

RESEARCH ARTICLE

ANALYSIS OF THE MAIN FACTORS INFLUENCING THE PROCESS OF DISINFECTING SURFACE WATER THROUGH ELECTRIC DISCHARGE

Askar Abdykadyrov ^{a,b}, Palvan Kalandarov^b, Sunggat Marxuly ^{a,*}, Anar Khabaya^{a,*}, Gulnar Sharipova^a, Maral Abulkhanova^a and Lyazzat Zhanbayeva^c

^aDepartment of Electronics, Telecommunications and Space Technologies,, Satbayev University, Almaty, Kazakhstan.

^bDepartment of Automation and Control of Technological Processes and Production, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers Tashkent, Uzbekstan.

^cDepartment of physics, Abay Kazakh national university, Almaty, Kazakhstan.

*Corresponding Author Email: sungat50@gmail.com; a.khabay@satbayev.university

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ABSTRACT

The corona discharge significantly affects the cluster structure of water, leading to the formation of shock waves, cavitation oscillations, and minor ultraviolet radiation. Before initiating the water disinfection procedure with corona discharge, it is necessary to consider all factors influencing this process.. The article reviews the results of previous studies examining the dependence of the physico-chemical properties of water on its ionic composition and external thermodynamic or electromagnetic influences. The research was conducted using the ETRO-03 pilot laboratory setup with a specific frequency of 13 kHz and a voltage of 21 kV. The dependencies of physico-chemical characteristics such as dielectric and magnetic permeability, specific electrical conductivity, dielectric losses, and specific heat capacity of water were analyzed and described. The patterns of their changes due to external influences were determined based on initial parameters and variations in temperature (up to 40°C) and the frequency of the applied electromagnetic field. In alternating electric fields, an increase in frequency leads to the emergence of a relationship between the coefficient of electrical conductivity, dielectric permeability, and dielectric losses of water. The numerous parameters affected by electric influence demonstrate the complexity of the water treatment process using electric gas discharge and the various factors impacting it. The established patterns of changes in physico-chemical parameters outlined in the research can serve as a basis for planning water disinfection experiments.

KEYWORDS

Electric discharge, water disinfection, physico-chemical properties, dielectric permeability, electromagnetic field, cavitation oscillations.

1. INTRODUCTION

Disinfection of surface water using electric discharge is a significant research topic in modern science and technology (Malik et al., 2001; Shang et al., 2019). Issues related to water pollution and its impact on human health and ecosystems have always been relevant. The electric discharge technology has garnered great interest as one of the methods for water purification, widely used due to its effectiveness and economic accessibility. This method aims to eliminate microbiological contaminants by altering the physico-chemical properties of water (Vanraes et al., 2016; Yang and Cho, 2017).

Corona discharge, or electric discharge, affects the structure of water clusters, generating shock waves, cavitation oscillations, and ultraviolet radiation (Abdykadyrov et al., 2023; Abdykadyrov A. et al., 2024). These effects enable the destruction of bacteria and viruses in the water. However, to effectively implement the water disinfection process, it is necessary to identify the main factors influencing its physico-chemical properties (Petrov et al., 2021; Lukes et al., 2012; Abdykadyrov, et al., 2023). During electric discharge, characteristics such as dielectric and magnetic permeability, specific electrical conductivity, dielectric losses, and specific heat capacity of water change. These changes depend on the ionic composition of the water and external thermodynamic or

electromagnetic influences. In alternating electric fields, increasing frequency leads to a relationship between the coefficient of electrical conductivity, dielectric permeability, and dielectric losses in the water (Sun et al., 2016; Abdykadyrov et al., 2023).

The purpose of this study is to analyze the main factors for efficiently organizing the disinfection process of surface water using electric discharge. During this study, the patterns of changes in the physico-chemical parameters of water were identified and their variations depending on initial parameters and external influences were examined. The results of this research will serve as a basis for planning future water disinfection experiments. Additionally, it is planned to carry out the disinfection of water using a high-frequency ETRO - 03 (13 kHz) corona discharge device. The cytotoxic effects of corona discharge and its impact on the physico-chemical properties of water have been demonstrated and described in previous studies (Astafyeva and Ivanova, 2017; Martusevich and Kovaleva, 2015). This effect is based on the formation of deep structural and functional changes in cells, leading to their death.

