Influence of the electric discharge and the power supply on the aqueous solution interface parameters

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Abstract. Laboratory electrical discharges that produce non-thermal plasma are used more and more for microbiological decontamination, surface treatment and depollution by the means of decomposing some complex molecules or in the field of modern medicine. Each application requires a power supply particularly adapted to the plasma reactor type used. If the first applications of these discharges were designed mostly for reactor types with high volume discharge capabilities, and the power supplies were simple and robust generating high power using industrial frequencies, in time the reactors decreased significantly in size and the power supplies used were working on higher frequencies. This trend was adopted on one hand out of the need for energy optimization of the power supplies used, and on the other hand for obtaining a better homogeneity of the treatment. This paper aims to provide a comparison of few AC and pulsed power supplies, working at different frequencies, with respect to the electrical parameters, from the point of view of active species production. The measured electrical parameters of the electrical discharges are the power and the specific energy. Also the results obtained for treatment of distilled water using three types of plasma reactors (classic GlidArc, Mini-torch plasma and Gliding Spark) will be shown. The analysis focus on the modification of pH of the distilled water in time after the plasma treatment.

1. Introduction

Due to the exploration of non-thermal plasma treatments in different areas, this technology is used more and more because of its advantages that include low costs, high efficiency and ease of use. With this extension of area and fields, the power supplies for non-thermal plasma treatment also need to evolve, because different voltage and current parameters provide different results with different reactor types. Among the non-thermal plasmas, the discharges using a gas flow, also called gliding discharges play a very important role. In this work three types of plasma reactors, using different gliding discharges have been used: GlidArc (figure 1), Mini-torch plasma (figure 2) and Gliding spark (figure 3), [1].
The classic GlidArc from figure 1 relies on a cylindrical geometry with two divergent electrodes supplied at high voltage. The discharge starts between electrodes at minimum distance and the air flow will elongate it towards the top of the electrodes. When the energy density will decrease below the threshold value the discharge will stop and a new one will start following the same cycle.

The plasma Minitorch takes the air flow and passes it through a metallic grill where the discharge takes place via two electrodes connected to a high voltage power supply. This reactor concentrates the plasma flow through a nozzle, providing a smaller treatment surface than the GlidArc. However, the plasma is better concentrated on the surface than for the previous reactor.

The Gliding Spark reactor relies on a confined space discharge delivered from a car spark plug. The spark takes place between the housing and the main central electrode of the spark plug. A high voltage is also necessary in order to ignite the discharge that is elongated with a lateral air flow. Plasma volume is the smallest of the three cases, and the outlet of the reactor is provided with a nozzle.
By comparing the volume of maintenance of the active species produced by the plasma in the three reactors it is observed that in the first case this volume is much higher than in the other two reactors. This means that injected energy is better used in the last two cases for surface treatments [2, 3], then in the first case. The classic GlidArc is better suited for volume treatments.

Three types of power supplies have been used for the experiments. The first one is a high voltage transformer, AUPEM type, supplied from the network at 230V, 50Hz. The voltage of the secondary winding, applied directly on the electrodes, is 10000V without charge and the electric current through the discharges is limited at 100mA by the dispersion inductance of the transformer.

The second power supply provides high voltage pulses with a frequency of 100Hz. It is based on a specialized circuit, βA145, and a classic induction coil which raises the voltage level to 15kV, applied directly on the electrodes, [4].

The third power supply uses an AT89S52 microcontroller and an electronic induction coil, VW6N0905104 type. The secondary voltage is pulsed with a frequency of 100Hz [4].

The efficiency of the electrochemical or depollution treatment with non-thermal plasma is indicated by several parameters. In order to examine the differences between the above mentioned reactors and power supplies, distilled water was chosen to be treat under different conditions. The pH of the distilled water was the indicator for the effectiveness of treatments [3].

2. Experimental setup
The first step taken for the analysis was to collect data from untreated distilled water in order to follow its acidity. The data was collected with the FISHER SCIENTIFIC XL600 analyzer, indicating the pH and the redox potential. All the power supplies were used on each type of reactor for measuring the pH parameter. The plasma treatment was set to 10 minutes and the initial value of the pH was 5 units. It was treated for each experiment a quantity of 200 ml of distilled water, placed at a distance of 25 mm or of 50 mm from the plasma. For the pH measurements the samples were collected every minute and the duration of the entire sampling was 10 minutes.

