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Spark discharge in water for bacteria inactivation

Abstract. *In this paper an investigation of spark plasma discharge in water for bacteria inactivation is presented. To optimize the river water treatment with our reactor, we first found the best parameters of the discharge. This was done through methylene blue dye decoloration. The efficiency of the bacteria inactivation was: for microorganisms growing at 36^{0}C – 80 %, for microorganisms growing at 22^{0}C – 80 %, for total Coli bacteria – 80 %, for E.Coli bacteria – 100 %.*

Streszczenie. *Praca dotyczy zastosowania wyładowania iskrowego do inaktywacji bakterii w wodzie. Optymalne parametry wyładowania ustalono wcześniej na podstawie efektywności odbarwiania błękitu metylowego. Wydajność iskrowego wyładowania do oczyszczania wody była następująca: dla mikroorganizmów wyhodowanych w 36^{0}C – 80%, dla mikroorganizmów wyhodowanych w 22^{0}C – 90%, dla wszystkich bakterii Coli – 80%, dla bakterii E.Coli – 100%. (**Zastosowanie wyładowania iskrowego do inaktywacji bakterii w wodzie**).*

Keywords: plasma water treatment, water purification, disinfection, water cleaning, spark discharge.
Słowa kluczowe: plazmowe oczyszczanie wody, oczyszczanie wody, dezynfekcja, wyładowanie iskrowe.

Introduction

In spite of extensive investigations in many laboratories, there is still not enough data on surface water (rivers, lakes) purification by the electrohydraulic discharges [1-4]. Electrohydraulic discharges in water cause the destruction and inactivation of viruses, yeast, and bacteria. It is generally assumed that the mechanism responsible for killing microorganisms through electrohydraulic discharges involves an electric field, shock wave, UV radiation and radical reactions [5]. The destruction of microorganism depends on the microorganism cell structure. It is different for each bacteria species and depends also on the mode of electrohydraulic discharge [6]. In the case of the corona discharge, *E. coli* bacteria cells are destroyed mainly due to reactions with oxidizing radicals OH and H_2O_2 with compounds forming the bacteria cell wall [6-11], whereas in the spark and arc discharges they are mainly damaged by shock waves and UV radiation [12-15].

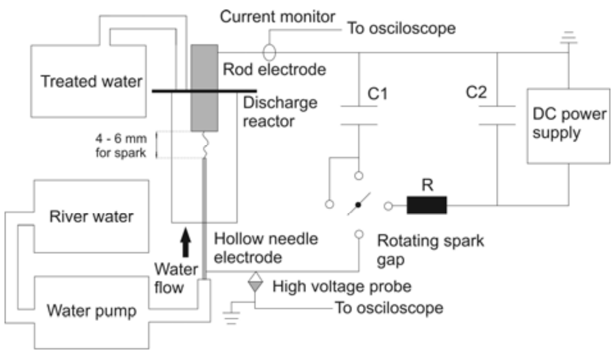


Fig.1. The corona and spark discharge reactor with water pumping/cooling system and pulsed power system ($C1$ = 2 nF, $C2$ = 22 nF, R = 10 kΩ)

In this work we investigated the influence of spark discharges in water on inactivation of all kinds of microorganisms, total *coli* and *E. coli*. Water samples were taken from the Strzyża river, in Gdańsk region. The Strzyża is a type IV sanitary class river, so it has a total coli number of over 3000 colony forming units (cfu) in 100 ml. Due to this fact, it cannot be used to supplying region inhabitants with drinking water. This would be possible only after complete removal of *coli* bacteria, e.g. by plasma processing.

Experimental setup

The processing of the river water samples was conducted in a PTFE tube reactor (inner diameter of 15 and 25 mm) equipped with water pumping and cooling system (Fig. 1).

Water samples were being pumped once through the reactor tube at same flow rate of 30 ml/min and different discharge voltages and gaps between the electrodes. A pulsed positive spark discharge was generated between a high voltage stainless steel hollow needle electrode and a grounded rod electrode (5 mm in diameter), both immersed in the water. The inner and outer diameter of the hollow needle were 1.4 mm and 1.6 mm, respectively. The discharge was generated at the tip of the hollow needle, whereas the rest of the needle was covered with an insulator. Spark discharge was generated when the needle-rod spacing was 4 and 6 mm. The single pulse energy was in the range of 0.4-0.8 J.

