

# Decomposition of Bromocresol Green Using a Nonthermal Atmospheric Pressure Plasma Jet <sup>†</sup>

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**Abstract:** This research study aims to decompose bromocresol green (C<sub>21</sub>H<sub>14</sub>Br<sub>4</sub>O<sub>5</sub>S) using direct irradiation of a nonthermal atmospheric pressure plasma jet. The absorbance spectra of the bromocresol green solution were measured, as was its electrical conductivity and its pH before and after different durations of irradiation. The results showed that the lengths of conjugated systems in the molecular structure of bromocresol green decreased, and the bromocresol green solution was decolorized as a result of the decomposition of bromocresol green. This result indicates that cold atmospheric pressure plasma jet irradiation is capable of decomposing and can also be used for water purification.

**Keywords:** decolorization; degradation; bromocresol green; cold atmospheric plasma; electrical conductivity; pH; spectrophotometry

## 1. Introduction

The interaction of plasma irradiation with liquids (both inside and in contact with) has been widely studied for different purposes, including sterilization, softening, and purification. To do so, different plasma sources, including dielectric barrier discharge (DBD), microhollow cathode discharge, and corona discharge, have been utilized [1–6]. Nonthermal (cold) atmospheric pressure plasma has recently captured a significant amount of attention for aqueous solution (including methyl orange, methyl violet, bromophenol blue, methanol, diuron, phenol, textile dyes, antibiotics, 1-naphthylamine, organophosphate pesticides, and pharmaceutical compound pentoxifylline) treatment due to its potential as a cost-saving treatment [7–15]. Bromocresol green is a dye of the triphenylmethane (anionic) family and is generally used as a pH indicator and DNA tracer. Bromocresol green is also used in the weaving industry, such as linen and cotton, and therefore can be found in wastewater. Several traditional methods have been used to remove bromocresol green from water, including sunlight photo-decolorization, photocatalytic degradation, solvent sublimation with a cationic surfactant, adsorption on *Ziziphus nummularia*, and using cadmium hydroxide nanowire loaded on activated carbon (Cd(OH)<sub>2</sub>-NW-AC) [16–20]. This paper aims to study the degradation of bromocresol green (also known as 3,3',5,5'-Tetrabromo-m-cresolsulfonphthalein, and BCG) dissolved in water using irradiation of a capacitively coupled argon plasma jet. Selected optical,

electrical, and chemical properties, including conductivity, pH, and absorbance of the solution samples were measured before and after different (1, 5, and 10 min) durations of plasma treatment.

## 2. Materials and Methods

### 2.1. Preparing a Bromocresol Green Solution

Bromocresol green powder (Merck) was used to prepare the sample solutions with the empirical formula of  $C_{21}H_{14}Br_4O_5S$ , CAS number of 76-60-8, and molar mass of 698.01 g/mol. The sample solution was prepared by dissolving the bromocresol green powder in distilled water with 10 mg/L concentration.

### 2.2. Plasma Jet

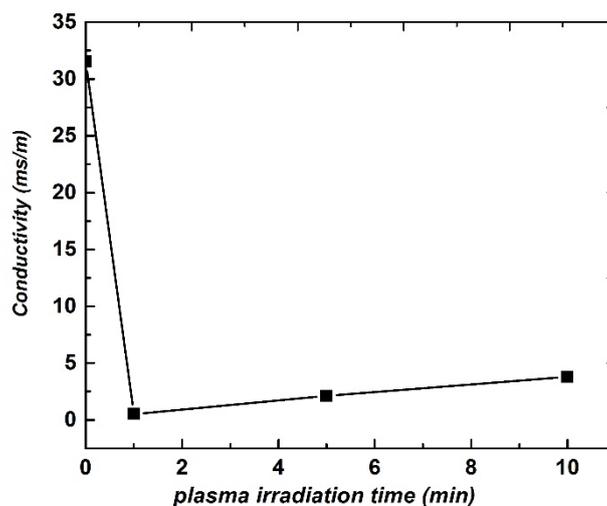
A customized capacitively coupled argon plasma jet has been used in this study. The gas discharge was generated using a power supply with an applied voltage of 5.4 kV (AC) and a frequency of 23 kHz. The gas was pure argon (Ar) with a purity of 99.999% and a 5 L/min flow rate. A glass tube was installed between two surrounding copper (Cu) tubes (discharge and grounding electrodes) to induce dielectric barrier discharge. More information regarding the customized plasma jet has been provided elsewhere [12]. The plasma jet was directed to the solution samples in glass Petri dishes at a distance of approximately 15 mm.