Before starting the water disinfection procedure, it is crucial to thoroughly investigate all factors that may influence this process to some extent. As is well-known when an electric current affects a microorganism cell, it becomes polarized and stretches towards the poles (Kakaurov, 2016;

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Ponomarev and Novikova, 2011; Rodionova and Novikova., 2013). Increased polarization leads to cell death. However, at low exposure levels, the opposite effect can occur, stimulating the cell and increasing its potential. Therefore, it is essential to determine how the parameters of the current passing through the water layer change to ensure maximum disinfection efficiency.

The impact of electric discharge on water is considered a complex physico-chemical phenomenon, accompanied by changes in initial parameters. This is explained by the formation of a spark above the water surface, saturation with darsonvalized oxygen, and the release of H and OH radicals. Additionally, corona discharge affects the cluster structure of water, generating shock waves, cavitation oscillations, and minor ultraviolet radiation. The objective of this study is to determine how the initial parameters change during the influence of electric discharges on water.

2. MATERIALS AND METHODS

Electric discharge on the surface of water acts as an activator of chemical reactions. Numerous theoretical and experimental studies have been dedicated to investigating the changes in the physico-chemical properties

of water under the influence of electrical energy (Semikhina, 2006; Khan et al., 2012; Kuznetsova, 2010; Bessonova and Stas, 2008; Sidorenko et al., 2016). However, all these studies have been asymmetric, as they were conducted at different frequencies, temperatures, and concentrations of impurities. Among them, studies on the dependence of physico-chemical parameters on the ionic composition of water and its thermodynamic parameters induced by external influences are of great interest to us. These studies are conducted using experimental methods such as dielectric spectroscopy. The data obtained from these studies are necessary for conducting theoretical calculations aimed at planning experiments for water disinfection using electric discharges. By knowing the dielectric parameters of water, it is possible to determine the extent to which electric discharge affects microorganisms in the water, as well as the penetration depth of electromagnetic radiation.

2.1 Theoretical Calculation of Factors Influencing the Process of Water Disinfection by Corona Electric Discharge

To conduct theoretical calculations, it is necessary to consider the main factors influencing the process of water disinfection by corona discharge. These factors include the electric field, current strength, frequency, temperature, and water composition (Figure 1).

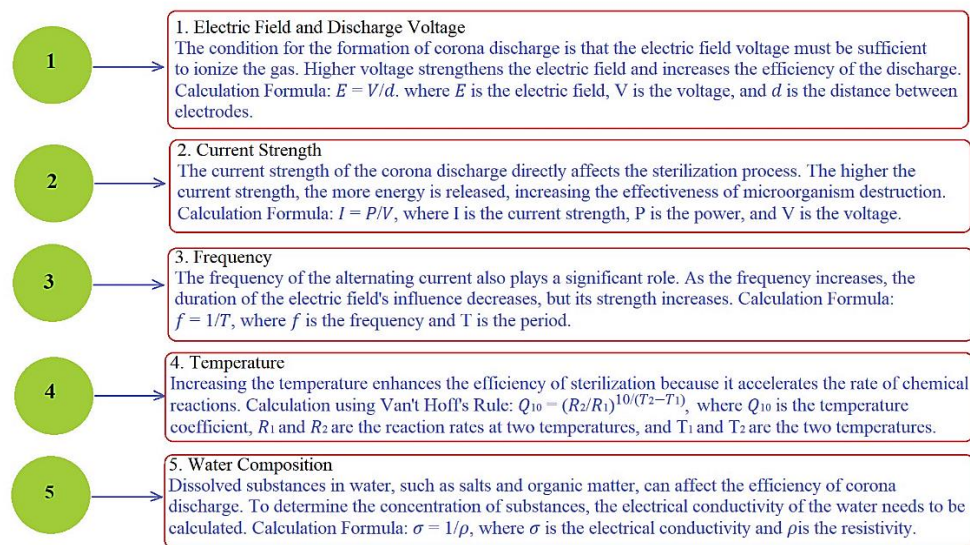


Figure 1: Factors Affecting the Efficiency of Corona Discharge and Calculation Formulas

This Figure 1 describes the five main factors affecting the efficiency of corona discharge: electric field and discharge voltage, current strength, frequency, temperature, and water composition. Each factor's impact on efficiency is explained, along with the corresponding calculation formulas. For example, higher voltage strengthens the electric field, while higher current increases the efficiency of microorganism destruction. The effects of frequency, temperature, and water composition on the corona discharge are also demonstrated.

