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# Sustainable Iodometric Assessment of Electric Discharge Cavitation for Eco-Friendly Water Purification

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## Abstract

Electric discharge cavitation is an effective method for water treatment that combines physical and chemical effects within a single process. It enables water disinfection, extraction acceleration, dispersion of solid particles, and enhancement of porous material permeability. Compared to conventional chemical treatment, it reduces the demand for reagents and minimizes secondary pollution. This new and developing technology significantly contributes to the preservation of natural aquatic ecosystems by providing a sustainable alternative to traditional decontamination methods, thereby reducing the overall anthropogenic pressure on the environment. This study focuses on developing a reliable method for assessing electric discharge cavitation intensity and controlling water purification processes. The proposed approach is based on the oxidation of iodide ions to molecular iodine by reactive species generated during electric discharge cavitation. The adapted iodometric method is sensitive, reproducible, and does not require complex optical or acoustic equipment. Experimental results confirmed that iodometry provides an accurate evaluation of cavitation intensity, allowing control of specific energy consumption and optimization of treatment parameters. Optimal operating conditions were established to control the water processing by electric discharge cavitation: stainless-steel electrodes, specific input energy not exceeding 280 kJ·L$^{-1}$, the presence of a free liquid surface in the working chamber, and a discharge pulse frequency below 10 Hz. The proposed method supports the development of energy-efficient, low-waste technologies for wastewater and natural water treatment and facilitates the integration of electric discharge systems into existing water treatment infrastructure, particularly under resource-limited conditions.

**Keywords:** electric discharge cavitation; cavitation intensity; iodometry; water remediation control; water treatment; hybrid oxidation processes



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## 1. Introduction

The present poses severe challenges to humanity regarding the state of the environment, requiring urgent action towards sustainable development and green technologies. These global problems, in particular, relate to the critical state of water resources, which is the basis for sustainable water supply. Problems related to the pollution of drinking water reserves are exacerbated: increased concentrations of microbiological contaminants and heavy metals, petroleum products, and biologically stable organic substances in freshwater sources are documented, which adversely affect the biochemical regime of water bodies [1–4]. In response to these threats, electric discharge cavitation has emerged as a promising advanced oxidation process for effective pollutant degradation. To ensure the sustainability of such a method, rigorous assessment is required to quantify active species and optimize energy consumption. This approach facilitates a truly eco-friendly water purification framework by eliminating the need for secondary hazardous reagents. Furthermore, the integration of precise monitoring techniques allows for the fine-tuning of treatment parameters to enhance remediation efficiency. Consequently, shifting towards sustainable analytical protocols for assessing cavitational effects represents a vital step in modern environmental and green processing [5–9].

In this regard, the development and implementation of methods that will serve as the basis for environmentally friendly and resource-efficient water treatment technologies are not only urgent but also vital scientific and technical tasks [10–12]. Currently, there are many fundamental methods of water treatment, including physical, chemical, and biological processes. Physical methods include, among others, filtration [13,14], flotation [15,16], sedimentation with and without surfactants [17,18], thermal treatment [19–21], UV irradiation [22–24], and acoustic impact [25–27]. Chemical methods encompass both advanced solutions, such as ion-exchange resins [28,29], and traditional processes using chemical reagents [30,31] and ozonation [32,33]. Advanced biological methods include activated sludge bioreactors [34,35] and biofilters [36]. The methods and devices based on these principles are sufficiently studied, and their advantages and disadvantages have been identified and summarized, for example, in [37]. However, over time, situations arise where the use of several methods simultaneously is necessary, as industrial needs may require purification from multiple pollutants of different natures. For instance, hospital wastewater can be hazardous due to microbiological contamination and may contain pharmaceuticals [38]. In such cases, the use of reagent-based treatment methods may lead to undesirable chemical reactions or low purification efficiency. The use of purely physical methods, not only classical filtration and flotation, but even in the case of the most advanced membrane purification, may be energy- and economically disadvantageous due to the need to ensure high process productivity and capital costs [39]. The application of biological methods is hindered by the fact that, in combating microbiological contamination, media used to support the growth and development of biologically active layers may stimulate the growth of contaminants [40]. The primary solution involves the use of sequential chains of methods and corresponding equipment; however, this can become significantly complicated when modernizing existing water treatment plants in urban environments and is obviously energy-intensive. There arises a need for a water treatment method that not only addresses specific tasks but is comprehensive, versatile, and easily implementable in existing technological schemes. The development of hybrid water purification methods that combine the advantages of physical and chemical methods to enhance purification processes is a promising direction for advancing water treatment technologies [41–43].