The air flow was adjusted from 5 to 32 l/min. The electric parameters were measured using the schematic shown in figure 4 [5].
The discharge voltage was measured with a compensated high voltage probe (HVP) with a 1:1000 ration. The electric current was measured with a shunt (SH). Both parameters were introduced into a digital oscilloscope, TDS210 type, and recorded on the computer as time evolutions. The instantaneous electric power of the discharge was determined by multiplication of the discharge voltage and the electric current. Only the power supply AUPEM type was used for these experiments and three different values of the air flow: 5 l/min, 10 l/min and 15 l/min. For the calculation of the specific energy the volume of the discharge was approximated with a different method for each type of reactor. From the electrical parameters measured during the real process the aberrant data were eliminated. Their number was 0.125% from the total number of data for each record.

The space between the electrodes of the GlidArc reactor was approximated by an isosceles triangle. The base of the triangle is 35 mm, and the height from the base to the top is 64 mm. The area of curvature of the electrodes was considered to be right and the sides of the isosceles triangle were calculated as being equal to 66.35 mm, from which the triangle area resulted. An outer rectangular space has been added to this area to compensate for both the area of curvature of the electrodes and the space between them, with a height of 40 mm. The area obtained from the sum of the two was multiplied with the thickness of the electrodes (4 mm), thus obtaining the maximum volume.

For the torch we considered a maximum cylinder volume of 2 mm in diameter and a height of 10 mm. For Gliding Spark, the maximum volume in the enclosure considered as cylinder was calculated for 1 cm height and 1 cm in diameter. Taking into account that the discharge takes place on a third of this volume, it was divided to 3 to get the final value.

The volume calculated for each type of reactor is increasing and decreasing on each half-period. The time delay between 2 samples of experimental values is 40 μsec. So the electric power, the volume and the others parameters are changing every 40 μsec. During this time the injected power is constant and is possible to calculate a value of instantaneous energy. This energy is divided to the plasma volume and the result is the specific energy. For all the instantaneous values of the specific energy is possible to calculate the average value, in order to compare these values corresponding to each reactor and each air flow. The minimum distance between electrodes was constant for all types of reactors. This distance influence the voltage breakdown and consequently the electric power and the specific energy of the non-thermal plasma electric discharges [6].

3. Results and discussion
The time variation of the pH from the distilled water after the plasma treatment with a classic GlidArc and the AUPEM power supply, at 25 l/min air flow is shown in figure 5.

![PH distilled water treated with GlidARC](image)

Figure 5. Variation in time of distilled water treated with Glid Arc.
It could be observed in figure 5 that immediately after the treatment, the acid effect of the plasma treated water is at the maximum value, indicating the maximum number of active species (ions in solution). After 4 minutes the pH will be constant near 3.25 units.

In figure 6 is depicted the time evolution of the pH distilled water solution due to the plasma torch reactor with the same power supply and gas air as for the previous test.

![Figure 6. pH variation in time for distilled water treated with Plasma Torch.](image)

In this case the pH reaches very low values in the first 2 minutes, but after a few minutes its value increases without stabilizing, indicating a rapid reduction in the number of active species.

In figure 7 the pH evolution was obtained using the Gliding Spark reactor.

![Figure 7. pH variation in time for distilled water treated with Gliding Spark.](image)

The values of the pH from figure 7 do not go down as much as in the previous cases and are approximately constant during the 10 minutes measurements.

For the pH measurement from figure 8, the parameters used are as follows: sample 1 - airflow 18 l/min, distance between treated surface and plasma 25 mm, exposure time 10 minutes, reactor type
GlidArc classic, power supply with $\beta A145$; sample 2 – the same parameters, except the airflow of 25 l/min; sample 3 – the same parameters excepting the airflow of 32 l/min and the distance between the sample and the non-thermal plasma of 50 mm.

The pH values from figure 8 are constant during the 10 minutes measurements. There is a low decreasing of the indicator parameter comparing to the initial value (5 units). The increasing of the gas flow will ameliorate the plasma treatment.

The next experiment was done using the plasma torch reactor type and the pulsed power supply based on $\beta A145$. The sample 1 has an air flow of 18 l/min, a distance of 25mm from plasma to the treated surface and an exposure time 10 minutes, the sample 2 was collected for similar conditions but for an airflow of 25 l/min and the sample 3 for similar conditions but for an air flow of 32 l/min and a distance of 50mm, see figure 9.

The values from figure 9 are similar with the values from figure 8. This indicates there is no big influence of the reactor geometry if was used the pulsed power supply based on $\beta A145$. However, there is an influence of the air flow and for sample 1 from figure 9 the pH values are slightly smaller than for sample 1 from figure 8.

