Gliding arc discharge for water treatment

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Abstract

The significant shortage of usable water resources necessitated the creation of safe and non-polluting ways to sterilize water and rehabilitate it for use. The aim of the present study was to examine the ability of using a gliding arc discharge to inactivate bacteria in water. Three types of Bacteria satisfactory were used to pollute water which are Escherichia coli (Gram-negative), Staphylococcus aureus (Gram-positive) and salmonella (Gram-negative). A DC power supply 12V at 100 Hz frequency was employed to produce plasma. pH of water is measured gradually during the plasma treatment process. Contaminated water treated by gliding arc discharge at steadying the gas flow rate (1.5 l/min) and changing the exposure time of the polluted water to the plasma during periods of 10, 20 and 30 min. The bacteria which used show different responses when expose to produced plasma, most of them inactivated when treated with plasma for 30 minutes. That’s means Survival rate decreased with treatment time. Results show that gliding arc plasma is a powerful and green tool to treatment water without generating any byproducts.

Keywords: Gliding arc discharge, Escherichia coli, Salmonella, Staphylococcus aureus, Water treatment

1. Introduction

Plasma treatment is a committed, non-chemical technique for inactivation of bacteria in water [1]. The plasma which used in this work is ionized gas own concentrated energy with highly localized temperature increases close the arc of the gliding arc discharge. It is known, that plasma has a good ability to generate highly reactive species. The gliding arc discharge is able to generate a considerable amount of active plasma species because of its exceptional plasma properties. The collision of the energetic electrons produced in the discharge with gas atoms or molecules is the main reason for the formation of highly reactive species. The reactive species which are formed in electrical discharges in liquid or gas-liquid medium, which causes the degeneration of the biological pollutants, are ozone $O_3$, hydrogen peroxide $H_2O_2$, and hydroxyl radicals. Also reactive oxygen species (ROS) and reactive nitrogen species (RNS) are generated in the plasma like superoxide, atomic oxygen, hydroperoxyl radicals, nitrogen oxides, nitrates, proxy nitrites as well as UV and electric fields. All of these plasma species may play a role in the inactivation of bacteria. Most of the active plasma varieties have very short life live on the order of $\mu$s or fewer [2-5]. The exceptions to these are ozone and $H_2O_2$, which have comparatively long half-lives, and as
a result, may be particularly useful in the treatment of contaminated water [6]. On the other hand, can be formed directly in water through the dismantling of water molecules by plasma discharges [7]. Gliding arc discharge plasma is an exemplary source of thermal plasma, however in some environments it may also produce non-thermal plasma (NTP). This discharge usually burns between two separating electrodes blown by injected gas. The discharge started in the narrowest inter-electrode area is wafted by flowing gas external the diverging area. The gliding arc collects the advantages of (thermal and non-thermal) plasma, i.e., non-thermal plasma conditions at a higher power [1]. The exploratory, we find that the gliding arc discharge plasma is in contact with water by feeding argon gas, for inactivation of three sorts of bacteria (E-Coli, salmonella, and Staphylococcus aureus). The cell dike of these bacteria is so thick and develops on a rich medium. Staphylococcus aureus is answerable for a large range of infections like mild skin contagion (folliculitis, impetigo). Salmonella which can be transported by drinking or eating dirtied water or nourishment, in explicit. Salmonella passes through the body and simply make its way out of gorge acid, also accountable for many diseases including puke and fever [8]. These microorganisms in water may transport to the body [9].

2. Experimental part

The experimental setup used in the present work is illustrated in Figure (1). The gliding arc plasma system consists of four main parts: Power supply, DC/AC converter, coil, and two Electrodes. The gliding arc was generated using a dc power supply 12V connected to the DC/AC converter circuit. DC to AC converter circuit is designed and implemented. The DC/AC converter circuit is consisting of two major parts; the first part is the pulse generator circuit part while the second part is the high voltage circuit part. The purpose of the DC to AC converter circuit is to convert the 12 volts DC power supply to AC voltage equal to about 220 volts. DC/AC converter circuit is joined to the coil which is used to raise the output voltage 3000 to 13000 volt. The output of this circuit is attached to two electrodes. The gliding arc discharge (GAD) reactor consists of two stainless steel diverging electrodes, 1 mm thick, located under a feeding gas nozzle. These electrodes attached to ceramic support placed between two thin rectangular glass plates. The discharge is produced by two knives-shaped electrodes 2.5 cm radius and thickness 1mm. The maximum gap between two electrodes is 2cm and the minimum is 4mm. The distance between the connecting points of the electrodes is 1 cm. The AC high voltage circuit provided 13kV at a frequency of 50 Hz. The gas Ar, (99.998% purity) is at a total flow of 0.5, 1and 1.5 L/min. The arc is pushed away by the supply gas flow, carding, along the increasing electrode cavity and breaks in a large plasma plume. This system has been used to treat bacteria-contaminated water.

Three types of bacteria were used in this work. Two of them are Gram-negative (salmonella and Escherichia coli) and the other Gram-positive (Staphylococcus aureus). The streaking method was used for isolation pure colony of each bacteria. Bacterial was activated by culturing it on nutrient broth for 24h at 37ºC and a second day takes a touch of activated bacteria by a loop and streaks it on nutrient agar. The concentration of peroxide (H₂O₂) was measured using test strips as follows 40 mL samples of treated water by gilding arc system were collected and a test strip was dipped into each water sample for about 20 seconds. After extraction strip of water, observed a change in color of a test strip and compared with the colors from the calibration standard data provided by the manufacture company. Also the acidification of samples was measured.