### 2.3. Conductivity, pH, and Absorbance Measurement

The conductivity and pH of solution samples were measured using a conductometer (Metrohm 712) and a pH meter (Metrohm 744), respectively. A spectrophotometer (Hach DR500) was employed to measure the absorption spectra of the solution samples. All the measurements mentioned above were conducted in four various conditions—namely, before plasma irradiation, 1 min after the plasma jet irradiation, 5 min after the plasma jet irradiation, and finally, 10 min after plasma jet irradiation.

## 3. Results and Discussion

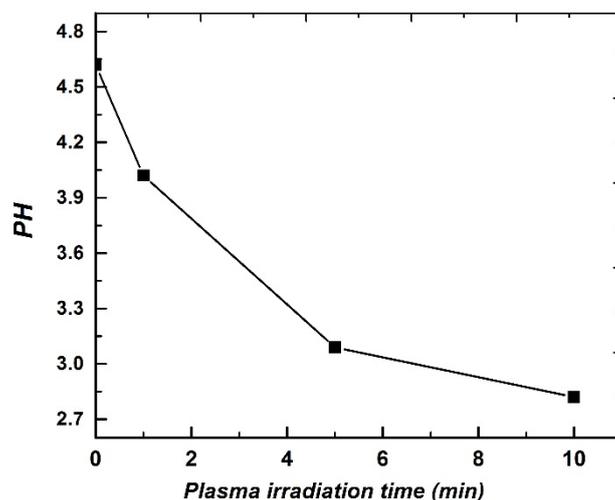
Figure 1 shows the variation of the sample solution's conductivity value after the different duration of plasma jet irradiation.



**Figure 1.** Variation of conductivity value of the sample solution after the different durations of plasma jet irradiation.

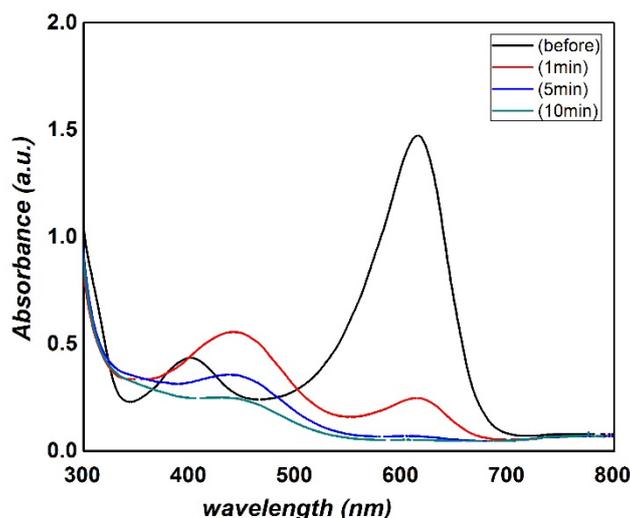
It is worth mentioning that distilled water's conductivity value was different from this sample solution [12]. The difference between the conductivity of distilled water and bromocresol green

solution is because of the fact that bromocresol green powder increased the level of impurity. As shown in Figure 1, the conductivity value has initially decreased, and then after 1 min, it slightly increased. It can be assumed that during the first minute of plasma jet irradiation, plasma irradiation quickly breaks the molecules of the solution into the neutral products, and afterward, the molecules in the bromocresol green solutions break up into the charged products. Similar behavior has been observed in plasma-irradiated bromophenol blue solution [12]. Figure 2 shows the variation of pH of the sample solutions with different durations of plasma jet irradiation.



**Figure 2.** Variation of pH of the sample solutions with different durations of plasma jet treatment.

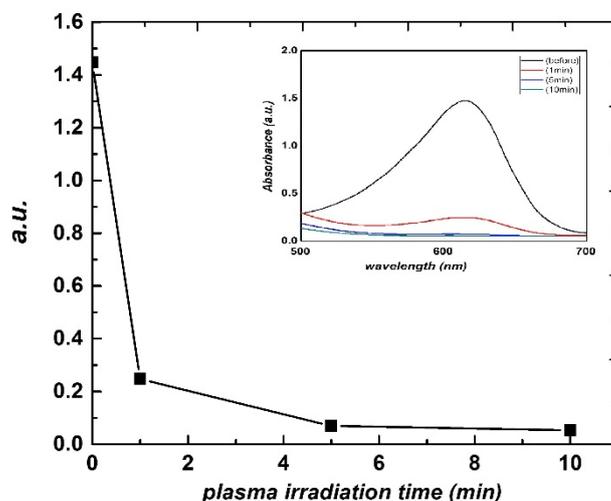
The observed decrease in the pH value is because of the generation of hydrogen ions ( $H^+$ ) in the sample solution. This result indicates that the concentration of  $H^+$  in the sample solution increases because of Ar plasma irradiation. This result agrees with the results shown in Figure 1 because the conductivity value increased with the increasing irradiation duration and, accordingly, the generation of  $H^+$  in the sample solution. Figure 3 shows the result of the spectrophotometry experiment.



