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USE OF MICROWAVE RADIATION FOR EFFECTIVE PURIFICATION OF WASTEWATER FROM ORGANIC COMPOUNDS

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Abstract. This article is devoted to the problem of using microwave radiation as a potentially effective method of cleaning wastewater from organic compounds. The problem of cleaning wastewater from organic contaminants in the food industry requires highly effective methods since protein compounds in wastewater can cause environmental hazards and complicate the cleaning process. The purpose of the work was to investigate the effectiveness of using microwave radiation to purify wastewater from organic compounds, particularly protein impurities, and to establish the possibilities of this method for improving the process of water purification in the food industry. The article mainly examines the use of microwave radiation for this purpose and analyses its effect on proteins usually present in wastewater from the food industry. Experimental studies have shown the possibility of adequate wastewater treatment using microwave radiation. The advantages of using microwave heating, as well as its speed and regulation accuracy, are analysed, making this method attractive for use in wastewater treatment and other industrial production processes. The study includes an analysis of microwave radiation's effect on proteins commonly present in wastewater from the food industry. The research methodology involves modelling the composition of wastewater and using a microwave oven to process protein solutions. The results of the experiments demonstrate the possibility of adequate wastewater treatment using microwave radiation, which opens up prospects for further use of this method in industry and environmental protection. The results indicate the success of using microwave radiation to purify wastewater from organic compounds, notably protein pollution.

Keywords: wastewater, food industry, denaturation, microwave radiation, heat exchange, mathematical model.

1. Introduction

Pollution of wastewater with organic compounds is a serious problem affecting water resources' quality and the environment. Organic compounds in wastewater may include fatty acids, carbohydrates, proteins, amino acids, phenols, and various chemical compounds originating from industrial processes, agro-industrial complexes, domestic use, and other sources (Barham et al., 2020). Organic pollutants in wastewater can severely impact aquatic ecosystems and human health. For example, some organic compounds can be toxic to aquatic organisms, causing their death or affecting their development and reproduction. Some organic pollutants can accumulate in aquatic organisms, which can cause problems in aquatic ecosystems. Also, organic compounds can cause water pollution, leading to a decrease in drinking water quality and limiting its use for other purposes, such as agriculture or industrial processes (Chen et al., 2014). Therefore, the problem of wastewater pollution with organic compounds requires attention and the development of effective cleaning methods that would ensure the preservation of the quality of water resources and the protection of human health and the environment. One of the methods of combating the problem of wastewater contamination with organic compounds is the use of

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microwave radiation. This method uses electromagnetic waves with a wavelength ranging from 1 mm to 1 m. These waves can penetrate deep into the liquid and pollutants distributed in wastewater and interact with molecules of organic compounds (Korablev et al., 2021).

Microwave radiation can break down organic contaminants into simpler compounds by heating the liquid and causing chemical reactions. This process can reduce the organic substances in wastewater to safe discharge levels (Kovacova et al ., 2009).

The advantages of using microwave radiation are:

1. High efficiency: Microwave waves can penetrate deep into liquids and decompose organic contaminants, even those in complex structures.

2. The speed of the process: The reactions of the decomposition of organic pollutants occur quickly enough to allow for the effective purification of wastewater in a short period of time.

3. Environmental safety: Microwave radiation does not require the use of chemical reagents, which avoids the generation of hazardous waste.

In general, using microwave radiation to purify wastewater from organic compounds opens a promising path to creating effective and environmentally safe technologies for the purification of water resources (Lai & Lai, 2006).

2. Experimental part

A series of experiments to study the denaturation processes of protein solutions, which model wastewater from food industry enterprises were carried out (Sabadash, 2023). In these experiments we used a microwave oven with a frequency of 2450 Hz for microwave radiation. These studies aimed to determine the possibility of using microwave radiation to effectively decompose protein contaminants in wastewater and subsequent purification (Sabadash, Lysko, 2023). As part of the experiment, protein solutions similar in composition and characteristics to pollutants found in wastewater from food processing enterprises were exposed to microwave radiation for different time intervals (Sabadash, Gumnytsky, 2018). During the experiment, samples were collected and analysed regularly to monitor the changes in the structure and properties of the protein under the influence of microwaves.