The next experiment was done using the same $\beta A145$ pulsed power supply and the reactor type used was Gliding Spark. The first sample contains the data treated at an air flow of 18l/min, exposure time 10 minutes, distance from plasma to treated surface of 25mm, the sample 2 – similar conditions, the air flow of 25l/min and the sample 3 – similar conditions, the airflow was set to 32l/min, the distance between plasma and surface treatment was 50mm. The values of pH parameter are shown in figure 10.

The pH values from figure 10 are slightly higher than those of the previous two figures. The values are constant during the 10 minutes measurement.
Using the third power supply, based on AT89S52 microcontroller, the first experimental data (three samples) were collected in the following conditions: Plasma Torch reactor type, 10 minutes exposure time, airflow 18l/min, distance between treatment surface and plasma was 25mm, the sample 2 – similar conditions but an air flow of 25l/min, the sample 3 – similar conditions excepting an air flow of 32l/min and a distance of 50 mm from the plasma to the treated surface, see figure 11.
Figure 11. pH variation in time for distilled water treated with Plasma Torch – powered by AT89S power supply.

The pH results from figure 11 are similar with the results from figure 9.

Using the Gliding Spark reactor, the data from figure 12 were obtained from the following samples: sample 1 - air flow of 18l/min, exposure time 10 minutes, distance between plasma and treatment surface 25mm, sample 2 – similar conditions but for an air flow of 25l/min, sample 3 – similar conditions but for an air flow of 32l/min and a distance of 50 mm from the plasma to the treated surface.

Figure 12. pH variations in time for distilled water treated with Gliding Spark – powered by AT89S power supply.

The pH results from figure 12 show the highest experimental values, so the worst treatment. As usual, these values are constant during the 10 minutes treatment.

In figure 13 (a) and (b) are shown the time evolution of the electric power and of the specific energy for a GlidArc reactor, an AUPEM transformer power supply and an air flow of 5 l/min.
If the air flow is increased from 5 l/min to 15 l/min, using the same reactor, the electric power and the specific energy will have a time evolution presented in figure 14.
Figure 14. Time evolution of the electric power and the specific energy for GlidArc reactor, 15 l/min air flow.

In figure 15 are shown the time evolution of the electric power and of the specific energy for Minitorch reactor, AUPEM transformer power supply and an air flow of 5 l/min.

Figure 15. Time evolution of the electric power and the specific energy for Minitorch reactor, 5 l/min air flow.
In figure 16 are included the time evolution of the same parameters in similar conditions with the previous experiment, but with an air flow of 15 l/min.

![Figure 16](image)

**Figure 16.** Time evolution of the electric power and the specific energy for Minitorch reactor, 15 l/min air flow.

By using the Gliding Spark reactor with an air flow of 5 l/min, the electric parameters power and specific energy have a time evolution as depicted in figure 17.

In figure 18 are shown the time evolution of the same parameters in similar conditions with the previous experiment, but with an air flow of 15 l/min.
The values of the electric power are the biggest in the case of the GlidArc reactor, followed by the Minitorch reactor and the Gliding Spark reactor. For the same air flow and the same power supply the average value of the electric power for the Gliding Spark is 6 times lower than for the classic GlidArc.
and about 3 times lower than for the Minitorch reactor. In the case of the specific energy the highest values are for the Minitorch reactor, then the Gliding Spark reactor and at the end for the classic GlidArc reactor. All these values are increasing with the air flow values in our experiments.

4. Conclusions
A very important role in the efficiency of cold plasma discharge performance, in addition to the reactor construction, is also provided by power supplies. Compared to the network that is an AC power source, the pulse power sources presented offer the possibility of using wider frequency beams. In addition, at high and medium frequencies, a higher volume uniformity of the plasma is obtained, which is useful for surface conditioning.

For the pH measurements the best results were obtained for the classic GlidArc reactor and the Mini Torch Plasma by using the AUPEM type transformer. For the most part of the experiments the pH values were constant during the 10 minutes measuring.

For the electric parameters the best results were in the case of Minitorch reactor. All the tests were done using the AUPEM transformer as power supply. The calculation of the specific energy for the plasma approximated volume showed than a lot of active species are dispersed in a great volume for the classic GlidArc reactor, so the useful power is not used efficiently. The influence of the air flow showed better results with increasing values, but the threshold of the maximum flow was achieved only for the Gliding Spark reactor. For values greater than 15 l/min the electric discharges could not start inside the Gliding Spark reactor.

The results presented in this paper provide an explanation regarding increasing use of power supplies in this respective area. As it can be seen the power supplies provide a much better understanding of the capabilities of higher frequency, lower current discharges in the treatment of surfaces.

5. References
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