Compact Ultrasonic Drier for Low-temperature Dehydration of Products in Food Industry

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Abstract **– The article is devoted to the method of low-temperature drying of materials of the food industry with the application of compact drier conssting of the ultrasonic vibration system with the alluminium stepped-variable in thickness disk radiator.**

Index Terms **– ultrasonic dehydration, disk radiator, ultrasonic vibration system.**

I. Introduction

At present for drying of different materials conventional (hot-air) driers are mostly used. They can be characterized by high power consumption, a high percentage of defective goodes because of overheating and irregular drying, continuous duration of drying, unsuitability for dehydration of thermoliable, inflammable and dangerously explosive materials. That is why processes of thermal high-temperature drying in many cases do not satisfy the modern requirements in functionality and efficiency (productivity and quality of final products) that causes the necessity of improvement of dehydration process.

One of the most effective way of solving the problem of is the application of non-contact power influence by high-intensity acoustic or ultrasonic vibrations [1]. Such tpe of drying does not lead to heating of material to be dried and it is one possible way of drying of temperature sensitive, easily oxidable and inflammable products. Moreover acoustic drying influences on consumer properties of products (for example, preserves flavouring properties of production, lengthens storage life and germinability of seeds, preservation and quality of regeneration of diary products, etc.) [2,3].

The main problem restricting practical use of non-contact power influence by high-intensity acoustic or ultrasonic vibrations for practical dehydration of materials and creation of industrial driers is connected with the difficulties of generation of high-intensity elastic vibrations in gas media.

II. Theory

It is known [4], that for acoustic or ultrasonic dehydration with the speed exceeding thermal drying the radiator should provide generation of elastic vibrations with the intensity of no less than 130 dB in gas media.

Acoustic dehydration systems desingned in our country and abroad at the end of 20^{th} century were based on the application high-intensity (more than 130 dB) radiation of jet-edge generators (whistles) at the frequency range of 3...10 kHz. They are not widely used because of high cost of compressor systems, which are necessary for supply of the jet-edge generators with compressed air, low reliability of the generators and difficulties with acoustic protection of the personnel.

At the same time drying by ultrasonic vibrations did have even laboratory application due to the absence of high-efficient radiators,which are able to generate high-intensity ultrasonic vibrations at the frequencies of more than 20 kHz.

As for the operation at ultrasonic frequencies jet-edge generatorsare not suitable because of their low radiated power (intensity), there is a need to design the radiators of new type. This radiator should consist of three main units: a piezoelectric transducer, a concentrator – an amplifier of mechanical vibrations and a radiator. The power supply of such radiators should be realized from the electronic generator providing transformation of power of electrical network into the energy of electric oscillation of ultrasonic frequency. In view of high Q of the piezoelectric transducer in the generators maintenance of optimum resonant mode and amplitude stabilization of radiated vibrations should be provided [5].

As it is known [4], at the central excitation of the flat thin disk distibution of vibrational displacement of bending vibrations along the disk surface will have a view o f standing waves. As different points of the disk surface radiate vibrations in opposite phases at some distance from the disk on its axis, acoustic radiation of separate parts of the disk is partly compensated. In order to reduce the influence of the parts of the disk radiating vibrations in minus phase the thickness of the disk in appointed areas was enlarged. That is why the radiator should be made in the form of stepped-variable disk in thickness Fig.1. It is evident from the distribution of vibrations, that vibration amplitude of "negative" zones reduces in comparison with vibration amplitude of "positive" zones. At that total cancellation of ultrasonic vibrations in air does not occur.

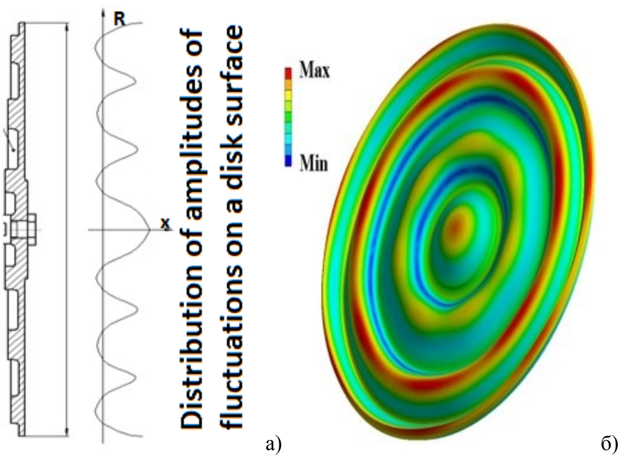


Fig. 1. Disk of stepped-variable section with primary radiation of one phase of vibrations

To provide maximum vibration amplitude and possibility of operation at maximum mechanical stress the radiators are made of titanium alloys. At present ultrasonic devices with titanium radiators of different diameter (from 200 up to 430 mm) are designed and applied in practice (от 200 до 430 мм) [6].