3. Results and Discussion

The process of heating the model solution in the laboratory setup is non-stationary, which means that the heating conditions constantly change during the heating process. In this experiment, a glass container made of quartz glass, which transmits electromagnetic radiation and is a nonpolar dielectric, is used for heating (Wong, 2006). During heating, the container contacts the environment through convective and radiative heat exchange, especially given that the environment has a lower temperature. It is also essential to consider that the thermophysical and optical characteristics of materials such as quartz glass change with temperature. The effect of microwave radiation on the object under study leads to the release of heat, which is evenly distributed in the volume of the solution. This means that as a result of heating with the help of microwave radiation, the entire solution was heated uniformly, which is essential for obtaining uniform research results.

First, we will turn to the study of the relationship between the intensity of the electromagnetic field generated in the resonator microwave chamber and the power of the microwave generator. For this, we will use the well-known equations of electrodynamics (Sabadash, Gumnytsky, 2018).

Specific power Π (W/m^2) is the amount of energy carried by an electromagnetic wave through a unit area in an arbitrary environment. The equation determines it:

$$\Pi = \nu \varepsilon \varepsilon_0 E^2, \quad (1)$$

where Π is the specific power Π (W/m^2); $\nu = \frac{c}{\sqrt{\varepsilon\mu}}$ is the frequency of the wave in hertz (Hz); c is the speed of light in the environment, (m/s); $\varepsilon_0 = 8.85 \times \times 10^{-12}$ F/m – dielectric constant; ε – relative dielectric constant of the medium; E is the intensity of the electric field.

In the free space of the microwave chamber, the electromagnetic wave moves at the speed of light in the medium and for air, as for vacuum.

In the free working space of the microwave chamber, the electromagnetic wave moves at the same speed as light in a vacuum. For air, similar to vacuum, the value of dielectric constant (ε) and magnetic permeability (μ) is equal to unity.

With the optimal load of the resonator microwave chamber, the specific power can be determined using the equation:

$$\Pi = \frac{P}{S}, \quad (2)$$

where P is the power of the microwave generator in watts (W), and S is the surface area of the product in square meters (m^2).

Equating the right-hand sides of expressions (1) and (2), we obtain the final formula for determining the intensity of the electromagnetic field E_0 under the experimental conditions:

$$E_0 = \sqrt{\frac{P}{\varepsilon_0 cS}}, \quad (3)$$

where E_0 is the intensity of the electromagnetic field on the product's surface. where ω is the power (W/m³); E – electric field strength in the product in volts per meter (V/m).

Next, it is necessary to determine the intensity of the electromagnetic field, which occurs directly in the product. This tension differs from the tension observed at the "product-working volume of the microwave chamber" boundary due to the dependence of the electromagnetic wave's propagation speed on the medium's dielectric characteristics. With the optimal load of the microwave resonator, all the energy of the electromagnetic wave is absorbed by the product; that is, the specific power P of the electromagnetic wave does not change at the "product-microwave camera" interface.

According to equation (1), we get:

$$v\varepsilon\varepsilon_0 E_{i0}^2 = c\varepsilon\varepsilon_0 E_0^2\ , \quad (4)$$

where E_{i0} is the intensity of the electromagnetic field penetrating the product; v is the frequency (Hz); ε is the relative dielectric constant of the medium.

Taking into account equation (3) and $c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$, we get:

$$E_{i0}{}^2 = \frac{P}{\sqrt{\varepsilon}\varepsilon_0 cS}\ . \quad (5)$$

Since the experiment used a container made of quartz glass, which has a much lower dielectric constant than aqueous solutions, the heating of the container can be ignored. Next, you need to consider the effect of the absorption of electromagnetic energy in the product from the surface to its centre; in other words, you need to calculate the power density of internal heat sources. To do this, we recorded the power balance for an arbitrary inner product layer of volume dV with surface plane S_V. According to equations (1) and (4) we get:

$$dV = -S_V d\Pi, \quad (6)$$

where ω is the internal thermal power in watts per cubic meter (W/m³); dV is the volume, m³; $d\Pi$ is the differential of the specific power Π (W/m ²); S_V – surface m².

