Behavior of the AB52 dye degradation in liquid medium by different electrical power non-thermal plasma at atmospheric pressure

Comportamiento de la degradación del colorante AB52 en medio líquido por plasma no térmico de diferente potencia eléctrica a presión atmosférica

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Abstract

The degradation of Acid Black 52 (AB52) dye in a liquid medium derived from exposure to a non-thermal plasma of air at atmospheric pressure is quantified experimentally. The changes observed in the dilution are measured and compared as a function of the electrical power of plasma generation (15.0 W, 22.5 W, 30.0 W, and 45.0 W), as well as the exposure time (two hundred minutes per electrical power). Dye degradation for each electrical power of plasma was established by comparing the results from UV / VIS spectrophotometry measurements (absorbance, concentration, and percentage of degradation), pH, COD, and TOC. In addition, the toxicity change dilution was determined by performing bioassays using *Lactuca sativa* lettuce seeds. The changes for each of the variables measured as a function of the electrical power of plasma generation show the following specific mathematical behaviors: Logarithmic (Temperature, TOC, and pH), potential (COD), and linear (Absorbance). Obtained results showed that the increase in the degradation of the dye and the change in toxicity depends directly on the electrical power and the time of exposure to plasma. The maximum degradation obtained from the samples analyzed at the end of the experiments corresponds to 45.0 W, that is, higher electrical power, a higher percentage of degradation.

Keywords: non-thermal plasma, water treatment, advanced oxidation processes, toxicity, degradation.

Resumen

Se cuantifica experimentalmente la degradación del colorante Negro Acido 52 (NA52) en medio líquido derivada de la exposición a un plasma no térmico de aire a presión atmosférica. Se miden y comparan los cambios observados en la dilución como función de la potencia eléctrica de generación del plasma (15.0 W, 22.5 W, 30.0 W y 45.0 W), así como del tiempo de exposición (200 minutos por potencia). La degradación del colorante para cada potencia generadora de plasma se determinó mediante la comparación de las medidas de espectrofotometría UV / VIS (absorbancia, concentración y porcentaje de degradación), pH, DQO y TOC. Se cuantificó también el cambio de toxicidad de la dilución a través de bioensayos con semillas de lechuga *Lactuca sativa*. Los cambios para cada una de las variables medidas como función de la potencia eléctrica de generación del plasma, muestran los siguientes comportamientos matemáticos específicos: logarítmico (Temperatura, COT y pH), potencial (DQO) y lineal (Absorbancia). Los resultados mostraron que el aumento en la degradación del colorante y el cambio de toxicidad depende directamente del tiempo de exposición al plasma, así como de la potencia eléctrica de trabajo. La máxima degradación obtenida al final de los experimentos corresponde al de potencia de 45.0 W, esto es, a elevada potencia eléctrica máximo porcentaje de degradación.

Palabras clave: plasma no térmico, tratamiento de aguas, procesos avanzados de oxidación, toxicidad, degradación.

1   Introduction

Globally, 3,928 km^3 of freshwater are withdrawn annually from rivers, lakes, and aquifers (WWAP, 2017). In Mexico, in 2020, 89,547.8 hm^3 of water were extracted, of which 75.7, 14.7, and 9.6% were used for agriculture, public supply, and industry, respectively, generating 8,829 hm^3 of municipal wastewater and 7,010 hm^3 of non-municipal wastewater (CONAGUA, 2022).

Industrial wastewater contains various contaminants, some of which may be toxic, carcinogenic, mutagenic, teratogenic, and/or persistent; in particular, dyes are dyes. These compounds are found in pulp and paper, food, organic chemical, plastic, and textile effluents and are designed to be chemically and photolytically stable and, consequently, may be resistant to degradation and are considered persistent, bioaccumulative, and toxic substances (Rocha *et al.*, 2017).

The colorants in the water, even in very low concentrations, cause an intense coloration. When discharged into bodies of water, colored wastewater affects aesthetics, hampers the photosynthetic process, and consumes dissolved oxygen, harming aquatic organisms (Agrawal *et al.*, 2014). From this perspective, conventional physicochemical processes such as sedimentation (Solís *et al.*, 2013), adsorption, membrane filtration, and flocculation-coagulation have been used to remove dyes from wastewater (Solís *et al.*, 2013; Arabzadeh and Salimi, 2016). However, these technologies cannot wholly remove colorants. In addition, the regeneration of the adsorbent and the membrane is necessary, as well as the sludge disposal. On the other hand, the toxicity of dyes causes degradation by conventional biological processes that are not carried out efficiently (Kapoor *et al.*, 2021), and, in particular, anaerobic biodegradation produces aromatic amines, which can be more toxic than the azo dye (Zhang *et al.*, 2021).