3. RESULTS AND DISCUSSIONS

The scientific research was conducted at the Kazakh National Research Technical University named after K.I. Satbayev. The study was carried out using the ETRO-03 pilot laboratory device, based on an electric corona discharge with a voltage of 21 kV and a frequency of 13 kHz (Figure 2).



Figure 2: General view of the laboratory ETRO - 03 pilot plant based on electric discharge

The generator of the device consists of the following elements: the ETRO - 03 pilot device (Figure 2) includes a transistor converter that converts to alternating current with a frequency of 8 - 13 kHz. The converter comprises a generator (DD₁, DD₂), a power amplifier (VT₁), a preamplifier (VT₂), and an output stage (VT₃) that produces a variable voltage of 10 - 21 kV. In the multiplier (C₆ - C₁₀ and VD₂ - VD₆), this voltage is increased by a negative ion generator, with the ions being emitted from the needles of the coronal electrode under high voltage. The T₁ transformer is wound on a 28x8 toroidal ferrite core. The primary winding (I) consists of 300 turns of PEL 00.15 mm wire, and the secondary winding (II) consists of 25 turns of PEL 00.33 mm wire. The T₂ transformer is on a ferrite core from an SDCS-208 line transformer. The primary winding (I) consists of 45 turns of PEL 00.53 mm wire, and the secondary winding (II) consists of 2500 turns of PEL 00.1 mm wire. The width of the T₂ winding is 10 mm, with a 50 µm thick fluoroplastic tape inserted between each layer. The T₂ transformer and the multiplier are encapsulated in a 2 mm thick textolite shell and filled with paraffin. The KT812A (VT₃) transistor is mounted on a heat sink, and the converter and its housing are grounded (to heating radiators or water pipes). The converter's power supply must provide two voltages: +30 V, 280 mA and +5 V, 40 mA.

3.1 Dielectric Constant (ε)

One of the most important and interesting characteristics of water for us is its dipole moment, which is significantly larger compared to other liquids. This leads to a high dielectric constant (ε) for water. The ε parameter is determined by the polar properties of the molecules, temperature, concentration, and the properties of impurities. Additionally, the value of ε can depend on the frequency of the external field it is in. It is known that ε significantly decreases with increasing temperature, and at a constant temperature, ε decreases with increasing field frequency (the temperature coefficient for measuring dielectric permeability at 105 - 108 Hz is approximately 0.35 °C⁻¹) (Khan et al., 2012).

In a wide frequency range, ε is characterized as a complex quantity and is

expressed as a complex number consisting of the real (ε') and imaginary (ε'') components of the dielectric constant. For each specific substance, both components of the dielectric constant show maximum variability in a certain frequency range where the oscillation period is close to the relaxation time. The presence of impurities in the water affects the value of ε: the presence of suspensions in the water leads to a sharp increase in the tangent of the dielectric loss angle.

The dielectric properties of distilled and fresh water are known to be the same for frequencies from 1 to 2·10⁴ Hz and linearly dependent on temperature in the range from 1.5°C (ε' = 87) to 45°C (ε' = 70).

The studies conclude that with an increase in solution concentration, ε gradually increases to a certain limit, after which it sharply decreases (Alexandrov, 20190). Considering that fresh water is a low-concentration electrolyte solution, its ε is somewhat higher than that of purified water. The characteristic change in ε with increasing concentration is explained by the increase in the spatial volumetric charge due to the increased number of ionic carriers, resulting in deformation. Under the influence of an alternating external field, ionic charges create local fields whose direction is opposite to the vector of the applied field. The intensity of the "internal field" increases, and the dielectric permeability rises.

The water for disinfection must meet the requirements of SanPiN 2.1.4.10749-01 "Drinking water requirements." According to these hygiene requirements for water quality, the concentration of impurities should be within the following limits: Cadmium, fluoride: no more than 0.02 mg/l; Arsenic, chlorine: no more than 0.05 mg/l; Lead, copper, iron: no more than 0.3 mg/l; Sulfur, calcium: 25-75 mg/l; Magnesium, table salt, sodium/magnesium sulfate: 200 - 250 mg/l.

In his research, measured the real dielectric permeability of fresh water at a frequency of 2.652 GHz at atmospheric pressure and various temperatures, obtaining the following dependencies (Figure 3) (Rassadkin, 2008).

