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Original Study Article

Microwave device for heat treatment of meat by-products and waste

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ABSTRACT

BACKGROUND: In the conditions of farms, there is a problem of neutralizing unpleasant odors during heat treatment of secondary meat raw materials to preserve the consumer properties of protein feed at low operating costs.

AIM: Development of the device for heat treatment with disinfection and neutralization of the unpleasant odor of crushed secondary meat raw materials with the integral effect of an ultra–high frequency electromagnetic field, a bactericidal flow of UV rays and ozone in a continuous mode with electromagnetic safety ensured.

METHODS: The raw materials are the stomach chambers of ruminants. The basic idea, principle of operation and design of the device are based on the propagation of microwave oscillations in a resonator with a spiral decelerating system. The microwave device contains a non-ferromagnetic cylinder with a perforated lower base, a coaxially arranged non-ferromagnetic spiral cylinder and an electrically driven fluoroplastic auger with a solid screw surface. The average perimeter of the annular volume, between the cylinder and the spiral cylinder forming the coaxial resonator, and its height are multiples of half-wavelength. Corona brushes are mounted to the annular base of the cylinder, under which electric gas discharge lamps powered by 1 kHz frequency generators are radially located, and a ceramic annular spherical surface is located under the lamps. Magnetrons are mounted along the perimeter of the outer cylinder with a shift of 120 degrees. The crackling is removed using a pneumatic conveyor.

RESULTS: The feature of the coaxial resonator is that the inner core is formed as a spiral decelerating system. Therefore, the intrinsic Q-factor of the resonator is high, about 115000, therefore, the expected thermal efficiency is 0.7–0.75. The factor of dielectric losses of raw materials with a decrease in humidity from 76% to 30% is reduced by five times. Thus, while keeping the electric stress at the level of 1.2–2 kV/cm, the electromagnetic field power dissipated in a unit of the volume of the crackling decreases by five times, from 34 500 to 6800 W/cm^3.

CONCLUSIONS: A new design solution with a spiral coaxial resonator, the use of a ceramic reflector, and a number of physical factors made it possible to develop the design of the operation chamber for the heat treatment of ruminant slaughter waste with the neutralization of unpleasant odors with a capacity of 30–35 kg/h and specific energy costs of 0.16–0.19 kWh/kg.

Keywords: electromagnetic field; corona brushes; ozone; ceramic surface; bactericidal flow; screw auger.

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Оригинальное исследование

СВЧ установка для термообработки вторичного мясного сырья

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АННОТАЦИЯ

Обоснование. В условиях фермерских хозяйств возникает проблема нейтрализации неприятных запахов при термообработке вторичного мясного сырья для сохранения потребительских свойств белкового корма при низких эксплуатационных затратах.

Цель работы — разработка установки для термообработки с обеззараживанием и нейтрализацией неприятного запаха измельченного вторичного мясного сырья комплексным воздействием электромагнитного поля сверхвысокой частоты, бактерицидного потока УФ лучей и озона в непрерывном режиме с обеспечением электромагнитной безопасности.

Материалы и методы. Сырьем являются камеры желудка жвачных животных. Основная идея, принцип работы и конструкция установки базируется на распространении СВЧ колебаний в резонаторе со спиральной замедляющей системой. СВЧ установка содержит в неферромагнитном цилиндре с перфорированным нижним основанием, соосно расположенный неферромагнитный спиральный цилиндр и электроприводной фторопластовый шнек, со сплошной винтовой поверхностью. Средний периметр кольцевого объема, между цилиндром и спиральным цилиндром, образующего коаксиальный резонатор, и его высота кратны половине длины волны. К кольцевому основанию цилиндра установлены коронирующие щетки, под которыми радиально расположены электрогазоразрядные лампы, запитанные от генераторов килогерцовой частоты, а под лампами расположена керамическая кольцевая сферическая поверхность. Магнетроны установлены по периметру наружного цилиндра со сдвигом на 120 градусов. Шквара удаляется с помощью пневмотранспортера.

Результаты. Особенность коаксиального резонатора — это образующая внутреннего цилиндра, которая представлена в виде спиральной замедляющей системы. Поэтому собственная добротность резонатора высокая, в пределах 115 000, следовательно, термический КПД может составить 0,7–0,75. Фактор диэлектрических потерь сырья с уменьшением влажности с 76 до 30% уменьшается в пять раз. Значит, при сохранении напряженности электрического поля на уровне 1,2–2 кВ/см, мощность электромагнитного поля, рассеиваемая в единице объема шквары, уменьшается в пять раз с 34 500 до 6800 Вт/см^3.

