Streamer discharge generator in water treatment system

V S Sisoev¹, A A Zavyalova², L M Makalsky² and A V Kuchno²

¹ Federal State Unitary Enterprise "Russian Federal Nuclear Center - All-Russian Scientific Research Institute of Technical Physics named after Academician E. I. Zababakhin", VNITS 900, 5, Zavodskaya str., Istra, 143502, Russia
² National Research University "Moscow Power Engineering Institute", 14, Krasnokazarmennaya str., Moscow, 111250, Russia

E-mail: aa.zavyalova@yandex.ru

Abstract. The article shows the possibility of using an avalanche-streamer discharge with a low-temperature plasma to remove such contaminants as petroleum products and metal ions from water. These pollutants are characteristic of the waters present in the technological cycle of energy enterprises. The scheme of a unique experimental stand is given. The importance of the operating parameters of the generator used in the discharge unit for the effective implementation of the cleaning process is indicated.

1. Introduction

Inorganic pollutants, petroleum products, metal ions, and living organisms can accumulate in the process waters of power plants. The reason for this can be both the operation of power equipment and the inflow of natural water into the technological cycles with natural contamination (inorganic, organic, microorganisms, etc.) [1]. At the same time, the increased temperature of liquids, for example, cooling water of power facilities, contributes to the intensification of pollution processes. Among the variety of used methods of water treatment for power plants of most interest are methods that do not require additional reagent economy, high efficient, allowing you to remove pollution of different nature in a wide range of concentrations with the lowest energy consumption. These requirements are fully met by electric discharge methods of water purification [1-2].

The physical processes that occur during the interaction of the discharge with pollutants ensure their oxidation to the formation of safe compounds, the transfer of dissolved substances to an undissolved form with further release in the form of precipitation.

Improving the degree of purification and its energy efficiency is ensured by optimizing gas-discharge processes.

The main technological element of electric discharge devices for cleaning water and gas media is a high voltage source [3]. Improvement of existing and creation of new methods of electrical actions using high-voltage sources allows to improve the quality of water treatment and energy efficiency of the process.

The choice of parameters for the pulse-periodic mode generator’s operation in frequency and voltage) is determined by the tasks that are solved with its specific using. The electrical and optical characteristics of a volumetric streamer discharge are recorded in the source. This allows us to obtain the relationship between the parameters of the streamer low-temperature plasma and the characteristics of the generated radiation and the results of exposure. The experiments were carried out on a unique
scientific installation http://www.ckp-rf.ru/usu/73578/ Complex High-Voltage Stand RFNC-VNIITF of the VNITS 900 branch (g. Istra) [4].

2. Materials and methods
The work is devoted to the development of a generator of high-voltage nanosecond pulses with a discharge gap (figure 1).

Figure 1. Scheme of a nanosecond streamer discharge generator with a three-electrode discharge gap.

To obtain streamer discharges, a three-electrode interelectrode gap scheme similar to [5-6]. To increase the radiation intensity (in contrast to [5]), the discharge gap was created in the form of two thin parallel wires (anode) and an isolated grounded plane (cathode). As the cathode, the authors used an aqueous solution with a depth of 1-2 cm. Periodic electrical closure of the plane with the water flow to the ground in the generator is carried out with the help of a peaker (pulse thyatron TGI-500/16). The voltage on the peaker was measured using a digital high-voltage oscilloscope Tektronix DPO (1GHz band)) with high-value divider (100 MOhm). The current in the discharge circuit was measured using an oscilloscope with a small inductive ohmic shunt with a resistance of 1 Ohm. Additionally, the voltage level at the source (anode wires) was monitored with a C-100 kilovoltmeter. Depending on the experimental purpose, the average current was additionally regulated by means of the throttle's magnetization.

Figure 2 shows examples of measured current and voltage waveforms (a), as well as a generator’s current-voltage characteristic (b). The avalanche-streamer discharge does not pass into the spark stage due to the presence of inductance in the discharge circuit and its adjustment due to the magnetization of the core (the generator current is limited). In this case, the parameters of partial inductance capacitances determine during discharge the shape of the front in the nanosecond range and the pulse.
duration in the hundreds of microseconds at the maximum values of the current in the reactor circuit (figure 2). The dependence of the current amplitude on the inductance is nonlinear.

![Oscillograms of the current and voltage of the generator (example) (a); typical current-voltage characteristic of an avalanche-streamer discharge (b).](image)

**Figure 2.** Oscillograms of the current and voltage of the generator (example) (a); typical current-voltage characteristic of an avalanche-streamer discharge (b).

In figure 3, you can see photos of an avalanche-streamer discharge plasma with a frequency of 1 kHz for a gap of 7 cm in the "two wires – plane" electrode system (the surface of an aqueous solution). Figure 3 (a) shows an ordinary photo, and figure 3 (b) shows a photograph taken with the multicam SCIR camera, which detects ultraviolet radiation with a wavelength in the range of 240-280 Nm. Such radiation is effective in the treatment of various media and objects for the purpose of disinfection.

