry product - at 17.8 - 18.8%.

Changing the heat agent temperature from 50 to 80°C reduces the drying time for wheat by 2.8, for barley by 2.67 and for oats by 2.4 times. Seed grain is dried during the period of falling speed with short-term heating of the material.

With the growth of the heat agent temperature, the seed heating rate also increases with a simultaneous increase in moisture evaporation from the material (Figure 1).

According to the second order orthogonal composite design, we obtained the response surfaces and regression equations from the three factor effects (heat agent temperature, heat agent flow rate and initial moisture of the material) on the drying duration and seed germination (Table 1 and Figure 2).

Table 1

Factors and levels of variation affecting the drying of wheat, barley and oat seeds

Indicators	Factors		
	Heat agent		Material
	Temperature, *t* [°*C*]	**Speed, *V* [m/s]**	**Initial moisture, $W_п$ [%]**
Upper (+1)	80	1.5	24
Medium (0)	65	1.0	20
Lower (–1)	50	0.5	16
Variation range	15	0.5	4
Code symbol	x_1	x_2	x_3

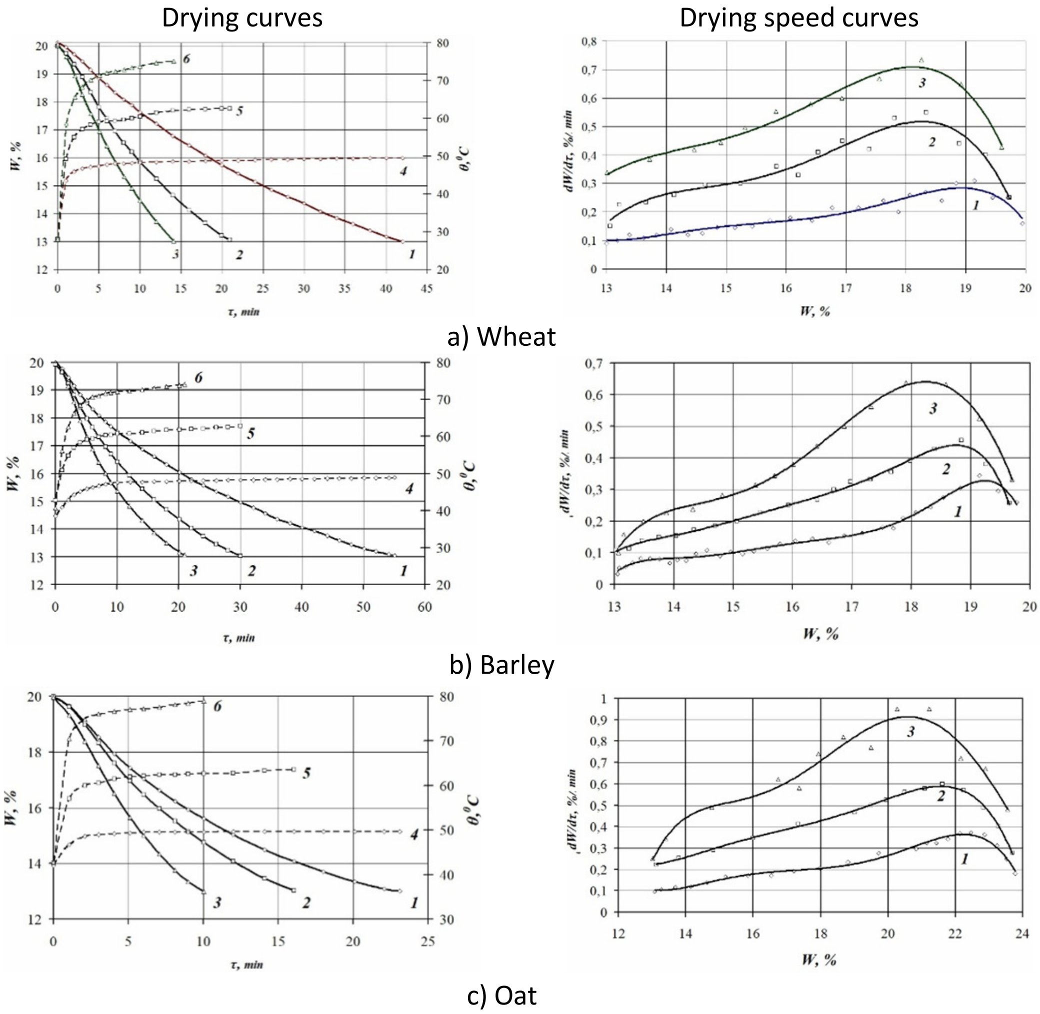


Fig. 1. *The influence of heat agent temperature on drying kinetics of grain seeds ($W_п$ = 20%; V = 1.5 m/s, d = 10 g/kg of dry product; δ = 0.002 m; 1 and 4 - 50°C; 2 and 5 - 65 °C; 3 and 6 - 80°C)*

$$\tau_W = 18.81 + 0.0172t^2 - 3.2V^2 - 0.092W^2 - 1.833t - 22.36V + \\ + 12.161W + 0.264tV - 0.091tW + 0.25VW \quad (1)$$

$$C_W = -578.37 + 18.45t + 45.98V + 11.58W - 0.141t^2 - 22.56V^2 - 3.7W^2 + \\ + 0.17tV - 0.006tW - 0.006V \quad (2)$$

$$\theta_W = 15.94 + 12.83t - 5.98V - 0.543W + 0.355VW - 22.36V + 12.161W + \\ + 0.264tV - 0.091tW + 0.25VW \quad (3)$$

$$\tau_b = -17.39 + 0.019t^2 + 6.88V^2 + 0.317W^2 + 0.086t - 24.3V + 6.928W + \\ + 0.132tV - 0.227tW - 0.25VW \quad (4)$$

$$C_b = -612.8 - 0.127t^2 - 27.52V^2 - 0.51W^2 + 16.758t + 55.04V + 23.848W - 0.064tW \quad (5)$$

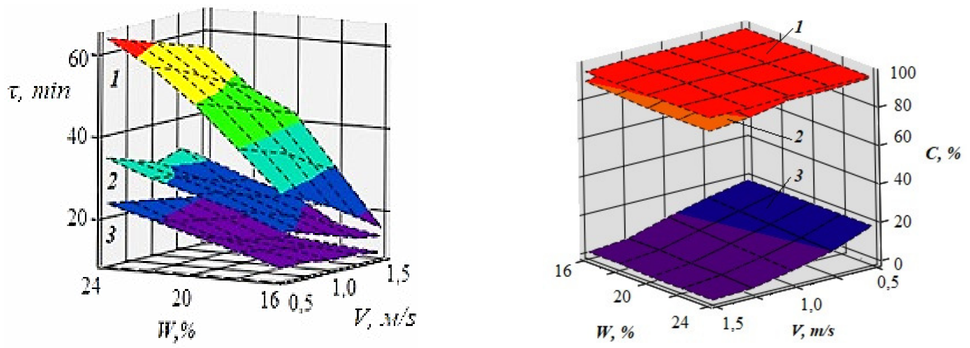
$$\theta_b = 8.19 + 0.85t - 0.68V - 0.12W \quad (6)$$

$$\tau_0 = -48.09 - 4V^2 + 0.483t - 1.64V + 5.335W + 0.132tV - 0.05tW - 0.375VW \quad (7)$$

