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EXPERIMENTAL STUDIES OF GRAIN DRYING WITH MW – CONVECTIVE CYCLIC ENERGY SUPPLY

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ СУШКИ ЗЕРНА ПРИ МХ-КОНВЕКТИВНОМУ ЦИКЛІЧНОМУ ПІДВОДІ ЕНЕРГІЇ

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Abstract. *The paper presents the results of a study of drying a dense layer of grain under conditions of using microwave field energy. Cyclic modes of supplying microwave energy to a layer of material, alternating with periods of air blowing, are considered. The influence of the duration of layer blowing and air temperature on the patterns of changes in temperature and moisture content of the material, drying speed and specific energy consumption is studied. Oats were used as grain material. A comparative analysis of the characteristics of the processes of microwave convective cyclic drying under various modes is presented.*

Key words: *plant scheme, blowing air through the layer, duration, temperature, moisture content, specific energy consumption, drying speed.*

Introduction.

Heat drying is the most important and most energy-intensive technological operation during post-harvest grain processing. Freshly harvested wheat grain should be dried to a moisture content of 14 percent or less within 48 hours to prevent sprouting and spoilage [1]. Most studies on grain drying are performed on the laboratory scale to study the factors that determine the quality of grains on a large scale. Such factors include air temperature and flow, grain layer thickness, raw material composition, and drying system employed [2]. Currently, convective dryers are the most common for drying grains; they have a number of significant disadvantages, which can be partially eliminated by microwave-convective heat supply. Studies of microwave convective drying of grain [3] have shown that the duration of the drying process in the presence of a microwave energy supply is reduced by 3.5 times compared to convective drying. When studying the kinetics of grain drying, convincing evidence was obtained of the applicability of microwave technologies and the feasibility of developing microwave dryers [4, 5]. Knowledge of the peculiarities of drying kinetics when using a microwave energy contributes to the selection of rational grain drying modes.

Experimental setup and experimental procedure

The experimental setup diagram is shown in Fig. 1. The setup provides research during microwave, microwave-convective and convective drying.

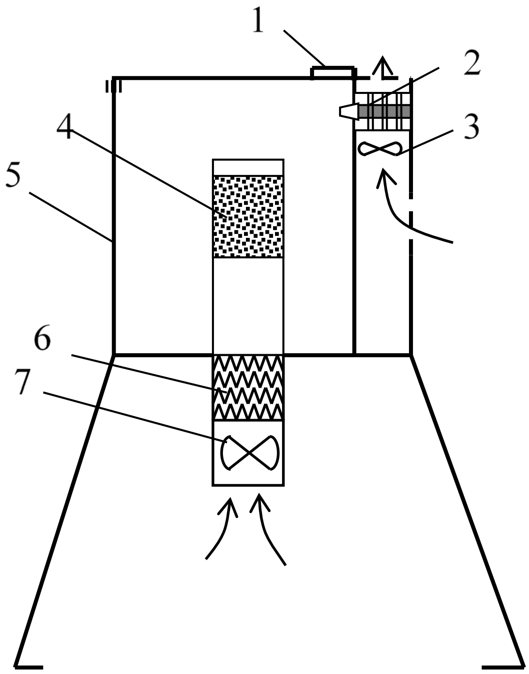

Figure 1 – Scheme of experimental setup for studying the kinetics of drying grain materials under microwave and convective heating

1 – door, 2 – magnetron, 3 – fan of the magnetron cooling system, 4 – experimental cell with grain, 5 – chamber, 6 – electric heater, 7 – fan

An air duct made of radio-transparent material was installed inside the working chamber, into which a cell made in the shape of a parallelepiped from a radio-transparent mesh material was placed. The dimensions of the cell strictly corresponded to the dimensions of the air duct, so that when the material was blown with air, no lateral leaks occurred.

The influence of the duration of blowing τ_c, as well as the temperature of the air blowing through the layer, on the patterns of changes in temperature and moisture content of the material, drying speed and specific energy consumption is studied. In this case, the duration of switching on the magnetron τ_{MW} in all experiments was the same.

When blowing with unheated air, 3 series of experiments are carried out, differing in duration τ_c. After each step, the material is weighed and the temperature of the layer is measured at several points, then a new portion of material with the same weight and moisture content is poured into the cell, and the experiment is carried out with the next period (MW or blowing).

Thus, the obtained initial data make it possible to determine the loss of moisture and the average temperature of the layer, as well as calculate the moisture content and specific energy consumption after each period. In the experiments, the initial and final masses (m_0, m_{f}) and temperatures (t_0, t_{f}) and the duration of blowing (τ_c) are measured.

0.1 kg of grain with an initial moisture content of 0.2 kg/kg was loaded into the microwave installation. Grain drying took place in a cyclic mode - periods of microwave heating alternated with periods of blowing. The duration of the microwave heating period in all experiments was the same and amounted to 10 s, the magnetron power was 600 W. The duration of the purge period was 10, 20 and 30 s. The air temperature was 20 °C, the filtration rate in the grain layer was 1 m⁄s. The initial grain temperature was 20 °C. In all experiments, oats were used as a grain material. The method for calculating drying characteristics from experimental data is given in [4].

Results and discussion.

Microwave drying with air blowing through the grain layer without preheating

During the experiment, the air temperature was 20 °C, the filtration rate in the grain layer was 1 m⁄s. The initial grain temperature was 20 ºC.