Заключение. Новое конструктивное решение со спиральным коаксиальным резонатором и использованием керамического отражателя, комплекса физических факторов позволило создать конструкции рабочей камеры для термообработки отходов убоя жвачных животных с нейтрализацией неприятного запаха, производительностью 30–35 кг/ч и удельными энергетическим затратами 0,16–0,19 кВт·ч/кг.

Ключевые слова: электромагнитное поле; коронирующие щетки; озон; керамическая поверхность; бактерицидный поток; винтовой шнек.

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BACKGROUND

Protein feed for animals is produced from meat waste from animal slaughter, as approved by the veterinary service for processing. In particular, these wastes include the stomach chambers of ruminant animals (rumen, honeycomb, manifold, and abomasum) as fat-containing substandard raw materials. Technical fat and greaves are strained from these wastes for animal feed [1, 2]. Therefore, devices that facilitate the direct contact of raw materials with hot water or direct steam are used (p. 322 in the book [3]). Simultaneously, a long duration of contact between raw materials and a high-temperature coolant reduces the quality of fat and greaves.

A microwave installation with a biconical resonator and packages of plates for heat treatment of confiscated meat and bones is identified (patent No. 2803127 [4]). Such an installation contains a vertically located biconical nonferromagnetic resonator in the form of conical shells. The outer and inner packages of fluoroplastic plates in the form of truncated cones are coaxially located inside the resonator. The internal package of plates is installed on an electrically driven dielectric shaft with a spiral dielectric screw in the lower conical shell. Other microwave installations for heat treatment of raw meat are also known [5–6]. Such installations can be used to improve the processing quality of secondary meat raw materials, but they do not neutralize the unpleasant odor.

The problem arises of neutralizing unpleasant odors during heat treatment of secondary meat raw materials to preserve the consumer properties of protein feed at low operating costs [7]. In farm conditions, odor neutralization during heat treatment of confiscated products is an urgent task.

This work aimed to develop a multigenerator radio-tight installation with a microwave energy supply, a bactericidal flow of UV rays, and ozone into a coaxial resonator for heat treatment with disinfection and neutralization of the unpleasant odor of crushed secondary meat raw materials in a continuous mode.

METHODS AND TOOLS OF RESEARCH

The stomach chambers of ruminant animals (rumen, manifold, honeycomb, and abomasum) and other meat waste are the crushed raw materials [8]. The main idea, operating principle, and installation design are based on the propagation of microwave oscillations in a resonator with a spiral slow-wave system. The generatrix of the inner cylinder is presented in the form of a spiral when designing a coaxial resonator. The deceleration coefficient of the system can be modified by varying the ratio of the length of one turn of the spiral to its pitch, and raw material particles can be passed between turns into the annular volume of the resonator in a continuous mode due to centrifugal force for heat treatment in the suspension state.

A microwave installation with a coaxial spiral resonator for heat treatment of secondary meat raw materials in a continuous mode (Fig. 1) contains a vertically installed nonferromagnetic cylinder 2 with a perforated lower base 7, a coaxially located nonferromagnetic spiral cylinder 4, and an electrically driven fluoroplastic auger 5, with a continuous helical surface and a fluoroplastic shaft. Under the loading container, the first screw of the auger comprises a nonferromagnetic material. The side surface of coaxially located nonferromagnetic and nonferromagnetic inner cylinders is represented by a spiral of nonferromagnetic material (nonferromagnetic spiral cylinder), forming a coaxial resonator 3 (annular volume). The average perimeter of the annular volume and the height of the coaxial resonator are multiples of half the wavelength. A nonferromagnetic cylindrical storage tank 8 with an inclined base containing an evanescent waveguide 9 with a ball valve is attached to the lower perforated base of the nonferromagnetic cylinder, and a nonferromagnetic loading tank 1 with a valve is installed on the upper nonferromagnetic annular base of the nonferromagnetic cylinder. Nonferromagnetic corona brushes 13 are installed on the inner side of the annular base of the cylinder with a radial shift, under which electric gas-discharge lamps 12 are radially located and powered by kilohertz frequency generators located on the outside of the lateral surface of the cylinder 2. Under the electric gas-discharge lamps, a ceramic annular spherical surface 11 exists, demonstrating a larger diameter than that of the outer cylinder by half the wavelength. From these annular holes (a hole in the ceramic annular spherical surface and an annular hole between the outer cylinder and the ceramic surface), the bactericidal flow of UV radiation spreads into the raw material, thereby remaining in a suspended state. Waveguides with magnetrons 6 and fans are installed along the perimeter of the cylinder lateral surface with a shift of 120° and a shift in height. A suction dielectric pipe 10 of the pneumatic conveyor, which is covered with a mesh and has cells that are smaller than greaves (5–6 mm), is found above the cylinder perforated base 7. The continuation of the dielectric pipe 10 of the pneumatic conveyor behind cylinder 2 comprises nonferromagnetic material.