Unfortunately parallel with certain advantages titanium radiators have a number of disadvantages. First of all it is high value of material and difficulties of working leading to high percentage of defective articles and resulting in essential distinctions of performance specifications of produced radiators. This restricts their practical application, requires further development and improvement of radiator construction. It is evident, that one of the ways of perfecting of radiators is search of new materials for their production.

In this connection to reduce the cost of the radiator and decrease of defective articles at the production it was proposed to produce the radiators of stepped-variable form from alluminium alloy B-95 and of small size (160 mm). Developed and produces device (the generator and the vibrating system) with such radiator is presented in Fig. 2.

Fig. 2. Ultrasonic device with disk radiator

Performance specifications of the device developed and used during the investigations are presented in Table 1.

TABLE I
PERFORMANCE SPECIFICATIONS OF ULTRASONIC TECHNOLOGICAL DEVICE

Consumed power, no more than, VA	160
Power supply from ac networks, V	220±22
Intensity of vibrations (1 m), dB, no less than	135
Overall dimensions of the electronic generator, mm	270×270×110
Overall dimensions of the vibrating system, mm	Ø160x150
Diameter of the radiator, mm	160
Frequency of radiating vibrations, kHz	22

During the experiments on drying of materials outside the drying chamber developed radiator did not provide effective and even drying because of low efficiency of of ultrasonic influence due to irrational use of energy of ultrasonic vibrations. As a result of this there is a need to design special technological volumes (drying chambers), which are able to provide maximum effective and even distribution of energy of generated ultrasonic vibrations.

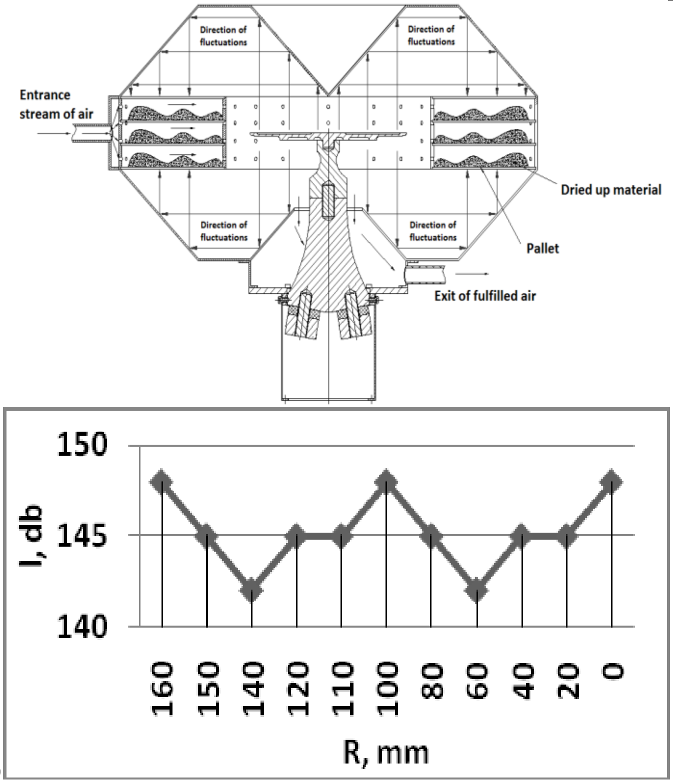
III. Construction Of Developed Ultrasonic Drier

At present different constructions of drying chambers are used in practice. The simplest modification of the drying chamber is hollow closed cylinder made of sound reflective material. Mixing of material to be dried is provided due to rotation of te technological volume. Supply of ultrasonic vibrations can be realized at the side of open butt or cylinder surface (through the net wall).

The application of developed compact (with the diameter of 160 mm) and low-powered (less than 160 W) radiator is impossible in such driers, as mean intensity of radiation in the volume does not exceed 135 dB, that does not allow to intensify the dehydration process.

For effective use of ultrasonic energy dehydration system with chamber of special form was designed [6…8], which allowed to realize the dehydration process at the temperature of drying agent of no more than 40° C, heated air was used as a drying agent.