The water treatment method based on the generation of intense cavitation in a heterogeneous aqueous environment by electric discharges is the hybrid one; it integrates both physical and chemical actions on the target medium and represents a novel direction among

combined methods, offering significant potential [44,45]. The key advantage of electric discharge cavitation for the intensification of chemical and technological processes is the generation of a large number of active particles (oxidizers) throughout the entire volume of the working chamber due to the dissociation of liquid molecules of the treated medium under the influence of a high-voltage discharge. Due to the presence of intensive oxidation processes, along with other processes inherent to electric discharge (ultraviolet irradiation, local shock waves, acoustic flows and turbulence, flotation effects, and rectified diffusion), contaminants are subjected to multifactorial physicochemical effects. The numerous phenomena accompanying electric discharges in liquids enable a much broader application of this method compared with conventional physical treatment techniques, even compared to the closest method—hydrodynamic cavitation, which occurs during fluid motion and requires complex equipment. Moreover, the generation of strong cavitation by electric discharges helps overcome limitations characteristic of other advanced water treatment methods. In particular, it has been reported [46] that the presence of large aggregates of solid particles in the aqueous environment significantly reduces the efficiency of plasma-chemical treatment methods due to substantial energy dissipation on these objects. To address this issue, plasma-chemical methods are currently supplemented with ultrasonic cavitation, which ensures fine dispersion of solid particles suspended in the liquid [46]. The use of ultrasonic cavitation enables reduced coagulant and flocculant doses, shorter process times, and higher water-purification rates. In methods based on electrical discharges, the main causative factor is cavitation generated upon electrical breakdown of the liquid, provided that appropriate process parameters are maintained [47]. The efficacy of electric discharge cavitation has been demonstrated across diverse applications, including the grinding of solid mineral particles [48], the extraction of water-soluble substances from plant materials [49], and the enhancement of permeability in natural porous formations [50]. However, the extensive versatility of electric discharge in cavitation mode—ranging from aqueous purification to ultra-fine milling of mineral media—requires careful control of impact intensity to optimize its implementation in modern green technologies. Thus far, the control and monitoring aspects of electrical discharge cavitation in water treatment processes have received little attention. Thus, to ensure an effective, energy-efficient, comprehensive electric discharge water treatment method, it is necessary to have a reliable methodology for assessing cavitation intensity in aquatic environments in a wide range of electric discharge energies.

Currently known methods for studying cavitation can be divided into four groups.

- The first, oldest group consists of studies of cavitation based on its impact on solid surfaces [51]. This approach to studying cavitation intensity is typical for researchers evaluating the destructive impact of cavitation occurring in hydrodynamic cavitators on the devices themselves. Typically, such cases involve large doses of energy that destroy metal surfaces, while the energy range sufficient for the formation of chemically active particles in aqueous systems under the influence of cavitation is characterized by low energy consumption.
- The second group includes methods for recording and analyzing acoustic emissions accompanying the collapse of cavitation bubbles [52], but such a method requires the use of rather bulky equipment and facilities specifically designed to obtain reliable results (e.g., measurement pools).
- The third group includes various optical methods, including photo and video recording of the cavitation area or individual cavitating bubbles [53].
- The fourth group consists of studies of test chemical reactions that do not occur in the absence of cavitation, but in cavitation conditions, while the yield of products of such reactions is proportional to their intensity (chemical dosimetry) [54,55].

For the specific investigation of electric discharge cavitation in water treatment processes, the methodologies categorized within the fourth group are the most substantiated. Significant and reliable information about cavitation intensity can be obtained relatively quickly and inexpensively based on the results of a test chemical reaction with a test object in the form of an aqueous potassium iodide solution. Such a test system allows measurements to be performed when the rate of formation of reaction products is minimally dependent on the concentration of derivative substances, pH, and exposure [56]. Additionally, this test system does not depend on the transparency of the liquid and therefore does not require special illumination.