With a ratio of 10 s MW - 10 s blowing (total duration of the process - 130 s), the specific energy consumption for the entire experiment was 9.07 MJ/kg, the average drying rate was $4.3 \cdot 10^{-4}$ kg/(kg·s) – Table 1, mode 1. At τ_c=20 s (total process duration – 190 s), the specific energy consumption for the entire experiment was 9.68 MJ/kg, the average drying rate for the entire experiment was $N = 2{,}77 \cdot 10^{-4}$ kg/(kg·s) – Table 1 mode 2. Average speed of microwave drying $N_{MW} = 2{,}01 \cdot 10^{-4}$ kg/(kg·s), average speed during the blowing period $N_c = 2{,}78 \cdot 10^{-4}$ kg/(kg·s).

When blowing air at τ_κ=30 s, the total duration of the experiment was 250 s. The specific energy consumption for the entire experiment was 8.96 MJ/kg, for the entire experiment the drying rate was $N = 2{,}0 \cdot 10^{-4}$ kg/(kg·s) - Table 1, mode 3. The average speed of MW drying was $N_{MW} = 1{,}57 \cdot 10^{-4}$ kg/(kg·s), the average speed during the blowing period $N_c = 2{,}33 \cdot 10^{-4}$ kg/(kg·s).

The drying rate during purging periods decreases as their duration increases. This is explained by a noticeable decrease in the temperature of the material during the period of blowing with cold air.

Microwave drying with heated air blowing through the grain layer

The results were obtained under conditions of blowing the layer with air heated to a temperature t_{air} = 50 ºC. The initial grain temperature was t_{grain} = 20 °C, magnetron power P = 600 W, air speed 1 m/s, flow rate 0.0118 kg/s. The duration of the microwave energy heating period was always 10 s.

When blowing with a period of τ_c=10 s (experiment duration 130 s), the specific energy consumption for the entire experiment was 11.72 MJ/kg, the average drying rate for the entire experiment was 3.54·10–4 kg/(kg·s) – table 1 mode 4. Average speed of microwave drying $N_{MW} = 2{,}57 \cdot 10^{-4}$ kg/(kg·s), average speed during the blowing period $N_c = 5{,}33 \cdot 10^{-4}$ kg/(kg·s).

When blowing with a period of τ_c=20 s (experiment duration 190 s), the specific energy consumption for the entire experiment was 14.33 MJ/kg. The average drying speed for the experiment was N = 2.94 10^{-4} kg/(kg·s) - Table 1, mode 5. The average speed of MW drying $N_{MW} = 1{,}24 \cdot 10^{-4}$ kg/(kg·s), the average speed during the blowing period $N_c = 4{,}32 \cdot 10^{-4}$ kg/(kg ·s). At the same air temperature, but shorter blowing duration, the drying rate was higher.

The characteristics of the processes of microwave convective cyclic drying under various modes are given in Table. 1. Duration of the MW heating period $\tau_{MW} = 10$ s, total MW heating time $\tau_{\Sigma MW} = 70$ s.

Table 1 - Characteristics of microwave convective cyclic drying

Name	Mode				
	1	2	3	4	5
Duration of the convective period τ_c, s	10	20	30	10	20
Total convective heating time $\tau_{\Sigma c}$, s	60	120	180	60	120
Total drying duration τ_{Σ}, s	130	190	250	130	190
Air temperature t_a, °C	20	20	20	50	50
Loss of moisture· Δm, 10^{-3}, kg	4,63	4,34	4,69	4,21	5,03
Final moisture content u_f, kg/kg	0,144	0,148	0,144	0,154	0,144
Final temperature t_f, °C	80,5	68	63,3	95,33	91
Drying speed· N, 10^{-4} kg/(kg·s)	4,3	2,74	2,0	3,54	2,94
Specific energy consumption q, MJ/kg	9,07	9,68	8,96	11,72	14,33

The final moisture content, as experiments have shown, is practically independent of the sequence of microwave and convective heating for a given initial moisture content. Specific energy consumption depends to a greater extent on the duration of microwave heating, and not on the order in which it is turned on.

Conclusion

The final humidity, is practically independent of the sequence of microwave and convective heating at a given initial humidity. The specific energy consumption depends to a greater extent on the duration of microwave heating, and not on the order in which it is turned on.

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Анотація. *У роботі представлені результати дослідження сушіння щільного шару зерна за умов застосування енергії мікрохвильового поля. Основою для конструювання нових установок є залежності для розрахунку температури та вмісту вологості дисперсного матеріалу в процесі сушіння, що є предметом дослідження даної роботи. Наведено схему експериментальної установки. Установка забезпечує проведення досліджень при мікрохвильовому, мікрохвильово-конвективному та конвективному сушінні. Розглядаються циклічні режими підведення теплоти із застосуванням періодів конвективного сушіння. Вивчається вплив тривалості продування шару та температури повітря на закономірності зміни температур та вмісту вологи матеріалу, швидкість сушіння та питомі витрати енергії. У мікрохвильову установку завантажувалося 0,1 кг зерна з початковим вмістом вологи 0,2 кг/кг. Сушіння зерна проходило в циклічному режимі - періоди МХ нагрівання чергувалися з періодами продування. Тривалість періоду МХ нагріву у всіх дослідах була однакова і становила 10 с потужність магнетрону 600 Вт. Тривалість періоду продування була 10, 20 та 30 с. Як зерновий матеріал застосовувався овес. Наведено порівняльний аналіз характеристик процесів МХ – конвективного циклічного сушіння при різних режимах.*

Ключові слова*. схема установки, тривалість продування, температура, вміст вологи, питомі енерговитрати, швидкість сушіння.*