Electric gas-discharge lamps for a bactericidal flow of UV radiation can be connected to kilohertz frequency generators, as in Ultraton (22 kHz) or in d'Arsonval (110 kHz) [9], or the lamps can light up due to the electromagnetic radiation energy in the microwave range. The temperature of the lamp bulb affects the intensity of ultraviolet radiation; the maximum radiation of the lamp corresponds to a temperature of its walls of 40 °C. In this case, the voltage across the lamp drops, the current increases, and the lamp power maintains its value due to a change in the resistance of the gas discharge. The lamp, together with the kilohertz frequency generator, is an oscillatory circuit, and the discharge that occurs in the lamp (with each change in the current direction) is a source of electromagnetic oscillations in the radio wave range. Electric gas-discharge lamps (40 W) with a bactericidal flow of UV radiation begin to exhibit corona and are accompanied by long sparks when located at a distance of 0.5–1 cm from the nonferromagnetic brush. Corona discharge occurs in brushes with thin nonferromagnetic needles. The area near the brush is characterized by higher values of electric field intensity (less than 15 kV/cm), around electric discharge lamps occurs a crown-shaped glow, ionization process and ozonation of air occur.

In this case, the main operating factors are a bactericidal flow, a sinusoidal current of the supersonic frequency, and a high-voltage (3.5 kV) corona discharge, which ensures air ozonation and heat generation. The presence of these factors in an ultrahigh frequency electromagnetic field (2,450 MHz) provides a unique bactericidal effect with disinfection and neutralization of unpleasant odors during heat treatment of crushed stomach chambers of ruminants.

The technological process of heat treatment, disinfection, and neutralization of unpleasant odors of secondary meat raw materials in a continuous mode in a microwave installation with a coaxial resonator is described as follows: pre-crushed pieces of secondary meat raw materials (chambers of ruminants, namely rumen, honeycomb, manifold, and abomasum) are loaded into a loading container 1 with the valve closed. The kilohertz frequency generators are activated, after which the electric gas-discharge lamps 12 light up and

