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COMPUTER-INTEGRATED TECHNOLOGY FOR STUDYING THE SPATIAL STRUCTURE OF A CORONA GAS DISCHARGE BASED ON FRACTAL DIMENSION ESTIMATION

The article analyzes the prospects for using the gas-discharge radiation method to study the properties of water and aqueous solutions. A review of modern achievements in the field of theoretical and experimental studies of water properties is provided. The main problems that arose in the study of water properties and the further need to improve models of the liquid phase of water are analyzed. The main ways of developing theoretical and experimental studies of the physical, chemical and biological properties of water are outlined. The relevance of studying the biological properties of water is analyzed based on modern ideas in the field of quantum electrodynamics about the presence of coherent domains in the structure of the liquid phase of water.

Experimental studies of water using the gas-discharge radiation method have revealed the regularities of the formation of individual gas discharges when an external pulsed electromagnetic field is applied to the liquid sample under study.

Analysis of the obtained images of gas-discharge radiation allowed us to establish the regularities of the formation of gas-discharge tracks for different types of water, which manifest themselves as various specific features of the geometric and photometric parameters of the images.

For the quantitative analysis of the obtained experimental data, the method of determining the fractal dimension was chosen, since the images of the formation of gas-discharge tracks have a tree-like geometric structure with pronounced signs of self-similarity.

The article presents the results and performs an analysis of experimental data and the results of their processing based on the procedure for determining the fractal dimension. The formation of a branched tree-like structure of gas-discharge tracks under the influence of an external pulsed electromagnetic field requires the presence of free charge carriers, the source of which can be coherent domains. The minimum values of the fractal dimension are characteristic of distilled water samples. The obtained result is consistent with the results of research in the field of quantum electrodynamics, since distilled water is characterized by a minimum degree of coherence.

Key words: *image analysis, computer-integrated technology, fractal dimension, gas-discharge radiation.*

Statement of the problem. Studies of various physical processes that are accompanied by the occurrence of a gas discharge have remained relevant for several decades. The study of the features of the formation of gas discharges is of interest to researchers from both a theoretical and a practical point of view. A gas discharge is one of the types of plasma, which is classified as a low-temperature plasma, in contrast to another type of plasma, which is called high-temperature plasma.

The features of the formation of a gas discharge are determined both by the external conditions during laboratory research (for example, temperature, humidity, pressure, air composition, etc.), as well as by the features of the object under study and the parameters of the electrode system used to create the electromagnetic field necessary to ensure an active measuring experiment during which a gas discharge is formed.

Analysis of recent research and publications. A gas discharge can be formed at atmospheric pressure, in which case the distance between the electrodes used to create the electromagnetic field has a significant impact on the course of this physical process [1].

Requirements for the design of devices for the formation of gas discharges can differ significantly and depend on the purpose of theoretical research or practical tasks. To date, numerous examples of the development and practical implementation of devices for the formation of a gas discharge and the registration of an image of its distribution are known.

The use of devices based on the formation of a gas discharge is known in the fields of biology and medicine [2, 3], biotechnology and agrophysics [4], the study of the properties of biological objects and liquids [5–7], the study of the properties of water and aqueous solutions [8, 9], and ecology [10–12].

Since water is one of the most common liquids on Earth and a necessary substance for the life and health of living beings, research into its properties has remained relevant for many years. Theoretical models of the existence of the liquid phase of water are being developed, and experimental methods for determining its characteristics, composition, and structure are being improved.

It should also be noted that theoretical and experimental studies of the properties of water are incomplete and require further improvement, since questions related to a number of so-called anomalous properties of water remain unresolved. Improving theoretical models of water leads to the possibility of a more detailed and comprehensive description of the properties of water, including its physical, chemical and biological properties.

The development of theoretical models of water in historical retrospect indicates that the anomalous properties of water discovered experimentally lead to attempts to further refine existing water models. Along with this, the improvement of methods and measuring instruments led to the experimental discovery of additional new anomalous manifestations of previously unknown properties of water, which necessitate new stages of the need to revise and improve water models. Thus, a continuous relationship is formed between theoretical and experimental achievements in the field of research into the properties of water, which complement each other and contribute to the further development of scientific achievements.

The tasks of studying the properties of water and building its models are not limited to establishing its physical and chemical properties in a static mode, since the movement of molecules and other dynamic phenomena in the structure of water are an integral aspect of its existence as an open system.

For example, the so-called classical model of the liquid phase of water was based on the concept that assumed the presence of hydrogen bonds. The hydrogen bond model was developed by Bernal J. D., Fowler R. H. [13]. A significant scientific achievement of this model was the idea of the structure of water in which individual molecules are connected by hydrogen bonds, which are organized in the form of a continuous three-dimensional network. However, experimental studies have revealed significant shortcomings of this model of the liquid phase of water, which consisted in the inability of the model to describe and explain non-monotonic dependences of a number of important characteristics of water, in particular such parameters as compressibility, volume, heat capacity as functions of other physical quantities, such as temperature.

