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Characterization of Atmospheric Electrical Discharge in Pin-water Configuration at Different NaCl Concentrations

Nabhan Abdulkareem Hamdon[1], Murad Mohamed Kadim[2], Qusay Adnan Abbas[2]

[1]*Department of Petroleum and Refining Engineering, College of Petroleum and Mining Engineering, University of Mosul, Mosul, Iraq*

[2]*Department of Physics, Collage of Science, University of Baghdad, Baghdad, Iraq*

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Corresponding Author:

Name: Nabhan Abdulkareem Hamdon

E-mail:

Tel:

ABSTRACT

The interaction between a pin-plate and plasma are representing an interest subject in plasma technology and applications. In this research, the influence of added NaCl to distilled water on the discharge characteristics that formed in the gap between pin-water surfaces was investigated in more details. Their electrical and optical characteristics serve as identifiers. It's found that all optical emissions intensity peaks as a results that detected are decreased with increasing of NaCl concentrations (300,400, and 500 mg). As well as, the emission intensity of neutral emission peaks are much higher than that of the ionic emission peaks. The addition of NaCl changes the liquid accessibility, which alters the kinetics of the discharge that forms in the pin-water surface gap. Also, its observed that the NaCl concentrations affected on the I-V characteristics. The data detected that the plasma frequency ((377.1176 - 279.1951)$*10^{11}$ rad/sec), electron number density ((4.4519 – 2.4401)$*10^{17}$ cm^{-3}) and electron temperature (2.1537 – 1.663 eV) decreased with increases of NaCl concentrations except the Debye length ((1.6342 – 1.93989)$*10^{-6}$ cm) shown a different behavior with increase of NaCl concentrations.

توصيف التفريغ الكهربائي تحت ظروف الضغط جوي في التركيب Pin-water لتراكيز مختلفة من NaCl

نبهان عبد الكريم حمدون [1] ، مراد محمد كاظم [2] ، قصي عدنان عباس [2]

[1] *قسم هندسة البترول والتكرير ، كلية هندسة البترول والتعدين ، جامعة الموصل ، الموصل ، العراق*

[2] *قسم الفيزياء ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق*

الملخص

تمثل تفاعلات التفريغ والسائل المتماسين موضوعًا مهمًا في تكنولوجيا البلازما وتطبيقاتها. في هذا البحث، تم دراسة تأثير تراكيز كلوريد الصوديوم (300,400, and 500 mg) والمضاف إلى الماء المقطر على خصائص التفريغ والتي تشكلت في الفجوة بين سطح ماء وقطب الدبوس تفصيليا. تتميز هذه المنظومة بخواصها الكهربائية والبصرية. وجدنا أن جميع قمم الكثافات للانبعاثات الضوئية والتي حصلنا عليها كنتائج والتي تم الكشف عنها تقل مع زيادة تركيزات كلوريد الصوديوم. بالإضافة إلى ذلك، وجدنا ان شدة ذروات الانبعاث الطبيعية أعلى بكثير من ذروات الانبعاث الأيوني. ان تغيير تراكيز كلوريد الصوديوم يودي إلى تغيير إمكانية السائل ومواصفاته وبالتالي في عملية التفريغ، اضافة الى تغيير في حركية التفريغ الذي يتشكل في فجوة بين سطح الماء والدبوس. كما لوحظ ايضا أن تراكيز كلوريد الصوديوم قد أثرت على خصائص (I-V) للتفريغ، وقد

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كشفت القياسات أن تردد البلازما ($377.1176 - 279.1951)*10^{11}$ rad/sec) وكثافة عدد الإلكترونات ($(4.4519 – 2.4401)*10^{17}$ cm^{-3}) ودرجة حرارة الإلكترونات (2.1537 – 1.663 eV) تنخفض مع زيادة تراكيز كلوريد الصوديوم باستثناء طول ديباي ($(1.6342 – 1.93989)*10^{-6}$ cm) الذي أظهر سلوكاً مختلفاً مع زيادة تراكيز كلوريد الصوديوم.