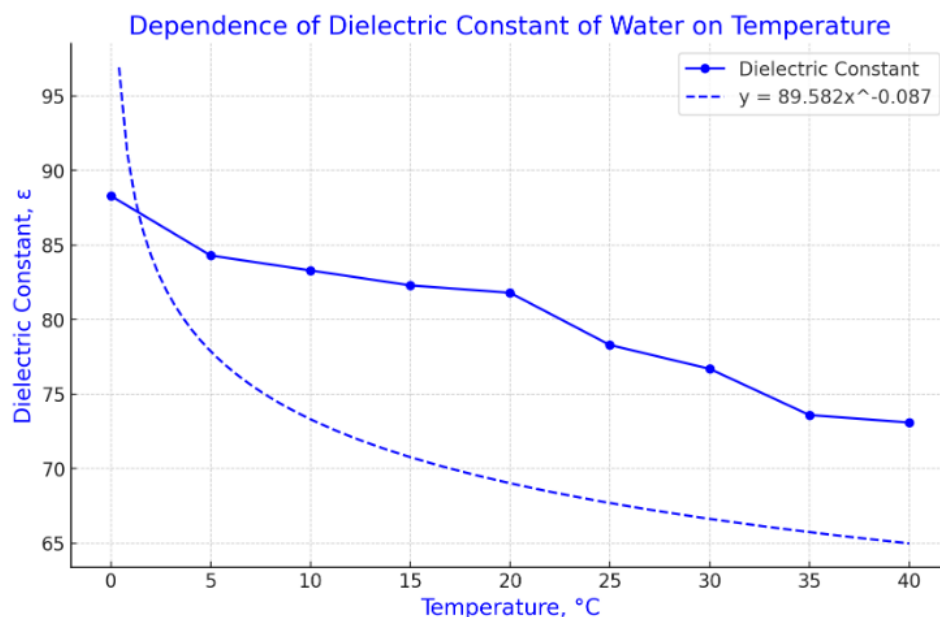


Figure 3: Dependence of Dielectric Constant of Water on Temperature

This graph in Figure 3 shows the dependence of water's dielectric permeability (ε) on temperature. It can be observed that dielectric permeability gradually decreases as the temperature increases. The initial high value at 0°C is 88.3, which decreases to 73.1 at 40°C. This change is due to the decrease in the polar properties of water molecules with increasing temperature. The curvature of the graph's line corresponds to the given formula: $y = 89.582x^{-0.087}$, which describes the exponential dependence of dielectric permeability on temperature. According to the obtained data, the temperature dependence of water's dielectric constant is determined by the following expression (1) (Shevelev and Mikhailova, 2019):

$$\epsilon' = 89.582 \cdot t^{-0.087} \quad (1)$$

3.2 Magnetic Permeability (μ)

Water is a diamagnetic substance and is classified as an "anomalous" diamagnetic material. Its ability to become magnetized under the

influence of an external magnetic field is characterized by magnetic susceptibility (χ_m), which is associated with the positive charges (H⁺) and negative charges (O⁻) of the water molecule forming intermolecular bonds. Any change in the external environment leads to the weakening of these bonds. It is known that at a temperature of 20°C, the value of water's diamagnetic susceptibility is $\pm 0.72 \cdot 10^{-6}$ H/m. With an increase in temperature from 5 to 70°C, the change in water's χ_m ranges from $-2.9 \cdot 10^{-6}$ to $-0.62 \cdot 10^{-6}$ H/m, indicating the presence of a temperature coefficient of water's diamagnetic susceptibility.

The magnetic susceptibility of water significantly depends on the type and concentration of impurities. For instance, even naturally dissolved O₂ (and in our case, direct oxygen saturation of the water surface occurs) often exhibits paramagnetism, which can surpass water's diamagnetism because the magnetic susceptibility of the solution is determined by its ionic and molecular components and their interactions with the solvent (water). In practice, for all types of water in different frequency ranges, temperatures, and solution concentrations, magnetic permeability is

usually considered a constant value, meaning that the magnetic constant μ_0 is used in calculations.

The specific electrical conductivity (κ) of water is a quantitative characteristic that determines its ability to carry an electric charge, measured in Siemens per meter (Cm/m). Since natural waters belong to the second type of conductive medium, where electric charges are carried by ions under the influence of an external electric field, this indicator is directly related to the content of dissolved minerals and temperature.