2.1 Treatment method

To test for inactivation of bacteria, 3 samples of distilled water (40 ml for each sample) were taken using a sterile pipette and placed in a petri dish and contaminated with three types of pathogenic bacteria (salmonella, Escherichia coli and Staphylococcus aureus). 20 ml of the contaminated water is put in a petri dish and placed on a magnetic stirrer. The contaminated water is exposed to the plasma generated
from the arc discharge and at a distance of 15mm between the surface of the water and the plasma. The contaminated water is treated by exposing it to plasma within a period of 10 minutes and changing the flow rate of argon gas (0.5, 1 and 1.5) l/min. It was also treated by stabilizing the gas flow rate (1.5 l/min) and changing the exposure time of the contaminated water to the plasma during periods of (10, 20 and 30) min; these times were chosen to get a gradual killing rate. After treatment completed, 5 microliters of contaminated water were pulled and placed over MacConkey agar, then the bacteria are distributed by using sterile swab over the agar. Then, the plates were incubated at 37°C for 24h and bacterial colonies were counted.

3. Results and discussion

The acidity of the water was tested before and after the water treatment for all samples. It was observed that the pH of the sample gradually decreases when the exposure time increases as a result of nitric and nitrate products such as HNO₃, NO₂, and HNO₂ dissolving in treated water. Figures 1, 3 and 3 represent the change of pH of plasma treated water during different treatment periods which have been previously contaminated by the three types of bacteria (salmonella and Escherichia coli and Staphylococcus aurous). This study discusses the effect of changing the concentration of H₂O₂ on the sterilization of contaminated water by the gliding arc discharge system. Experimental results indicate that the gliding arc discharge reacts with water. It causes decreasing the pH of water but it generates H₂O₂. When water is exposed immediately to the Gilding arc discharge, the reactions begin with the dissociation of water molecules as follows [10].

\[ e + H₂O \rightarrow H + OH + e^- \] (1)
e + H₂O → H⁻ + OH \hspace{1cm} \ldots \ldots \ldots \ldots \text{(2)}

M⁺ + H₂O → H₂O⁺ + M \hspace{1cm} \ldots \ldots \ldots \ldots \text{(3)}

H₂O⁺ + H₂O → H⁺(H₂O) + OH \hspace{1cm} \ldots \ldots \ldots \ldots \text{(4)}

After that H₂O₂ is produced from the recombination of hydroxyl radicals.

OH + OH + M → H₂O₂ + M \hspace{1cm} \ldots \ldots \ldots \ldots \text{(5)}

Figure 5 shows the relationship between the peroxide concentration and the exposure of the contaminated water to the gilding arc discharge.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{image}
\caption{PH changing of water polluted with staphylococcus bacteria before and after treatment by Gilding arc plasma.}
\end{figure}
Figure 3. PH changing of water polluted with salmonella bacteria before and after treatment by Gilding arc plasma.

Figure 4. PH changing of water polluted with E-coli bacteria before and after treatment by Gilding arc plasma.
3.1 Inactivation of Bacteria

‘Figure (6)’, ‘Figure (7)’, ‘Figure (8)’, ‘Figure (9)’, ‘Figure (10)’, ‘Figure (11)’ respectively show the effect of treatment by Gliding arc discharge on Escherichia coli, Staphylococcus aureus and Salmonella bacteria colonies, respectively. One can be observed from the figures that the rates of killing increase with an increase in the exposure time of the polluted water to the plasma formed by the Gliding arc discharge. These Figures refer to the high efficiency of the gliding arc discharge plasma water treatment method to inhibit bacteria. When H$_2$O$_2$ form in low pH water, it becomes a powerful oxidizer and an active tool for the inhibition of bacteria. It has an immediate effect on the outer membrane of bacteria because of the peroxidation of cell membranes.

When increasing the exposure time, the number of bacteria colonies was decreases. E-coli bacteria are more resistant than the other types of bacteria, where at 20 minutes a few colonies were killed. While salmonella bacteria were the most affected compared with other types of bacteria. At 20 min, there is no trace of salmonella colonies appears.

![Figure 5. Concentration of peroxide of treated water.](image)

![Figure 6: E-coli bacteria inactivation at different time: a) control, b) 10, c) 20 min, d) 30 min](image)
Figure 7. Histogram effect gliding arc plasma of different time in cell No. viability of Escherichia coli. All data are expressed as a mean± standard deviation LSD test (ANOVA).Statistical significance was considered as P<0.01.

Figure 8. Photograph of the Staphylococcus aureus bacteria inactivation at different time : a) control, b) 10min, c) 20min, d) 30min
**Figure 9.** Histogram effect gliding arc plasma of different time in cell No. viability of Staphylococcus aureus. All data are expressed as a mean ± standard deviation LSD test (ANOVA). Statistical significance was considered as P<0.01.

**Figure 10.** Photograph of the Salmonella bacteria inactivation at different time: a) control, b) 10min, c) 20min, d) 30min
Figure 11. Histogram effect gliding arc plasma of different time in cell No. viability of Salmonella. All data are expressed as a mean ± standard deviation LSD test (ANOVA). Statistical significance was considered as P<0.01

4. Conclusion

The gliding arc discharge method is very efficient in the treatment of biologically contaminated water. A large volume of water can be treated by this method. The pH value of treated water a bit decreases with increasing treatment time, and the product of \( \text{H}_2\text{O}_2 \) in water increases safely with increasing treatment time. The colonies density decreases gradually with increasing exposure time and there is no trace of bacteria (salmonella) at 20 min but the (Escherichia coli and Staphylococcus aureus) killed at 30 min. When peroxide is formed in a low pH water, it becomes a strong oxidizer and has high efficiency in inhibiting bacteria.

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