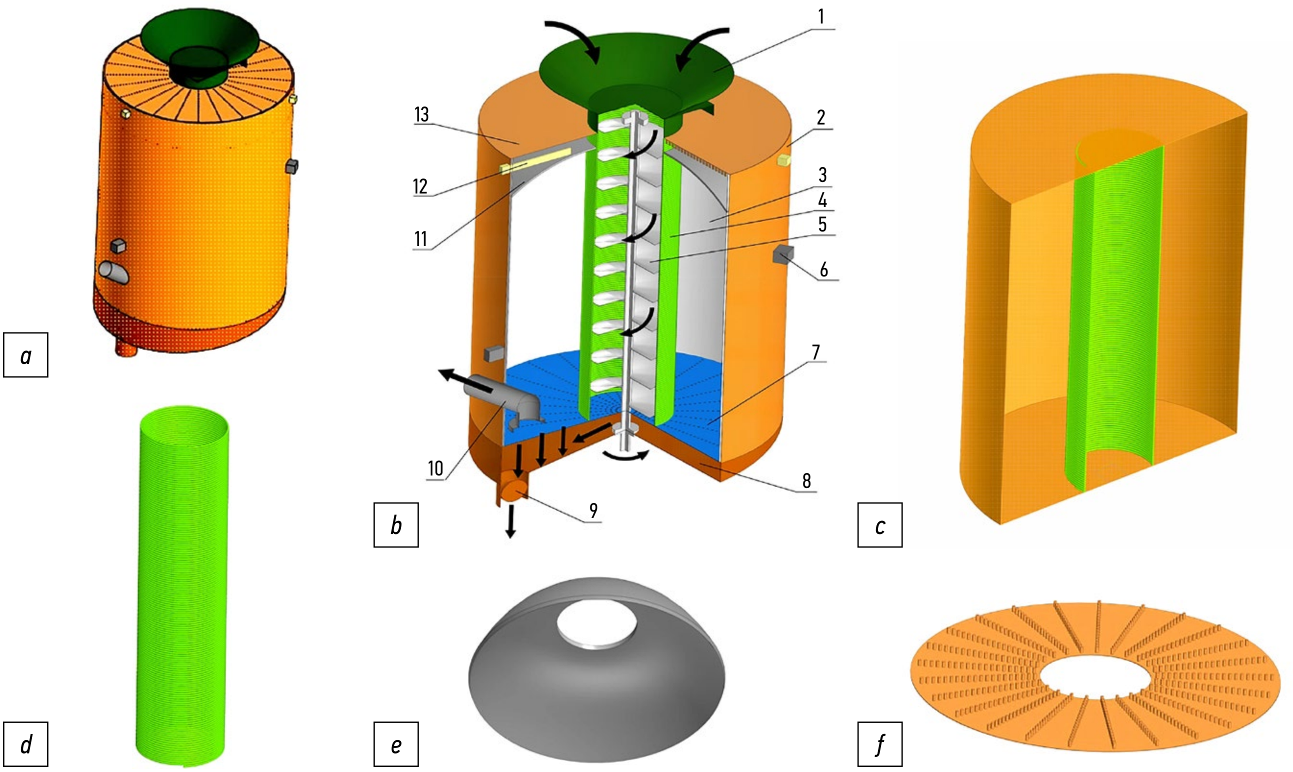

Fig. 1. The microwave device for heat treatment of meat by-products and waste in a continuous mode: *a*) general view; *b*) general view in section with positions; *c*) coaxial resonator in section; *d*) non-ferromagnetic spiral cylinder; *e*) ceramic annular spherical surface; *f*) non-ferromagnetic corona brushes at the upper base of the cylinder; *1* — non-ferromagnetic loading tank; *2* — non-ferromagnetic cylinder with a perforated lower base *7*; *3* — non–ferromagnetic coaxial resonator; *4* — non–ferromagnetic spiral cylinder; *5* — fluoroplastic auger; *6* — air-cooled magnetrons; *8* — non-ferromagnetic storage tank; *9* — transcendental waveguide; *10* — dielectric tube of the pneumatic conveyor; *11* — ceramic annular spherical surface; *12* — electric gas discharge lamps; *13* — non-ferromagnetic corona brushes.

Рис. 1. СВЧ установка для термообработки вторичного мясного сырья в непрерывном режиме: *a*) общий вид; *b*) общий в разрезе с позициями; *c*) коаксиальный резонатор в разрезе; *d*) неферромагнитный спиральный цилиндр; *e*) керамическая кольцевая сферическая поверхность; *f*) неферромагнитные коронирующие щетки на верхнем основании цилиндра; *1* — неферромагнитная загрузочная емкость; *2* — неферромагнитный цилиндр с перфорированным нижним основанием *7*; *3* — неферромагнитный коаксиальный резонатор; *4* — неферромагнитный спиральный цилиндр; *5* — фторопластовый шнек; *6* — магнетроны воздушного охлаждения; *8* — неферромагнитная накопительная емкость; *9* — запредельный волновод; *10* — диэлектрическая труба пневмотранспортера; *11* — керамическая кольцевая сферическая поверхность; *12* — электрогазоразрядные лампы; *13* — неферромагнитные коронирующие щетки.

begin to exhibit corona on the nonferromagnetic brushes 13. Ozone is then released, ensuring sterilization of the surfaces of all elements of the processing chamber. Afterward, turning on the electric drive of the fluoroplastic auger 5 and opening the valve in the loading container are required. The crushed pieces of secondary meat raw materials are then moved downward using the solid screw surface of the auger, and the magnetrons 6 with fans are activated. In the annular volume, which is presented as a coaxial resonator 3 between the nonferromagnetic cylinder 2 and the nonferromagnetic spiral cylinder 4, a uniform superhigh frequency electromagnetic field (SHF EMF), namely a traveling wave field, is excited. The SHF EMF frequency is 2,450 MHz, the wavelength is 12.24 cm, the depth of the wave penetration into the raw material is 1.7–2 cm, and the particle size of the finished greaves is 5–6 mm. Ceramic annular spherical surface 11 ensures the concentration of SHF EMF energy in the annular volume of the resonator and reduces radiation losses due to their low dielectric losses (p. 360 in [10]).