Innovative technologies are currently being used for the degradation or even the mineralization of dyes present in water. These technologies are known as advanced oxidation processes and are characterized by the generation of hydroxyl radicals, highly oxidizing species capable of degrading most organic compounds (Silvestri and Foletto, 2017; Ángel-Hernández *et al.*, 2021).

Among such technologies are heterogeneous photocatalysis treatments with titanium dioxide that require ultraviolet radiation (Miao *et al.*, 2018; Zaruma-Arias *et al.*, 2021). However, it has the disadvantage that the rapid recombination of pairs of holes of photogenerated electrons affects the efficiency of the process (Arabzadeh and Salimi, 2016). Others are ozonation, UV/H_2O_2, Fenton, plasmas, and photo Fenton. The latter has been shown in the case of the degradation of azo dyes to be more feasible and profitable, even though it has certain disadvantages (Ramos *et al.*, 2020; Rahim Pouran *et al.*, 2014).

Plasma is an advanced oxidation process technology that has aroused much interest in recent years due to its efficiency and the fact that it does not require particular pressures or temperatures to be carried out. The electrical discharge plasma causes the formation of radicals (•H, •O, •OH), molecules (H_2O_2, O_3, among others), shock waves, ultraviolet radiation, and electrohydraulic cavitation (Jiang *et al.*, 2014), which they act on pollutants, transforming them into simpler compounds, including CO_2. Plasma treatment can be affected by different factors: reactor geometry, electrode, applied voltage, current intensity, temperature, solution pH, gas inlet, liquid conductivity, and electrolytic components (Jiang *et al.*, 2014; Wang *et al.*, 2012).

On the other hand, about costs. According to the treatment systems identified by the Mexican Institute of Water Technology (IMTA), in its documentation for the application of the costs of wastewater treatment plants concerning the systems identified in the national inventory; advanced primary treatment, activated sludge, biological filter, aerated lagoons, stabilization lagoons, and wetlands. Regarding the costs for energy consumption of the plant, a value of 200 mg BOD/L (Biochemical Oxygen Demand) and a treatment capacity of 0.5 m^3/s were established as an average value of the real data available at the national level, obtaining an energy consumption value of 3,000 kWh. Considering a cost for energy consumption of 3,229 kWh, according to the current rate of the Federal Electricity Commission (CFE) in Mexico regarding excess domestic consumption, there is a cost for energy consumption of $9,687 MXN/kWh. On the other hand, the treatment proposed in this work, considering the same tariff, would cost $960 MXN/kWh per m^3, which represents an alternative for the treatment of industrial effluents (Martínez *et al.*, 2018).

In the present study, the degradation of the Acid Black 52 (AB52) dye was carried out using a non-thermal plasma at atmospheric pressure to determine the discoloration of an aqueous solution of the azo

dye after exposure to different powers, which were obtained by modifying current intensity (10, 15, 20 and 30 mA) and keeping the voltage constant (1500 V).

Acid Black 52 is an azo dye used to dye wool, nylon, silk, and leather. Its chemical formula is $C_{20}H_{12}N_3NaO_7S$; its molecular weight is 461.38 g/mol, and its maximum absorbance peak is approximately 570 nm.

In particular, this research aims to check and experimentally establish the behavior of AB52 dye degradation in a liquid medium by non-thermal plasma as a function of the electrical power of plasma generation.

2 Materials and methods

2.1 Study Solution (AB52)

The experimentation was conducted considering an initial concentration of 0.10 mM or 46.2 mg / L. To obtain this value, 0.0231 g of powdered AB52 colorant was added to 500 mL of distilled water. The dye was weighed using an ADAM brand analytical balance, model PW 254. This concentration was chosen for all the experiments carried out. Arondyes Chemicals supplied Acid Black 52 dye. AB52 dye is identified by C.I: 15711 and CAS: 5610-64-0.

2.2 Experimental device

A schematic of the device is shown in Figure 1. It consists of a 1.0 L capacity glass reaction chamber, two tungsten electrodes (electrode (a) and electrode (b)), and a high voltage source. The lower end of the electrode (a) is placed inside the solution, while the lower end of the electrode (b) is very close to the surface of the solution but not touching it. The latter is an adjustable electrode that allows varying the distance to the surface of the solution under study and is where the plasma generation takes place. The system has a mercury thermometer in the solution all the time, allowing the temperature to be verified while the process is being carried out.