**Figure 3.** The recorded absorption spectra of solution samples for different durations of plasma irradiation.

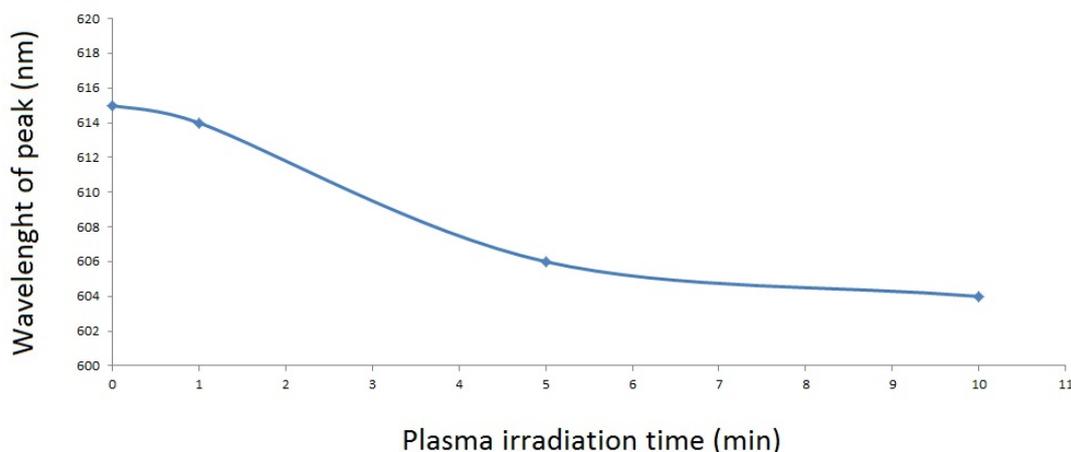
As shown in Figure 3, by increasing irradiation duration, the absorption of samples decreased. The peak wavelengths of bromocresol green samples were observed around 600 nm. Figure 4 shows

the intensity of absorption peak around 600 nm, before and after atmospheric pressure plasma irradiation.



**Figure 4.** The decrease in the intensity of the absorption peak around 600 nm.

Figure 5 shows a change in the peak wavelengths (at ca. 600 nm) for different plasma jet irradiation durations.

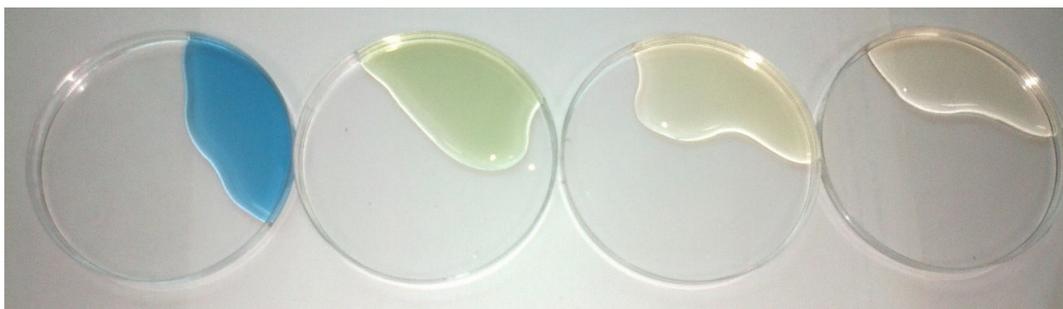


**Figure 5.** Change of the absorption peak wavelengths for different plasma jet irradiation durations.

The absorption peaks wavelength shifted to a shorter wavelength region as the plasma jet irradiation time was increased. The wavelength of an absorption peak is related to the lengths of conjugated systems in the sample’s molecular structure. The absorption peak moves to shorter wavelengths when the lengths of conjugated systems decrease, and it moves to longer wavelengths when the lengths of that increase [21]. Therefore, the observed shift of peak wavelength to a shorter wavelength indicates that the bromocresol green molecular structure’s conjugated system length has decreased because of plasma jet irradiation.

Figure 6 shows the color variation of different sample solutions for different irradiation durations.

The solution lightened when the duration of plasma irradiation increased and became almost transparent after ten minutes of irradiation. This result is in line with the recorded absorption spectra.



**Figure 6.** Decolorization of the sample solution after the different durations of Ar plasma irradiation.

#### 4. Conclusions

The degradation process of bromocresol green solution by direct irradiation of cold atmospheric pressure argon plasma jet was experimentally studied. The conductivity, pH, and absorption spectra of the sample solutions were measured before and after the different Ar plasma jet irradiation durations. The results demonstrated that the length of the conjugated systems in the bromocresol green structure was decreased, and therefore the sample solution was decolorized at the end. Therefore, such a plasma jet has the potential to be used for the treatment of aqueous solutions.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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