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Stability and energy efficiency of pulsed corona discharge in treatment of dispersed high-conductivity aqueous solutions

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ABSTRACT

Pulsed corona discharge (PCD) is an energy-efficient method of water treatment, although its instability in treatment of conductive solutions showered onto the electrodes presents a problem. The impact of conductivity and gaseous ozone concentration on the discharge stability and the energy transfer efficiency was established. The discharge was stabilized by adjusting the voltage pulse shape. Energy dissipation increases with the treated solution conductivity due to ohmic losses reaching 30% of the energy delivered to the reactor at 45 mS cm^{-1}. The PCD energy efficiency and safety was improved by the modified electrode system design reducing the losses.

1. Introduction

Various pulsed electric discharge systems have been studied during the last decades making use of physical and chemical effects induced by electric discharges, such as UV-radiation, pressure and shock waves, pulsed electric fields and oxidants [1–6]. The oxidants, including hydroxyl radical, ozone, hydrogen peroxide and other species, such as nitrous and nitric acids, are considered to be exerting the strongest impact on the treated water. The highest energy efficiency of oxidation was so far achieved in gas-phase pulsed corona discharge (PCD) placed above water surface [7], in water-air aerosol [8] and water showers [9,10].

Gas-phase PCD with water droplets and jets of 1–3 mm in diameter in the discharge zone has an advantage of the mass transfer exceeding the one in 'corona above water' reactors, resulting in substantially higher oxidation efficiency numbers [9]. Water showering is also advantageous over the discharge in aerosol avoiding energy expenses for aerosol generation and providing substantially higher flow-through capacities. However, water showering between electrodes alters the electric field pattern in the inter-electrode gap changing the routes of streamer propagation. As a result, high-temperature spark discharges may form having destructive effect on the electrodes. Also, a part of the energy delivered to the reactor is lost in conductive water droplets, jets and films [11].

Optimized energy transfer from a high voltage pulse generator to the PCD plasma allows reaching maximum energy efficiency of pollutants oxidation. Several studies have been reported disclosing certain aspects of energy transfer at various stages of corona plasma generation [12–14]. These models, however, describe processes observed in homogeneous gas-phase PCD, the descriptions of phenomena observed in PCD with liquid droplets present in the inter-electrode gap are rare. For example, Minamitani and Yamada [15] described the character of the discharge streamers concentration at the droplets of deionized water at the conductivity of 0.1 μS cm^{-1}. The experimental study in the impact of high conductivity of the aqueous solutions spread in droplets, jets and films in the PCD zone on the pulse parameters, energy transfer efficiency to the discharge and the stability of the latter was undertaken for the first time.

The objective of the present research is characterization of the air-phase PCD with highly conductive aqueous solutions droplets dispersed in the plasma zone. Two basic characteristics are targeted: (1) the energy transfer from the pulse generator to the PCD reactor described in terms of energy losses dependent on the

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treated aqueous solution conductivity and (2) the PCD stabilization in the presence of highly conductive electrolyte solution droplets, jets and films in the discharge zone. The concept of stability of PCD includes two principles: (1) substantial reduction of probability of PCD transformation to the spark discharge and (2) reduction of the energy of still probable spark discharges to the safe level sufficient to leave no damage to the electrodes.

2. Materials and methods

2.1. Experimental device and discharge parameters

For PCD treatment of aqueous solutions, a stainless steel rectangular reactor shown in Fig. 1 was assembled. The reactor of 200 × 200 mm sprinkled horizontal cross-section and 1.0 m height comprised of four electrode sections connected in parallel. In each section, horizontal high-voltage electrodes made of 0.5-mm stainless steel wire were positioned between vertical grounded plates. The reactor was installed on top of a stainless steel 40-L storage tank. The distance between the wire electrodes and the grounded plates was adjustable within 15–30 mm at the overall wire length of 20 m. Aqueous solutions were circulated through the reactor with a pump (Calpeda, Italy) at a flow rate of 1.2 m^3 h^{-1}, i.e. 30 m h^{-1}. Solutions were pumped from the storage tank to the sprinkling compartment located on top of the reactor to be dispersed through a perforated plate with 400 1-mm orifices.

The electrode section is outlined in Fig. 2. The electrodes were organized in two different ways: insulators supporting both grounded plates and high-voltage wires (Reactor 1) and insulators supporting high-voltage and grounded electrodes separately (Reactor 2). These arrangements make the path length between the electrodes along the wet insulator surface approximately 50 and 150 mm in Reactor 1 and 2, respectively.