2.3 Exposure of solution to plasma

Exposure of dye in a liquid medium (concentration of 0.10 mM) to plasma is carried out by depositing 500 mL of the solution in the reaction chamber.
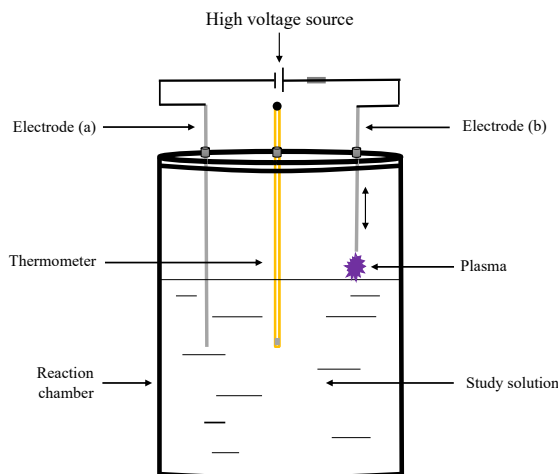

Figure 1: Scheme of the experimental device used for the treatment of the solutions by nonthermal plasma.

The thermometer is inserted, and the electrodes are adjusted to start the non-thermal plasma. The plasma is obtained by establishing the values corresponding to the electrical power of interest in the high voltage source (SPELLMAN SL600). Specifically, four different plasma generating electrical powers were considered (T1 = 15.0, T2 = 22.5, T3 = 30.0 and T4 = 45.0 W). The exposure to the solution lasted 200 minutes by treatment (electrical power).

2.4 Measurement of interest parameters

After 20 minutes of starting the exposure of the solution to the plasma, the temperature is monitored, the exposure process is stopped, and a sample is extracted to measure the pH (HI 9813-6N potentiometer), the absorbance (Hach DR 3900 spectrophotometer), and determine the germination percentage of lettuce seeds (*Lactuca sativa*). Once this is done, the exposure of the solution to the non-thermal plasma is restarted, repeating this procedure until reaching two hundred minutes and concluding the experiment.

The change in concentration and percentage of degradation of the dye in the study solution is determined in terms of the calibration curve and the measured absorbance value. COD and TOC are measured at the treatment's beginning, middle, and end (Hach DRB 200 digester, Hach DR 3900 spectrophotometer).

2.4.1 Toxicity bioassays

This test allows evaluating the phytotoxic effects of complex mixtures or pure compounds through statistical analysis of the seed germination percentage. In the germination stage, numerous physiological processes occur in the seeds in which the presence of a toxic substance can interfere with the normal development of such a process. The Toxic substances in a solution used to hydrate seeds will decrease the total number of germinated seeds due to toxicity.

Seeds with specific characteristics according to established protocols are used (Sobrero and Ronco, 2004). They are seeds of the *Lactuca sativa* species, whose germination percentage is equal to or greater than 90 %, not cured, that is, without fungicides or pesticides.

A negative control (distilled water) and positive control (AB52 solution at a concentration of 0.10 mM without exposure to plasma) were used. The seeds were hydrated when the treated solution reached room temperature (23 ± 0.5 ° C). Three repetitions were made for each electric power.

2.4.2 COD and TOC

Chemical oxygen demand and total organic carbon values were determined according to the procedure established by the Hach method. Low range and mid-range vials were used (3 - 150 mg O_2 / L, 0.3 - 20.0 mg C / L and 15 - 150 mg C / L).

All tests were done with analytical-grade chemicals.

2.4.3 Percentage of degradation

The percentage of degradation is calculated using equation 1.

$$\%Degradation = \left(1 - \frac{C}{C_0}\right) \times 100\% \qquad (1)$$

Equation 1 requires the concentration values of the dye at determinate times of treatment by plasma (C), as well as the value of the initial concentration (C_0), that is, the concentration of the dye in solution without treatment.

Equation 2 allows obtaining the (C) required concentration values, as a function of absorbance.

$$y = 22.014x - 0.0251 \qquad (2)$$

Employing a linear fit of the calibration curve (Figure 2), equation 2 is determined.

2.4.4 Calibration curve

Figure 2 shows the calibration curve used for the AB52 dye, whose adjustment equation is $y = 22.014x - 0.0251$. The calibration curve relates the absorbance values to the concentrations in mM of interest dye at wavelength $\lambda = 570$ nm (wavelength magnitude at which the absorbance value is experimentally maximum). It was obtained by measuring the absorbance of ten different dilutions of known dye concentration.