1. Introduction

In plasma physics science and technology, the study of plasma-liquid interactions is becoming of increasing importance. 'Experiments on Air', a famous work by Cavendish from 1785, may be the earliest account of plasma-liquid contacts and the nitric acid production by an electric spark in the atmosphere [1-3]. Plasma-liquid interactions lead to complicated physical and chemical processes, ranging from multiphase species transport in the gas phase to mass and heat transfer in the liquid phase to interfacial reactions and extremely complex liquid phase chemistry. This chemistry is primarily determined by the reactivity of oxygen and nitrogen species produced in the liquid phase by secondary reactions or transferred from the gas/plasma phase in the case of low-temperature plasma sources operating in atmospheric air conditions (cold atmospheric plasma) [4,5], In general, these discharges can start either directly in the liquid, close to the water's surface, or between one electrode above the liquid and the liquid's surface acting as the counter electrode.[6,7] Studies additionally leaned to configurations using plasma jets or hollow needles [8,9] fed at high voltage. [10] The discharges can be triggered by pulsed high voltage, AC, or DC. [11,12] Applications for non-equilibrium plasmas with liquid state span everything from environmental remediation to material science and healthcare. [9,13] The non-thermal plasmas (NTPs) within and around liquids have been the subject of much study by many researchers. The unusual chemical activity of liquids in contact with the plasma is the primary cause. The intense UV radiation, shock waves, and reactive radicals (OH, atomic oxygen, hydrogen peroxide, etc.) generated by discharges in and in contact with liquids are thought to be great deactivators and converts of many different kinds of biological and chemical components [11,14]. The degradation of contaminants in water and biomedical applications are two areas where NTPs have been identified as a developing technology of interest [15]. A rapidly growing area of study, plasma medicine combines biology, medicine, and plasma science and technology [16]. Atmospheric pressure plasma jets have been identified as one of the most well-liked effective sorts of equipment in this field, despite the fact that there are a number of various atmospheric pressure plasma sources that can be used. The most critical steps of species formation, transport, fundamental physics, and interactions with liquids have all been extensively explored for these devices [17,18]. A rapidly growing area of study, plasma medicine combines biology, medicine, and plasma science and technology [19]. Regarding the fact that there are a numerous of various sources for atmospheric pressure plasma which can be used, (APPJ) have been designated as one of the most well-liked and efficient equipment in this field. For these devices, the most important phases of species generation, its transport, principal physics, and its interactions with liquids have all been thoroughly investigated [10-12]. In the present work, the effect of the NaCl concentrations on the discharge characteristics of pin-liquid configuration at atmospheric pressure will be investigated in more detail. In addition, the experimental set-up is investigated and the typical results and their discussion are given.

2. Theoretical Consideration

One of the most used techniques for diagnosing plasma is optical emission spectroscopy (OES), which is based on the detection of continuum, half-width lines, and line shifts. When atoms or molecules are excited to a high energy state by the action of electrons, they release photons with energy equal to the difference between the two energy states when they relax to a lower energy state, which causes the emission of light from plasma [19,20]. To determine the makeup of the species that produces, spectral emission data and photon energy analysis (wavelength of light analysis) can be used. Laser Emission Both the electromagnetic light spectrum and the UV spectrum (130-800 nm) are a part of spectroscopy [5,9]. In this technique, the emitted radiation from plasma beam is examined to determine the plasma's parameters. Information regarding the plasma parameters, such as the electron temperature, plasma density, and type, is gathered using (OES). This study's primary goal is to use optical emission spectroscopy (OES) to examine plasma properties utilizing spectral lines given off by nitrogen atoms around the plasma [21,22].

2.1 Electron Temperature ($\mathbf{T_e}$):

The electron temperature (T_e)(in eV) was one of the most important variables used for evaluating plasma properties. It calculated by the Boltzmann plot method as follows [23,24]:

$$\ln\left(\frac{I_z\lambda_{ki,z}}{g_{k,z}A_{ki,z}}\right) = -\frac{1}{k_BT_e}E_{k,z} + ln\left(\frac{hcL_{n,z}}{4\pi P_Z}\right) \ldots (1)$$

Where the indices Z, c, k_B, $L_{n,z}$, h, E_k, Z, and $g_{k,z}$ represent the ionization state with respect to the species, light speed, boltzmann constant, plasma's characteristic length, Planck constant, energy, and degeneracy of the upper energy level k, respectively.

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Optically the integrated intensity I_Z of a species in ionization stage Z. P_Z represents the partition function regarding species in ionization stage Z. The slope (-$1/T_e$) of the linear fitting to the relationship between the electron temperature (T_e) in (eV) and $\ln\left(\frac{hcL_{n,z}}{4\pi P_Z}\right)$, and $E_{k,z}$ [25].

