

Eco-Friendly Principles on the Extraction of Humic Acids Intensification from Biosubstrates

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ABSTRACT

It is necessary to find innovative ways to improve the environmental performance of production processes and products. The technology of extracting valuable components from raw materials of plant origin is often used in technological processes of the food, pharmaceutical, chemical and other industries. Extraction is the most energy intensive step. The factors contributing to the extraction of humic acids from plant substrates under the action of electric discharge were studied. The purpose of the work was to study the efficiency of humic acids extraction from the biosubstrate under the action of electric discharges. The physical experiment showed that the main factor influencing the intensity of extraction is the degree of grinding of the solid phase of the biosubstrate-water suspension. The efficiency of electric discharge grinding depends on the pressure amplitude at the distance of the inner radius of the chamber and the number of discharge pulses. It was established that the number of chemical reagents (alkalis), usually used in the process of extracting humic acids from peat, can be reduced many times due to the appearance of radicals and peroxide compounds in the peat-water suspension resulting from the action of an electric discharge. The prospects of the non-thermal electric discharge method of intensification of the extraction of humic acids from biosubstrates were determined.

Keywords: eco-friendly technologies, environmental security, extraction, electric discharge, humic acids, biosubstrates, peat.

INTRODUCTION

Today, green initiatives are considered priorities in terms of technology development in various areas of the economy. The concept of sustainable development is a roadmap for the development of a modern civilized society. Intensification of technological processes while reducing energy consumption is one of the principles of eco-friendly technologies of modern production. The concept

of sustainable development and the implementation of green technologies are leading in the development of European countries (Bezsonov et al., 2017; Ishchenko et al., 2019; Hlavatska et al., 2021; Mitryasova et al., 2017; Pohrebennyk et al., 2019, Petrov et al., 2020). Under the conditions of the modern development of production, with a constant decrease in resources, there is a need for optimization of differences in technological process requirements and supporting resources

environmental security. On the way to the sustainable development of production and technological processes, it is necessary to find innovative ways to improve the environmental performance of production processes and products (Ishchenko et al., 2017; Kardasz et al., 2018; Pohrebennyk et al., 2016; Mitryasova et al., 2020).

The technology of extracting valuable components from raw materials of plant origin is often used in the technological processes of the food, pharmaceutical, chemical and other industries. Extraction is the most energy intensive step. The main drawback of traditional technologies for extracting target components from “raw material-extractant” suspensions is low efficiency due to incomplete extraction, high energy intensity and long process time, and in some cases the need to use chemical reagents that require further utilization.

The known widely-used methods of intensification are very energy-consuming and not always acceptable due to high-temperature regimes, the use of which leads to the destruction of extracted biochemical substances. Therefore, the improvement of resource-saving non-thermal methods of intensification of the processing of raw materials of plant origin with the aim of more complete and rapid extraction of target substances is a promising and urgent task within the framework of the concept of sustainable development. Special attention is drawn to such intensification due to the effect on the suspension of the “raw plant-extractant” complex of the compound that accompanies an electric discharge in a liquid working medium. The effect of an electric discharge on small-sized particles of a biosubstrate, most often porous and capillary, which are immersed in a liquid, allows significantly increasing the degree of disintegration of the material, reducing the time of dispersion or the time of moving the liquid along the capillaries several times, as well as significantly reducing the processing temperature, which will ensure resource-saving and increase environmental safety. However, the insufficient study of the kinetic regularities of extraction processes under the influence of complex electric discharge phenomena, and the lack of the experimental data on the effectiveness of mass transfer acceleration under such influence requires a thorough study of many factors affecting the completeness and quality of the extraction of target substances, including from biosubstrates.

An integral part of any soil is organic matter, i.e. the totality of living biomass and organic remains of plants, animals, microorganisms, products of their metabolism, and specific newly formed dark-colored humus substances that evenly permeate the soil profile. The organic matter of the soil contains all the chemical components of plants, bacterial and fungal plasma, as well as the products of their further interaction and transformation. The source of humus is the organic remains of higher plants, microorganisms and animals living in the soil. The remains of green plants enter the soil through ground sediment and the dead root system of plants. The amount of organic matter entering the soil varies depending on the soil-vegetation zone, composition, age and density of plants

According to modern ideas, humic substances are considered a connecting link between living and inanimate matter (Coal and Peat Fires, 2015). They are the end product of the transformation of plant cell wall components (Steelink, 1999) and make up to 90% of soil organic matter (Taylor, 1981), up to 50% of peat and up to 60% of brown coal (Sopo, 2004).