In a coaxial resonator, the lateral surface of the inner cylinder is presented in the form of a spiral with a sufficiently large length of turn and a certain pitch of turns, between which pre-crushed raw materials that are smaller than the wave penetration depth pass into the annular volume (in the coaxial resonator) during fluoroplastic auger rotation due to centrifugal force. The raw material particles in the ring resonator remain in a suspended state and are uniformly heated to 85 °C–95 °C due to polarization currents in the SHF EMF and then disinfected [11]. The fat is melted and flows through a perforated nonferromagnetic base 7 into a nonferromagnetic storage tank 8 with an evanescent waveguide 9, through which the liquid fraction can be drained by opening the ball valve. When the fluoroplastic auger 5 rotates, the greaves are discharged to the periphery and side surface of the nonferromagnetic cylinder due to the centrifugal force and are then sucked in by the dielectric pipe 10 of the pneumatic conveyor through a mesh, hindering the transport of unmelted particles of raw materials.

The coaxial resonator should have an EMF, which is excited in the form of oscillations H011 and covering a helical-shaped unit, to ensure the stability of the operation of air-cooled magnetrons. Therefore, the side surface of the inner cylinder is a spiral. A sinusoidal type of vibration is realized in the turns when the spiral is connected to the upper annular base and the lower perforated base of the outer cylinder. The types of oscillations in a coaxial resonator that differ from H011 lag behind in frequency quite strongly and can thus be effectively suppressed, ensuring the presence of only sinusoidal oscillations in the interaction space (p. 192 in [12]). This suppression will substantially increase the power of the radiation flux in the coaxial resonator. Simultaneously, the flow of radiation power passes into the spiral cylinder through the interturn gap, which comprises a fluoroplastic auger. The intrinsic quality factor of the entire resonant system, i.e., the frequency stability, increases due to the large volume of the coaxial resonator with a small surface area (a spiral-shaped surface). Interaction occurs in cases where the frequency of the microwave wave coincides with or is a multiple of the frequency of sinusoidal oscillations in the spiral turns. Therefore, the microwave energy of the traveling wave in the volume of the coaxial resonator is enhanced by selecting the spiral pitch and the length of one turn. The radio-tightness of the installation is ensured by the nonferromagnetic first screw (under the valve in the loading tank 1) of the fluoroplastic auger 5, as well as the evanescent waveguide in the storage tank 8.

Existing safety regulations indicate that operating personnel should not be exposed to electromagnetic radiation with an intensity greater than 10 μW/cm^2.

RESEARCH RESULTS AND DISCUSSION

The low dependence of deceleration on the frequency of the electromagnetic field is a unique feature of the spiral deceleration system. Therefore, at a frequency of 2,450 MHz, the possibility of using a spiral instead of a generatrix of an internal cylinder, twisted similar to a round cylinder of radius a with a constant pitch d, is considered to amplify microwave energy in a coaxial resonator. If the diameter of a nonferromagnetic wire is smaller than the spiral diameter, then it can be considered a cylinder with an infinite conductivity in the direction of the spiral turns and equal to zero in the perpendicular direction (p. 99 in [13]).

The deceleration (m) of the electromagnetic wave in the longitudinal axis direction of the spiral z is approximately equal to the ratio of the wavelength of the spiral turn to its pitch (p. 16 in [14]):

$$m \approx 2 \cdot \pi \cdot b / h = \operatorname{tg} \varphi , \qquad (1)$$

where b is the radius of the spiral along the center of the cross-section of the nonferromagnetic wire, cm; h is the spiral pitch, cm; and φ is the angle between the direction of the turns and the longitudinal axis of the spiral z.

Inside and outside the spiral (i.e., in the annular volume of the resonator), the longitudinal components of the electric field strength individually change.