The processed water was taken from the Strzyża river in Gdańsk. The water initial characteristics was as follows: temperature 21ºC, pH=8.4, conductivity 573 µS, total number of *coli* bacteria 144 cfu/ml, number of *E. coli* 53 cfu/ml, total number of microorganisms at 36°C and 22°C were 1452 cfu/ml and 1042 cfu/ml, respectively.

Positive high voltage pulses were applied to the hypodermic needle electrode from discharge capacitor C_1 (1.4 nF) – Fig. 2. The capacitor was charged from a DC power supply through a resistor R (10 kΩ) 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. The amplitudes of the voltage and current corona pulses were measured using a TEKTRONIX P6015A high voltage probe and a PEARSON 2878 current monitor (Rogowski coil), respectively. The waveforms were observed and recorded on a TEKTRONIX TDS 3052B oscilloscope after being averaged over up to 256 acquisitions to eliminate the random noise.

Every treated sample was tested for microbiological markers such as: number of microorganisms after 24 h of growing in 36°C, number of microorganisms after 72 h of growing in 22°C, total number of *coli* bacteria and number of *E. coli* bacteria.

In all samples the concentration of the total organic carbon was determined using Sievers InovOx TOC analyzer.

Results

Initial experiments with the Methylene Blue showed optimal parameters for maximum oxidation in water should be as following: inner diameter of reactor 15-25 mm, electrode gap from 4 to 6 mm The decoloration efficiency for reactor of 15 mm diameter are shown in Fig. 2. We see that efficiency increases with the electrode gap, but if the gap is too large (over 6 mm) the discharge is changing from spark to corona which is not efficient in water disinfection.

Typical spark discharge waveforms registered on the osciloscope are shown in Fig. 3. It has to be noted, that the discharge voltage width varied between 0.5 μs and 3 μs randomly. So, the pulse energy is an averaged value taken from 256 pulses.

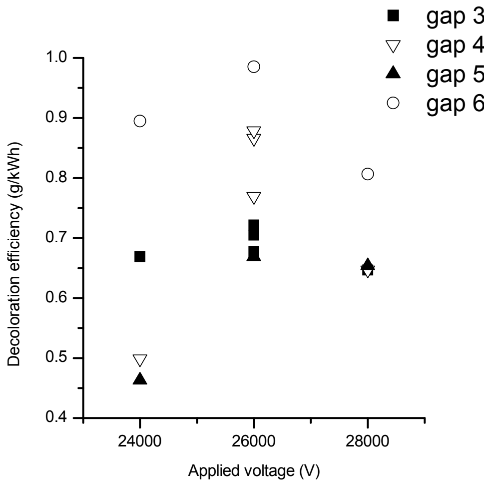


Fig.2. Decoloration efficiency of Methylene blue in reactor with inner diameter of 15 mm

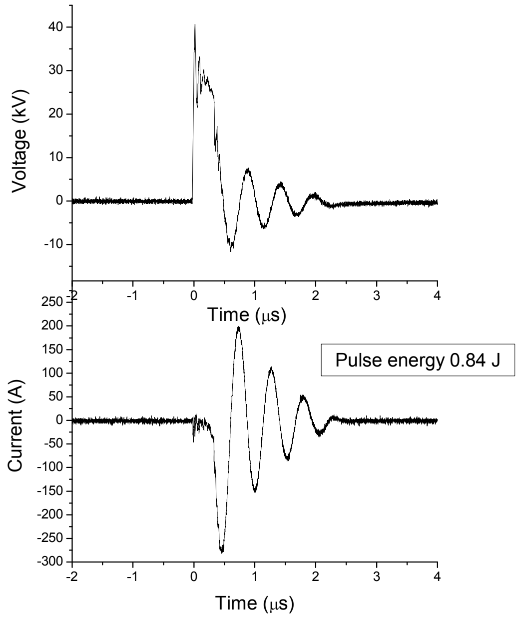
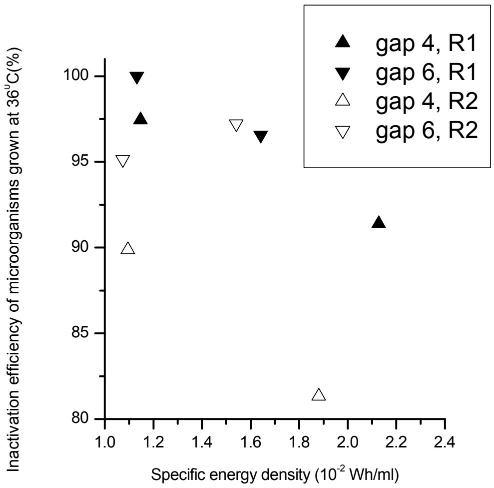