The main functional role of humic substances is the regulation of ecosystem stability. Humic substances do not have clear descriptive criteria as a class of organic compounds; this is a group of dark-colored organic compounds extracted from organogenic rocks with hydro-alkaline solutions and having similar chemical composition and properties. The process of humic substances formation can be described as spontaneous polymerization (Tombacz and Rice, 1999). Although a clear understanding of the structure of humic substances has not been formed, it has been established that they are biogeopolymers of an aromatic nature (Cook and Langford, 1999).

One of the most important derivatives of humus of natural origin is humic acids – a complex of high-molecular organic compounds, nitrogen-containing oxyacids with an aromatic core. The extract of humic acids, which is obtained from soils, peats and muddy water sediments, is a homogeneous system of brown, brown or yellow shade. Humic acids in the soil and the biosphere as a whole perform a large number of regulatory, transport, physiological and other functions (Ghabbour and Davies, 2001; Hayes et al., 2017). The main criterion for dividing humic acids into humic, humatomelanic, and fulvic acids is primarily their different solubility in water, acids, alkalis, and ethanol.

Fulvic acids are a group of humic acids soluble in water, alkalis, and acids; humic acids – a group of dark humic acids, soluble in alkalis and insoluble in acids; Hymatomelanic acids are a group of humic acids soluble in ethanol (Zanella et al., 2018).

The main areas of application of humic acids are agrochemical, medical, pharmaceutical, chemical, textile and petroleum industries. In the agrochemical industry, the preparations based on easily soluble salts of humic acids are widely used. Such drugs act at the cellular level, change the permeability of cell membranes, increase the activity of enzymes and the speed of physiological and biochemical processes, stimulate the processes of respiration, synthesis of proteins and carbohydrates in plants. On the basis of humic acid salts, new types of organo-mineral fertilizers of prolonged action, mineral humate-containing fertilizers, ameliorants, which provide a high level of digestibility of nutrients, contributing to increased productivity, improved quality of agricultural production and environmental security, have been developed (Zanella et al., 2018a; Ahmadkalaei et al., 2021; Rashid et al., 2020; Zhang et al., 2022).

The use of humate substances as feed additives in poultry and animal husbandry leads to an acceleration of weight growth, a decrease in morbidity, and an increase in resistance to poultry or animal diseases (Cammack et al., 2009; Kucukersan et al., 2005; Petty and Francis-Floyd, 2004). Persuasive evidence of the high efficiency of humates in this field of application has been obtained, and peat, lignite, plant waste, and vermicompost can be used as raw materials for the production of humic preparations.

Salts of humic acids have surface-active properties, the ability to stabilize colloidal systems and good compatibility with polymers of various molecular structures, suitable for use in the textile industry. They are included in the mixture for dyeing (coloring) textile materials, and are also used when sizing yarn. When small amounts of peat humates are added to the starch mixtures for sorting, the increased resistance of starch to retrogradation and the possibility of storing the sorting without stratification is obtained (Hayes et al., 2017; Shathi et al., 2020; Saba et al., 2021; Paul et al., 2020).

Along with surface-active properties, derivatives of humic acids also have effective binding properties. The effectiveness of the use of humic reagents to minimize the effects of oil-contaminated water and soil environments has been

proven. The maximum effectiveness of reagents based on humic acids, which are characterized by a high content of aromatic carbon, hydrophobicity and affinity to petroleum hydrocarbons, is shown (Lesage et al., 2001). Humic acids with iodine solutions are used for better solubility of hydrophobic organic substances and removal of aromatic hydrocarbons from polluted aquifers (Opekunov et al., 2022).

Recently, the technology of detoxification of spent drilling fluids and drilling muds with humic acids has been actively discussed with the aim of further use as ameliorants in the reclamation of disturbed lands (Ma et al., 2014). The complex reagent, obtained based on water-soluble salts of humic acids and lime, is used in the processing of clay drilling fluids with increased mineralization. The use of such solutions leads to a decrease in filtration parameters, an improvement in the balance of coagulation, and an improvement in lubricating properties (Ma et al., 2014a; Li et al., 2014; Kumar and Leggate, 2022).