Since the experiment used a container made of quartz glass, which has a much lower dielectric constant than aqueous solutions, we can neglect the heating of the container itself. Consider the effect of the absorption of electromagnetic energy by the product from the surface to its centre. This means we have to calculate the power density of the internal heat sources. We record the power balance for an arbitrary inner product layer of volume dV with surface plane S_V to do this.

Based on equations (1) and (4), we obtain:

$$\omega dV = -S_V d\Pi. \quad (7)$$

As a result of integration (6), we obtain:

$$\int_0^V \omega dV = -\int_0^\Pi S d\Pi, \quad (8)$$

$$\omega = -\frac{S\Pi}{V} = -\frac{P}{V}\ .$$

Given formula (4) and the fact that $v = \frac{c}{\sqrt{\varepsilon\mu}}$, where l is the linear size, m, and δ is the thickness of the material layer, we get the formula (9):

$$2\pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon \cdot tg\delta \cdot E^2 dV = -c \cdot \varepsilon_0 \cdot \varepsilon\sqrt{\varepsilon} S_V dE; \quad (9)$$

$$l = \frac{c}{2\pi f\varepsilon_0\varepsilon \cdot \mathrm{tg}\,\delta},$$

where l is the linear size, m; $\mathrm{tg}\,\delta$ is the loss angle tangent.

We will calculate the temperature distribution in the object under study. Based on formula (9), we obtain the following differential equation:

$$\frac{dE^2}{E^2} = -\frac{1}{l}\frac{dV}{S} = -\frac{1}{l}dr, \quad (10)$$

where r is the distance from the surface to the inner layer of the product along the regular dV.

The solution of this differential equation under the boundary condition has the form:

$$E^2 = E_0^2 e^{-\frac{r}{l}}. \quad (11)$$

This equation will allow us to obtain the distribution of the intensity of the internal electromagnetic field relative to the distance from the surface to the inner layer of the product.

By substituting equation (11) into (7) taking into account $l = \frac{c}{2\pi f\varepsilon_0\varepsilon\cdot\mathrm{tg}\,\delta}$; we obtain the calculation formula for the investigated solution.

$$\omega = \frac{1}{2}\cdot\varepsilon_0\cdot\varepsilon'\cdot\omega\cdot E^2\cdot\mathrm{tg}\,\delta\cdot e^{-\frac{r}{t}}\ . \quad (12)$$

Based on equations (7) and (5), we determine the average value of the specific power of internal heat sources by integration:

$$\omega' = \frac{1}{2}\cdot\varepsilon_0\cdot\varepsilon'\cdot E_{i0}^2\cdot\mathrm{tg}\,\delta\cdot\int_0^R e^{-\frac{r}{l}}\cdot\frac{dV}{S}\ , \quad (13)$$

where ω' is the awerage internal heatl power.

The heating power of a body of arbitrary shape at a moment of time is determined by the formula:

$$Q = m \cdot c' \cdot (T_2 - T_1)\ , \tag{14}$$

where m is the mass of the object to be heated, in kilograms; $T_1$and T_2 is the initial and final temperatures of the object under study in Celsius degrees; c' is the heat capacity of the material in J/(kg* K); t is the time in seconds.

Let's rewrite equation (12) in the following in the form of:

$$\omega = \frac{cm(T_2 - T_1)}{\tau V} \frac{l}{R} \left(1 - e^{-\frac{r}{l}}\right), \tag{15}$$

where $R = \frac{V}{S}$ is the ratio of the volume of the product to its surface area in meters.