The shape of the drying chamber provides resonant amplification and even distribution of ultrasonic vibrations radiating from both sides of the disk at the surface of the material to be dried, which is placed on trays [9]. Scheme of ultrasonic drier, directions of ultrasonic vibration propagation and air flows are shown in Fig. 3 (a).



a)
b)

Fig. 3. Scheme of ultrasonic dehydration system (a) and distribution intensity level of ultrasonic vibrations in the close volume of the drying chamber (b)

The dehydration system consists of developed radiator with the diameter of 160 mm made of alluminium alloy B-95 and the case of the drier. The The case has lower and upper reflectors, they are shown together with the radiator in Fig. 3 (a). The lower reflector (cover) is made removable and is used loading material to be dried.

To prove the efficiency of designed dehydration system a number of experiments were carried out. At the first stage the distribution of the intensity level of ultrasonic radiation in the volume of the drying chamber was studied. This distribution is shown in Fig. 3(b). Speed and quality of drying depends on the value and uniformity of distribution of the intensity of ultrasonic vibrations respectively.

Measurement of intensity level of vibrations took place in locked volume with closed upper cover. At this due to the drying chamber of special size a standing wave mode should be provided in all volume of drying chamber.

Thus from the presented results it is evident, that this drying chamber provides practically uniform distribution of ultrasonic vibrations with the intensity of 145 dB in all internal volume (it is possible due to establishing of a standing wave mode), which is enough for realization of ultrasonic drying. Electric power consumed by the electronic generator does not exceed 160 W.

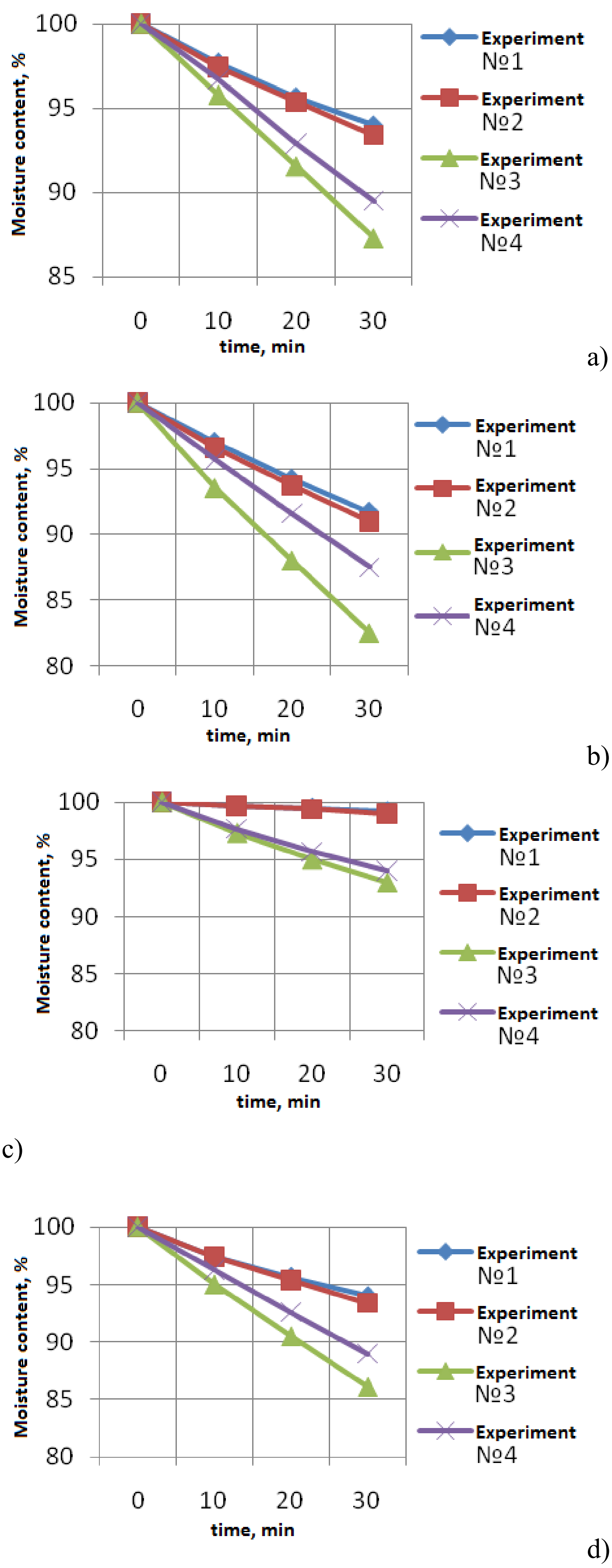
To prove the efficiency of developed dehydration system drying of different materials was studied.

