

## ***Coli* bacteria inactivation by pulsed corona discharge in water**

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**Abstract—** The inactivation of *coli* bacteria during pulsed corona discharge in the river water was investigated. The bacterial suspension of volume 157 ml was polluted with *E. coli* and total *coli* with concentration of 230 cfu/100 cm<sup>3</sup> and 1500 cfu/100 cm<sup>3</sup>, respectively. The processing was conducted in tube reactor with hollow needle-rod electrode system. The 2 min. of treatment caused decrease of total *coli* concentration by three orders of magnitude leaving only 3 cfu/100 cm<sup>3</sup>. The same final concentration was obtained for *E. coli*. Obtained energy efficiency was 0.15 cfu/J, which was a result of low bacteria initial concentration and too high specific energy density.

**Keywords—** water purification, pulsed corona discharge, *coli* bacteria

### I. INTRODUCTION

The most frequent reason of epidemic formation is the pollution of the surface and drinking water by wastewater bacteria. The largest part of this pathogenic microorganisms are fecal bacteria, for example *Escherichia coli* (*E. coli*). The wastewater treatment plants reduce the amount of the fecal bacteria by 1 – 3 orders of magnitude, so the water contamination is decreased to the order of 10<sup>3</sup> – 10<sup>5</sup> cfu/ cm<sup>3</sup> of fecal bacteria, depending on the initial number of bacteria [1]. To enhance efficiency of bacteria inactivation in the wastewater various methods are tested, like electrochemical [2] and photocatalytic [3] disinfections, chlorination, ozonation, Fenton reaction [4, 5], UV irradiation [6, 7] and electrohydraulic discharges [8-12].

In spite of extensive investigations in many laboratories, there is a lack of data on waste and drinking water purification by the electrohydraulic discharges. Analysis of the literature allows determining the influence of electrohydraulic discharges in deionised or distilled water on several organic compounds such as phenols, trichloroethylene, polychlorinated biphenyl, perchloroethylene and pentachlorophenol, acetophenone, organic dyes (such as methylene blue), aniline, anthraquinone, monochlorophenols, methyl tert-butyl ether (MTBE), benzene, toluene, ethyl benzene (BTEX), and 2,4,6-trinitrotoluene, 4-chlorophenol, and 3,4-dichloroaniline [8, 13-19]. The electrohydraulic discharges in water also cause the destruction and inactivation of viruses, yeast, and bacteria. It is generally assumed that a mechanism of microorganism killing by the electrohydraulic discharges involves an electric field, shock wave, UV radiation and radical reactions. The destruction of microorganism depends on the

microorganism cell structure, different for each bacteria species and on the mode of electrohydraulic discharge [8]. In the case of the corona discharge, *E. coli* bacteria cells are destroyed mainly due to reactions with oxidizing radicals OH and H<sub>2</sub>O<sub>2</sub> with compounds forming the bacteria cell wall [9], whereas in the spark and arc discharges they are mainly damaged by shock waves and UV radiation [10, 11].

In most investigations concerning the application of the electrohydraulic discharges for water purification, the deionised water with additives regulating conductivity was used. There was no studies on the influence of electrohydraulic discharges on the chemical pollutants and microorganism present in surface water, i.e. from rivers and lakes. There are several papers on pulsed electric field application for liquid food and drinking water pasteurization/sterilization [20, 21], however, they concern electric field before inception of electrical discharge. In this paper we present results only on sterilization effect of pulsed corona discharge in surface water.

In this work we focused on the influence of corona discharge in water on inactivation of *coli* bacteria present in the river water. Both *total coli* and *E. coli* were enumerated in samples of river water treated by a pulsed positive corona discharge. The water samples with the *coli* bacteria were taken from the Reda river, in Gdańsk region. According to the 2005 annual report of the Voivodship Sanitary and Epidemiological Station in Gdańsk, the Reda river is one of the most polluted river in the region with the number of *total coli* corresponding to either A3 or A4 class, i.e. the number of *total coli*, measured as cfu (colony forming unit) in 100 ml of water is in the range 5000 – 50000 or over 50000, respectively. Due to such a large concentration of *coli* bacteria, the Reda river cannot be used for supplying region inhabitants with drinking water. This would be possible only after complete removal of *coli* bacteria, e.g. by electrohydraulic discharges.