There are several main methods of extracting humic substances from natural raw materials, which include chemical (mechanochemical, biochemical extraction) and reagentless methods based on the development of the surface of contacting phases with variable parameters of temperature, pressure, flow rate (mechanical, cavitation, ultrasonic impact), and also combinations of these methods (Stevenson, 1994; Paul et al., 2020).

Natural humic acids are quite diverse, because they are not individual compounds, but a complex mixture of macromolecules of variable composition and irregular structure. Their isolation is difficult due to variability, and detection and identification are based only on isolation methods. The ability of humic acids to dissolve in alkalis and form precipitates when the medium is acidified is considered its only real sign, actively used in practical activity.

Today, there are methods for the extraction of humic acids, the most common of which are methods of extraction with solutions of alkalis and alkaline salts. Alkaline extraction from humate-containing raw materials is based on the dissolution of humic substances in aqueous alkali solutions with the formation of soluble humates and subsequent acidification of the solution to precipitate free humic acids. At the same time, humic and hymatomelanic acids precipitate, and fulvic acids and non-specific substances remain in the solution (Tabakaev et al., 2020). The

following alkaline reagents are used to implement this extraction method: sodium and potassium hydroxides, ammonia, soda, sodium fluoride, sulfuric acid, oxalic acid, and sodium pyrophosphoric acid, oxalic ammonium, as well as organic solvents, for example, acetyl bromide.

To obtain humic acids, sodium hydroxide can be used in a concentration of up to 10%, and the number of necessary sequential alkaline treatments can be from one to ten. Alkaline extraction is carried out at a temperature from 20°C to 100°C. The use of a boiling alkaline solvent facilitates the extraction of humic acids, which lose their solubility during drying, but at the same time increase the solubility of bitumens and pectins. Methods of extracting humic acids using chemical reagents have significant drawbacks. The use of alkaline extraction harms the structure of humic acids, reduces their biological and chemical activity, as well as destroys the natural structure of humic preparations; at the same time, part of the humic acids does not change into a water-soluble form.

Mechanochemical methods of obtaining humic substances from plant products are based on simultaneous dispersion and alkaline extraction. The development of the surfaces of the contacting phases occurs through mechanical processing of plant raw materials, and the addition of specially selected reagents increases the yield of target substances. The advantage of the mechanochemical approach is a certain reduction in the number of chemical reagents (Joseph et al., 2019; Wen et al., 2019).

Biochemical technologies are based on alkaline extraction of humic substances from the soil followed by purification by microorganisms. The concentration of alkalis in this case is reduced several times compared to purely chemical methods (Wershaw, 2004; Khammar, et al., 2004). Reagent-free extraction methods are interesting due to the simple hardware design of the process and the high environmental friendliness of the resulting product. However, these methods realize extraction at elevated temperature of the medium, elevated pressure, and high velocity of solid particles flowing around extractants (Rocha et al., 1998; Kim et al., 2018).

To increase the efficiency of reagent-free extraction, preliminary grinding of raw material particles is first of all necessary. The most effective non-reagent method is the cavitation effect on treated suspensions, which provides a high degree of particle grinding, and also leads to the active transition of water-soluble organic substances

into the extractant. The substances passing into the extractant have physiological activity and ensure a high rate of hydrothermal synthesis reactions (Stevenson, 1994). To implement cavitation extraction, rotary impulse devices, cavitators, and ultrasonic devices are used, in which the processes of dispersion and extraction take place, the release of humic substances from the internal structures of the processed material is intensified (Giannouli, 2009, Gholami et al., 2019; Dudkin and Zmanovskaya, 2014; Segura et al., 2019). During cavitation extraction, the physiological activity of humic preparations increases and the neutral level of the hydrogen indicator pH of the resulting solution is preserved (in the conditions of aqueous extraction).

Special attention is drawn to the intensification of the extraction of humic acids due to the effect on the suspension of the “raw material-extractant” complex of the compounds accompanying the electric discharge in the liquid working medium.