2.2 Electron Density (n_e):

The full width at half maximum (FWHM) and lorentzian fitting were used for determining the electron number density. (n_e) (in cm^{-3}) with the variation of NaCl concentrations using stark broadening of (N_2I) for the following wavelengths (337.13, 357.69 and 380.49)(nm)) that is collected through the following relation [24,26]:

$$n_e(cm)^{-3} = \left[\frac{\Delta\lambda}{2\omega_S(\lambda_D T_e)}\right] N_r \quad .....(2)$$

A method is more efficient than another and offers facts with high accuracy. In equation (2), Δλ refers to the Stark full-width at half-maximum (FHWM), Nr denotes the reference electron density that equals (10^{16} cm^{-3}) for neutral atoms and (10^{17} cm^{-3}) for singly charged ions, and ωs is the electron impact parameter, tabulated in Griem [22].

2.3 Plasma Frequency (ω_p):

The plasma frequency (ω_p) (in a rad/sec) was obtained from the electron number density as follows [11,25]:

$$\omega_p = \sqrt{\frac{e^2 n_e}{m_e \varepsilon_0}} \quad .....(3)$$

Where me, ε_0, n_e, and e are electron mass, vacuum permittivity, electron number density, and electronic charge, respectively [27].

2.4 Debye Length (λ_D):

The electron Debye length (λ_D) (in m) was defined as a microscopic maximum spatial scale for the charge-separation which represents the shielding distance or the thickness of the plasma sheath which is calculated as [24,26,27]:

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k B T_e}{e^2 n_e}} = 7430 \left(\frac{T_e(eV)}{n_e}\right)^{1/2} \quad (4)$$

2.5 Plasma Parameter (N_D:)

Plasma parameter (N_D) denote no. of particles exited in a Debye sphere, or a sphere of radius equal to Debye length (λ_D), using the equation [25,27]:

$$N_D = \frac{4\pi}{3} n_e (\lambda_D)^3 \quad (5)$$

3. Materials and Methods

Figure (1) the single pin to liquid discharge device that was employed in this experiment is displayed. (which is, highly efficient, simple, easy to operate, and low cost). The cathode pin electrode (iron, 100 mm length, 4 mm radius) is supplied by a variable a high voltage D.C. power source (model HLD-20C Hi-Rikesuta, 0-25 kV, 100 μA), and below this cathode is placed a glass vessel which contain a (100 ml) of tap water with different NaCl concentrations (300, 400, and 500 mg). The liquid contact and the pin electrode are (5 mm) apart. At the vessel's bottom is placed the circular anode (brass) disc (2 mm thickness and 20 mm radius) inside the tap water. A D.C. high-voltage was applied to create a discharge between the cathode pin and the metal anode which is submerged in water with different NaCl concentrations. The discharge water container ignited between the metal pin electrode and the tap water surface. The interaction between a pin-plate and plasma can vary depending on various factors such as the plasma density, temperature, and the material properties of the pin and plate. By using an OES (Optical Emission Spectrometer) (German-made THOR model), the atoms or molecules are excited by electrons and when relaxing to a lower energy level, photons are released with high energy equal to the difference between the two energy states the emission light of the resulting air plasma discharge which detected via a digital camera with higher resolutions. This results in the emission of light spectra from the air plasma [28]. Photon energy analysis (wavelength of light) and spectral emission data of the species can be used to determine the composition of the species it generates at the gap between the pin and water surface when various dissolved concentrations of NaCl are used. The pin acts as the cathode and the plate as the anode. Electrons are emitted from the pin and accelerated towards the plate, causing ionization of the gas and the formation of a glow discharge.

4. Results and Discussion

4.1 Emission Spectra:

There are three main categories that can be used to group electrical discharges that are produced above the liquid surface, direct electrical discharges inside the liquid, electrical discharges in vapour and bubbles inside liquids. Because of their similar breakdown strengths in atmospheric gas, the plasma formation and gas phase breakdown above the liquid surface in the zone of electrical discharges that generate above the liquid surface are almost identical to the gas electrical discharge.

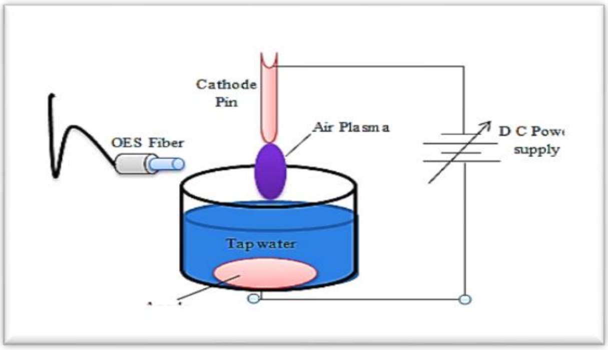

Fig. 1: Experimental setup of Pin–Liquid configuration

However, in case of electrical discharge on liquid surfaces using liquid as an electrode, the presence of the solution surface impacts both the physical behaviour of the discharge and the chemical reactions taking place at the gap between the gas and solution

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interface. This is because the ions, which have far lower mobility's than metal electrons which make the discharge current across the water electrode. Water is also easier to deform and evaporate than metals and has a lower secondary electron emission coefficient.