The intrinsic quality factor of the coaxial resonator was calculated as the main indicator for efficiency assessment. The CST Studio Suite program was used

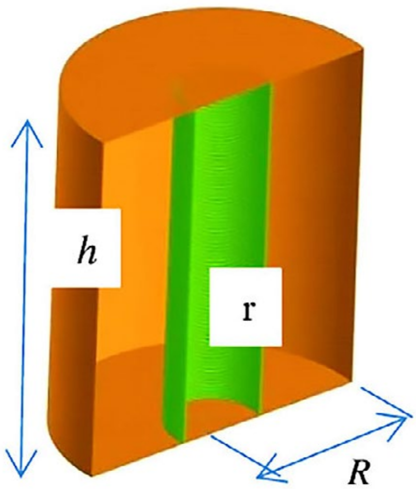

Fig. 2. Dimensions of the coaxial resonator: R = 30,6 cm; r = 9,2 cm; h = 76,5 cm.
Рис. 2. Размеры коаксиального резонатора: R = 30,6 см; r = 9,2 см; h = 76,5 см.

to study the distribution of electric field strength in a coaxial resonator with a spiral shell in the inner cylinder [15]. The intrinsic quality factor was calculated through the volume (V, m^3) and surface square of the aluminum resonator walls (S, m^2), considering the thickness of the skin layer (Δ = 1,72 μm) at a frequency of 2,450 MHz and the features of the slot resonator [14, 16]. The volume and surface square of the coaxial resonator (Fig. 2) were calculated using the following equations:

$$V_{\text{coax}} = \pi \cdot h \cdot (R^2 - r^2) = \\ = 3{,}14 \cdot 76{,}5 \cdot (30{,}6^2 - 9{,}2^2) = 204592 \text{ cm}^3, \quad (2)$$

$$S_{\text{coax}} = 2\pi\left[R \cdot h + R^2 \cdot k_1 + r \cdot h \cdot k_2\right] = \\ = 2 \cdot 3{,}14 \cdot \left[30{,}6 \cdot 76{,}5 + 30{,}6^2 \cdot 0{,}5 + 9{,}2 \cdot 76{,}5 \cdot 0{,}7\right] = \\ = 20735 \text{ cm}^2, \quad (3)$$

where k_1 is a coefficient that considers the reduction in the surface area of the resonator due to the base perforation (k_1 = 0,5), and k_2 is a coefficient that considers the reduction in the surface of the inner cylinder, made in the form of a spiral (k_2 = 0,7).

The intrinsic quality factor of a coaxial resonator is calculated as follows:

$$Q = \frac{2 \cdot V}{S \cdot \Delta} = \frac{2 \cdot 0{,}204592}{2{,}0735 \cdot 1{,}72 \cdot 10^{-6}} = 114732. \quad (4)$$

Calculation results revealed that the intrinsic quality factor of a resonator of this design is within 115,000. Therefore, the thermal efficiency can be 0.7–0.75.

Changes in the dielectric parameters were analyzed during heat treatment in an electromagnetic field of ultrahigh frequency (Figs. 3, 4) to calculate the electromagnetic field power (W/cm^3) dissipated per unit volume of raw materials in Eq. (5).

$$P = 0{,}556 \cdot 10^{-12} \cdot k \cdot E^2 \cdot f \,, \quad (5)$$

where k is the dielectric loss factor of the raw material; E is electric field strength, V/cm; and f is the frequency of the electromagnetic field (2,450 × 10^6 Hz).

Analysis results of the dielectric characteristics of raw meat at a frequency of 2,400 MHz reveal their dependence on fat content (p. 67 [17]).

The dependences of dielectric constant (ε), dielectric loss factor (k), and dielectric loss tangent (tgδ) on fat content (F, %) of raw meat are described using the following empirical equations:

$$\varepsilon = 52{,}63 \cdot e^{-0{,}022 \cdot F}, \\ k = 19{,}64 \cdot e^{-0{,}025 \cdot F}, \quad (6) \\ \text{tg}\,\delta = 0{,}37 \cdot e^{-0{,}025 \cdot F}.$$

The decrease in dielectric characteristics with increasing fat content in raw meat (Fig. 4) is due to a reduction in moisture content. Melted fat flows through the perforated base of the resonator during heat treatment of raw materials, and the moisture content of the greaves decreases. The dielectric characteristics of the raw material then change depending on the moisture content (Fig. 5).

