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EXPERIMENTAL INVESTIGATION OF THE ACOUSTIC-CONVECTIVE DRYING OF UNHUSKED KOREAN RICE

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Experiments on determination of the kinetic curves of drying of unhusked Korean rice have been conducted on two (small- and large-scale) acoustic-convective dryers of capillary-porous materials of the Institute of Theoretical and Applied Mechanics of the Siberian Branch of the Russian Academy of Sciences. Different regimes of drying were used. The characteristic time of drying to a prescribed final humidity has been determined; the absence of the influence of the scale factor on the kinetics of drying of rice has been shown. The coefficient of moisture conductivity of rice has been evaluated.

Brief Description of Experimental Equipment. Drying of materials (wood, whole wheat grain) in a high-intensity acoustic-convective field is less power-consuming per unit of products compared to traditional thermal-convective drying as a rule [1]. Furthermore, it occurs at low (room) temperatures, which is important for preserving the quality of products. We note that it was first shown in [2] that the rise in temperature in material dried by acoustic-convective action is slight: as small as a few degrees. Acoustic-convective dryers of the Institute of Theoretical and Applied Mechanics of the Siberian Branch of the Russian Academy of Sciences make it possible to carry out a series of works on investigation of the kinetics of drying of unhusked Korean rice and to determine the drying times for a prescribed intensity of the acoustic field and range of initial and final humidity of rice.

Figure 1 gives the diagram of a small-scale experimental setup for physical investigations on acoustic-convective drying of materials. The sample is placed in the channel of a drying chamber of rectangular cross section 8. The transverse dimensions of the chamber are 52 × 52 mm. The entry and egress of air from the setup are shown by the arrows. The Hartmann generator 3 is used as the sound source. The operating regime of the setup is determined by the stagnation pressure of the working gas in the nozzle prechamber P_0 (pressure gauge 2), by the position of pistons 1 and 6, and by the nozzle–resonator distance. The level of acoustic-field intensity and the temperature of the incident flow in the drying chamber are measured by a pressure gauge 4 and thermocouple 5. The humidity of the spent air in the sound generator is determined by a moisture meter. Also, there is a light source (light-emitting diode) 7 which illuminates samples via an optical window 10 and a video camera 9 (they were not used in these experiments).

The large laboratory setup on which we conducted experiments on drying, too, is not fundamentally different from the above-described small-scale setup; the differences are only in dimensions. Its rectangular metallic channel has a 0.2 × 0.2 m cross section and a length of 3 m. Gauze holders of length 1 m and height 5 cm into which the unhusked rice grain to be dried is poured are arranged over the width of the drying-chamber channel.

Procedure of Preparation of Rice for Investigations. In preparing rice for experiments, we used two procedures of its soaking: 1) the entire portion of water necessary for bringing the humidity of rice to the required final value followed by holding the rice for a few days was poured in at once; 2) unhusked rice was soaked in water portions ensuring an increase of 2% in the humidity a day, during which it was placed in a refrigerator. This was because of the necessity of preserving the reproductive properties of rice and the integrity of its coating. The rice humidity was measured accurate to 0.1% by a HPEUFFER moisture meter. The humidity of the rice obtained for experiments amounted to 13–15%; after its preparation for the experiments on acoustic-convective drying, it was 22.4–24.3%.

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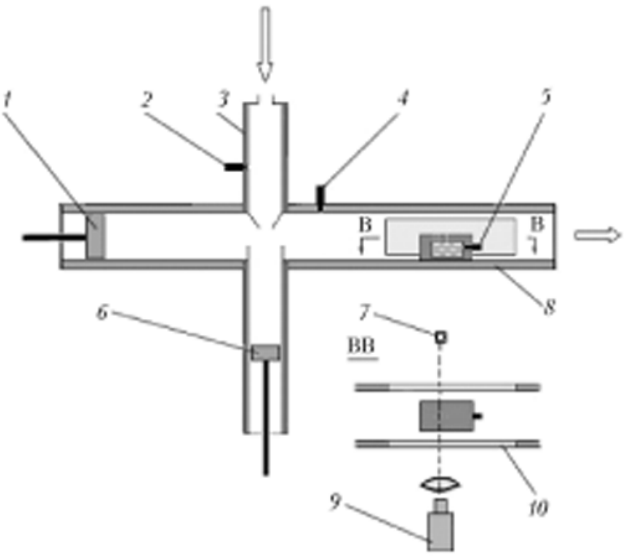


Fig. 1. Diagram of the small-scale experimental setup.