The specific electrical conductivity of water and its solutions is determined by the number of ions that conduct electric current and their mobility (Shevelev and Mikhailova, 2019).

$$X = \alpha CF(U_+ + U_-) \quad (2)$$

where α is the degree of dissociation of the liquid; C is the molar concentration of the equivalent, mol/m³; F is the Faraday constant, 96,485 C/mol; U_+ and U_- are the absolute mobilities of the cation and anion (mobility in a potential gradient of 1 V/m), m²V⁻¹s⁻¹.

Thus, the purer the water, the poorer it conducts electric current. For example, at a temperature of 18°C, relatively clean water has $\kappa = 3.8 \cdot 10^{-6}$ Cm/m, whereas in purified water, due to the absence of any impurities, $\kappa = 2 \cdot 10^{-4}$ Cm/m. When discussing electrical conductivity, it is important to note the so-called critical frequency (f_{cr}), at which displacement currents can be neglected compared to conduction currents (Table 1 and Figure 4).

Table 1: Calculated values of f_{cr} for some liquid media

Substance	κ , Cm/m	ϵ	f_{cr} , Hz
Aqueous solution of KCl (0.01 mol)	0,1	80	$2,2 \cdot 10^7$
Water (double-distilled water)	$1 \cdot 10^{-4}$	80	$2,2 \cdot 10^4$

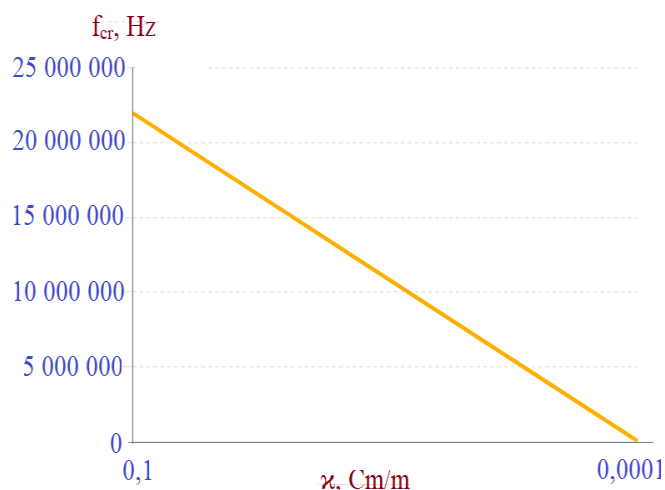


Figure 4: Dependence of Conductivity in Liquid on Frequency

This graph shows the calculated values of the critical frequency (f_{cr}) in a liquid medium. The abscissa (x) axis of the graph represents electrical conductivity κ (S/m) in a logarithmic scale, while the ordinate (y) axis shows frequency f_{cr} (Hz) in a logarithmic scale. The liquid media used are an aqueous solution of KCl with a concentration of 0.01 mol and double-distilled water. In this graph, we see that the frequency for the KCl solution is higher due to its higher electrical conductivity. Although the dielectric constant (ϵ) is the same for both liquid media, the value of electrical conductivity significantly affects the frequency.

Considering the complex nature of the dependence of κ on the frequency of the electromagnetic field, a value called the "quiet frequency range" is distinguished, where the properties of the liquid medium are practically independent of frequency [25,26]. For example, the quiet range for distilled and fresh water is between 10^7 and 3×10^8 Hz. As for the temperature coefficient of electrical conductivity, it was found that for different types of water with varying degrees of impurity concentration, it ranges from 2.1% to 3.0% per 1°C. That is, with an increase in water temperature from 0 to 30°C, its κ increases by 1.7 to 2 times.

Another important factor to consider when subjecting water to electric current is dielectric losses, which are understood as the amount of energy converted into heat in an insulating material under the influence of an electric field. To describe these losses, the dielectric loss angle (δ) is used,

which is the angle that complements the phase shift angle between current and voltage to 90° (see Figure 5) (Shevelev and Mikhailova, 2019).