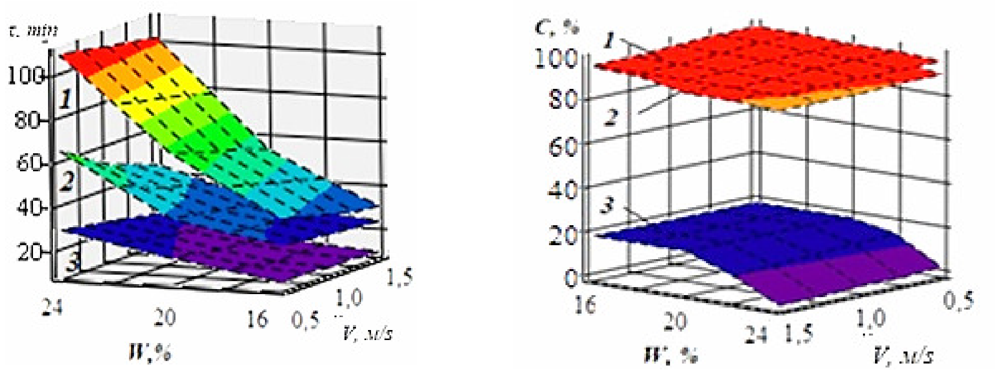
$$C_0 = -617.92 + 16.91t + 67.11V + 15.32W - 0.112t^2 - 31.4V^2 - 4.07W^2 - 0.2tV - 0.017tW \quad (8)$$

$$\theta_0 = 24.18 + 0.004t^2 + 0.333t + 0.76V - 0.148W \quad (9)$$

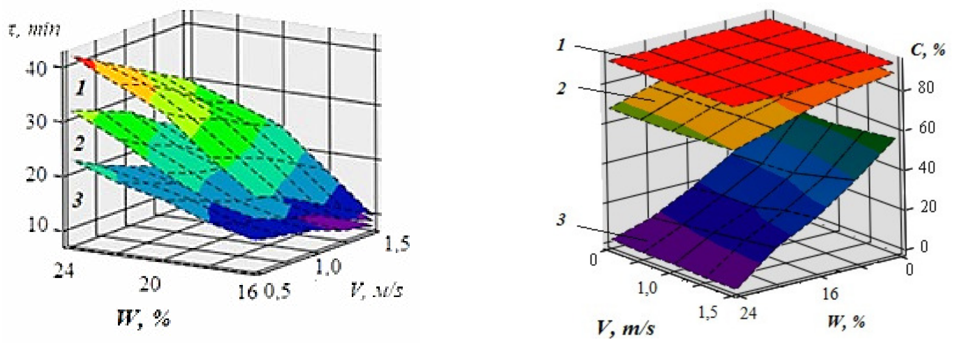
Drying curves Drying speed curves



a) Wheat



b) Barley



c) Oat

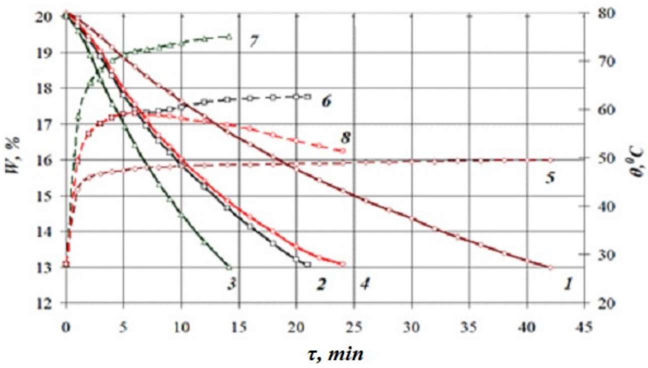
Fig. 2. *Response surfaces of the influence of heat agent temperature on the drying kinetics and grain seed germination ($W_п$ = 20%; V = 1.5 m/s; d = 10 g/kg of dry product; δ = 0.002 m; 1 and 4 - 50°C; 2 and 5 - 65°C; 3 and 6 - 80°C)*

We obtained the regression equations of drying duration, germination and heating temperature of the wheat (1-3), barley (4-6) and oat seeds (7-9).