An electric discharge in a liquid, among other things, is known as a tool for creating powerful nonlinear volume cavitation, and as such a tool, it has found application when affecting small-sized objects. Electro discharge cavitation allows significantly increasing the degree of processing of the material, reducing the time of dispersion or the time of moving the liquid through the capillaries several times, significantly reducing the processing temperature and decreasing the number of necessary chemical reagents (Malyushevskii et al., 2004; Malyushevskii et al., 2004a; Malyushevskii and Maliushevskaya, 2016; Malyushevskii et al., 2017; Maliushevskaya et al. 2021).

However, the processes of extraction of target substances from biosubstrates under the complex electric discharge effect have not yet been studied enough, although the arsenal of phenomena accompanying the electric discharge is very promising for increasing efficiency, as well as for introducing eco-friendly technologies (Malyushevskaya et al., 2022).

The purpose of the work was to study the efficiency of humic acids extraction from the biosubstrate under the action of electric discharges.

METHOD

The peat produced by Zhytomyrtorf LLC was used as a biosubstrate. The manufacturer declared the following characteristics of this batch

of peat: humidity – 52.66%; pH – 3.64; ash content – 28.76%; organic matter – 35.62%; degree of decomposition – 41%; content of humic acids – 32.44%; calcium – 0.98%; total nitrogen (in dry matter) – 1.56%; total phosphorus (in dry matter) – 0.06%; total potassium (in dry matter) – 0.04%; nitrogen, easily hydrolyzable – 660.8 mg/kg; mobile phosphorus – 490 mg/kg; mobile potassium – 465 mg/kg; copper – 1.16 mg/kg; lead – 2.19 mg/kg; cadmium – 0.22 mg/kg; manganese – 41.2 mg/kg; boron – 5.43 mg/kg; cobalt – 0.68 mg/kg; molybdenum – 0.148 mg/kg; zinc – 1.54 mg/kg.

The botanical composition of the peat is pine bark, sphagnum moss, *Scheuchzeria palustris*, sphagnum magellanicum, sphagnum fuscum.

Peat-water suspension was prepared by adding peat to water in a weight ratio of peat:water – 1:4, that is, 0.3 kg of raw material was added to 1.2 kg of technical (water) water and mixed before loading into the technological reactor. The choice of such a ratio of solid and liquid phases was justified by the specific electrical conductivity of the liquid component (filtrate) of the suspension after it settled for 10 minutes and filtered on standard paper filters of type F. Under these conditions, the specific electrical conductivity of the filtrate of the suspension ranged from 350 to 410 $\mu\text{S}/\text{cm}$. Such electrical conductivity of a liquid is not an obstacle to the occurrence of an electric discharge in it with the whole complex of accompanying phenomena. The temperature of the initial suspension was 20 °C (Poklonov, 2010).

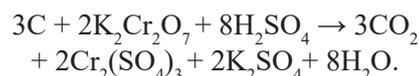
A reactor with housing made in the form of a vertically arranged was used thick-walled steel cylinder with a hemispherical bottom, equipped with a flat steel cover with a cup, in which a positive high-voltage electrode is vertically fixed in a polyethylene insulator (Malyushevskii and Malyushevskaya, 2020).

The bottom of the reactor functioned as a counter electrode and was connected to an individual ground circuit. The working volume of the reactor was equal to 1.5 dm³, the cover, hermetically fixed to the housing, was equipped with a device for the removal of gases that are formed in significant quantities when the suspension is affected by electric discharges. The length of the working gap (the distance between the tip of the high-voltage electrode and the bottom of the reactor) and the diameter of the reactor were chosen taking into account the condition of creation by the expanding channel of the electric discharge of the pressure amplitude at a distance of the inner

radius of the chamber, approximately equal to the mechanical strength for crushing (cubes with an edge of 1 cm) of coal from conifers and soft hardwoods. Such a condition was accepted as sufficient for an approximate assessment, since such an indicator of mechanical strength is not stable for the peat itself.