According to studies described in [44,45], electric discharge cavitation caused by the action of acoustic radiation in the ultrasonic range on liquids leads to the formation of chemically active particles. Ions ($H^+$, $H_3O^+$, $HO_2^-$, $OH^-$), molecular formations ($H_2$, $O_2$, $H_2O_2$), and highly reactive radicals ($O\cdot$, $H\cdot$, $OH\cdot$, $O_2\cdot$) exhibit high oxidative and reductive capacities, with the number of particles formed directly proportional to the intensity of the cavitation process. Moreover, oxidation processes in the cavitation field in aqueous environments are enhanced by the fact that molecular oxygen and nitrogen dissolved in water naturally are also ionized in cavitation bubbles. The ionization of iodine requires a significant amount of energy, approximately 1000 kJ/mol; nevertheless, a level of this kind of energy impact is realistic by an electric discharge, especially considering the small quantity of iodine in the test solution.

Since the intensification of water purification technological processes using electric discharge cavitation is aimed firstly at chemical impact on the treated object, adapting the iodometric method for studying redox reactions to evaluate the efficiency of the consequences of electric discharge processes is entirely justified.

The objective of this work is to enhance the controllability of electric discharge cavitation for water treatment processes. Achieving this goal necessitates the adaptation of the iodometric method for quantifying cavitation intensity to the specific context of electric discharge treatment of aqueous media, within the framework of green chemistry and sustainable engineering.

## 2. Materials and Methods

### *2.1. Experimental Setup and Cavitation Methods*

A comparative study was conducted to evaluate the intensity of cavitation initiated in an aqueous medium using two distinct methods: electric discharge in a specialized mode and ultrasonic treatment.

#### 2.1.1. Electric Discharge Cavitation Parameters

The study was conducted using the same laboratory electric discharge installation as in [44] (Figure 1), the laboratory setup is a development of the Institute of Pulse Processes and Technologies, Mykolaiv, Ukraine. During these experiments, the laboratory setup operated at a voltage (U) of 25 kV, with a capacitor bank capacitance (C) of 0.25 μF. According to our previous studies [44,45], these electrical parameters fall within the range of high-voltage electric discharge modes that enable post-discharge cavitation generation. The discharge frequency was set to 1 Hz, as the volumetric cavitation effect of interest occurs within milliseconds following the breakdown of the liquid.

The high-voltage pulse current generator was connected to an industrial three-phase mains supply. It comprised three identical inductors 1, three identical high-voltage capacitors 2, a three-phase high-voltage rectifier 3, a capacitive energy storage device 4, a high-voltage switch 5, a working chamber with an electrode system 6, and a protection

system 7. The generator was also equipped with a three-phase frequency converter 8 and a dividing capacitor 9.

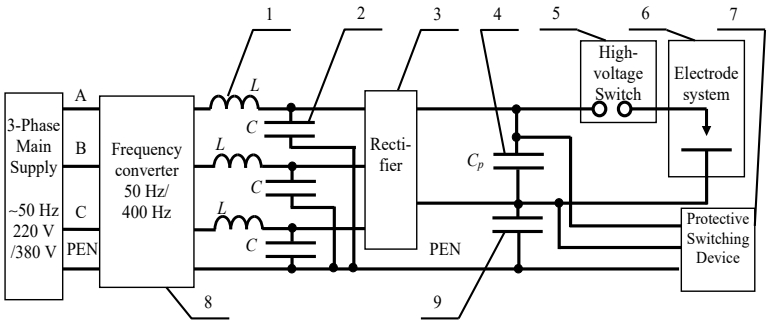


**Figure 1.** Schematic of the laboratory electric discharge installation [44].

All experiments were performed in a 2 L stainless steel reaction chamber equipped with organic glass windows for visual observation of the cavitation phenomena. To ensure chemical inertness and prevent potential catalytic interference with the iodometric reaction, four electrode materials were evaluated: titanium, stainless steel, aluminum, and copper.