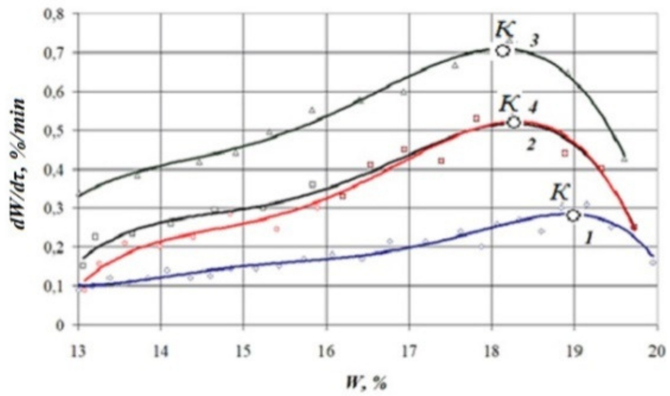
The increase in intensity of the one-stage drying schedule through the temperature of the drying agent is limited by the qualitative characteristics of the material (the best grain germination is 50°C, according to the previous studies) [15, 18], thus the introduction of the two-stage descending low temperature schedule may be a solution [1].

The two-stage descending schedules provide for material warm-up at a higher temperature during the first stage and drying at decreasing heat agent temperature during the second stage.

The suggested two-stage descending low-temperature schedule of 65/50°C allows for short-term warm-up of the material at the heat agent temperature of 65°C, followed by the drying of the seeds at the temperature of 50°C with the quality of the seed material being preserved. In Figure 3 it is shown a comparison of the drying kinetics of wheat seeds in single-stage schedules of 50, 65, 80°C and the two-stage schedule of 65/50°C. The drying time in the two-stage 65/50°C schedule is reduced by 83% as compared to the 50°C drying schedule.



a)



b)

Fig. 3. *The effect of the heat agent temperature in one- and two-stage schedules on the kinetics of drying wheat seeds (Wп = 20%; V = 1.5 m/s; d = 10 g/kg of dry product; δ = 0.002 m; 1 and 5 - 50°C; 2 and 6 - 65°C; 3 and 7 - 80°C; 4 and 8 - 65/50°C*)

As can be seen from Figure 3, in the drying schedule of 65/50°C at the beginning of the drying process at the heat agent temperature of 65°C the material is warmed up for the short term of 5 minutes until it reaches the temperature of 59.18°C, and at the end of the process it gradually decreased to 54.1°C.

At the beginning of the drying process, the stepwise drying schedule is close to the temperature of 65°C, and then the drying speed is decreased (Figure 3b). The presented drying rate curves indicate the advisability of introducing a consecutive schedule that exceeds the drying rate at the temperature of 50°C by 76%.

As a result of the proposed energy-efficient two-stage descending drying schedule of 65/50°C, the specific relative energy consumption for the process of drying wheat seed grain was reduced by 62% (Figure 4).

Figure 5 shows the drying curves of barley, wheat and oat seeds in correlation of the stepwise mode of 65/50°C and drying time.

The drying process of the presented grain crops in the stepwise drying schedule of 65/50°C is the fastest for oat seeds (19 minutes), and the longest one is for barley seeds (37 minutes).

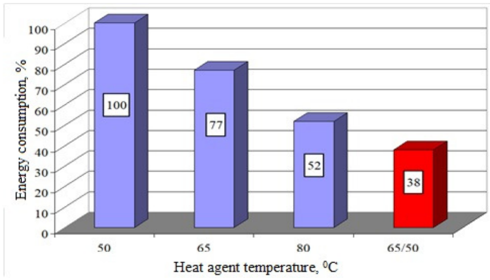


Fig. 4. *Correlation between energy consumption for drying wheat seeds and heat agent temperature (Wп = 20%; V = 1.5 m/s; d = 10 g/kg of dry product; δ = 0.002 m)*

The final heating temperature of oats is higher than the heating temperature of the presented grain crops and amounts 58°C, while the lowest heating temperature is the one of wheat seeds.

