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Predictive Designation and construction of a Darsonval Device for Investigating Chemical Properties of DBD Plasma-Activated Sodium Chloride

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Abstract. This study investigates the effect of plasma treatment on a NaCl solution using a darsonval corona device. Absorption spectroscopy was used to detect the spectra of the NaCl solution and after treating the solution with plasma for 5 ms a wavelength range between 200 and 290 nm was observed, with a small shoulder around 220 nm. The disappearance of the Cl^- peak and the emergence of a new peak around the HOCl wavelength indicate that plasma treatment induces significant chemical changes in the NaCl solution. The formation of hydroxyl radicals (OH^-) during plasma treatment suggests that these reactive species play a crucial role in the oxidative processes occurring in the solution. Additionally, the presence of nitrite and nitrate ions in the treated solution suggests that plasma treatment enhances the production of these reactive species, leading to their increased presence in the solution. These results provide valuable insights into the mechanisms of plasma-induced chemical reactions and highlight the potential applications of plasma technology in water treatment and chemical synthesis.

Keywords: plasma activated, sodium chloride, dielectric barrier discharge, darsonval device, plasma chemistry

Introduction

Plasmas are the fourth state of matter. It consists of electrons, ions, free radicals, different species, ultraviolet (UV) radiation and an electrical field (Yasoob *et al*., 2022). Free radicals, reactive oxygen and nitrogen species impact cell and tissue physiology and improve cellular health and pathology (Babajani *et al*., 2024; Kozlov *et al*., 2024; Koga *et al*., 2024). Plasmas are divided into thermal and non-thermal types. In thermal plasma, the temperature of electrons and ions is on the order of 10–100 electron volts (eV). But in nonthermal plasma, the temperature of electrons is on the order of 10–100 eV, while the temperature of other species is in the range of room temperature. Thermal plasma is used for tissue removal, cutting, cauterization and sterilization of thermally stable medical instruments. Nonthermal atmospheric pressure plasma (NTAPP) can be used in blood coagulation, wound healing, decontamination, and dermatology (Zadeh *et al*., 2024; Jafari *et al*., 2024; Chen *et al*., 2022; Suresh *et al*., 2022; Sarkar *et al*., 2021; Boeckmann *et al*., 2020; liu *et al*., 2017). NTAPP is a novel noninvasive method that combines the effects of ultraviolet light with exposure to ozone, nitric oxide and the electromagnetic field jet plasma and a dielectric barrier discharge (DBD) device are used to produce NTAPP. Their safety of use and cheap price make them suitable for solving skin problems. NTAPP's effect on lipids, proteins and nucleic acids in living cells and signaling pathways. Jacques Arsène d'Arsonval proposed an instrument that produces NATPP. As plasma irradiates the liquid, its chemical properties can be changed. There are several conventional methods for measuring the concentration of species present in a liquid. Among them, may be mention the calorimetric and the spectroscopy method. Kung and colleagues used spectroscopy to measure active aquatic species (Liu *et al*., 2017). There are two types of spectroscopies: absorption and emitted spectroscopy. For which the absorption method is used in this article. Sodium chloride is one of the most important disinfections used as an effective agent in medicine for retaining moisture, reducing dryness and reducing mild bleeding and inflammation. Recent literature on NTAPP and sodium chloride highlights the antimicrobial activity and potential applications of plasma-activated sodium chloride in clinical settings (Kim *et al*., 2021; Kaushik