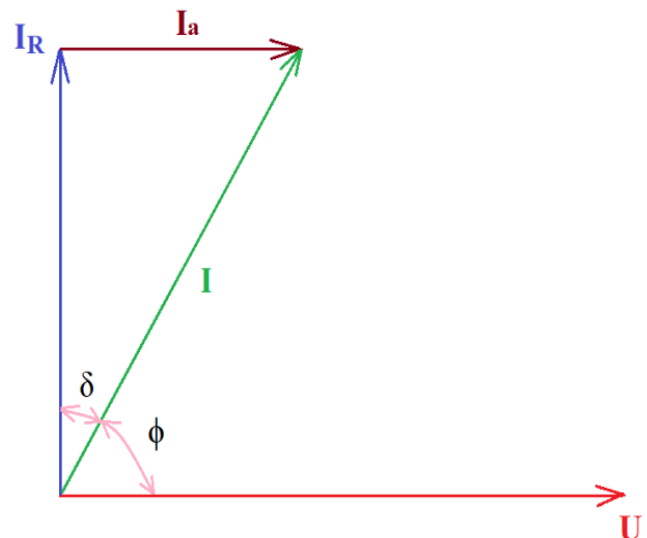


Figure 5: Vector diagram of electrical parameters in the dielectric: U – supply voltage; I – full current; I_a , I_R – active and reactive components of the total current, respectively; ϕ – phase shift angle between applied voltage and total current; δ – is the angle between the total current and its capacitive component

The ratio of the active component of the current (I_a) to the reactive component (I_R) determines the value of the tangent of the dielectric loss angle.

$$tg\delta = \frac{I_a}{I_R} \cdot 100\% \quad (3)$$

The value of the dielectric loss angle usually does not exceed a few hundredths or tenths of a unit (therefore, the dielectric loss angle is often expressed as a percentage). The value of dielectric losses depends on the temperature of the water, the frequency of the applied electromagnetic field, and the composition of the impurities (Parsokhonov et al., 2022).

In his study states that for aqueous solutions with $\kappa < \kappa_{max}$ and $\gamma < 0.1$ mol/l concentrations, the dependence of the f_{max} frequency on the conductivity (κ) of the solutions is independent of their chemical composition (Semikhina, 2006). The individual properties of different impurity ions begin to affect the dielectric parameters of solutions only at concentrations of $\gamma < 0.3$ mol/l. In this case, increasing the concentration of impurities leads only to a shift in the dispersion region of ϵ and the frequency f , at which the maximum $tg\delta$ is observed. Tables 2 and 3 below show the dependencies of the dielectric constant and $tg\delta$ on frequency and temperature for relatively pure water (Shevelev and Mikhailova, 2019).

Table 2: Dependence of ϵ and $tg\delta$ on temperature and frequency

f , Hz	t , °C	ϵ	$tg\delta$
$3 \cdot 10^9$	3	79	0,30
$3 \cdot 10^9$	10	79	0,23
$3 \cdot 10^9$	20	78	0,17
$3 \cdot 10^9$	40	74	0,09

Table 3: Dependence of ϵ and $tg\delta$ on temperature and frequency

f , Hz	t , °C	ϵ	$tg\delta$
$9,5 \cdot 10^9$	3	30	0,90
$9,5 \cdot 10^9$	10	36	0,60
$9,5 \cdot 10^9$	20	36	0,47
$9,5 \cdot 10^9$	40	64	0,36

Since water has the property of heating under the influence of electric energy, which directly affects its dielectric properties, we provide the values of the specific heat capacity (C_p) of water at normal atmospheric pressure (Figure 6).

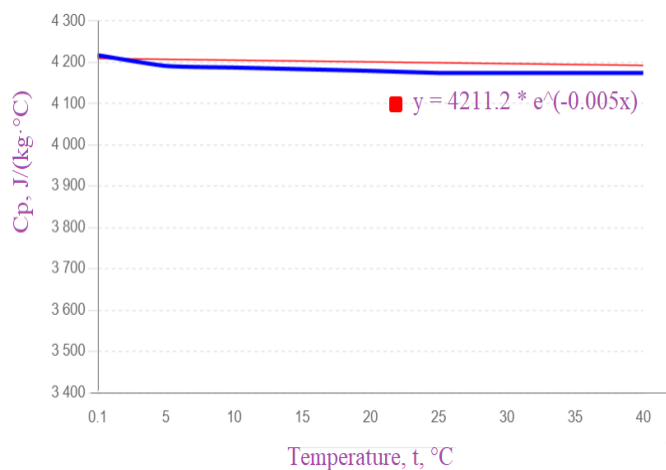


Figure 6: The dependence of the specific heat capacity of water temperature

The graph shows the relationship between the specific heat capacity of water (C_p) and temperature in degrees Celsius (t). The specific heat capacity slightly decreases as the temperature rises from 0.1°C to 40°C. Data points are plotted in blue, with C_p values annotated at each temperature. An exponential decay equation $y = 4211.2 \cdot e^{-0.005x}$ is fitted to the data and displayed in red.