Fig.3. Typical pulse current and voltage waveforms

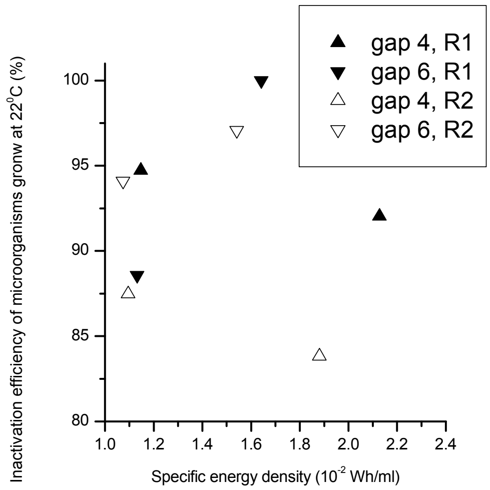
Results of the experiment show that processing by spark discharge is efficient in river water disinfection causing 100% decrease in the number of *E. coli* (Fig. 4). Other microorganisms are more resistive to biocidal effects of the spark discharge. It was revealed that the gap between electrodes influences the disinfection efficiency. When it is fixed at 6 mm the number of surviving microorganisms is lower comparing to results obtained at gap of 4 mm. Even in the case of *E. coli* this influence is seen, however, only at the lowest specific energy – at higher specific energy always all *E. coli* bacteria are inactivated. The influence of gap between electrodes is more dramatic in the wide reactor. When comparing results obtained using both reactors with the discharge gap fixed at 6 mm one can see that there is no significant difference. On the other hand, at the gap of 4 mm the inactivation efficiency observed in the wide reactor is very low.

The total organic carbon concentrations (TOC) measured in every water sample are similar, i.e. 6±0.6 ppm. It means that TOC concentrations were not affected by the treatment in this experiment. This proves that spark discharge did not oxidize organic compounds to CO_2.

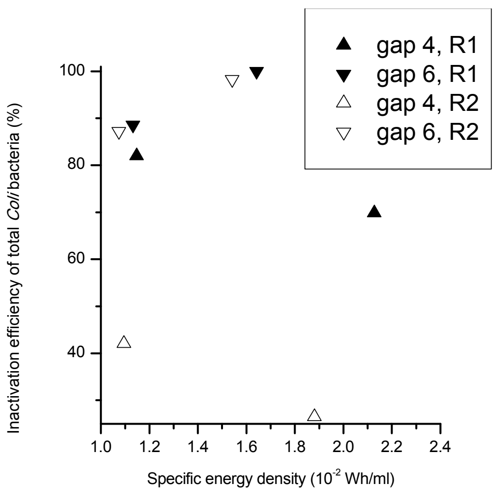
a)



b)



c)



d)

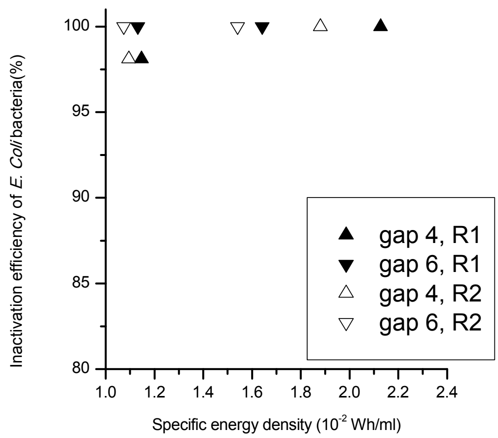


Fig.4. Inactivation efficiency of *a)* microorganisms grown in 36°C, *b)* microorganisms grown in 22°C, *c)* total number of *coli* bacteria, and *d) E. coli* by pulsed spark electrohydraulic discharge: *R1* – reactor of inner diameter 15 mm, *R2* – reactor of inner diameter 25 mm.

Conclusions

Our experiment demonstrated that the pulsed spark electrohydraulic discharge in water is capable of killing 100% of the *E. coli* bacteria and decrease significantly the number of other microorganisms, with minimum amount of energy spent 15 (mWh/ml). Such results are possible after optimisation of the reactor's inner diameter, discharge electrode shape and discharge gap, we have made.

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