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et al., 2019; Su *et al*., 2018; Hänsch *et al*., 2015). Studies have explored the mechanisms of action of plasma-activated sodium chloride and its effectiveness in killing microorganisms and promoting wound healing. The use of plasma-activated sodium chloride has shown promise in various medical applications, including wound healing and disinfection. Despite the promising results of previous studies, there are still several areas that remain unexplored or under-investigated in the field of NTAPP and sodium chloride. Some of these areas include the long-term effects of NTAPP on sodium chloride, the effect of NTAPP on different types of microorganisms, the mechanism of action of NTAPP and the potential of NTAPP in other medical applications. Further investigation is needed to fully understand the potential of NTAPP and sodium chloride in various medical applications and to identify any potential limitations. There is a lot of research on plasma-activated sodium chloride and its effect on microorganisms and cancerous tumors (Liu *et al*.,2017). But it is still an open area for research. The aim of this experiment is to investigate the effect of plasma on 0.65% sodium chloride. In the next section, details regarding the darsonval device, which was designed and fabricated for investigating activated sodium chloride, will be provided. Additionally, findings on the effect of plasma on sodium chloride will be presented and the comparison between activated and inactive sodium chloride will be made. In conclusion, the importance of investigating the effect of plasma on sodium chloride is highlighted by the research conducted.

Materials and Methods

To produce NTAPP, the darsonval corona device was designed and constructed. It consists of a power supply and electrodes with different shapes. The voltage range of the power supply can vary from 18 to 25 kV and its frequency range is approximately 100 kHz. As shown in Fig. 1, the pulse generator consists of a semiconductor switches (X1), pulse transformers (T1) and different types of capacitors and inductors. When the main switch is turned on (220V applied to circuit), capacitor C3 charges to approximately 220 V *via* Inductor L1 and primary side of T1. Upon receiving the trigger signal produced by the RC modulator, Switch X1 turns on, causing capacitor C3 to discharge. This results in a pulse voltage being fed to the primary side of T1. Subsequently, when the voltage across C3 drops below the main power supply level, it continues to charge to around 220 V *via* Inductor L1 and the primary side of T1. The RC modulator comprises capacitor C1, Resistors R1, R2, R3 and potentiometers R4 and R5. The key characteristics of this pulse generator include a high voltage output of up to 25 Kv and a working frequency of 100 ±10 kHz. The voltage and frequency can be adjusted by changing the resistors in potentiometers R4 and R5. The output voltage was modulated with the network; the pulse frequency was 100 Hz±10Hz. The discharge current was regulated by changing the voltage in the device. The capacitor C2, diode D1 and diode D2 were protected voltage and current of thyristor X1 as indicated in Fig. 2.

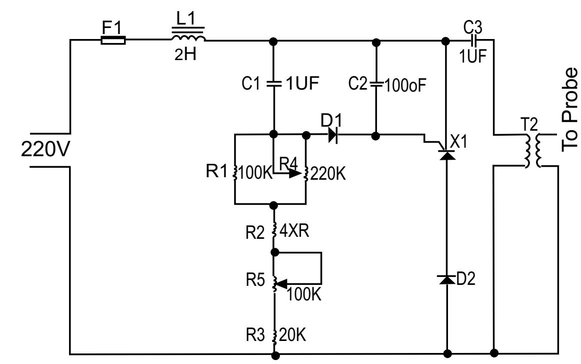

Fig. 1. Schematic diagram of circuit for the two-stage MPC system.

The shape of probes varies depending on their applications. In this experiment, mushroom probe had used which consists of a central electrode, referred to as the powered electrode. This electrode is encased in

Fig. 2. High frequency, high voltage power supply in which was made by "Dorsa hydroderm company and mushroom electrode.

quartz glass with a diameter of 30 mm, filled with Neon gas as shown in Fig. 3.

After a high voltage is applied to the electrode, the Neon gas and ambient air become ionized, resulting in plasma production. The liquid's surface serves as the second electrode and the plasma induces chemical changes within the liquid as refer to Fig. 4.

A plastic container with a diameter of 40 mm and a volume of 10 mL, filled with sodium chloride, was used in the experiment. The mushroom probe was connected to the surface of the liquid for 5 min as shown in Fig. 5.

The chemical variation in the liquid was detected by the PerkinElmer Lambda 25 UV/Vis spectrometer as mention in Fig. 6. The spectrometer measures the absorption of radiation as a function of wavelength.