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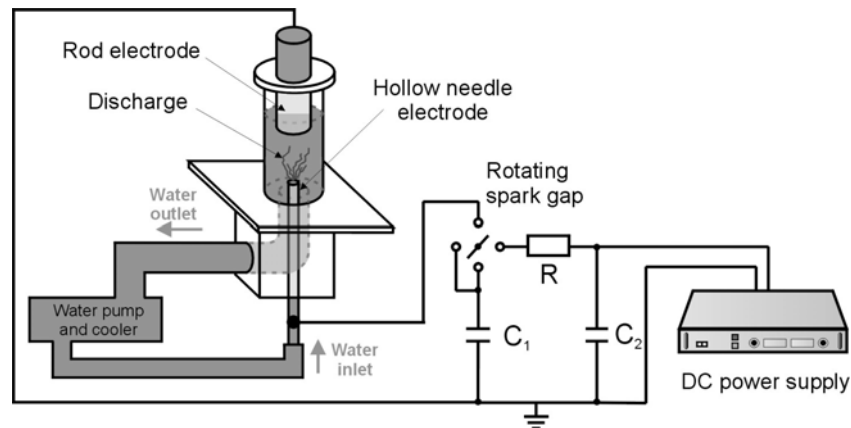


Fig. 1. The corona discharge reactor with water pumping and cooling system and pulsed power system:  $C_1 = 2 \text{ nF}$ ,  $C_2 = 22 \text{ nF}$ ,  $R = 10 \text{ k}\Omega$ .

## II. EXPERIMENTAL SETUP

The processing of the river water samples was conducted in a glass tube reactor (inner diameter of 22.5 mm) equipped with water pumping and cooling systems (Fig. 1). The water (volume of  $157 \text{ cm}^3$ ) was circulating in the closed loop with a flow rate of  $80 \text{ cm}^3/\text{min}$ . A pulsed positive discharge was generated between a stressed stainless steel hollow needle electrode and a grounded brass rod electrode (the diameter of 10 mm), both immersed in the water. The inner and outer diameter of the hollow needle was respectively 1.4 mm and 1.6 mm. The discharge was generated at the edge of the hollow needle, whereas the rest part of the needle was covered with an insulator. The needle-rod spacing was 45 mm.

The processed water was taken from the Reda river in June 2007 at the point located close to the river mouth. The water initial characteristics was as follows: conductivity -  $365 \text{ }\mu\text{S}/\text{cm}$ , pH - 7.5, temperature -  $18^\circ\text{C}$ , number of *E. coli* in 100 ml – 230 cfu, number of *total coli* bacteria in 100 ml – 1500 cfu. The water samples were inspected for the number of bacteria before and after experiments by The Regional Inspectorate in Gdańsk, using the fermentational-test tube method specified by the Polish Standards PN-77/C-04615.07 and PN-77/C-04615.05.

The positive high voltage pulses were applied to the hollow needle electrode from a discharge capacitor  $C_1$  (2 nF) – Fig. 1. The capacitor was charged from a DC power supply through a resistor  $R$  (10 k $\Omega$ ) and a capacitor  $C_2$  (22 nF). The pulse repetition rate of 50 Hz was fixed by the rotation velocity of a rotating spark gap switch. Typical waveforms of the voltage and current pulses recorded during the corona discharge are shown in Figs. 2a and 2b, respectively. The amplitudes of the voltage and current pulses were up to 56 kV (Fig. 2a) and 10 A (Fig. 2b), respectively, with a pulse width up to 20  $\mu\text{s}$  and an energy of 2.63 J.