The electrical circuit of the experimental setup was built according to the classical principle; the setup provided operating voltage on the discharge gap up to 50 kV, the capacity of the storage unit varied from 1 to 4 μF . Preliminary calculations have shown that the following combination of energy parameters will be effective in terms of creating pressure amplitudes on the periphery of the chamber necessary for peat dispersion: the energy in a single pulse is 1250 J, the electric field strength in the discharge gap is 48.6·10⁵ V/m. Under such conditions, the suspension was treated with electric discharge, pursuing the goal of dispersing the solid phase and simultaneously intensifying the extraction of humic acids from it into the working liquid. The modes of treatment of the peat-water suspension also varied in terms of the number of pulses and their frequency. Several samples were obtained from the suspension, into the liquid phase of which chemical reagents were previously introduced – sodium hydroxide, ammonia, sodium bicarbonate in a concentration of 1% by weight relative to the mass of the liquid phase. To determine the fractional composition of the initial peat and material after processing, methods of sedimentation analysis (Wigner sedimentometer) were used.

The concentration of humic acids in the filtrate before and after treatment was determined by a method based on the oxidation of soil humus with a potassium dichromate solution $\text{K}_2\text{Cr}_2\text{O}_7$ in H_2SO_4 with subsequent photocolometric determination of the trivalent chromium content equivalent to the content of humus. The reaction proceeds according to the scheme:



The amount of potassium dichromate used for humus oxidation is employed to judge its quantity. A calibration graph was preliminarily obtained, connecting the presence of humic acids in the extractant and its optical density. To construct a calibration graph, water and a reducing agent were added to 9 test tubes containing 10 ml of the chromium mixture in the following proportions (Table 1).

Table 1. The ratio of the comparison solutions

Number	1	2	3	4	5	6	7	8	9
Volume of water, dm ³	0.04	0.038	0.036	0.032	0.030	0.025	0.020	0.015	0.010
The volume of the reducing agent solution (0.1 N Mohr's salt), dm ³	0	0.002	0.004	0.008	0.010	0.015	0.020	0.025	0.030
Mass of humus corresponding to the amount of reducing agent in the comparison solution, mg	0	1.03	2.07	4.14	5.17	7.76	10.30	12.90	15.50

The optical density ($\lambda=590$ nm) of the prepared reference solutions was determined using a KFK-2 photocolimeter. On the basis of the obtained data, a calibration graph was built in the coordinates of humus mass, mg – optical density (Fig. 1). To determine the mass of humic acids in the original and processed samples, 0.7 g of solid matter was weighed. After processing, the highly compressed samples were previously crushed to homogeneity in a mortar, 10 ml of the chromium mixture was added to the tubes with the samples; they were placed in a boiling water bath and kept for 1 hour from the moment of boiling for the full course of the oxidation reaction. After cooling, 40 ml of distilled water was added to the test tubes and photocolimetry was performed at $\lambda=590$ nm.

The percentage content of humic acids in the samples was calculated according to the formula:

$$w = M \cdot K \cdot 100/m, \quad (1)$$

where: M is the mass of humic acids in the analyzed soil, found according to the calibration chart; K – correction for the concentration of the reducing agent; 100 – conversion factor in %; m – mass of the soil sample, mg.

The degree of extraction of humic acids was determined as the difference between their content in the original and processed samples, respectively.

RESULTS AND DISCUSSION

A detailed description of the conditions for obtaining samples by the electric discharge method from a peat-water suspension is given in Table 2.

Electro discharge processing of a peat-water suspension confirmed the wide possibility of using the complex of phenomena accompanying the electric discharge for dispersing the solid phase. The obtained results regarding the prevailing sizes of peat particles are presented in Table 3.

It should be noted that the sedimentation analysis of the peat suspension obtained during electric discharge treatment with the addition of sodium hydroxide by two hundred electric discharge pulses (sample 1*, Table 2) demonstrated a bimodal distribution of particle radii ranges.

This can be explained by the fact that as a result of the interaction of humic substances with strong alkalis, among other things, the ability of particles to form agglomerates changes. Humic acids and alkalis enter into a neutralization reaction, as a result of which salts of humic acids are formed. The surface activation of peat particles in the presence of salts then leads to particles sticking together due to a significant increase in their specific surface area and the simultaneous formation of an electrolyte (salt solution) and a rapid increase in its concentration.

