Effectiveness of using acoustic oscillations of ultrasonic frequency on the process of removing moisture from porous material

Victor A. Nesterov, *Vladimir* N. Khmelev, *Sergey* A. Terentiev, *Pavel* P. Tertishnikov*, and *Andrey* V. Shalunov

Biysk Technological Institute (branch) of Altai State Technical University named after I. I. Polzunov, Biysk, Russia

Abstract. The article presents the results of a study of the ultrasonic drying process which is a promising way to intensify the process of moisture removal at low temperatures. An experimental stand was developed for the research. The stand is an ultrasonic dryer with automatic maintenance of the set temperature. A flexural-oscillating disk radiator was used as a source of ultrasonic action. The conducted studies have shown that changing the speed of the drying agent from 0.1 m/s to 0.2 m/s during convective drying can slightly reduce the drying time from 100 minutes to 90 minutes (10%). Change of the speed of the drying agent from 0.1 m/s to 0.2 m/s allows reducing the drying time by 10 minutes, from 80 minutes to 70 minutes with ultrasonic action. Due to the ultrasonic exposure at a drying agent speed of 0.2 m/s, the drying time is reduced from 90 minutes to 70 minutes. At a drying agent temperature of 400C, the drying time is reduced by 25% due to ultrasonic exposure (from 160 minutes to 120 minutes).

1 Introduction

The drying process is a rather long and costly stage in the production of various materials. According to the US Department of Energy (no such statistics are kept in the Russian Federation), up to 12% of all energy resources generated in the country are spent on the implementation of drying processes in various industries. And, according to the forecasts, the cost of energy resources for drying will only increase.

In addition, in the modern world there are trends in the active development and promotion of the biopharmaceutical, food and chemical industries, which actively use the drying process in their production. Due to the need to ensure a high preservation of the original properties of the dried products, for example, chemical composition, taste, color, smell [1,2], high requirements are imposed on the drying process, namely, lowering the drying temperature. At the same time, the process time is significantly increased.

Today, one of the most common ways to remove moisture is the convective method, which has a number of disadvantages, such as:

- high energy consumption;

* Corresponding author: nva@u-sonic.ru

- low drying speed;
- thermal damage to the dried sample.

Attempts to increase the temperature of the drying agent in order to reduce the drying time lead to the destruction of useful substances and the deterioration of consumer properties of products.

One of the possible ways to intensify moisture removal (increase the efficiency of convective drying) at low temperatures is to use the energy of ultrasonic vibrations (non-contact acoustic impact of ultrasonic frequency) [3,4].

Ultrasonic action provides intensification of the moisture evaporation process at the gas-liquid interface and accelerates the process of moisture transfer from the inner layers to the surface. In addition to this, ultrasonic treatment makes it possible to disperse liquid from the surface of dried materials, excluding the most energy-consuming stage of liquid evaporation [5, 6].

However, the obsolete sources of acoustic impact used today, such as gas-jet emitters, have a number of significant drawbacks, which limits their widespread use:

- high consumption of compressed air;
- efficiency less than 50%;
- high wear of mechanical components;
- low, insufficient for ultrasonic drying generated sound pressure level, less than 140 dB;

Along with this, the generated low-frequency impact (not higher than 16 kHz) at a sound pressure level of 140 dB is dangerous for humans.

The ultrasonic emitters developed to date, based on piezoelectric oscillatory systems, have a number of advantages compared to gas-jet ones [7,8]:

- the level of efficiency exceeds 50%;
- small weight and size characteristics;
- the ability to form the level of acoustic pressure in the air above 150 dB;
- ability to function at high temperatures of the gaseous medium;
- exposure frequency more than 20 kHz.

Despite the obvious advantages of acoustic drying compared to convective drying, the former has not found widespread use in various industries. The reduced attention to ultrasonic technologies is due to the lack of comprehensive studies that made it possible to determine the optimal regimes and conditions under which ultrasonic exposure maximally intensifies the drying process and the removal of moisture from the material [9].

Thus, carrying out experimental studies of ultrasonic drying in order to identify the optimal modes and conditions that provide an increase in the efficiency of the process is an urgent task and needs to be addressed.