A "point-to-point" configuration of the electrode system was employed for the electrodischarge treatment; both electrodes were metal rods in a dielectric housing, fixed in the bottom and lid of the working chamber, and opposed to each other. The uninsulated ends of the rod electrodes were given a cone-shaped form, with the cone height in both cases equal to the radius of the base. The distance between the electrode tips ($l_p$ in Figure 2) was not varied in this study. (Figure 2).

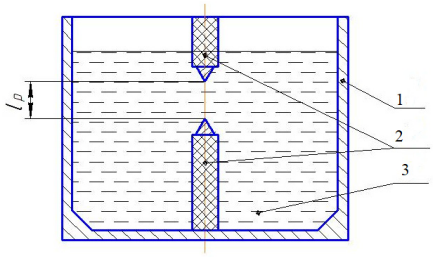


**Figure 2.** Schematic of the working chamber with electrode system: 1–working chamber body, 2–electrodes, 3–working liquid.

The duration of working liquid treatment by electric discharges was selected on the condition that the energy per one pulse was approximately 78.13 J, and the maximum total energy of the medium during electric discharge cavitation was set at 780 kJ (10,000 pulses). This level of input energy significantly exceeds that required, for example, for water disinfection (2500 J, as was shown in [44]), but is entirely feasible for effective electric discharge dispersion of solid mineral particles.

As the working medium for the experiment, an aqueous solution containing 1 g·L$^{-1}$ of potassium iodide was used. Identical volumes of the aqueous solution were treated step-by-step with 500, 1000, 1500, . . ., 10,000 discharge pulses, and after each step, samples were taken to measure the molecular iodine formed. For each electrode material and at every experimental step, the total number of discharge pulses was held constant.

The experimental data were obtained with three replicates of measurements. The tables and graphs present arithmetic mean values and standard deviation.

Preliminary tests with blank samples were conducted to determine the limit of detection (LoD) and limit of quantification (LoQ) under the experimental conditions. The limit of detection and limit of quantification of the iodometric titration method were calculated

statistically based on the results of blank sample analysis (n = 10). The LoD and LoQ values were $5 \times 10^{-6}$ mol·L$^{-1}$ and $1 \times 10^{-3}$ mol·L$^{-1}$, respectively.

#### 2.1.2. Ultrasonic Cavitation Parameters

For the acoustic treatment, a UZDN-M1200T ultrasonic disintegrator (LLC "R&D Enterprise Akademprylad", Ukraine) operating at a frequency of 22 kHz was used. Identical volumes of the aqueous solution were treated for a maximum duration of 3 h, with sampling conducted every 10 min, and after each step, samples were taken to measure the iodine formed.

### *2.2. Determination of Cavitation Intensity by the Iodometric Method*

#### 2.2.1. Principle of the Iodometric Method

The amount of iodine formed was determined by titration with sodium thiosulfate, using starch as an indicator. In general, the iodometric method is based on the oxidation of aqueous potassium iodide solutions to molecular iodine under the action of secondary factors accompanying the emergence of powerful nonlinear cavitation in the volume of the working electric discharge chamber or under the action of ultrasonic cavitation on the aqueous solution. Under the conditions for the formation of active chemical particles in the medium, the process proceeds according to the following schemes: [Ox] + 2KI $\rightarrow$ $I_2$ + 2K and $I_2$ + 2$Na_2SO_3$ $\rightarrow$ 2NaI + $Na_2SO_4$. Starch in iodometry is most often used as an indicator due to its high sensitivity—visible blue coloration with starch is observed in an aqueous iodine solution already at a concentration of $2 \times 10^{-7}$ M. It should be noted that the sensitivity of the starch indicator sharply decreases with increasing temperature, so titration is usually carried out at a temperature of 20 $\pm$ 3 °C; in all experiments, the temperature of the aqueous medium was monitored before and after treatment. Additionally, starch should be added to the solutions being titrated only when the majority of iodine has already been titrated; otherwise, the presence of iodine causes starch coagulation, contributing to its decomposition, which makes titration inaccurate.