The existing contradictions between the theoretical description in the form of a water model and the results of experimental studies have led to the need to improve theoretical models. In the course of further development of theoretical scientific research on the properties of water, a number of other theoretical models have been proposed. For example, models based on the percolation theory [14] have been proposed, in particular cluster and mixed cluster-fractal models, etc.

However, despite the large number of developed theoretical models, there are still many unresolved issues in this field. As noted in [15], there are problems in scientific research of microscopic structures in the liquid phase of water, which are caused by fluctuations in the structure of the network consisting of hydrogen bonds.

Along with scientific developments based on the study of clusters in the structure of water, theoretical and experimental studies of water are being carried out within the framework of the direction of quantum dynamics. These studies are based on the idea of the existence of coherent domains in the structure of the liquid phase of water.

A variant of the theoretical model of the existence of the liquid phase of water based on the idea of the presence in its structure of certain areas in the form of coherent domains turned out to be extremely important from the point of view of explaining the key role of water in the cells of living beings. The vast majority of previously developed theoretical models of the liquid phase of water were based on an analytical description of the structure of water as a set of molecules connected by H-bonds, a characteristic feature of which is their existence on the basis of short-term static forces. Within the framework of quantum electrodynamics, a model of water was proposed that took into account the presence of an electromagnetic field and dynamic interactions in the structure of water.

Considering the structure of water in this way allowed us to develop a new model based on the representation of certain areas in its structure as coherent domains, for the characterization of which a physical variable in the form of a phase is used, which is related to the electric potential and the vector of magnetic potentials [16].

In parallel with these studies, which were related to the development of a theoretical model of the liquid phase of water, scientific research

was conducted, as a result of which coherence phenomena were established in the nature of living beings [17]. As a result of the studies performed in work [16], it was concluded that the developed model of the liquid phase of water allows solving the problem of thermodynamic inconsistency based on the use of the concept of coherent domains and phase correlation between molecules in the water model. In work [18], the importance of studying phenomena caused by coherence for describing the properties of water in the cells of living beings is considered.

Task statement. Analysis of theoretical and applied achievements in the field of application of research methods based on the formation of a gas discharge around objects indicates the relevance of further improvement of measuring technologies for detecting specific geometric and photometric features of gas discharge images, which depend on the properties of the object under study.

The statement of the scientific research task is aimed at studying the properties of water and aqueous solutions based on the application of the method of forming a corona gas discharge around a liquid sample based on the use of a system of electrodes to create a pulsed electromagnetic field.

Outline of the main material of the study. Studies of water properties related to coherence phenomena in the structure of water are proving to be an important aspect in determining the properties of water in the fields of biology, medicine, and ecology. The works [6, 19] present the results of studies that indicate the prospects of using the gas-discharge radiation method to study the biological properties of water, which are due to the existence of coherent domains in its structure.

Since the gas-discharge radiation method involves the impact on the sample of the liquid under study by an external electromagnetic field, the physical processes of the emergence and maintenance of the corona gas discharge are associated with the emission of free charge carriers from the surface and upper layers of the sample of the liquid under study. As follows from the model of the liquid phase of water, built on the basis of the ideas about the existence of coherent domains in its structure [16], the emission of free charge carriers occurs with greater intensity from the surface of coherent domains, since this requires less energy consumption compared to other areas not organized into coherent domains.

The general appearance of gas discharge radiation images includes characteristic areas that correspond to the following image elements:

1) image background;

2) an inner circle with the location of the liquid sample under study, the quantity and volume of which is formed by a special device that is part of the gas discharge radiation image recording device;

3) an image area that consists of gas discharge tracks radially located around the liquid sample under study, the spatial superposition of which forms the resulting corona gas discharge picture.

When studying the physical processes of emission of free charge carriers from the surface of a liquid sample, the focus of attention is on the features of the formation of gas discharges in radial directions from the inner circle of the image, which corresponds to the area of the liquid drop.

In [19], a method for analyzing images of gas discharge radiation was proposed, which is based on the analysis of high-frequency components of the image brightness profile, which is formed only along one radial direction. Further development of computer-integrated technologies for a detailed study of the features of the emission of free charge carriers from the surface of a liquid-phase object, the corresponding geometric and photometric properties of corona gas discharge images is based on the application of fractal geometry methods to analyze the geometry of the structure of gas discharge tracks.

Fractal geometry methods for determining the characteristics of gas discharge radiation images around liquid samples were selected based on the analysis of the features of the images, which consist of a superposition of a set of gas discharge tracks.

The images obtained as a result of corona gas discharge registration have a characteristic shape of radially arranged gas discharge tracks, which resemble a tree-like structure of individual branches that can intersect each other, forming complex geometric spatially distributed fragments.

Corona gas discharge fragments for the same liquid sample, on the one hand, have a stochastic nature of geometric and photometric features, and on the other hand, have a certain repeatability of textural features in the radial direction within one corona gas discharge image.