Figure (2) shows the emission spectra of air plasma in a pin-to-liquid discharge setup at various NaCl concentrations. It may be pointed out from these spectra that there are multiple emission peaks of neutral nitrogen lines (N2 I) corresponding to wavelengths (337.13, 357.69, and 380.49 nm). The production of chemical active species are determined by neutral nitrogen energy yields related to the energy consumption of the whole inter electrode system which the same result as in [29]. Emission-neutral atomic nitrogen peaks (N I) appear also at wavelengths (674.17 and 734.76 nm). The ionic nitrogen lines (N II) were also detected in the spectra at wavelengths (435.22, 631.88, 659.66, 697.56, 701.47, and 715.68 nm). All emission's peak intensity is decreased with increasing NaCl concentrations.

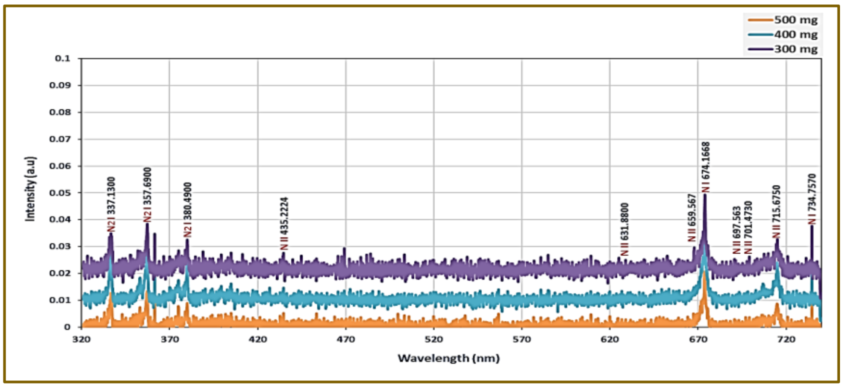

Fig. 2: Emission spectra of glow discharge in pin-liquid configuration at different NaCl concentrations for the wavelength range (320-740 nm).

These peaks are of different intensities because of the varying probability of transition and the exciting levels of statistical weight. As well as, the emission intensity of neutral emission peaks is much higher than that of the ionic emission peaks. These results indicated the plasma produced contained more atomic N than that ionic N.

4.2 Effect of NaCl Concentration on the discharge channel:

Figure (3) illustrated the image makes it very evident that the rising NaCl concentration in water causes the dynamical change of the air plasma characteristics that formed in the gap between the pin electrode and the water surface. This result means that the conductivity of the liquid (water) will affect the plasma characteristics that formed (where the increasing of NaCl concentration causes to increase in water conductivity as in ref. 29). The pin and plate can also experience charging effects in a plasma. When exposed to a plasma, the surfaces can accumulate charges due to the differential flow of ions and electrons. This can lead to the formation of an electric field around the pin and plate, which can affect the plasma properties and the interaction between the pin and plate.

Figure (4) illustrated the intensity of emission light in the air gap between the pin electrode and surface water at different NaCl concentrations which seem the same behaviour with the result of [27]. And this figure shows that as the concentration of NaCl increased, the light intensity decreased.

4.3 Current- Voltage Curve:

Figure (5) demonstrated the effect of NaCl concentrations on the I-V curve. It is evident that an abnormal glow discharge.

was created, increasing the current with the discharge voltage. We also observed that when the NaCl concentration is increased, the discharge current increases.