3 Results and discussion

The changes generated in the AB52 dye solution in a liquid medium are presented. Transformations were obtained by exposing the study solution to non-thermal plasma of different electrical power generated at atmospheric pressure. What is found is analyzed regarding the change in temperature, absorbance, concentration, percentage of degradation, pH, chemical oxygen demand, total organic carbon, and toxicity bioassays.
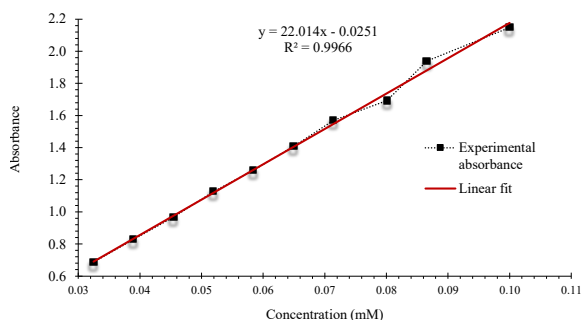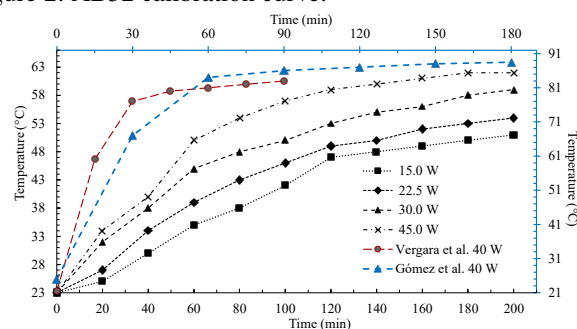

Figure 2: AB52 calibration curve.

Figure 3: Temperature change of the Acid Black 52 solution after its exposure to air plasma as a function of the exposure time and the electrical power of plasma generation.

The results of this experiment are compared with those obtained by other investigations for the same dye and plasma treatment of similar characteristics. The fundamental differences between the current experiment and the other investigations are observed in the following: volume of solution studied, initial concentration, electrical power of plasma generation, time of exposure to plasma, and catalyst used to optimize degradation processes.

4 Temperature

Given the conditions in which the present experiment is carried out (atmospheric pressure, volume of solution treated, and plasma exposure time), the temperature of the solution increases.

It is observed in Figure 3 that as the exposure time to the plasma increases, the change in temperature shows two different behaviors. The first in which the temperature rise is relatively fast and the second where such growth is slower.

An increasing and asymptotic temperature change are shown for all treatments. Such behavior is accentuated as plasma generation's electrical power increases, and the amount of volume treated decreases.

In the first one hundred minutes of treatment, the solution temperature of the present experiment increases relatively quickly, changing from 23 °C to 42 °C, 46 °C, 50 °C, and 57 °C, respectively. From these values, the temperature change is slower, reaching temperatures of 51 °C, 54 °C, 59 °C, and 62 °C at the end of the treatments.

The described behavior of temperature change of interest solution exposed to the plasma is more noticeable when the volume of the solution is smaller and when the electrical power of plasma generation is
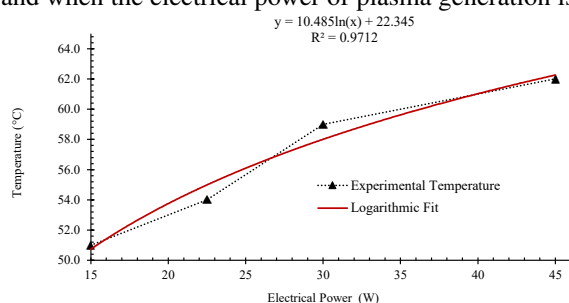
greater. In the case of the 250 ml studies of solution (Gómez *et al*., 2017) and 100 ml of solution (Vergara Sánchez *et al*., 2017), both at one mM concentration, such behavior is verified. They change from 25 °C to 84 °C in 60 minutes and from 21.5 °C to 77 °C in 30 minutes, respectively-both at electrical power of plasma generation of 40 W.

Figure 4 shows the change in temperature as a function of the electrical power of each plasma treatment used. It is observed that as the electrical power increases, the temperature value also increases. The increase is not directly proportional between both variables; it is closer to a logarithmic relationship modeled by the considered adjustment.

Such behavior is explained based on the process of solvent evaporation. For molecules to study solution to leave the surface and join the vapor, the system must be supplied with energy (heat). This energy is provided as the solution is exposed to the plasma and increases as a function of the electrical power plasma. However, in evaporation, the solution loses its most energetic molecules, and the temperature of the liquid decreases slightly. This process is maintained due to the increase in energy supplied to the system.

4.1 Absorbance, concentration, and degradation percent

Figure 5 shows the change in absorbance of dye aqueous solution as a function of the time of exposure to air plasma and a function of electrical power of plasma generation.

The behavior of the absorbance of the interest solution has a decreasing trend for all treatments over time. The decrease in the absorbance value is directly related to the electrical power applied in each treatment; the more significant the power applied, the greater the reduction in absorbance over time.