The analysis results of the characteristics show that the dielectric loss factor of the raw material (k) during heat treatment (with a decrease in moisture content) decreases five times, from 17.6 to 3.5. Therefore, while maintaining the electric field strength at the level of 1.2–2 kV/cm, the power of the electromagnetic field (p. 259 in [18]), which is dissipated per unit volume of greaves, decreases five times.

$$P = 0{,}556 \cdot 10^{-12} \cdot k \cdot E^2 \cdot f = \\ = 0{,}556 \cdot 10^{-12} \cdot (17{,}6 \div 3{,}5) \cdot (1{,}2 \cdot 10^3)^2 \cdot 2450 \cdot 10^6 = \\ = 34523{,}6 \div 6865{,}5 \text{ W/cm}^3. \quad (7)$$

Thus, the specific dielectric losses and the amount of heat released per unit volume of raw materials decrease from 34,500 W/cm^3 to 6,800 W/cm^3.

The performance of the installation depends on the number and power of magnetrons and electric gas-discharge lamps and the power of kilohertz frequency sources, as well as the type of fat-containing raw materials. Table 1 presents the technical characteristics of the installation.

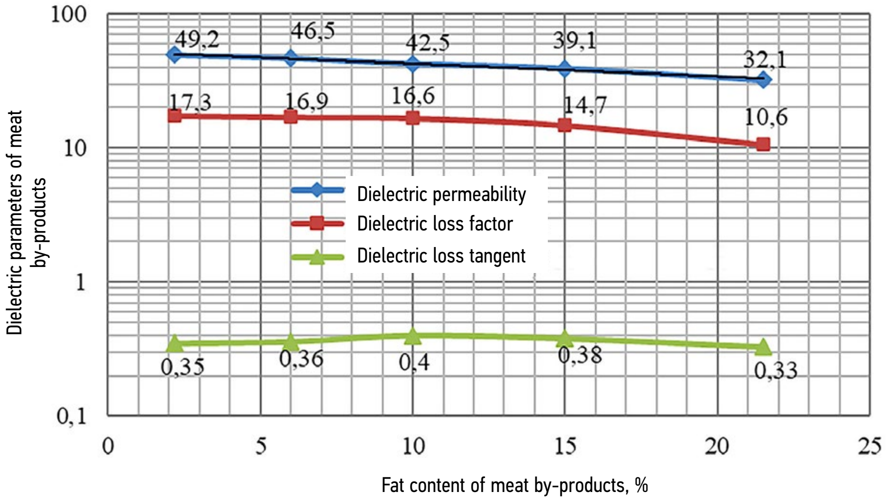

Fig. 3. Dielectric characteristics of meat by-products and waste depending on fat content at a temperature of 20°C and a frequency of 2450 MHz Dielectric [17].
Рис. 3. Диэлектрические характеристики мясного сырья в зависимости от жирности при температуре 20°C и частоте 2450 МГц [17].

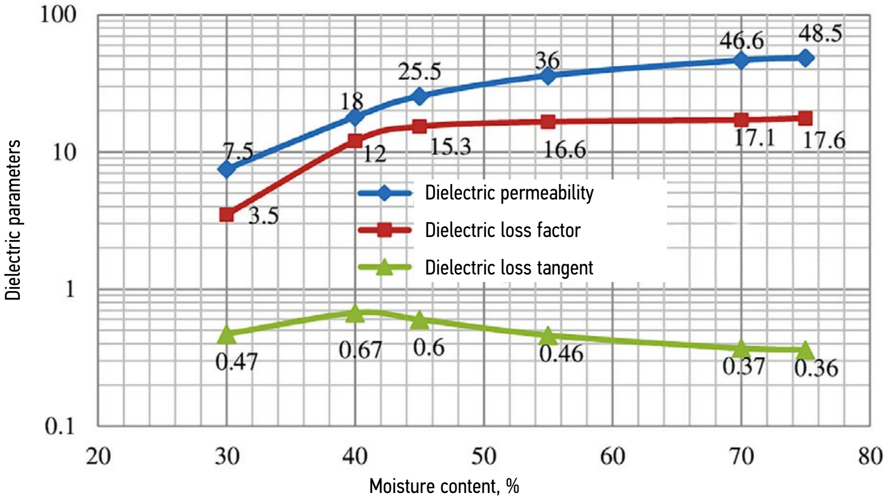

Fig. 4. Dielectric characteristics of meat by-products and waste depending on humidity at a temperature of 20°C and a frequency of 2450 MHz [17].
Рис. 4. Диэлектрические характеристики мясного сырья в зависимости от влажности при температуре 20°C и частоте 2450 МГц [17].