#### 2.2.2. Quantification of Cavitation Intensity: Iodometric Titration and Reagent Standardization

For measuring cavitation intensity, the following reagents were used: potassium iodide KI (15% solution), sodium thiosulfate $Na_2S_2O_3 \cdot 5H_2O$ (0.1 N solution and 0.01 N solution), starch (0.5% solution), potassium dichromate $K_2Cr_2O_7$ (0.05 N solution), and sulfuric acid $H_2SO_4$ (1:4). To a conical flask equipped with a ground stopper, 10 mL of distilled water is added, followed by 10 mL of a 15% potassium iodide KI solution, 5 mL of diluted (1:4) sulfuric acid $H_2SO_4$, and 20 mL of a 0.05 N potassium dichromate solution. All chemical reagents are produced by the "abcr GmbH", Germany. After mixing, the solution was left to stand in the dark for 5 min and then titrated with a sodium thiosulfate solution in the presence of 1 to 2 mL of starch solution as an indicator.

Next, a microburette is filled with a sodium thiosulfate solution of the specified normality, and a conical flask for titration with a volume of 0.5 L is filled with 250 mL of an aqueous potassium iodide solution with a concentration of 1 g·L$^{-1}$, previously treated with electric discharge or acoustic radiation. Titration is carried out until a pale yellow coloration of the solution appears. Then, 1 to 2 mL of starch solution was added, and the titration continued slowly, with stirring, until the blue coloration disappeared.

The iodine concentration was calculated by [57], using:

$$I_2 = \frac{(a-b) \cdot k \cdot N \cdot 254 \cdot 1000}{V \cdot 2}$$

where *a*–volume of $Na_2S_2O_3$ used for titration of the sample, mL; *b*–volume of $Na_2S_2O_3$ used in the blank experiment, mL; *k*–correction factor for adjusting the concentration of the $Na_2S_2O_3$ to the specified normality; *V*–volume of the sample being analyzed, mL; *N*–normality of the $Na_2S_2O_3$ solution; 254—molar mass of iodine, g·mol$^{-1}$. In some experiments, to accelerate iodine formation, a small amount of tetrachloromethane ($CCl_4$) was added to the derivative solution, which acts as an electron mediator in the described oxidation-reduction reaction.

## 3. Results and Discussion

As demonstrated in [44,45], electric discharges in liquids are accompanied by various physicochemical factors that can affect chemical reagents dissolved in water. These include high pressure and temperature in local regions of the medium, the light and sound components of electric discharge radiation, the catalytic and chemical actions of electrode material ions, oscillatory processes characteristic of vapor-gas cavities, and pulsed electrolysis. Consequently, to address the objective of this study, it was necessary to experimentally verify the hypothesis that the oxidation of iodide ions is solely due to the action of oxidants formed under the influence of electric discharge cavitation. The predominant effect of electric discharge cavitation is the production of abundant chemically active species, which greatly enhances oxidation processes [45]. These species exhibit antimicrobial efficacy while posing considerably lower environmental risks. It is precisely due to this that the amount of chemical reagents required for water disinfection can be reduced tenfold. For example [44], the majority of the active chlorine otherwise needed for disinfection can be substituted by reactive species formed from the water medium itself. Other factors accompanying electric discharges—including local shock waves, acoustic flows and turbulences, flotation effects, and rectified diffusion—play a secondary, but important role as well.

Possible chemical reactions initiated by electric discharge in cavitation mode that lead to the formation of active oxidants [45]:

$$H_2O,\ N_2,\ O_2 \xrightarrow{cavitation} H\cdot,\ O\cdot,\ H_2O_2,\ N_2^+,\ O_2^+$$

There is a high probability of interaction between those free radicals and individual atoms, resulting in the formation of other chemical compounds and free radicals. For example, the following reactions may occur:

$$OH\cdot + OH\cdot \rightarrow H_2O_2$$

$$H\cdot + H\cdot \rightarrow H_2$$

$$OH\cdot + OH\cdot \rightarrow H_2O + O^-$$

$$O\cdot + O\cdot \rightarrow O_2$$

$$H_2O_2 + OH\cdot \rightarrow H_2O + HO_2\cdot$$

$$HO_2\cdot + H\cdot \rightarrow H_2O_2$$

$$H_2O_2 + HO_2\cdot \rightarrow H_2O + O_2 + OH\cdot$$

$$N_2^+ + O_2 \rightarrow NO^+ + NO$$

$$N_2^+ + O_2 \rightarrow NO_2 + N^+$$

$$N + O_2 \rightarrow NO + O$$

The resulting oxidants can interact not only with the aqueous medium but also with the materials from which the electrodes are made. So, the initial phase of the study focused on identifying an electrode material that remained inert within the reaction system. This was essential as metal ions with variable valence can act as electron mediators, potentially interfering with the oxidation-reduction processes fundamental to the iodometric method. In the experiment, titanium, stainless steel, aluminum, and copper were used as electrode materials. Figure 3 illustrates the concentration of iodine formed in an aqueous solution of potassium iodide under the influence of electric discharge cavitation, comparing the performance of titanium and stainless steel electrodes.

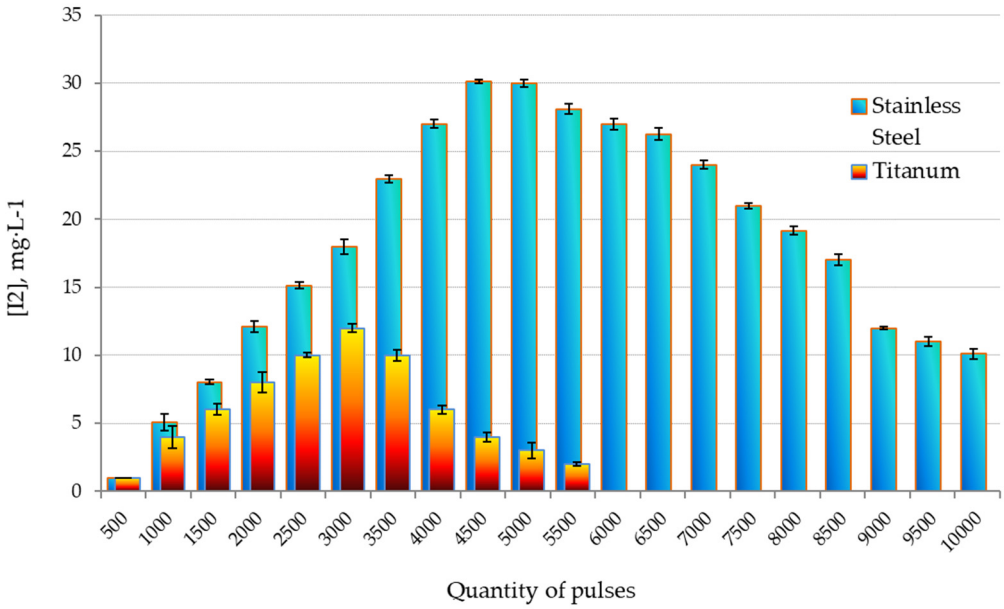


**Figure 3.** Concentration of iodine formed in an aqueous potassium iodide solution as a result of electric discharge treatment using titanium and stainless steel electrodes. The error bars correspond to the standard deviation for three parallel measurements. In some cases, the error bars lie within the data point symbols.

Based on the relationship between iodine concentration and the number of pulses (as well as the corresponding specific energy input), the iodometric method for assessing cavitation intensity remains reliable up to approximately 280 kJ·L$^{-1}$ when using stainless steel electrodes. Conversely, for titanium electrodes, this reliability threshold is limited to approximately 140 kJ·L$^{-1}$. The observed decrease in the concentration of iodine formed as a result of cavitation acting on potassium iodide is due to the adsorption of iodine on the surface of finely dispersed metal particles eroded during electric discharge processes. The lower iodine content observed with titanium electrodes, compared to stainless steel, is likely due to the reaction between titanium and iodine vapor, leading to the formation of titanium iodides—a process traditionally utilized in the refining of this metal [58]. Consequently, titanium is unsuitable for the iodometric determination of electric discharge cavitation intensity.

The nature of the dependence of the iodine concentration formed when using copper and aluminum electrodes is similar to that observed for stainless steel electrodes (Table 1). Considering the higher cost of copper and aluminum, and their lower resistance to electrical erosion, further experiments on iodometric determination of electric discharge cavitation were conducted using stainless steel electrodes.