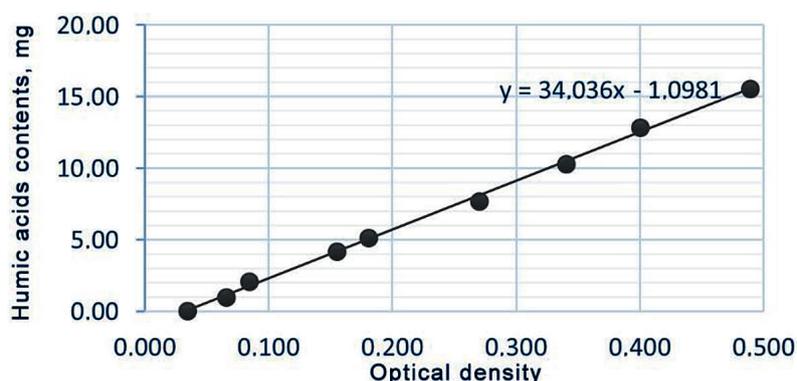
**Fig. 1.** Calibration graph for determining the mass of humic acids in peat

Table 2. Conditions for obtaining samples by the electric discharge method

Number of sample	Source voltage current, kV	Number of pulses	Frequency of the current source, Hz	Energy introduced into the suspension, kJ	Chemical reagents dissolved in the liquid phase of the suspension
1*	50	200	3	250	NaOH 1 wt. %
2*	50	200	3	250	NH ₃ 1 wt. %
3*	50	200	3	250	Na ₂ CO ₃ 1 wt. %
4	50	200	3	250	-
5	50	10	3	12.5	-
6	50	30	3	37.5	-
7	50	30	6	37.5	-
8	50	150	3	187.5	-
9	50	100	3	125	-
10	50	50	3	62.5	-

Note: * Chemical reagents were added to the liquid phase of the suspension.

Table 3. Prevailing equivalent radii of peat particles in suspension after electric discharge treatment

Serial N	Number of discharges	The range of particle radii prevailing in the suspension	Share of particles prevailing in the suspension, %
1	0	more than 300	39
2	10	more than 300	29
3	30	from 250 to 300	21
4	50	from 100 to 150	22
5	100	from 100 to 150	26
6	150	from 50 to 150	38
7	200	from 10 to 50	30

The bimodal type also has the distribution of the radii of the particles of the solid phase of the peat suspension obtained by processing with two hundred electric discharge pulses with the addition of ammonia (sample 2*, Table 2).

This may be due to the increased tendency to form aggregates of peat particles under the condition of an active increase in their specific surface in an aqueous solution of ammonium hydroxide and the formation of a large number of soluble salts of humic acids (electrolyte). At the same time, for the suspension, which was obtained by electric discharge two-hundred-pulse treatment with the addition of sodium bicarbonate (sample 3*, Table 2), the particle size distribution turned out to be normal, that is, peat particles are not prone to clumping.

It is known that in aqueous solutions, sodium hydroxide has a slightly alkaline pH and the formation of humic acid salts is slowed down compared to previous cases; thus, the concentration of the formed electrolyte is quite low. Interestingly the share of particles whose radius lies in the range from 10 to 50 μm is almost the same as for

the sample obtained by the same treatment, but without the addition of chemical reagents.

The peat samples treated with electric discharges, after drying to a constant mass, were subjected to further extraction of humic acids from them. The obtained data on the content of humic acids in the samples after treatment were compared with the content of humic acids in the control sample of peat in the initial state (Table 4).

The obtained data unambiguously illustrate the efficiency of the transfer of humic acids into the liquid phase of the suspension under the condition of adding alkali. It should be noted that the traditional technology for extracting humic acids from plant substrates (including peat) involves the use of alkalis, for example, the same sodium hydroxide, usually at a concentration of 10% of weight when the suspension is heated to 90°C for 2–3 hours.