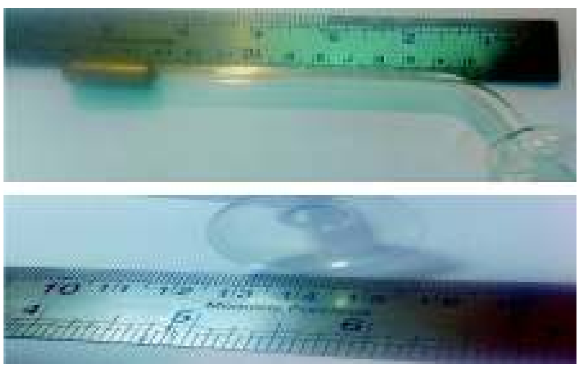

Fig. 3. Mushroom probe used in this experiment.

Fig. 4. Mushroom probe filled by Neon gas and plasma produced after applying high voltage to the probe.

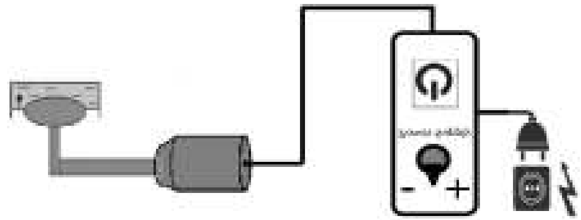

Fig. 5. Typical schematic of the set up of treatment sodium chloride by NTAPP.

Fig. 6. PerkinElmer Lambda 25, used to detect the spectrum of species in active liquid.

Result and Discussion

The spectra of the solution were detected by absorption spectroscopy as shown in Fig. 7. The wavelength range is between UV absorbance spectrum, showing an absorbance peak at approximately , which depicts the presence of hydroxyl radical (OH) in the NaCl solution.

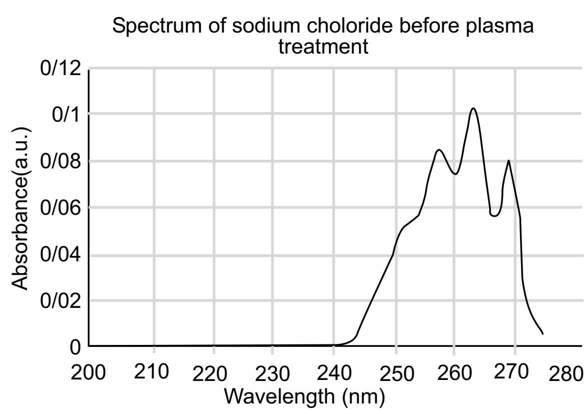

Fig. 7. Absorption spectrum of solution in the absence of plasma.

After the solution was treated 5 ms with plasma, the spectrum of the active NaCl solution was detected. The results indicate that after plasma treatment of the NaCl solution, the wavelength range observed is between 200 and 290 nm as shown in Fig.8.

Notably, a small shoulder around 220 nm is visible on the spectrum. Given that Nitrite NO_2^- and Nitrate NO_3^- exhibit peaks at 210 nm and 222 nm, respectively, it appears that the broad spectrum encompasses at least these two chemical species. Additionally, the intensity of species in the solution increased significantly compared to the situation with no plasma treatment. Another species that arises due to the presence of chlorine in active NaCl is hypochlorous acid (HOCl) and Hypochlorite Ion (COl^-), each exhibiting a predominant peak around 236 nm and 292.5 nm, respectively. They convert to each other with respect to the acidity or alkalinity of the medium. Another species that exists due to the presence of chlorine in active NaCl is HOCl and OCl^-, with a predominant peak of around 236 and 292.5 nm, respectively. They convert to each other with respect to the acidity or alkalinity of the medium. As seen in the spectroscopy results of the activated liquid, the peak OCl^- that was observed in the untreated liquid spectrum was omitted, and the peak around the ($HOCl^-$) wavelength has appeared, which confirms the potential of hydrogen of the solution increased after applying plasma (Brisset *et al*., 2016) Other species in activated sodium chloride solution are Nitrite ions, Nitrate ions and ozone. The main reactions that lead to their production are as below:

$$NO_2^- + O_3 \rightarrow O_2 + NO_3^- \quad (1)$$

ozone has a great tendency to react with NO_2^- and consume rapidly. Ozone concentration in activated sodium chloride is higher due to low nitrate concentration. Also, NO_2 reacts with Cl_2 and produces, HOCl which is the reason for its low concentration in treated sodium chloride. Also, reacts Cl_2 with according to the relation (2),(3) and produces, HOCl which is the reason for its low concentration in treated sodium chloride.