Figure 4: Final temperature (two hundred minutes) of the Acid Black 52 solution as a function of the electrical power plasma.
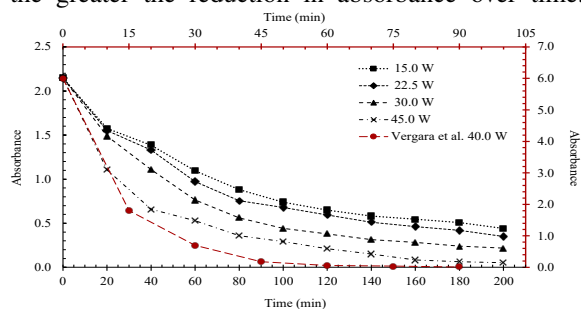

Figure 5: Absorbance change of dye Acid Black 52 in aqueous solution after exposure to air plasma as a function of exposure time and electrical power to generate the plasma.

At the end of treatments (T1, T2, T3, and T4), the absorbance value decreases as a function of the electrical power used to generate the plasma. It changes from 2.148 to 0.350, 0.217, and 0.053, respectively, showing the efficiency of each of the processes given the present experiment's characteristics.

The absorbance change curve for each treatment is characterized by being divided into two regions that depend on the exposure time and the plasma generation current. The first region shows a drastic change in absorbance value, corresponding approximately to the first eighty minutes of exposure to treatment T1, T2, and T3 and forty minutes of treatment T4. The second curve region shows an asymptotic behavior and a minor change in absorbance values over time. It is presented approximately from minute one hundred onwards for the first three treatments and from minute sixty onwards for treatment T4. Analogous behavior is observed in results obtained by Vergara Sanchez *et al*. (2017). In this case, the first region corresponds to the first thirty minutes of treatment, and the second region goes from minute forty-five onwards.

Figure 6 shows the absorbance behavior as a function of the electrical power used in each plasma treatment. As the electrical power increases, the absorbance value decreases markedly at the end of each treatment. The decreasing behavior and the distribution of the experimental data suggest a directly proportional dependence between both variables. A linear relationship is satisfied according to the equation corresponding to the mathematical model proposed as a fit of the experimental data.

The energy supplied to the experimental system in each treatment induces a decrease in the absorbance of the solution exposed to plasma, which suggests the breakdown of the groups responsible for the black color of the dye of interest (azo groups) (Vergara-Sánchez *et al*., 2017). Such splitting increases linearly as a function of energy, which means that the splitting of the chromophore group, in this case, depends directly on the power supplied to the system. According to the methodology followed to determine the change in concentration and the percentage of dye degradation in the solution, a similar dependence behavior is expected in such variables.

Using Equation 2 of the calibration curve and absorbance values measured by spectrophotometry at different treatment times, it is possible to calculate corresponding values of solution concentration change. Figure 7.
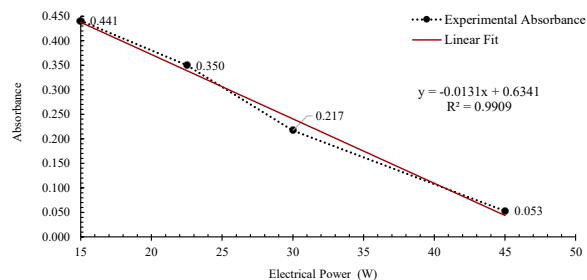

Figure 6. Final absorbance (two hundred minutes) of the Acid Black 52 solution as a function of the electrical power plasma.
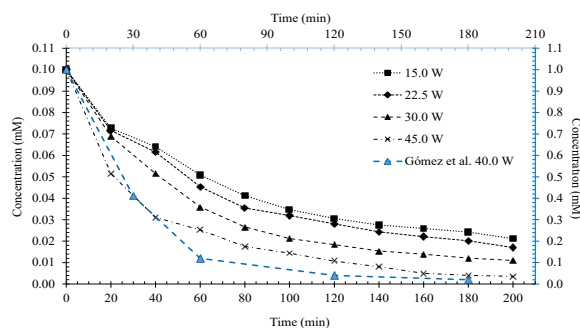

Figure 7: Concentration change of Acid Black 52 dye solution as a function of exposure time and electrical power of plasma generation.
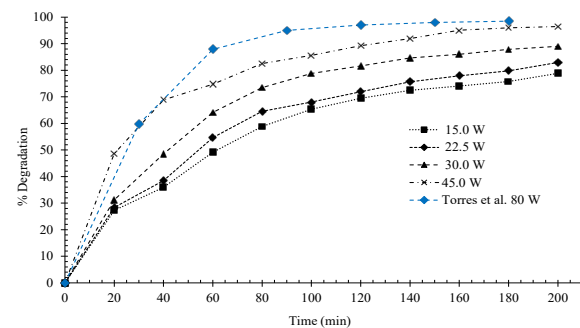

Figure 8: Percent degradation change of Acid Black 52 dye solution as a function of exposure time and electrical power of plasma generation.