The obtained result is the transition to the liquid phase of a suspension of 17.5 wt.% of humic acids from 33.44% by mass. The initial ones were obtained at an ambient temperature of 20°C without artificial heating, processing took about

Table 4. The content of humic acids in peat samples that have undergone electric discharge treatment as part of a peat-water suspension (the numbers of the peat samples correspond to Table 2)

Name of the sample	Optical density, relative unit	Mass of humic acids, mg	Content of humic acids, %
control	0.72	234.08	33.44
1*	0.36	111.55	15.94
2*	0.41	128.57	18.37
3*	0.39	121.76	17.39
4	0.44	138.78	19.83
5	0.45	142.18	20.31
6	0.44	138.78	19.83
7	0.44	138.78	19.83
8	0.46	145.59	20.80
9	0.4	125.16	17.88
10	0.45	142.18	20.31

70 seconds, and the concentration of sodium hydroxide in the suspension was only 1% by mass, that is, there is an obvious advantage of the considered processing method from the point of view of environmental friendliness and energy saving.

A good result was also shown by the use of sodium bicarbonate (1 wt.% Na_2CO_3) in the composition of the suspension, which is a more environmentally friendly substance. Moreover, without artificial heating, after electric discharge treatment for 70 seconds, 16.05% by mass of humic acids passed into the liquid phase of the suspension. The effort to intensify the process of extraction of humic acids into the liquid phase of the suspension without the use of chemical reagents with an electric discharge gave a result that can be compared with the previous one: in the case of processing a suspension of hundreds of electric discharge pulses, 15.56% by mass passed into the liquid phase of humic acids.

It should be noted that in this suspension after processing, not the smallest particles prevailed (with an equivalent radius of 100 to 150 μm). It is known that the greater the surface area of the phase interface, the more particles can react per unit of time and the faster the chemical process proceeds. If one compares the obtained data on the electric discharge dispersion of peat with the results of the extraction of humic acids into the liquid phase, it becomes obvious that the maximum extraction efficiency is not in the case of the most finely ground solid phase (200 electric discharge pulses – 30% of particles with a radius of 10 to 50 μm). This result testifies to the processes of resorption of humic acids by the solid phase of the suspension during electric discharge

processing of such a porous material as peat. Then it will be obvious that the maximum efficiency of extraction is not in the case of the most finely ground solid phase (200 electric discharge pulses – 30% of particles with a radius of 10 to 50 μm). This result testifies to the processes of resorption of humic acids by the solid phase of the suspension during electric discharge processing of such a porous material as peat.

Thus, during the processing of the “biosubstrate-water” suspension due to the complex phenomena accompanying the electric discharge, the solid particles are crushed, which leads to an increase in the surface of the phase contact, the opening of pores, and mechanical activation. The movement of liquid flows in the discharge chamber causes pulsations of pressure and flow velocities, intense turbulence and developed cavitation. Cumulative jets that arise during the collapse of cavitation bubbles transmit impact to solid particles. Acoustic impact includes macropulse of pressure in liquid streams and shock spherical waves during pulsations of cavitation bubbles. Such an intensive multifactorial effect on the suspension makes it possible to obtain a thin dispersion.

Chaotic turbulent fluctuations in the speed of different layers of the suspension create significant shear forces on the surface of solid particles; this contributes to a decrease in the size of the diffusion layer, increases its mobility, and ensures the flow of fresh liquid to the surface of the particles. There is also heating of the suspension in the local volume and redistribution of heat flows as a result of the mixing of its layers; however, the heating of the suspension during electric discharge treatment in a volume of 1.5 dm^3 during

the time required for the intensification of extraction did not exceed 3°. Potentially, such heating will ensure the safety of enzymes and vitamins of the target substances of biosubstrates. Discrete, concentrated and localized multifactorial impact significantly intensifies the process of mass transfer of bioactive substances from solid particles to liquid due to large specific energy dissipation in a small volume in a short time, and, accordingly, increases the efficiency of extraction.

CONCLUSIONS

Electric discharge treatment of peat-water suspensions with and without chemical reagents showed the effectiveness of intensifying the processes of extraction of humic acids from the biosubstrate.

Simultaneous use of chemical reagents (for example, 1% sodium hydroxide solution) and an electric discharge makes it possible to extract the maximum amount of humic acids in 1 treatment cycle. Compared with the traditional extraction technology, the time required to extract humic acids is reduced by 10 times, the concentration of the chemical reagent is reduced by 10 times, and artificial heating of the suspension is not required.

The electric discharge method of aqueous extraction of humic acids without the use of chemical reagents also makes it possible to achieve almost similar degrees of extraction of humic acids into the solution.

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