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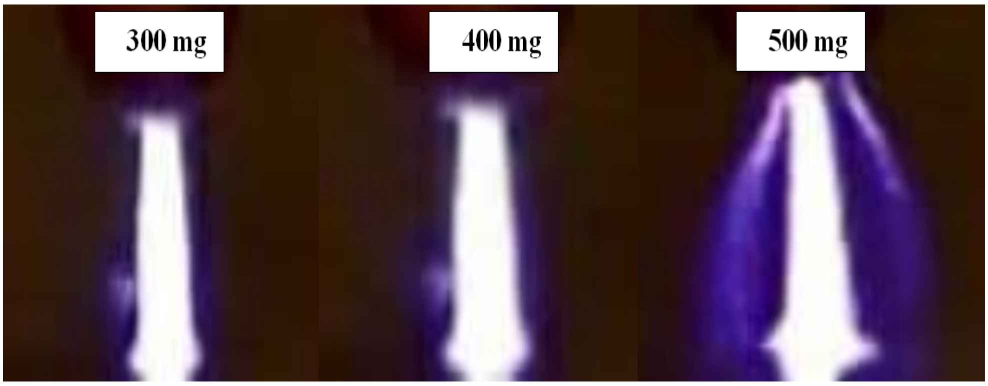

Fig. 3: Typical images of the influence of NaCl concentration on the discharge channel in the gap between (pin–liquid surface).

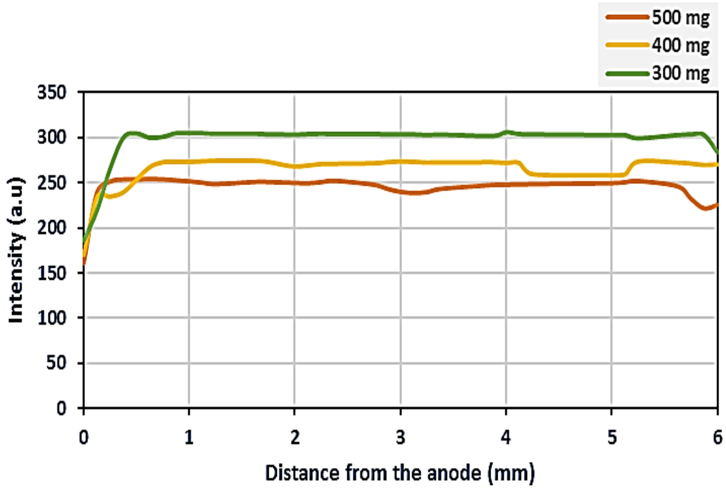

Fig. 4: Influence of NaCl concentrations on the emission light intensity in the air pag between (pin - water surface)

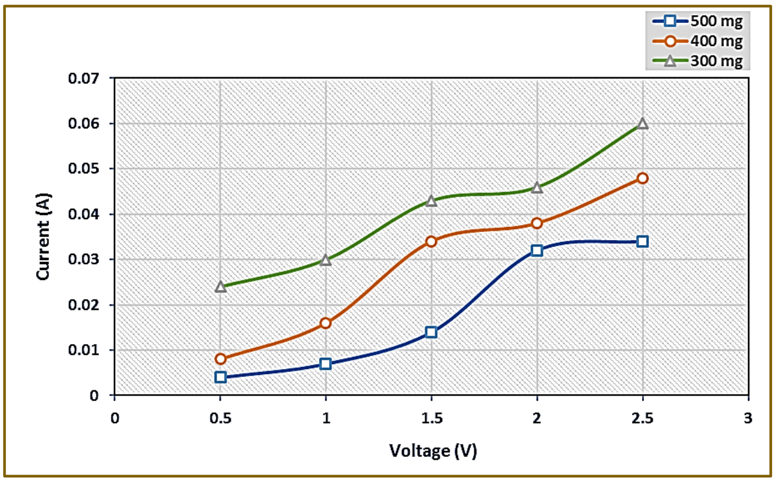

Fig. 5: Influence of NaCl concentration on the I-V curve.

4.4 Influence of NaCl Concentrations on the Electron Temperature:

In this section, the electric discharge that formed along the water surface with added NaCl has been investigated. The essential plasma metrics used to determine the plasma state is (T_e). The electron temperature was determined in this work using the Boltzmann plot method (equation 1) and the data listed in table (1).

Figure (6) display the boltzmann plots using the selected ionic nitrogen lines (N II) for the air plasma between the pin electrode and water surface at three different NaCl concentrations. On the other hand, the (n_e) was determined.

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Figure (7) The variation of the (T_e & n_e) with NaCl concentrations was plotted in The data detected the fact (T_e & n_e) are reduced with increasing NaCl concentration. One can observe that, the increases in NaCl concentrations cause to reduction in most plasma parameters under study.

Table 1: N II standard lines which used to calculate electron temperature and its characteristics.