In particular, the magnitude of interest solution concentration decreases for treatments T1, T2, T3, and T4, from an initial experimental value of 0.10 mM to estimated values of 0.021, 0.017, 0.010, and 0.003 mM, respectively. These values correspond, as shown in Figure 8, according to equation 1, to approximate degradation percentages of 78, 82, 89, and 96 %, respectively.
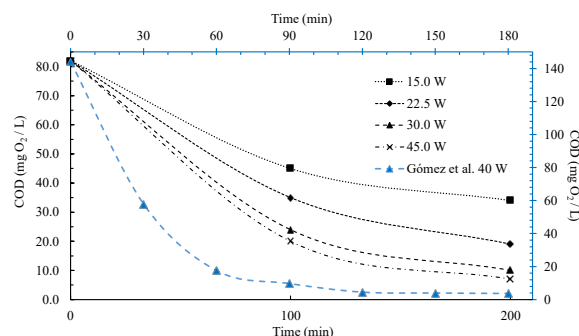
Figure 9: COD change of the Acid Black 52 solution after its exposure to air plasma as a function of the exposure time and the electrical power of plasma generation.
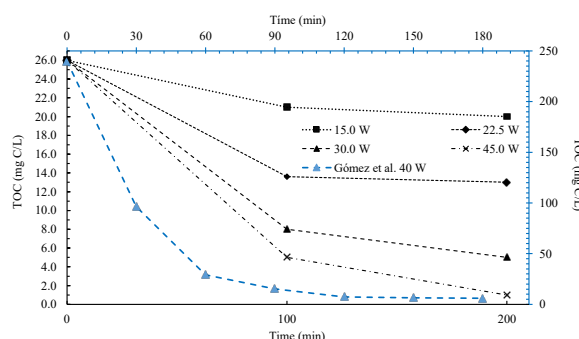

Figure 10: TOC change of the Acid Black 52 solution after its exposure to air plasma as a function of the exposure time and the electrical power of plasma generation.

A qualitatively similar behavior shows the concentration results obtained by Gómez *et al.* (2017) and the degradation percentage results determined by Torres Segundo *et al.* (2019).

In general, the values of measured absorbance and estimated concentration decrease as the electrical power of plasma generation increases, corresponding to an increase in dye degradation percentage in the

solution.

This study was carried out for the treatment of an aqueous solution of a single dye, but it has been reported that when two dyes are mixed, their discoloration and degradation do not change appreciably (Merouani *et al.*, 2015; Torres-Segundo *et al.*, 2019; Vergara-Sánchez *et al.*, 2020). However, the presence of inorganic salts can negatively impact the degradation of dyes (Merouani *et al.*, 2015).

4.2 Chemical oxygen demand and total organic carbon

Figures 9 and 10 show the change in COD and TOC of the solution for the four treatments as a function of exposure time. In both cases, a decrease in the values is observed as a function of the time of exposure to the plasma and the electrical power used.

Table 1 shows the COD and TOC values for each treatment at 100 and 200 minutes. At 100 minutes and applying an electrical power of 30.0 W, organic matter removal of 70 % is obtained, while by increasing the electrical power to 45.0 W, a 75.61 % removal is obtained. These data show that the increase in the electrical power of the plasma generates a more significant change in the removal of COD.

Regarding the TOC, at 100 minutes of exposure, maximum removal of 80.77 % is reached using a power of 45.0 W, while at 200 minutes for treatments of 15.0 and 22.5 W, the removals do not reach such a value (80.77 %). The maximum change of TOC is reached in the 45.0 W treatment, obtaining removal of 96.15 %.

The results obtained from COD and TOC suggest that the plasma treatment mineralizes the organic matter into CO_2 and H_2O.

Gómez *et al.* (2017), using a similar methodology, supported by a catalyst in the solution and considering the experimental particularities, obtained values like those achieved in this research.

Table 1. Removal of Acid Black 52 dye (COD and TOC) as a function of the electrical power of plasma generation.

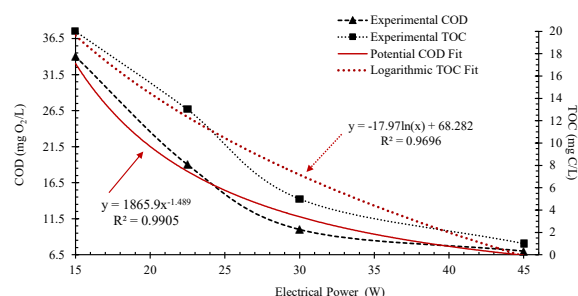| Electrical power (W)	100 min				200 min			
	COD $\left(\frac{mg\ O_2}{L}\right)$	AB52 Removal (%)	TOC $\left(\frac{mg\ C}{L}\right)$	AB52 Removal (%)	COD $\left(\frac{mg\ O_2}{L}\right)$	AB52 Removal (%)	TOC $\left(\frac{mg\ C}{L}\right)$	AB52 Removal (%)
15.0	45	45.12	21.0	19.23	34	58.54	20.0	23.08
22.5	35	57.31	13.6	47.69	19	76.83	13.0	50.00
30.0	24	70.73	08.0	69.23	10	87.80	05.0	80.77
45.0	20	75.61	05.0	80.77	07	91.46	01.0	96.15