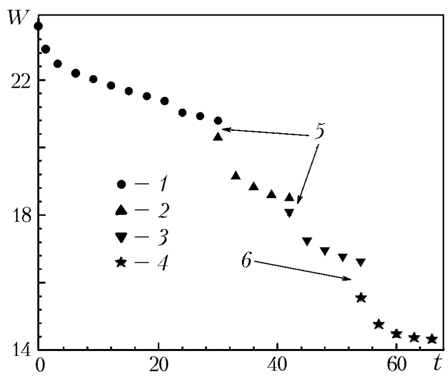
Fig. 2. Gauze holders with poured rice grain and their arrangement in the channel of the large laboratory setup.

Experimental Investigation of the Kinetics of Acoustic-Convective Drying of Rice on the Small-Scale Setup. Experiments on drying of rice on this setup were conducted in three regimes.

First Regime of Drying. Rice prepared according to the first procedure was placed in a cloth container secured in the drying channel. The process of drying continued until the kinetic curve leveled out, i.e., until the drying was stabilized. The derivative of humidity with respect to time became close to zero, which demonstrated that the limiting (for this step of drying) values of humidity had been attained. Then this portion of rice was placed, for 24 hours, in a closed container where the humidity distributions in individual grains were equalized. A day later, the portion of rice was subjected to drying again and was placed in the container. This process was repeated (see Fig. 3, where the total time of acoustic-convective drying is plotted).

The level of acoustic-field intensity on this setup was 167 dB in all the regimes; the frequency was 415 Hz. The relative humidity and the temperature of the incident convective flow of the air spent in the sound generator was equal to 3.5% and 22°C respectively. The average velocity was 22 m/sec. The initial and running weight of the rice portion was determined with a CCF T 12 RI balance; from these readings and the measured initial humidity, we calculated the running humidity. The results of these experiments are presented in Figs. 3 and 4.

As follows from the resulting kinetic curves, the humidity of rice diminishes in each of the four cycles in a qualitatively similar manner. First, in the first step of the cycle, we have a sharp change in the humidity, which is characterized by a strong drop in the drying rate. Next, in the second step of drying, its rate changes to a lesser degree. We note that the qualitative form of the kinetic curves is preserved for all steps (this is true with allowance for



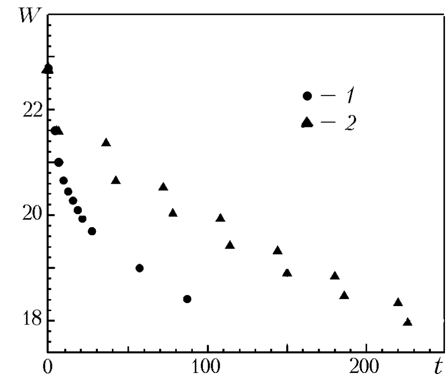


Fig. 3. Kinetic curve of drying of rice in the front regime: 1) on the first day of drying; 2) on the second day; 3) on the third day; 4) on the fourth day; 5 and 6) after holding for 24 hours and for three days respectively. W, %; t, min.

Fig. 4. Kinetic curves of drying of rice: 1) second regime of drying; 2) third regime of drying. W, %; t, min.

the difference in the time intervals of the first and subsequent steps). The data of Fig. 3 make it possible to evaluate the coefficient of moisture conductivity of unhusked Korean rice. Portions 2–4 in this figure show that, over a period of 24 hours, moisture from the internal region of the grains approaches the surface, which causes the initial drying rate to increase.

The one-dimensional equation of moisture conduction in the transverse direction for an individual rice grain can yield an estimating expression for the coefficient of moisture conductivity D:

$$D \approx \frac{l^2}{T} \, . \tag{1}$$

Let us take $l \simeq 1.3$ mm and $T \le 24$ h for unhusked rice. Substituting these values, we obtain $D \ge 2 \cdot 10^{-7}$ cm^2/sec (for the sake of comparison the moisture conductivity, e.g., of pine is equal to $4 \cdot 10^{-6}$ cm^2/sec).