IV. EXPERIMENTS

During experimental investigations the temperature in the drying chamber was 40°C, humidity was 50 – 65 %.

The experiments were directed on determining of the efficiency of drying by ultrasonic vibrations of samples of different products with various size and form. Carrots cut into disks with the diameter of up to 28 mm and thickness of 5 mm, carrots cut in bars 35x5x3 mm, whole ginseng root, and ginseng roots cut into disks of 5 mm thickness were used as experimental samples. The total weight of dryable samples of each type was 3 kg. Each type of samples was exposed to four combinations of energy deposition: experiment №1 without additional influence; experiment №2 at the influence of ultrasonic vibrations; experiment №3 at the influence of ultrasonic vibrations with airflow of heated air; experiment №4 at the influence of air flow heated up to 40^0C.

Fig. 4 shows dependence of residual moisture content in carrots and ginseng on the duration of drying. These results demonstrate, that in both cases noticeable effect after influence of ultrasonic vibrations can be achieved only after supply of heated drying agent and it can remove as much as 50 g of moisture from 1 kg of mass of dryable sample. At that effect of ultrasonic radiation increases with the duration of drying. It can be explained, that during the drying by heated air alone, on the surface of the carrots there is a layer with low moisture content, which prevents effective moisture removal from the surface.



a) – carrot cut into disks; b) – carrot cu into bars; c) – whole ginseng root

d) – ginseng root cut into disks

Fig. 4.Dependence of resudial moisture content of carrot and ginseng on duration of drying

The thickness of this layer increases over time decreasing moisture removal. With ultrasonic vibrations this does not occur. It means, that during the drying of samples with a capillary-porous structure ultrasonic vibrations help to transfer moisture from the inner layers of the drying material to the surface, where it can be removed with the help of the drying agent. The effect of the application of ultrasonic vibrations is very significant in the case shown in Fig. 4 (b) corresponding to larger total surface of the mass transfer.

Fig. 4 (c) and (d) show behavior of residual moisture content of ginseng samples on the duration of drying.

Diagrams in Fig. 4 (c) indicates the low efficiency of drying of whole ginseng root. The contribution into the efficiency of the drying is negligible. The effect of the application ofultrasonic vibrations and heating of the drying agent is not observed. Obtained results can be explained by the presence of peel on the ginseng root surface, which blocks active moisture evaporation and prevents moisture emission from the inner layers of the root to the surface under influence of ultrasonic vibrations minimizing the effect of the use of ultrasound. In contrast, the dependences in Fig. 4 (d) shows substantial changes contributed by ultrasonic vibrations to the efficiency of drying achieving additional moisture removal of up to 29 g from 1 kg of sample mass.

Thus after 30 min of carrot drying under the influence of acoustic vibrations with heated airflow its final moisture content was approximately 87% and 82%, powerinputs was 0.6 kW. When ultrasonic drier with jet-edge generator was used for drying of such amount of gelatin, it took 230 min, and power inputs were 2.3 kW.

After drying of ginseng root for 30 min under the influence of acoustic vibrations with flows of heated air its residual moisture content was approximately 93% and 86% for both samples, power inputs were 0.6 kW. At the application of drier with jet-edge generator it took 300 min for drying of the same amount of genseng root, power inputs were 3 kW.

V. Conclusion

As a result of carried out reearches the device for ultrasonic drying was developed, where the tasks of efficiency uncrease of ultrasonic influence and increase of drying speed were solved due to:

1) design and application of piezoelectric ultrasonic vibrating system with the transducer in the form of a flexural-vibrating disk with the diameter of 160 mm made of alluminium alloy B-95 as a source of ultrasonic vibrations, this disk lets generate ultrasonic radiation with the intensity of no less than 135 dB, and consumed power of less than 160 W;

2) development of drying chamber of special form providing a standing wave mode to increase the intensity of ultrasonic influence up to 145 dB at the use of designed radiator of 160 mm diameter from alluminium alloy and full use of the energy of ultrasonic vibrations to increase the efficiency of dehydration process.

Carried out experimental researches proved the efficiency of developed equioment for ultrasonic drying and the perspective of application as a compact industrial drying systems.

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