Figure 11: Final COD and TOC (two hundred minutes) of the Acid Black 52 solution as a function of the electrical power plasma.
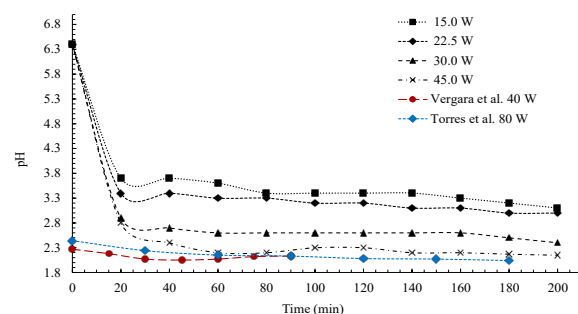

Figure 12: pH change of the Acid Black 52 solution after its exposure to air plasma as a function of the exposure time and the electrical power of plasma generation.
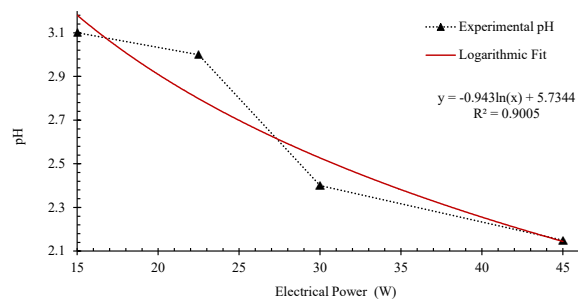

Figure 13: Final pH (two hundred minutes) of the Acid Black 52 solution as a function of the electrical power plasma.

Figure 11 shows the graph and the adjustment equation for the COD and TOC data obtained at the end of each treatment (15.0, 22.5, 30.0, and 45.0 W) at 200 minutes of plasma exposure.
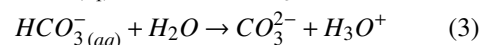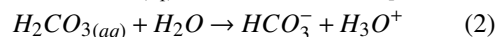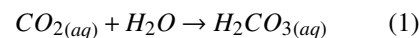
As can be seen, the trend of both is not linear; both decrease as a function of the applied plasma power. The experimentally determined COD (▲) follows a potential behavior, while the TOC (■) is a logarithmic behavior, according to the proposed mathematical adjustment. According to the mathematical equations, the correlation coefficients for COD and TOC were 0.99 and 0.98, respectively, showing a solid relationship between these quality parameters and the applied plasma power.

4.3 pH

Figure 12 shows the change in hydrogen ion concentration [H^+] of the Acid Black 52 solution as a function of exposure time. In all the experiments, a rapid decrease in pH can be observed during the first 20 minutes, while after 40 minutes, the pH remains stable in all the tests. The observed pH values at 200 minutes of treatment were 3.1, 3.0, 2.4 and 2.15 for 15.0, 22.5, 30.0 and 45.0 W respectively. These results show that the decrease in pH is a function of the applied power; the solutions obtained were more acidic at the end of each treatment. Similar results were obtained in Vergara Sánchez *et al.* (2017) and Torres Segundo *et al.* (2019); they obtained pH values of 2.13 and 2.04, respectively, at the end of the treatment. In these works, the initial value of the solution was adjusted using H_2SO_4.

The decrease in pH in the solution of interest is attributed to the chemical reactions that occur during the plasma application. The solution under study is in direct interaction with the air located inside the reactor. Air contains CO_2, a compound that, when reacted with the plasma system, contributes to the increased generation of hydronium ions. Reactions (1)-(3).

$$CO_{2(aq)} + H_2O \rightarrow H_2CO_{3(aq)} \qquad (1)$$

$$H_2CO_{3(aq)} + H_2O \rightarrow HCO_3^- + H_3O^+ \qquad (2)$$

$$HCO_{3\ (aq)}^- + H_2O \rightarrow CO_3^{2-} + H_3O^+ \qquad (3)$$

In the reactor chamber, the electrical discharges produced by the application of the plasma in interaction with the water surface and the presence of air induce a change in the pH of the solution (Fahmy *et al.*, 2018; Shimizu *et al.*, 2020; Alarcón-Hernández *et al.*, 2022), due to the generation of compounds such as HNO_3, HNO_2, among other products that can be formed in plasmas of moist air or water.