3.3 Discussion of Scientific Research

The scientific research investigated the factors influencing the process of disinfecting water with corona electric discharge. The studies identified the significant impact of corona discharge on the cluster structure of water, including the formation of shock waves, cavitation oscillations, and ultraviolet radiation. Physico-chemical properties, such as dielectric and magnetic permeability, specific electrical conductivity, dielectric losses, and specific heat capacity, were examined. The patterns of changes in these properties depending on initial parameters and external influences were identified. The effects of changes in temperature and the frequency of the applied electromagnetic field were particularly noted. In alternating electric fields, the increase in frequency showed a relationship between the coefficient of electrical conductivity, dielectric permeability, and dielectric losses in water.

The numerous parameters affected by electrical influence demonstrate the complexity of the process of treating water with electric gas discharge. This complexity and the impact of many factors require consideration to enhance disinfection efficiency. The patterns presented in the study can serve as a basis for planning experiments on water disinfection. These research results contribute to the improvement of water purification technologies. Figure 7 below shows the main stages of the water disinfection process using corona electric discharge:

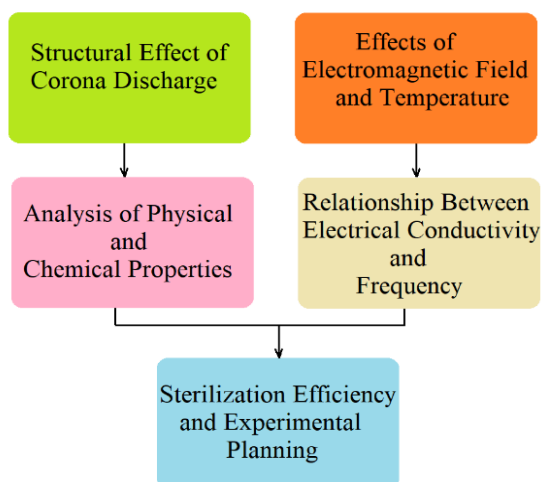


Figure 7: The Effects of Electrical and Physicochemical Factors

In this schematic diagram, special attention can be given to the main stages of the water disinfection process using corona electric discharge:

1. *Structural Impact of Corona Discharge:* Attention was focused on the

impact of corona discharge on the cluster structure of water, including the formation of shock waves, cavitation oscillations, and ultraviolet radiation.

2. *Analysis of Physico-Chemical Properties:* Special emphasis was placed on the dielectric and magnetic permeability, specific electrical conductivity, dielectric losses, and specific heat capacity of water.
3. *Effect of Electromagnetic Field and Temperature:* The impact of temperature and the frequency of the electromagnetic field was studied.
4. *Conductivity and Frequency Relationship:* The relationship between the coefficient of electrical conductivity, dielectric permeability, and dielectric losses in water with increasing frequency was examined.
5. *Disinfection Efficiency and Experimental Planning:* Experiments were conducted considering the patterns of changes in physico-chemical parameters to enhance disinfection efficiency.

These steps help to consider all the necessary factors for effective water disinfection.

4. CONCLUSION

It has been determined that the physical and chemical characteristics of water, due to the structural composition features, change with slight external influences, whether electromagnetic, acoustic, or thermal. The scientific research examined the patterns of changes in water characteristics caused by external influences. This study reliably demonstrates that parameters such as dielectric constant, specific electrical conductivity, and dielectric losses depend to varying degrees on the concentration of impurities in the water, temperature, and the frequency of the applied magnetic field. It was found that in weak electric fields, the dielectric constant is not dependent on the intensity of the field. In the case of alternating electric fields, a relationship emerges between the coefficient of electrical conductivity, dielectric constant, and dielectric losses with increasing frequency. The presence of numerous parameters affected by electric energy indicates the complex nature of the water purification process using electric discharge, as well as the numerous factors influencing it. The established patterns of changes in the physico-chemical parameters presented in this scientific research form the basis for planning disinfection experiments with water.

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