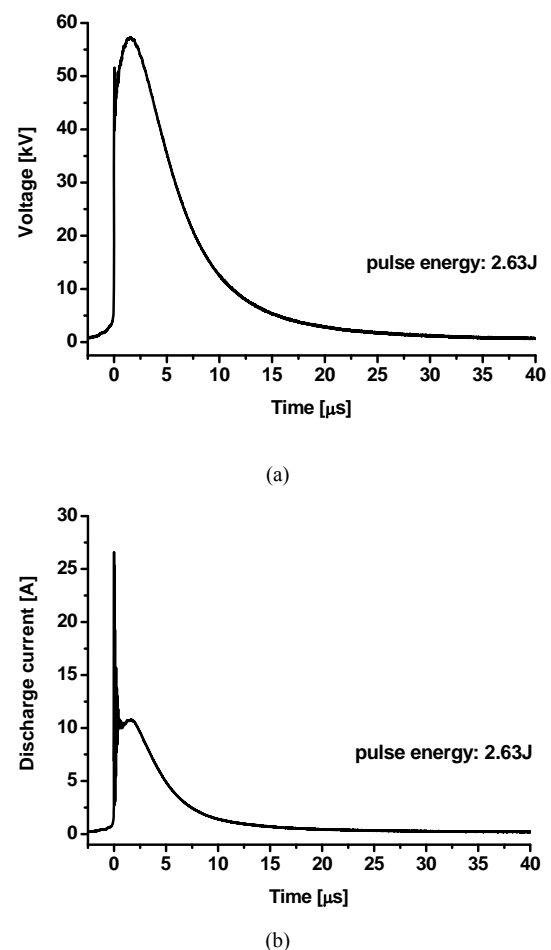


Fig. 2. Typical waveforms of the corona discharge voltage (a) and current (b) pulse in the Reda river water. Pulse energy 2.63 J.

The water sample with *coli* bacteria was processed for 10 minutes and the water samples were taken before and after 0.5, 1.5, 2, 3, 4, 5 and 10 minutes of treatment.

### III. RESULTS

Concentration of *total coli* and *E. coli* in water treated by the corona discharge is presented in Figs. 3 and 4, respectively. It is seen that 2 min. processing (6000 pulses) caused decrease in the number of *total coli* from initial 3.18 log (1500 cfu/100 cm<sup>3</sup>) to 0.48 log (3 cfu/100 cm<sup>3</sup>) with specific energy density 100 J/ml (Fig. 3). During this processing time the whole water sample volume (flowing in the closed loop) passed through the discharge region, what resulted in almost complete destruction of *coli* bacteria. This number remained constant and corresponds to the bacteria killing efficiency of 99.80% and energy efficiency of 0.15 cfu/J (after 2 min. processing).

As we can see in total coli number only 230 cfu/100 cm<sup>3</sup> (2.36 log) of *E. coli* was observed

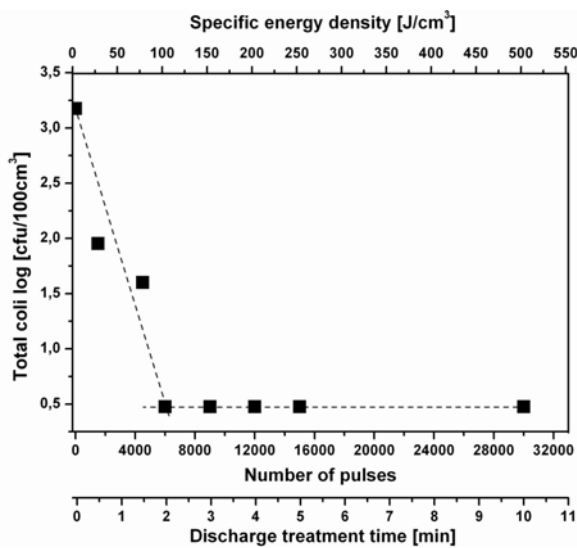


Fig. 3. Total coli disinfection during corona discharge as a function of applied specific energy density.