Likewise, since the system feeds on high-energy electrons, causing ionization, dissociation, and recombination processes with water molecules, $OH^\bullet$ and $H^\bullet$ radicals are generated, as described in the following reaction (Jiang *et al.*, 2014; Safenraider *et al.*, 2020).

$$H_2O + e \rightarrow OH^\bullet + H^\bullet + e \qquad (4)$$
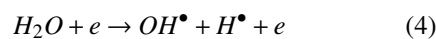
The OH$^\bullet$ radicals in the solution recombine generating hydrogen peroxide.

$$OH^\bullet + OH^\bullet \rightarrow H_2O_2 \qquad (5)$$
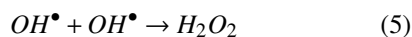
In the literature, it has been reported in investigations that use non-thermal plasmas in hybrid experimental systems that the pH tends to decrease in the study solution (Shimizu *et al*., 2020; Alarcón-Hernández *et al*., 2022; Sarangapani *et al*., 2016).

Figure 13 shows the graph and the fit equation for the pH data obtained at the end of each treatment (15.0, 22.5, 30.0, and 45.0 W) at 200 minutes of plasma exposure. The obtained pH data decrease as a function of the applied plasma power; the experimental values follow a logarithmic behavior according to the proposed mathematical adjustment.

4.4 Toxicity bioassays

The exposure of the Acid Black 52 dye solution to the different plasma treatments generates significant changes in the parameters considered regarding the quality of the solution; the information provided by such tests is complemented by carrying out toxicity bioassays. Figure 14 shows the percentage of germination and the average values of germination for each treatment as a function of the exposure time.

The positive control indicates that the initial solution of Acid Black 52 is relatively toxic, germinating on average only 58% of seeds used in all tests. Such percentage is modified (increases or decreases) as the solution is exposed to the plasma and depending on the electrical power to generate the plasma. An increase and decrease in seed germination percentage are observed for all treatments during the two hundred minutes of exposure.

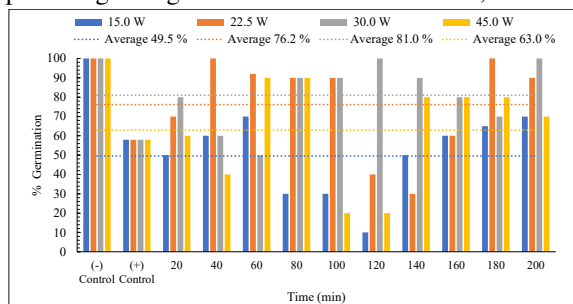For treatment one (15.0 W), the maximum percentage of germination reached is 70%, and the

Figure 14: Percentage of germination of Acid Black 52 solution as a function of plasma exposure time and the electrical power plasma.

minimum is 10%, achieving on average, for the ten measurements carried out during the entire exposure time, only 49.5% of seed germination. The minimum average value of the four treatments. Treatments two and three (22.5 and 30.0 W) are the ones that reached the highest average values of germination percentage of 76.2 and 81.0 %, respectively, with minimum germination values of 30 % and 20 % and a maximum of 100 %. For treatment four (45.0 W), a minimum germination percentage value of 20 % was recorded and a maximum of 90 %, achieving an average germination percentage of 63 %.

The decrease in the percentage of seed germination below the value recorded for the positive control indicates the presence of residual toxic compounds derived from the transformation of the original molecule of the study dye. In this case, the seed germination percentage registers values below the positive control value (58%) for all treatments at different exposure times and depending on the electrical power to generate plasma.

On the other hand, only treatments T2, T3, and T4 (22.5, 30.0, and 45.0 W) reach germination percentage values greater than 80% (minimum desirable value) at some point in the treatment. Treatment T2 and T3 are the ones that reach values of 100% germination.

All samples of the Acid Black 52 dye solution show positive changes in germination percentage after plasma exposure time. Corresponds to treatment T3 (30.0 W) a value of 100% germination at 200 minutes of treatment, a time in which the different measured parameters reach a minimum value.

Conclusions

The degradation and toxicity process of the dye AB52 in a liquid medium by non-thermal plasma, generated at atmospheric pressure utilizing different electrical power values, was quantified and compared. According to the associated mathematical adjustment, the experimental data showed a logarithmic behavior for temperature, TOC, and pH as a function of the electrical power of plasma generation. A potential behavior for COD and a linear behavior for absorbance.

The increase in the degradation of the dye and the change in toxicity depends directly on the time of exposure to plasma and the electrical power of work. The longer the exposure time and the higher the electrical power to generate the plasma, the higher

the percentage of dye degradation. The maximum degradation was reached for the experiments carried out at 45.0 W of electrical power, and the minimum average toxicity for the experiments carried out at the electrical power of 30.0 W. It is concluded that non-thermal plasmas at atmospheric pressure are effective for treating water with Acid Black 52 dye.

Acknowledgments

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