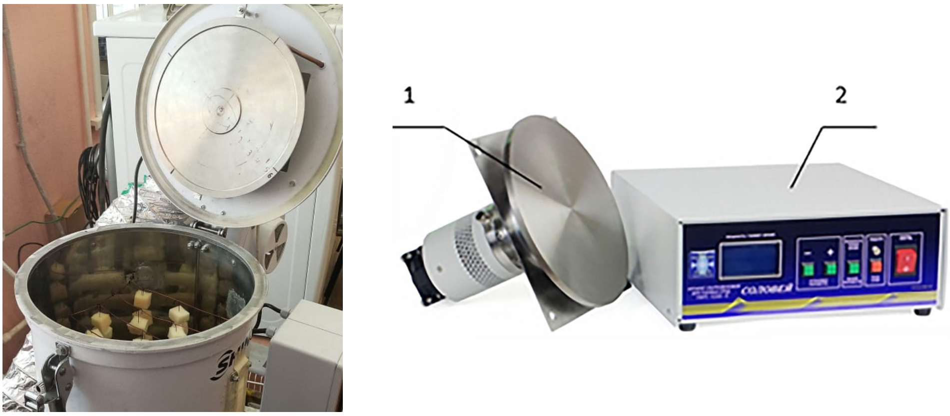
The experimental data obtained will make it possible to develop specialized drying equipment that provides optimal modes and conditions that maximize the drying process. Also, based on the results of the research, the requirements for sources of acoustic impact will be determined and existing ultrasonic emitters will be developed and/or modified to form the required distribution of oscillations in a gaseous medium [10].

2 Materials and methods

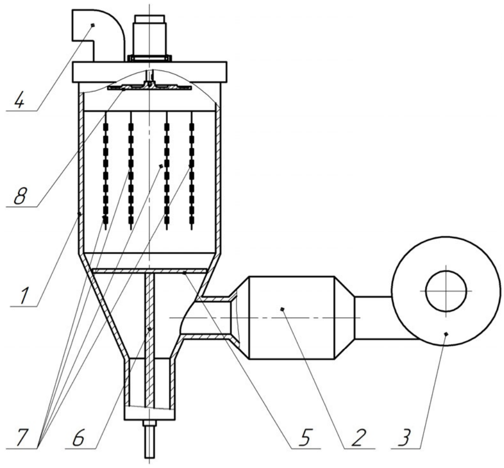
For research, a specialized experimental stand for ultrasonic drying was developed (Figure 1).

The stand is a cylindrical heat-insulated chamber (1) (technological volume with a diameter of 390 mm and a length of 450 mm).

 https://doi.org/10.1051/e3sconf/202339001017



a) 1 – ultrasonic oscillatory system with a disk emitter; 2 - electronic generator



b) 1 – technological volume; 2 - heater; 3 - ventilation unit; 4 - outlet pipe; 5 - reflector; 6 - guide; 7 - dried material; 8 - ultrasonic disk emitter

Fig. 1. The equipment Used: a - photo of the drying plant and ultrasonic disk emitter; b - scheme of the drying plant.

A source of ultrasonic vibrations (8) is installed inside the chamber. The source of ultrasonic vibrations is made in the form of a piezoelectric oscillatory system with a radiating element in the form of a flexural oscillating disk made of titanium alloy (Figure 2a). The ultrasonic transducer is powered by an electronic generator with a phase locked loop system. Technical characteristics of ultrasound equipment are presented in Table 1.

Table 1. Technical characteristics of the ultrasonic emitter.

Parameter	**Value**
Emitter diameter, mm	250
Resonant frequency of the oscillatory system, kHz	23.15
Maximum power consumption, W	150
Oscillation amplitude of the disk emitter, μm	40

 https://doi.org/10.1051/e3sconf/202339001017

The heater (2) together with the ventilation unit (3) are designed to heat the drying agent and pump it into the technological volume - the drying chamber.

The removal of the outgoing drying agent is carried out through the outlet pipe (4). A drying agent (heated air) is supplied from the conical part of the drying chamber using a fan heater (2, 3) with a power of 2 kW with a temperature stabilization system.

Control and stabilization of the temperature of the drying agent is carried out by means of a PID controller, while the temperature sensor is installed at the outlet of the heater.

The flow rate of the drying agent is carried out by means of an anemometer installed on the outlet pipe, while the flow rate is controlled using a slide gate at the inlet of the ventilation unit.

To implement the resonant amplification of ultrasonic vibrations in order to increase the level of sound pressure in the volume of the drying chamber, a reflector (5) is installed opposite the ultrasonic emitter. The reflector has the ability to move along the technological volume. To provide the possibility of adjusting the distance from the reflector to the emitter in order to identify the optimal (resonant) distance, the reflector is installed on the lead screw-guide (6).

To reduce the degree of absorption of ultrasonic vibrations by additional structural elements, the material to be dried (7) is evenly placed on wire hangers. In addition, such fastening of the dried material has a minimal effect on the distribution of gas flows inside the chamber.

3 Results and discussion

Before carrying out experimental studies, the sound pressure level was measured. Next, the position of the reflector was adjusted in order to form a standing wave in the volume of the drying chamber. The sound pressure level was measured with an Ecophysics-110A sound level meter. The measurements showed that the sound pressure level was about 162dB.