Table 1. Technical specification of the centrifugal device
Таблица 1. Технические характеристики центробежной установки

Name	Parameters
Capacity, kg/h	30–35
Total power of the installation, kW	5,6
Specific energy costs, kWh/kg	0,16–0,19
Total power of microwave oscillators, kW	3,3
Fan power for cooling magnetrons, kW	0,45
Power of the kilohertz frequency generator, kW	0,45
Pneumatic pump power, kW	0,4
Power of screw screws, W	1,0
Diameter and height of the resonator, cm	61,2; 76,5

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CONCLUSIONS

Based on the results of a preliminary study of the heating dynamics of finely ground raw materials, thermal processing with fat melting with a productivity of 30–35 kg/h can be realized using a microwave generator power of 5.6 kW and a kilohertz generator power of 0.45 kW with specific energy costs of 0.16–0.19 kWh/kg.

New opportunities for improving the design and technological parameters of a microwave installation for thermal processing of secondary meat raw materials were identified using modern software in modeling the distribution of the electromagnetic field in such a resonator design. The use of new material in the form of a ceramic reflector; other physical factors, such as corona discharge, providing ozonation and a bactericidal flow of UV radiation; and new design solutions enabled the creation of processing chamber designs for heat treatment of ruminant slaughter waste with neutralization of unpleasant odors, which are considerably superior to their prototypes. This resonator design can be classified as a metal–dielectric resonator.

The generatrix of the inner cylinder is presented in the form of a spiral when designing a coaxial resonator. The deceleration coefficient of the system can be modified by varying the ratio of the length of one turn of the spiral to its pitch, and raw material particles can be passed between turns into the resonator annular volume in a continuous mode due to centrifugal force for thermal processing in suspension state.

The presented concept for the development of a microwave unit with a non-standard resonator design, which combines the functions of a spiral decelerating system for the heat treatment of secondary meat raw materials, will improve the process efficiency during continuous operation.

The use of a microwave unit with a non-standard coaxial resonator is recommended to ensure electromagnetic safety without an additional shielding housing in continuous mode in the slaughterhouses of farms.

The assessment results of the effect of gas-discharge lamps located in the electromagnetic field of a microwave on the nutritional value of the product allow us to determine the direction of research when studying the action mechanisms of gas-discharge technologies.

ADDITIONAL INFORMATION

Authors' contribution. E.V. Voronov — analysis of the existing technology of processing chambers of ruminant animals, text revision, approval of the final version of the manuscript; G.V. Novikova — work on the implementation of the innovative idea of neutralizing the odor of meat by-products and waste in a coaxial resonator with sources of electrophysical factors; justification of effective modes of heat treatment of meat by-products and waste; O.V. Mikhailova — formation of the structure of the article, text editing; building of a 3D model of the device; studies of electrodynamic parameters of the "generator-resonator" system; M.V. Prosviryakova — complex analysis of scientific literature on the research problem, description of the principle of operation of the device, preparation of initial conclusions; S.A. Suslov — formulation of the main directions of the research, text revision; drawing conclusions. All the authors made a significant contribution to the research and preparation of the article, read and approved the final version before publication.

Conflict of interest. The authors declare the absence of obvious and potential conflicts of interests related to the publication of this article.

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ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Е.В. Воронов — анализ существующей технологии переработки камер желудка жвачных животных, доработка текста, утверждение окончательной версии рукописи; Г.В. Новикова — работа над реализацией инновационной идеи нейтрализации запаха сырья в коаксиальном резонаторе с источниками электрофизических факторов; обоснование эффективных режимов термообработки сырья; О.В. Михайлова — формирование структуры статьи, анализ и дополнение текста статьи; построение 3D–модели установки; исследования электродинамических параметров системы «генератор-резонатор»; М.В. Просвирякова — совместный анализ научной литературы по проблеме исследования, описание принципа действия установки, подготовка первоначальных выводов; С.А. Суслов — формулирование основных направлений исследований, доработка текста; составление выводов. Авторы подтверждают соответствие своего авторства международным критериям *ICMJE* (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

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