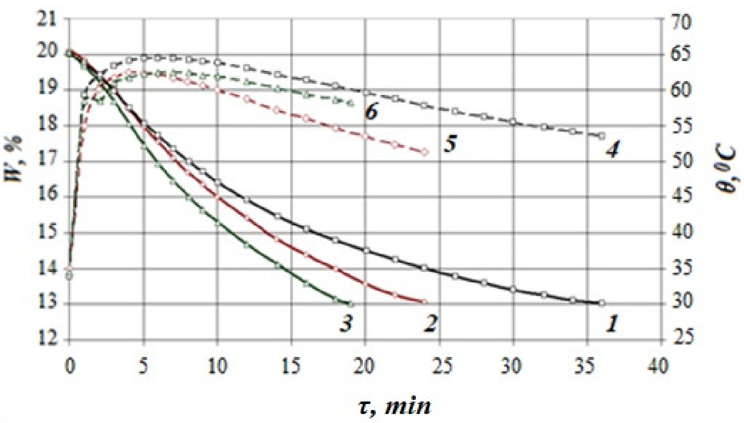


Fig. 5. *Comparison of stepwise seed schedules for τ barley, wheat and oats as they impact the duration of drying (t = 65/50°C; V = 1.5 m/s; d = 10 g/kg of dry product; δ = 2 mm; 1 and 4 – barley; 2 and 5 – wheat; 3 and 6 – oats)*

On the basis of the conducted studies we developed the design of the 3-zone column type drying installation with energy-efficient stepwise schedule of grain seeds drying (Figure 6).

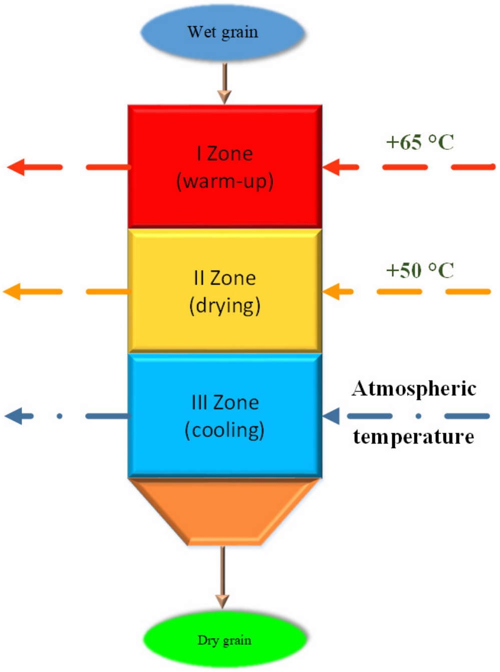


Fig. 6. *Energy efficient scheme for drying grain seeds*

It is recommended to carry out the drying process in the 3-zone column-type drying unit. The technical solution allows for the stepwise drying mode of 65/50°C: warming up the seeds at the heat agent temperature of 65°C in the zone I, drying at 50° in the zone II and cooling at atmospheric temperature.

Based on the proposed scheme of stepwise low-temperature drying of grain material (Figure 6), an experimental prototype of a column-type sectional grain dryer was developed.

Approximate technical characteristics:

- Productivity – 5 t/h;
- Heating agent – flue gas;
- Heat generator – solid fuel boiler, W=1.5 MW.
- Heat transfer – four-section heat exchanger;
- The device for transportation of grain – bucket elevator;
- Automation tools – optical grain level sensors, coolant temperature sensors, grain temperature sensors, grain moisture content sensors, relative humidity sensors.

To carry out production tests, this prototype was installed and put into operation on the farm ”Lyudmila-Agro“ in the Vinnytsia region (Figure 7).

Fig. 7. *Installation of the column type grain dryer with the capacity of 5 t/h*

Production tests were carried out in order to test the operating schedules of the equipment and adjust its design and technological parameters.

4. Conclusions

As a result of the conducted researches it was substantiated that to increase the energy efficiency of the drying process and maintain the necessary quality of seed material at the same time, it is expedient to apply the stepwise descending low-temperature schedule of drying. Such schedules can be implemented in the developed 3-zone column-type drying installation. Authors plan to carry out further research in the direction of the study of its schedule parameters in production conditions.

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