**Table 1.** Concentration of iodine formed in an aqueous potassium iodide solution as a result of electric discharge treatment using copper and aluminum electrodes.

| Material of Electrodes; Iodine Concentration / Quantity of Pulses | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al; $[I_2]$, mg·L$^{-1}$ | 1.0 | 4.2 | 6.1 | 8.1 | 10.0 | 11.8 | 9.8 | 6.1 | 4.2 | 3.0 | 2.1 | 1.0 |
| Al; SD, mg·L$^{-1}$ | 0.15 | 0.35 | 0.21 | 0.26 | 0.06 | 0.26 | 0.21 | 0.21 | 0.20 | 0.10 | 0.06 | 0.00 |
| Cu; $[I_2]$, mg·L$^{-1}$ | 1.1 | 4.0 | 6.1 | 8.0 | 10.0 | 12.1 | 10.0 | 6.0 | 4.1 | 2.8 | 2.0 | 1.1 |
| Cu; SD, mg·L$^{-1}$ | 0.12 | 0.10 | 0.17 | 0.10 | 0.20 | 0.23 | 0.15 | 0.15 | 0.10 | 0.29 | 0.25 | 0.06 |

$[I_2]$–arithmetic mean, SD–standard deviation.

As demonstrated earlier [47], the cavitation regime of electric discharge is highly sensitive to process parameters. This study examined the influence of a free liquid surface in the working chamber on the process of electric discharge cavitation. Compression and expansion waves arising from the expansion and collapse of vapor-gas cavities of electric discharges interact with the free surface of the liquid, reflect in antiphase, and excite post-discharge cavitation. To clarify the role of this factor, discharges were also performed in the absence of an air gap between the liquid and the chamber lid, i.e., when the free liquid surface was absent. In preliminary experiments, the absence of cavitation bubbles was recorded within the observed volume of the discharge chamber. The concentration of iodine formed during the treatment of an aqueous potassium iodide solution, at identical specific energy values introduced into the liquid volume, was ten times lower than under cavitation conditions. Thus, the significant influence of the free surface of the treated liquid on the intensity of active oxidant formation was confirmed.

The next factor of the electric discharge, the effect of which on redox processes needed to be verified, was the acoustic component of the radiation. For this purpose, comparative studies of the formation of molecular iodine under ultrasonic and electric discharge treatments of potassium iodide solutions were conducted. The experiment showed that even ultrasonic treatment at a frequency of 22 kHz for 3 h did not lead to iodine formation. Small amounts of tetrachloromethane led to the formation of iodine in small quantities—5 mg·L$^{-1}$ after ultrasonic treatment at a frequency of 22 kHz for 3 h. In electric discharge treatment conditions, molecular iodine was formed both in the presence and absence of $CCl_4$. The energy consumption for ultrasonic and electric discharge treatments was $3 \times 10^{-8}$ mol·L$^{-1}$·J$^{-1}$ and $3.2 \times 10^{-10}$ mol·L$^{-1}$·J$^{-1}$, respectively. These data led to the conclusion that the contribution of the ultrasonic component at a frequency of 22 kHz in electric discharge treatment can be neglected. However, acoustic radiation in a wide ultrasonic range (up to 120 kHz), which is specific to electric discharge in cavitation mode, has a significant impact on the formation of active chemical particles and is an important feature that allows the effective use of electric discharge for water treatment technologies [45].

The next step was to investigate the possibility of photolytic oxidation of potassium iodide to iodine, as an electric discharge is a source of optical radiation. For this experiment, a hermetically sealed quartz tube filled with air, containing an electrode system, was immersed in a potassium iodide solution, and an electric discharge was performed between the electrodes with characteristics close to those of the underwater discharge described above (operating voltage 22 kV, energy storage capacitance 0.1 μF, pulse frequency 6 Hz). As a result of such treatment of the potassium iodide solution, even at a specific energy expenditure three times higher than that of the underwater electric discharge, iodine was not formed. This indicates that the light component of the electric discharge does not affect the formation of chemically active particles.

During the treatment of an aqueous potassium iodide solution with electric pulses, an increase in the solution's temperature was observed, due to the dissipation of electrical energy. To verify the influence of the temperature factor on the formation of chemically active particles, the KI solution was heated in a water bath for 2 h at a temperature of 90 to 95 °C. It was established that thermal treatment does not cause the formation of molecular iodine, meaning that potassium iodide is a thermally stable compound and does not oxidize with atmospheric oxygen under elevated temperature conditions.