$$Cl_2 + NO_2^- \rightarrow ClNO_2 + Cl^- \quad (2)$$

$$HOCl + NO_2^- \rightarrow ClNO_2 + OH^- \quad (3)$$

The spectroscopic analysis reveals significant changes in the chemical composition of the NaCl solution after plasma treatment. The disappearance of the peak observed in the untreated liquid spectrum and the emergence of new peaks indicate the formation of reactive species such as hydroxyl radicals, hypochlorous acid, hypochlorite ions, nitrite ions, nitrate ions and ozone. These findings confirm that plasma treatment enhances the production of these reactive species, leading to their increased presence in the treated solution. Compared to previous results, this study demonstrates a more comprehensive understanding of the chemical transformations occurring during plasma treatment.

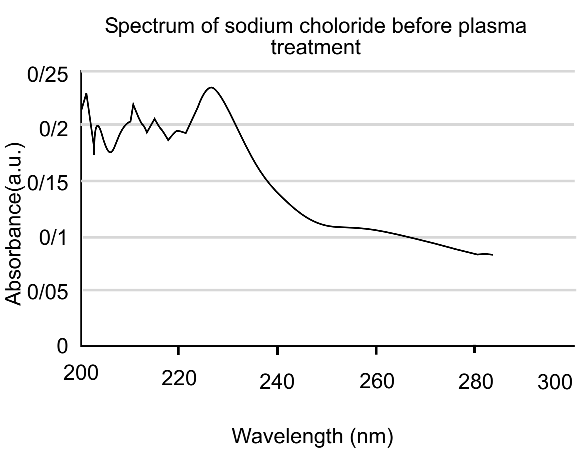

Fig. 8. Absorption spectrum of NaCl solution after plasma application with an applied voltage 22kV, repetition frequency of 100 kHz and application time of 5 min.

Conclusion

In this paper, the effect of plasma treatment on a solution has been investigated. For this purpose the darsonval corona device was designed and constructed. It consists of a power supply (25 kV,100kHz) and electrodes with mushroom shapes. the spectra of the solution were detected by absorption spectroscopy. After the solution was treated 5ms with plasma, the wavelength range observed is between 200 and 290 nm. Notably, a small shoulder around 220 nm is visible on the spectrum. Considering that NO_2^- and NO_3^- exhibit peaks at 210 nm and 222 nm, respectively, it appears that the broad spectrum includes at least these two chemical species. As seen in the spectroscopy results of the activated liquid, the peak OCl^- that was observed in the untreated liquid spectrum was omitted and the peak around the

HOCl wavelength has appeared, which confirms the potential of hydrogen (PH) of the solution increased after applying plasma.

The disappearance of the Cl^- peak and the emergence of a new peak around the HOCl wavelength indicate that plasma treatment induces significant chemical changes in the NaCl solution. The formation of hydroxyl radicals (OH^-) during plasma treatment suggests that these reactive species play a crucial role in the oxidative processes occurring in the solution. This finding highlights the potential of plasma treatment to enhance the reactivity and chemical composition of the treated NaCl solution. Additionally, the presence of nitrite and nitrate ions in the treated solution suggests that plasma treatment enhances the production of these reactive species, leading to their increased presence in the solution. These results provide valuable insights into the mechanisms of plasma-induced chemical reactions and highlight the potential applications of plasma technology in water treatment and chemical synthesis.

Conflict of Interest. The authors declare that they have no conflict of interest.

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