Second and Third Regimes of Drying. In the second regime of drying, rice prepared according to the second procedure was subjected to continuous drying (without holdings) to a prescribed level of humidity. In the third regime, drying was carried out by alteration of six-minute acoustic-convective actions and half-hourly holdings of the rice.

Figure 4 gives the kinetic curves of drying of rice in the two regimes. Curve 1 corresponds to continuous drying of rice for 90 minutes. The humidity diminished from 22.8 to 18.5% over this period. Curve 2 corresponds to the third regime of drying. As is seen, half-hourly holdings of rice do not cause the drying rate to subsequently increase, as is noted in Fig. 3. This means that the process of moisture conduction is not manifested over such a short period.

Experimental Investigation of the Kinetics of Acoustic-Convective Drying of Rice on the Large Laboratory Setup. In this case the experiments were conducted at a level of acoustic-field intensity of 167 dB and a frequency of 130 Hz. The temperature and relative humidity of the incident convective flow were the same as those on the small-scale dryer; the average velocity was 20.5 m/sec.

In the channel of the drying chamber, we arranged two rice-filled holders (see Fig. 2) whose running weight was determined with a beam balance. The procedure of processing of experimental data was the same as previously. The results are presented in Fig. 5, where the kinetic curves of drying of rice, obtained on the small- and large-scale dryers, are shown. Here curves 1 and 2 are obtained on the small-scale dryer in the second and third regimes; curves 3 and 4 are obtained on the large dryer, the first and second holders respectively (fourth regime of drying). As is seen, curves 3 and 4 are virtually identical. This is due to the properties of the acoustic-convective flow which are uniform over the drying-chamber cross section.

The most significant result of the investigations is that the rates of drying of rice in the massive holders are quite coincident with the rates of drying of small portions of rice on the small-scale setup. It is noteworthy that the

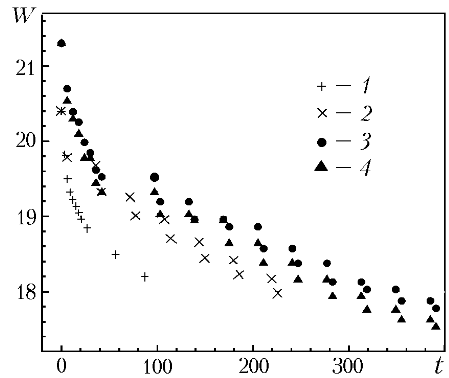


Fig. 5. Kinetic curves of drying of rice: 1 and 2) on the small-scale dryer (second and third regimes); 3 and 4) on the large dryer, the first and second holders respectively (fourth regime of drying). W, %; t, min.

experiments on the large and small dryers were conducted at differing frequencies. Nonetheless, the drying rates in these processes are close. This suggests that the influence of the acoustic-field frequency is insignificant in this range.

As is seen from the resulting kinetic curves, the first step of drying with a constant rate where the process is determined by the phenomena on the material surface is virtually absent from these regimes [3]. The basic physical mechanism limiting the rate of drying of unhusked Korean rice is the process of moisture conduction within rice grains. Also, it is seen that a holding of 0.5 h makes it impossible for the comparatively slow process of moisture conduction to be manifested.

CONCLUSIONS

1. Unhusked Korean rice is quite efficiently dried on acoustic-convective dryers.
2. The scale factor weakly influences the kinetics of drying of rice, and the influence of the acoustic-field frequency is absent from the frequency range considered.
3. A constant-rate period is virtually absent from the kinetics of drying; the process is mainly determined by the moisture conductivity of grains.
4. The procedure of continuous drying is a more rapid process compared to the procedure with short-duration holdings.
5. The procedure with long-duration holdings of rice will make it possible to more efficiently use the natural process of moisture conduction within rice grains, which will be less power-consuming.

NOTATION

D, coefficient of moisture conductivity of rice, m^2/sec; l, half the characteristic transverse dimension of a rice grain, m; P_0, stagnation pressure of the working gas in the nozzle prechamber, Pa; T, characteristic time of the process of moisture conductivity in a rice grain, sec; t, drying time, sec; W, humidity of rice, %.

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