The next stage of research was filling the volume of the drying chamber with the material to be dried. Foam rubber cubes (dimensions 15x15x15 mm) were used as the dried material, since foam rubber has stable geometric dimensions at different moisture content and different temperatures, which reduces the likelihood of additional factors that reduce the accuracy of the results of experimental studies. The initial moisture content of foam rubber was 900%. The initial mass of foam rubber was 6 grams. In the process of removing moisture from the material with simultaneous convective and acoustic effects, the sound pressure level inside the drying chamber was measured. Figure 2 shows the dependence of the sound pressure level on the moisture content of the dried material.

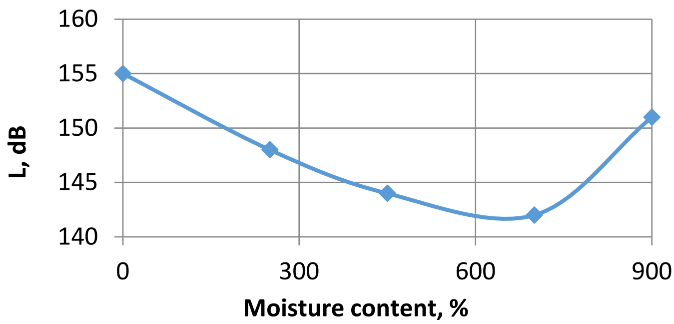


Fig. 2. The dependence of the sound pressure level on the moisture content of the foam rubber.

The analysis of the data obtained allowed us to draw the following conclusions: in the presence of dry foam rubber on suspensions, the sound pressure level decreases due to the absorption of acoustic vibrations by the foam rubber. The sound pressure level in the presence of dry foam rubber on suspensions was 155 dB.

Foam rubber with a moisture content of 900% absorbs ultrasonic vibrations much more strongly, which leads to a decrease in SPL to 151 dB.

As can be seen from the graph, there is an extremum at a foam rubber moisture content of 700%. With such a moisture content, a sufficient amount of moisture is formed on the surface of the foam rubber cube, which ensures maximum absorption of acoustic vibrations.

The next stage of the study was to identify the effect of drying agent consumption on drying efficiency at a constant temperature (600 C). Figure 3a shows the curves of moisture removal from foam rubber at a drying agent temperature of 600C at a drying agent speed inside the drying chamber (0.1 m/s and 0.2 m/s) both in the presence and in the absence of ultrasonic exposure.

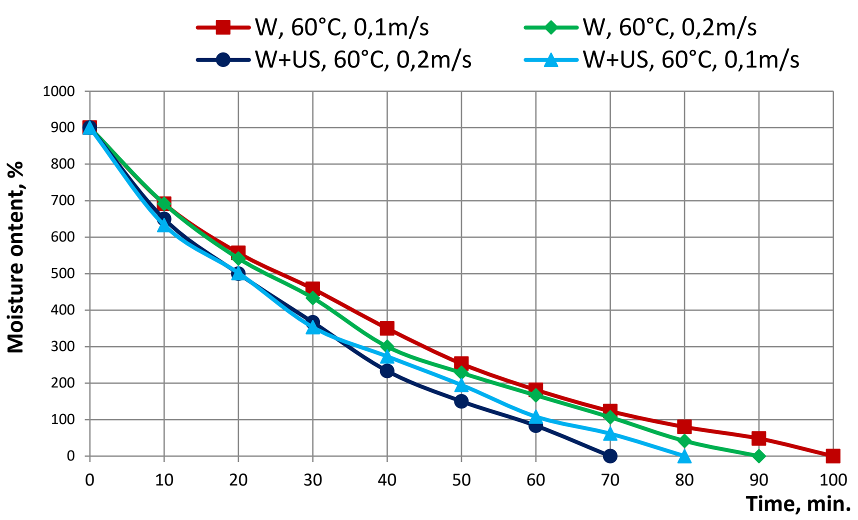


Fig. 3. Experimental foam drying curves under various conditions at a temperature of 600C.

It can be seen from the graphs (Figure 3) that changing the speed of the drying agent from 0.1 m/s to 0.2 m/s during convective drying (without ultrasonic exposure) can slightly reduce the drying time from 100 minutes to 90 minutes (10%). Changing the speed of the drying agent does not have any significant effect on the drying efficiency.

With ultrasonic action, changing the speed of the drying agent from 0.1 m/s to 0.2 m/s reduces the drying time by 10 minutes, from 80 minutes to 70 minutes. Due to the acoustic impact during the drying process with a drying agent speed of 0.2 m/s, the drying time is reduced by 20 minutes, from 90 minutes to 70 minutes.