The PCD was energized using a thyristor pulse generator with magnetic compression stages shown schematically in Fig. 1. The C_1 capacitor was charged from a resonant charging unit and discharged via a thyristor VS_1 to the primary of the high-voltage transformer T_1. The high-voltage capacitor C_2 was charged for 10 μs Three compression stages shortened the pulse duration, making the output capacitor discharged to the electrode system for 120 ns The capacitance of each capacitor C_2, C_3 and C_4 was 1000 pF. The output of the pulse generator was connected to the reactor

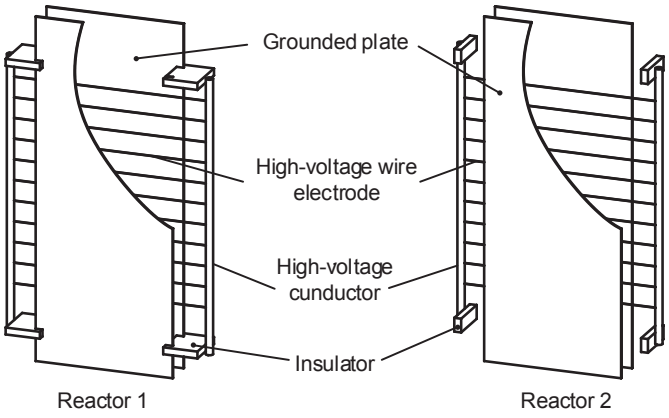

Fig. 2. Outline of the electrode section.

using a high voltage coaxial cable of 50 Ω wave resistance.

The charging voltage of C_1 was adjusted to 360 or 500 V: the lower voltage allowed measuring electrical parameters of the reactor without electric discharge, whereas the higher voltage resulted in PCD formation. The voltage at the generator output capacitor C_4 resulted in 12 kV and 27 kV, respectively. The pulse repetition rate was variable from 100 to 1000 pulses per second (pps). In most experiments, the pulse repetition rate of 500 pps was used, if not otherwise specified.

The voltage pulse duration was controlled by a saturable inductor L_4 connected to the generator's output parallel to the PCD reactor. The voltage pulse duration measured at 0.1 U_{max} thus shortened from 600 to 180–200 ns. Installation of L_4 also resulted in the unipolar pulse shape changed to the bipolar one [16].

2.2. Measurements

Waveforms of voltage and current were registered using Tectronix P2014 oscilloscope with 100 MHz bandwidth, Tektronix P6015 voltage divider (both Tektronix Inc., USA), and a current monitor Pearson 2878 (Pearson Electronics, Inc., USA). Geometric capacitance and inductance of the reactor were measured using E7-8 RLC-meter (Russia).

Ozone concentration in the gas phase of the reactor was

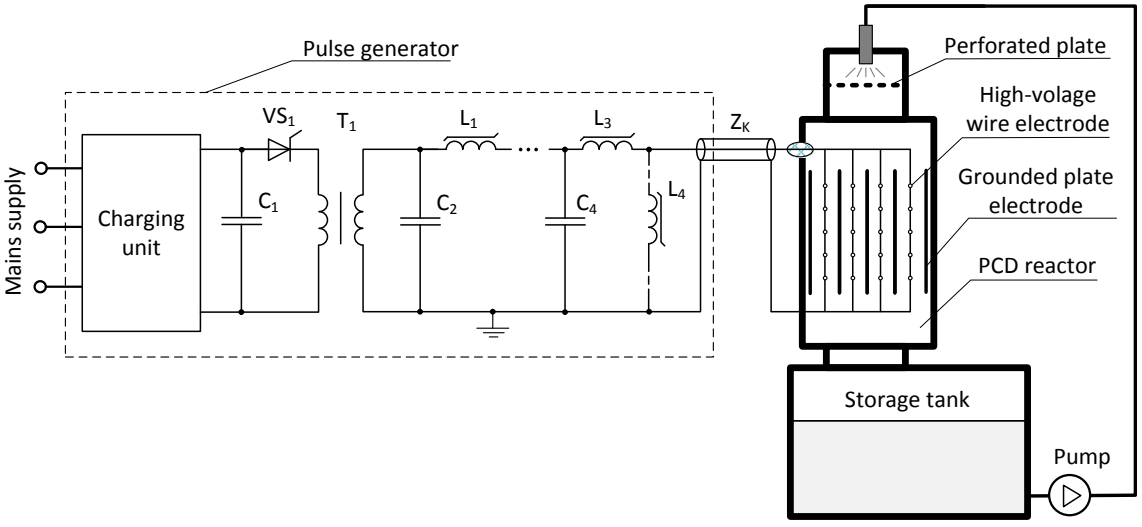

Fig. 1. Outline of the experimental setup.