The temperature of the subject-object arbitrary forms at the moment τ after heating in microwave ovens poly can be calculated sleepy equation (16):

$$T_2 = -\frac{cmT_1 - cmT_1 e^{-\frac{r}{l}} + w\tau v R}{cm\left(e^{-\frac{r}{l}} - 1\right)},$$

$$T_2 = \frac{T_1 e^{-\frac{r}{l}}}{e^{-\frac{r}{l}} - 1} - \frac{T_1}{e^{-\frac{r}{l}} - 1} - \frac{w\tau v R}{cm\left(e^{-\frac{r}{l}} - 1\right)} \text{ or}$$

$$T_2 = T_1 - \frac{w\tau v R \cdot e^{\frac{r}{l}}}{cm\left(1 - e^{-\frac{r}{l}} - 1\right)}\ . \tag{16}$$

To compare theoretical data with experimental ones, we conducted a study that changed the temperature of the researched object. Analysis comparison of theoretical and experimental data (Fig. 1) allows the conclusion that the proposed model can accurately determine thermophysical parameters process to temperatures up to 100 °C.

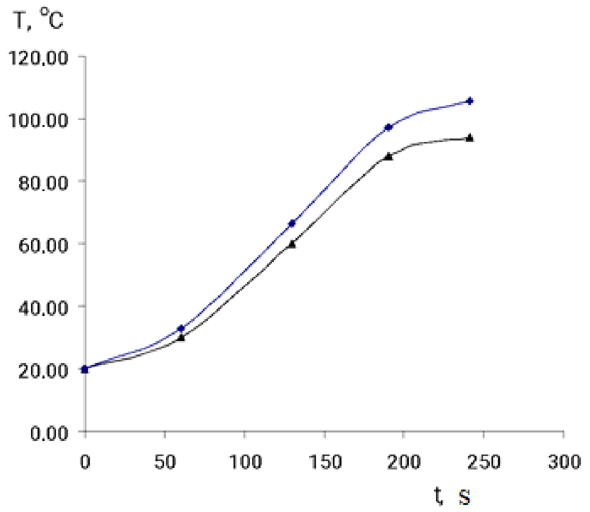

Fig . 1. Kinetics of heating protein solutions in the microwave field,♦ – theoretical data; ▲ – experimental data

To study the impact of microwave protein irradiation and purification pollution, several experiments were conducted on wastewater. The model solution was responsible for the composition of food wastewater production, which contained albumins and caseins, which are typical protein pollution. The research included an analysis of process denaturation solutions proteins that simulated the composition of the food wastewater industry in conditions in a microwave furnace with a frequency of 2450 Hz. The research was directed to study the effect of microwave radiation on the structure of proteins and their degradability during cleaning wastewater. These experiments have essential value for the development of new methods of cleaning wastewater, as they allow finding out the efficiency and possible consequences of using microwave radiation in the process of cleaning the water environment. Fig. 1 shows the change in temperature solutions for squirrels under the influence of microwave radiation (MHF) over time.

The schedule shows how the temperature changes from the initial moment to a certain one at a later time under the influence of microwaves. It allows us to watch the dynamics of thermal influence on solutions when microwaves are processed to achieve a certain temperature point. Analysis of such graphs allows for the evaluation of the efficiency and parameters of processing solutions protein by the microwave method (Sabadash & Gumnytsky, 2018).

One of the key advantages of using microwave radiation is its high efficiency in removing organic compounds from wastewater. This method allows the breakdown and deactivation of organic pollutants, ensuring water purity without significant losses and is safe for the environment. Microwave radiation can be more energy efficient than other traditional cleaning methods. This is especially important in the context of the ever-increasing energy costs and the need to reduce environmental impact. Wide range of applications: Microwave method treatment can be successfully used to treat wastewater from various types of organic compounds, including food waste, organic pollution production origin and others. To maximise the potential microwave wastewater treatment method, it is necessary to continue scientific research and develop appropriate technologies. This includes improving processes, developing new materials and equipment, and searching for optimal application conditions. When using any cleaning method, it is important to consider its impact on the environment and human health. Therefore, it is necessary to carry out appropriate risk assessments and ensure relevant standards and norms are implemented. Therefore, using microwave radiation for wastewater treatment from organic compounds can be an important step towards creating more efficient, environmentally friendly and sustainable water treatment systems. However, the success of this approach will depend on further research, technological development and implementation.