For example, images of distilled water samples are characterized by a more uniform light color of the image fragment corresponding to the gas discharge formation area, but without the presence of clearly defined individual gas discharge tracks. For natural water samples, the corona gas discharge consists of clearly defined individual gas discharge tracks, which have a tree-like geometric structure and are characterized by greater intensity compared

to images of the corona gas discharge of distilled water.

Qualitative analysis of corona gas discharge images obtained when an external pulsed electromagnetic field is applied to liquid samples indicates the validity of the choice of fractal geometry methods for highlighting specific features of gas discharge radiation images.

From the analysis of gas-discharge radiation images of different types of water, it can be concluded that it is possible to detect self-similarity of fragments for image textures. The pattern of formation of individual gas-discharge tracks is characterized by a tree-like structure with specific patterns. At the same time, methods of fractal image analysis provide the possibility of quantitative analysis of self-similarity, i.e. certain repetitions in the geometry of patterns at different image scales [20].

Table 1 shows several examples of the results of fractal dimension calculations for different types of water.

For each type of water, three samples with identical physicochemical properties were selected. The analysis of the obtained results shows that the smallest value of fractal dimension corresponds to the distilled water sample. This result is consistent with the results of modern scientific research in the field of quantum electrodynamics, since distilled water is characterized by a minimal degree of coherence.

Conclusions. The article presents the results of the development of a computer-integrated technology for studying the spatial structure of a corona gas discharge based on the assessment of fractal dimension. The article reviews modern ideas about the structure of water and formulates the main problems and ways to improve theoretical and experimental studies of water properties.

Table 1

Determining fractal dimension for gas discharge radiation images

Water sample	Fractal dimension		
	Sample 1	Sample 2	Sample 3
Distilled	0.95098	0.94832	0.94982
Natural (concentration of dissolved impurities TDS 700 mg/l)	1.3047	1.3154	1.3208
Natural (concentration of dissolved impurities TDS 1060 mg/l)	1.4396	1.5173	1.4491

The results of an experimental study of the properties of water of various types based on the application of the gas-discharge radiation method are obtained. The computer-integrated technology includes a stage of calculating the fractal dimension of gas-discharge radiation images.

The obtained experimental data and the results of their processing with the procedure for quantitative assessment of the self-similarity of the geometry of gas-discharge tracks indicate the prospects for further improvement of methods for studying water properties using the gas-discharge radiation method.

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Глухова Н.В. КОМП'ЮТЕРНО-ІНТЕГРОВАНА ТЕХНОЛОГІЯ ДОСЛІДЖЕННЯ ПРОСТОРОВОЇ СТРУКТУРИ КОРОННОГО ГАЗОВОГО РОЗРЯДУ НА БАЗІ ОЦІНКИ ФРАКТАЛЬНОЇ РОЗМІРНОСТІ

У статті виконаний аналіз перспектив застосування методу газорозрядного випромінювання для дослідження властивостей води та водних розчинів. Виконаний огляд сучасних досягнень в галузі теоретичних та експериментальних досліджень властивостей води. Проаналізовано основні проблеми, які виникали при вивченні властивостей води, та подальша необхідність удосконалення моделей рідкої фази води. Окреслено основні шляхи розвитку теоретичних та експериментальних досліджень фізичних, хімічних та біологічних властивостей води. Проаналізовано актуальність дослідження біологічних властивостей води на базі сучасних уявлень в галузі квантової електродинаміки про наявність когерентних доменів у структурі рідкої фази води.

Проведені експериментальні дослідження води методом газорозрядного випромінювання дозволили виявити закономірності формування окремих газових розрядів при впливі на досліджуваний зразок рідини зовнішнього імпульсного електромагнітного поля.

Аналіз отриманих зображень газорозрядного випромінювання дозволив встановити закономірності формування газорозрядних треків для різних типів води, які проявляються як різні специфічні ознаки геометричних та фотометричних параметрів зображень.

Для кількісного аналізу отриманих експериментальних даних був обраний метод визначення фрактальної розмірності, оскільки зображення формування газорозрядних треків володіють деревоподібною геометричною структурою з вираженими ознаками самоподібності.

У статті наведено результати та виконаний аналіз експериментальних даних і результатів їх опрацювання на базі процедури визначення фрактальної розмірності. Формування розгалуженої деревоподібної структури газорозрядних треків при впливі зовнішнього імпульсного електромагнітного поля вимагає наявності вільних носіїв заряду, джерелом яких можуть виступати когерентні домени. Мінімальні значення фрактальної розмірності є характерними для зразків дистильованої води. Отриманий результат узгоджується з результатами досліджень в галузі квантової електродинаміки, оскільки дистильована води характеризується мінімальним ступенем когерентності.

Ключові слова: *аналіз зображень, комп'ютерно-інтегрована технологія, фрактальна розмірність, газорозрядне випромінювання.*