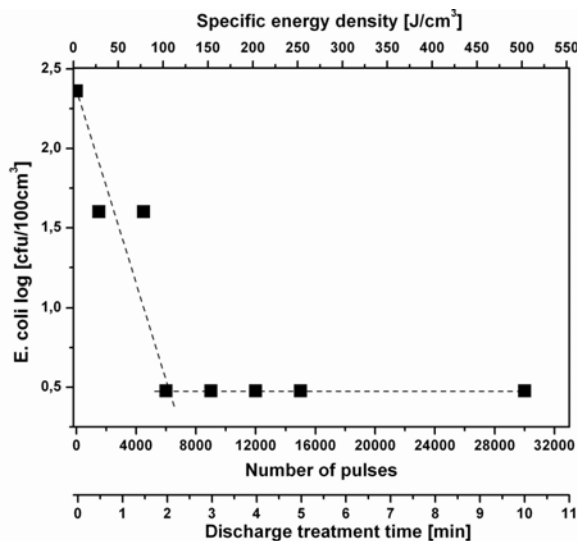


Fig. 4. *E. coli* disinfection during corona discharge as a function of applied specific energy density.

(Fig. 4). After 2 min. of processing also only 3 cfu/100 cm<sup>3</sup> (0.48 log) survived, what corresponds to the bacteria killing efficiency of 98.70% and energy efficiency of *E. coli* disinfection of 0.02 cfu/J (after 2 min. processing).

Table 1 summarizes the results of *total coli* inactivation experiments mentioned in this paper and in [9, 20]. The best results in *total coli* inactivation of 10<sup>4</sup> cfu was achieved by Abou-Ghazala et al. [9], giving energy efficiency of 5 cfu/J with specific energy density 20 J/ml and treatment time of 2 min. 40 sec. (16 pulses). The same range in *total coli* inactivation, but with smaller energy efficiency of 1.82 cfu/J, was obtained by Vykouk et al. [20]. Smaller energy efficiency results from higher specific energy density of 55 J/cm<sup>3</sup> and longer treatment time of 15 min (45000 pulses). Our results show, that the energy efficiency of 0.15 cfu/J is 12 times lower than in the work [20]. The reason is that the specific energy density is two times higher (100 J/cm<sup>3</sup>) and the number of *total coli* inactivated is one order lower (10<sup>3</sup> cfu) than in the work [20], although the treatment time was only 2 min. (6000 pulses). The important thing is that in work [9] and [22] the *total coli* is determined as *E. coli*, because bacterial suspension contained only *E. coli* cells. So the bacteria inactivation during the corona discharge was related only to *E. coli*, while in our experiments total coli inactivation was related to all *coli* bacteria not only *E. coli*.

TABLE 1  
A COMPARISON OF TOTAL COLI DISINFECTION USING PULSED CORONA DISCHARGE.

	Our results	[9]	[20]
Bacterial suspension volume [cm <sup>3</sup> ]	157	10	1600
Bacterial suspension conductivity [μS/cm]	365	1600	200
Total coli initial number [cfu/100 cm <sup>3</sup> ]	1500	--	10 <sup>7</sup>
Voltage [kV]	+56	-25	+23.3
Pulse energy [J]	2.63	13.5	1.9
Pulse frequency [Hz]	50	0.1	50
Discharge time [sec]	120	160	900
Pulses number	6000	16	45000
Specific energy density [J/cm <sup>3</sup> ]	100	20	55
Number of total coli inactivated [cfu]	1497	10 <sup>4</sup>	10 <sup>4</sup>
Final number of total coli [cfu/100 cm <sup>3</sup> ]	3		10 <sup>3</sup>
Energy efficiency [cfu/J]	0.15	5	1.82

### V. CONCLUSION

Our experiments demonstrated that the corona discharge effectively disinfected river water polluted with *coli* bacteria. The number of *total coli* inactivated was reduced by three orders of magnitude up to 3 cfu after only the 2 min. of treatment time. This is one order lower than in the work [10] and [20], because we started from lower bacteria initial concentration. The higher *coli* inactivation as well as better energy efficiency could be possible with higher bacteria initial concentration. However, in Poland there is no river or lake water

polluted with much higher number of coli bacteria than that used in our experiment.

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