4. Conclusions

The study showed that using microwave radiation is an effective method of cleaning wastewater from organic compounds. This approach ensures a high degree of purification and reduces the content of impurities in the water. Introducing the microwave treatment method can be economically beneficial for enterprises, as it reduces the costs of wastewater treatment and reduces the negative impact on the environment. Despite the successes achieved in this study, there is a need for further scientific research and technology development to optimise the cleaning process and increase its efficiency. The introduction of new wastewater treatment technologies is an important step towards the preservation of natural resources and the preservation of the environment for future generations. The results indicate the possibility of effective use of microwave radiation for denaturing protein impurities in wastewater. It was found that under the influence of microwave radiation, rapid and effective decomposition of protein structures occurs, leading to a decrease in their water concentration and facilitating their further removal. These results open perspectives for the use of microwave radiation as an effective method of cleaning wastewater from biological contaminants in industrial conditions, contributing to the reduction of the negative impact of the food industry on the environment. Therefore, using microwave radiation for wastewater treatment can become a promising development direction in water treatment and environmental protection.

References

Barham, J. P., Koyama, E., Norikane , Y., & Yoshimura, T. (2020). Microwave Flow Chemistry. In *RF Power Semiconductor Generator Application in Heating and Energy Utilization* (pp. 91–117). Springer Singapore. doi: https://doi.org/10.1007/978-981-15-3548-2_4

Chen, Z., Afzal, M. T., & Salema , A. A. (2014). Microwave Drying of Wastewater Sewage Sludge. *Journal of Clean Energy Technologies*, 282–286. doi: https://doi.org/10.7763/jocet.2014.v2.140

Korablev , R. A., Belocurov , V. P., & Busarin , E. N. (2021). Effect mechanisms of ultrahigh-frequency radiation on biological objects. *IOP Conference Series: Earth and Environmental Science*, *875* (1), 012017. doi: https://doi.org/10.1088/1755-1315/875/1/012017

Kovacova , M., Lovas , M., Jakabsky , S., Romero, M., & Rincon, J. M. (2009). Microwave Vitrification of Model Heavy Metals Carriers From Wastewater Treatment. *MRS Proceedings*, *1193*. doi: https://doi.org/10.1557/proc-1193-323

Lai, K.-L., & Lai, G. (2006). *Effects of Microwave on Backside Grinder Wastewater Treatment* [Thesis]. Retrieved from http://ndltd.ncl.edu.tw/handle/39116388857525025350

Mudhoo, A. (2012). Microwave-Assisted Organic Pollutants Degradation. In *Advances in Water Treatment and Pollution Prevention* (pp. 177–200). Springer Netherlands. doi: https://doi.org/10.1007/978-94-007-4204-8_7

Sabadash, V. (2023). Adsorption of Oil Products by Natural Sorbents. In *Studies in Systems, Decision and Control* (pp. 137–158). Springer Nature Switzerland. doi: https://doi.org/10.1007/978-3-031-44351-0_7

Sabadash, V. V., & Gumnytsky , J . M. (2018). Extraction of proteins from wastewater of food industries using UHF radiation. *Scientific Works*, *82* (1). doi: https://doi.org/10.15673/swonaft.v82i1.1011

Sabadash, V., & Lysko , V. (2023). Studies on Adsorption of Petroleum Products in Static Conditions. *Journal of Ecological Engineering*, *24* (10), 40–46. doi: https://doi.org/10.12911/22998993/169997

Wong, W.T. (2006). *Applications of microwave technology to wastewater treatment* [Thesis]. Retrieved from http://hdl.handle.net/2429/18361.