The complex of electric discharge factors can affect not only the oxidation of iodide ions to molecular iodine but also the chemical equilibrium of this redox reaction. This appears so that part of the molecular iodine formed may be reduced back to iodide ions, which underestimates the results of iodometric determination of electric discharge cavitation. To determine whether a reverse reaction occurs, an aqueous iodine ($I_2$) solution with a concentration of 35 mg·L$^{-1}$ was subjected to electric discharge treatment under the same conditions as the previously described aqueous potassium iodide solutions. The total specific energy of the treatment of the aqueous iodine solution was 140 kJ·L$^{-1}$. It was revealed that under these conditions, there is no change in iodine concentration compared to the initial solution, which means that only the forward oxidation reaction occurs.

Finally, another factor of the electric discharge that could affect the formation of molecular iodine from the iodide solution is pulsed electrolysis. It is known that during pulsed electrical treatment of solutions of various substances, pulsed electrolysis processes may occur. It was previously shown in [44] that the treatment of a sodium chloride solution with high-voltage electric discharges in cavitation mode does not lead to the formation of molecular chlorine via the reaction characteristic of pulsed electrolysis:

$$2Cl^- - 2e^- \rightarrow Cl_2$$

The impossibility of analogous reactions occurring is indicated by the fact that under conditions of non-cavitation mode of electric discharge and absence of cavitation, molecular iodine is not formed, although the amount of electricity passing through the solution is the same as in the presence of post-discharge cavitation.

Studying the influence of various electric discharge factors on the process of cavitation intensity measuring by the iodometric method, a sharp increase in the yield of chemically active particles was obtained at a pulse frequency of 10 Hz and above. This dependence of oxidant yield on frequency is likely due to an increase in the concentration of bubbles with a lifespan greater than 0.1 s, i.e., close to the time interval between two pulses. A hypothesis was put forward that the cavitation process acquires a resonant character, and a detailed study of this variant of cavitation development under the influence of electric discharge is a topic for future research.

## 4. Conclusions

The feasibility of the simplified iodometric method to quantify the intensity of electric discharge cavitation in aqueous media, offering a low-cost, reagent-minimizing alternative to complicated acoustic or optical techniques, was demonstrated. The method was adapted specifically for high-voltage pulse discharges, with the following validated recommendations:

- Electrode material is stainless steel;
- KI concentration is 0.5–1.0 g·L$^{-1}$;
- Specific input energy is no more than 280 kJ·L$^{-1}$;
- Free liquid surface in the working chamber is mandatory;
- Pulse frequency should not exceed 10 Hz.

Under optimal conditions, the iodometric response is linearly correlated with cavitation intensity up to 280 kJ·L$^{-1}$, with a detection limit of 5 × 10$^{-6}$ mol·L$^{-1}$ and a quantification limit of 1 × 10$^{-3}$ mol·L$^{-1}$. The implementation of the optimized parameters ensures control and monitoring of a highly efficient, low-impact purification process that aligns with the principles of green engineering by minimizing chemical waste and preventing the degradation of natural aquatic habitats.

Compared to conventional methods for cavitation assessment, the proposed approach avoids bulky acoustic measurement pools and demands optical transparency, while remaining sensitive in turbid or opaque industrial waters. It also covers the low-to-medium energy range (up to 280 kJ·L$^{-1}$), where surface erosion methods are insensitive.

The iodometric method enables operators to optimize energy consumption for disinfection or pollutant degradation without relying on expensive sensors, but it is not applicable when specific input energy exceeds 280 kJ·L$^{-1}$ due to iodine adsorption.

A promising task for the development of the method of creating electric discharge cavitation in aqueous environments is the investigation of the resonant cavitation regime at a frequency of 10 Hz for possible intensification without extra energy input.

The adapted iodometric method supports the sustainable engineering of electric discharge cavitation systems, enabling energy-efficient, low-chemical water purification that aligns with the circular economy and the reduction in anthropogenic pressure on aquatic ecosystems.

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