At the next stage, it was proposed to reduce the temperature of the drying agent to 400C, while the gas velocity in the chamber was 0.2 m/s.

This temperature is required when drying very temperature sensitive, thermolabile products. Figure 4 shows foam rubber drying curves under these conditions (drying agent temperature 400C together with and without ultrasonic treatment).

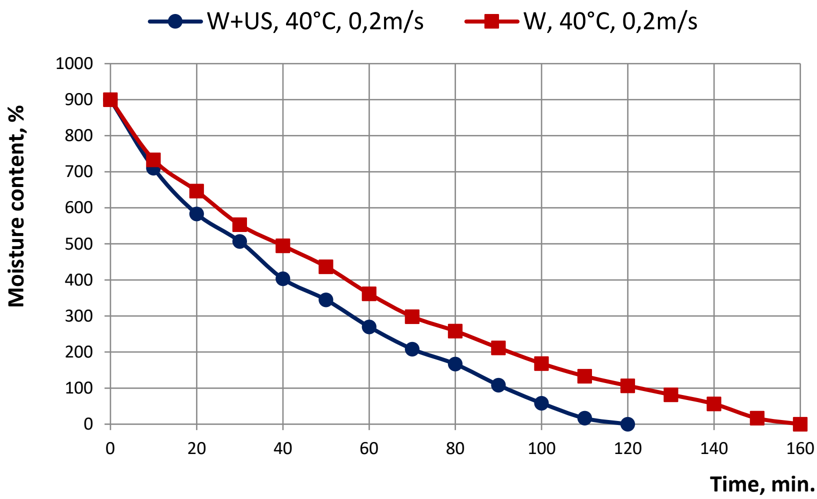


Fig. 4. Experimental foam rubber drying curves under various conditions at a temperature of 400 C.

Analysis of the obtained data showed that at a temperature of the drying agent of 400C - the dependences in Figure 4, due to ultrasonic exposure, the drying time is reduced by 25% (from 160 minutes to 120 minutes).

4 Conclusion

In the process of conducting experimental studies, a stand was developed for drying with automatic maintenance of the set temperature. A flexural-oscillating disk radiator was used as a source of ultrasonic action. The conducted studies have shown that changing the speed of the drying agent from 0.1 m/s to 0.2 m/s during convective drying can slightly reduce the drying time from 100 minutes to 90 minutes (10%). In the presence of ultrasonic action, changing the speed of the drying agent from 0.1 m/s to 0.2 m/s allows reducing the drying time by 10 minutes, from 80 minutes to 70 minutes. Due to the ultrasonic exposure at a drying agent speed of 0.2 m/s, the drying time is reduced from 90 minutes to 70 minutes. At a drying agent temperature of 400C, the drying time is reduced by 25% due to ultrasonic exposure (from 160 minutes to 120 minutes). The drying chamber provides a sound pressure level of at least 143dB.

The study was carried out by a grant from the Russian Science Foundation (project № 21-79-10359), https://rscf.ru/en/project/21-79-10359/.

References

1. D. Piotrowski, A. Lenart, O. Borkowska, Pol. J. Food Nutr. Sci. **57 2(A)** 141-146 (2007)
2. G. Grdzelishvili, P. Hoffman, *Infrared drying of food products* (Czech Technical University in Prague, 2012)
3. N. Adak, N. Heybeli, C. Ertekin, Food Chemistry **219** 109-116 (2017)
4. G. Musielak, D. Mierzwa, J. Kroehnke, Trends in Food Science & Technology **56** 126-141 (2016)

5. Y. Liu, Y. Sun, S. Miao, F. Li, D. Luo, J. Food Sci. Technol. **52(8)** 4955-4964 (2015)
6. Ch. Peng, Ayyoub M. Momen, Saeed Moghaddam, Energy **138(C)** 133-138 (2017)
7. H. Sabarez, J.A. Gallego-Juarez, E. Riera, Drying Technology: An International Journal **9** 989-997 (2012)
8. K. Fan, M. Zhang, A.S. Mujumdar, Ultrason Sonochem **39** 47-57 (2017)
9. V.N. Khmelev, A.V. Shalunov, V.A. Nesterov, Ultrasonics **114** 10641 (2021)
10. H. Xian, D. Liu, F. Shang, Y. Yang, X. Du, A.S. Mujumdar, L. Huang, Drying technology **4** 723-729 (2007)
11. V.N. Khmelev, A.V. Shalunov, D.S. Abramenko, R.V Barsukov, A.N. Lebedev, Journal of Zhejiang University **12(4)** 247-254 (2011)