![Photos of an avalanche streamer discharge: a- ordinary camera, b- SCIR camera.](image)

**Figure 3.** Photos of an avalanche streamer discharge: a- ordinary camera, b- SCIR camera.

The experimental stand (figure 4) made it possible to study the complex physical and chemical interaction of an avalanche-streamer discharge (plasma radiation) with contaminants in water, as well as the process of oxidation of metal ions in water by chemically active particles formed during the discharge.

Methods for measuring and investigating the properties of avalanche-streamer discharges that are important for the impact on pollution and methods for determining the results of their impact on contaminated water solutions were developed.

Based on the current-voltage characteristics of an avalanche-streamer discharge, the efficiency of the contribution of consumed electrical energy to the discharge for cleaning water solutions from contamination is estimated. The obtained value was from 30 to 40% (depending on the operating mode). In the experimental setup, ionization caused by an electric field provided the appearance of avalanches of electrons and streamers.
Figure 4. Scheme of an experimental setup for studying the effects of an avalanche-streamer discharge on water pollution (1- reactor vessel, 2- air inlet, 3- purified water output, 4- contaminated water supply; 5- ground electrode, 6- source of the avalanche streamer discharge, 7- the ionizing electrode, 8- gas from the reactor removal; 9 - contaminated water; 10- container for collecting the treated liquid).

At the same time, ultra – high-frequency radiation in the range of 0.05-5 GHz (β-radiation) with an energy of up to 10 kV was recorded. Soft (λ=0.30÷0.35 µm) and hard (λ=0.23÷0.28 µm) ultraviolet radiation was also detected. A low-temperature plasma appeared in the discharge gap. This led to the appearance of ozone (O$_3$), hydroxyl OH -, atomic and singlet oxygen (O), nitrogen oxides (NO$_3$). Hydrogen peroxide (H$_2$O$_2$) was formed in an aqueous solution.

3. Results and Discussion
At the first stage, a series of experiments was carried out to purify water from petroleum products. Water contaminated with petroleum products is usually formed during the transportation of fuel.

The experiments used water contaminated with fuel oil M-40 (GOST 10585 – 99), made from high-paraffin oil, and M-100, produced on the basis of residues of atmospheric and vacuum distillation of oil with the addition of heavy gas oil fractions. The fuel is used as a boiler, as well as for heating systems, furnaces, steam heating systems and technological installations. Experiments have shown that as the discharge is affected, the fuel oil film evaporates. It is established that the resulting gas fractions from fuel oil do not burn and do not ignite when irradiated with an avalanche-streamer discharge.

A series of experiments on the effect of the discharge on solutions containing metal ions was also carried out. To demonstrate the effect of the avalanche-streamer discharge plasma on metal compounds present in dissolved water, experiments were also carried out using a 20% aqueous solution of KMnO$_4$. As a result of the action of the discharge plasma on the salt solution, an insoluble precipitate was formed in water. With an increase in the dose of exposure to the solution, the size of the hydrosol particles increased from 0.03 to 1.0 microns. Experimental studies have shown that the treatment of contaminated solutions with an avalanche-streamer discharge leads to a significant decrease in metal ions in them and have demonstrated the possibility of their removal from the solution by filtration or precipitation.

Experiments were also carried out on the effect of lead ions on water contaminated with lead ions. It is shown that discharge treatment significantly (2-3 times) reduces the total amount of free lead ions in water.
4. Conclusion

The paper analyzes the parameters of discharges in the air, which for the first time revealed a number of features of the transition from a corona discharge to an avalanche-streamer and spark discharge. This made it possible to develop principles, schemes and components for the use of avalanche-streamer discharge in the treatment of polluted effluents generated in the energy sector.

A variant of implementing a high-voltage electric generator for producing avalanche-streamer gas discharges based on a DC source is selected. The source circuit was supplemented with a resonant inductance and a controlled sharpener to obtain a stable avalanche-streamer discharge.

To create optimal parameters for the impact of an avalanche - streamer discharge on contamination, a system of electrodes "two wires-a plane" was selected. The influence of the alloy of electrode systems, the composition of gases in the interelectrode gap and the components of contamination in water on the development of the discharge is formulated.

The presence of a low-temperature plasma in a resonant avalanche-streamer discharge ensures long-term interaction of chemically active and charged particles with various molecules in plasma-chemical reactions, including in an aqueous solution. The resulting low-temperature plasma increases the efficiency of the interaction of active particles with pollutants, including the formation of hydrogen peroxide in water.

A series of experiments on the effect of an avalanche-streamer discharge on model solutions was carried out. The composition of the model solutions was selected taking into account the impurities that need to be removed in the process of water treatment and water treatment at power plants. Also, an important condition when choosing these solutions was to obtain a clear result of the cleaning process. The results of the experiments made it possible to evaluate the effect of an avalanche-streamer discharge on aqueous solutions containing hydrocarbon compounds, and metal ions.

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