λ(nm)	$A_{ji} \times g_i$	E_i(eV)	χE_j(eV)
631.8800	15.1×104	23.239296	25.200902
659.567	2.11×104	24.374310	26.253573
697.563	1.03×104	23.415330	25.192229
701.4730	175×104	23.425232	25.192229
715.6750	11.4×104	24.531351	26.263284

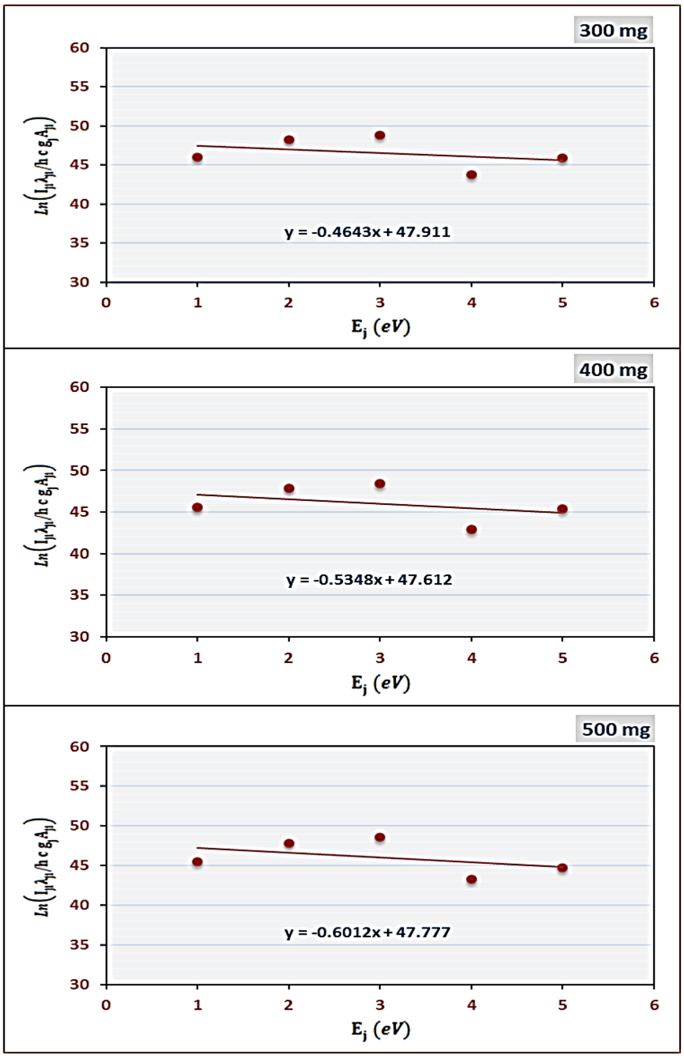

Fig. 6: Boltzmann plot for N II peaks using the DBD system at three different concentrations.

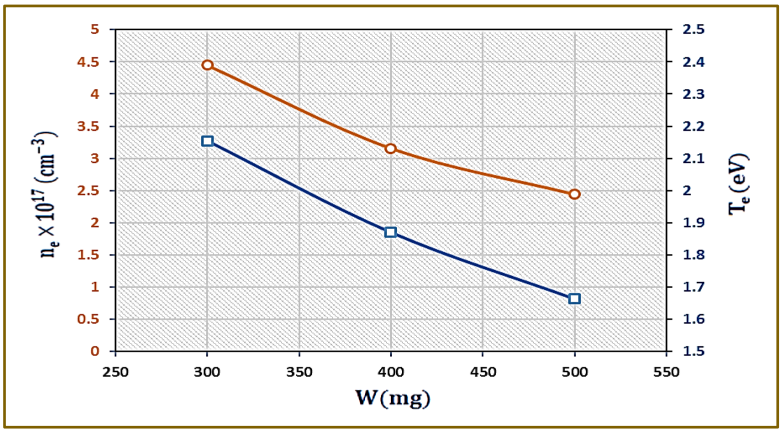

Fig. 7: Influence of NaCl concentrations on the electron temperature and electron number density

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Furthermore, table (2) depicts the effect of the NaCl concentrations on the air discharge parameters. The data detected that the plasma frequency and the plasma parameter decreased with increases in NaCl concentrations except the Debye length showed a different behavior with an increase in NaCl concentrations. The variation of plasma parameters with adding NaCl concentration can be described as the increase in NaCl concentrations leading to an increase in free ions in the solution.

Similar to resistive electrodes, liquid electrodes maintain the discharge, preventing it from contracting at the electrode. Although other mechanisms are probably also at play, the dispersed resistivity may be the cause of the stability.

Table 2: The variation of plasma parameters of air plasma with NaCl concentrations

N_D	$\lambda_D \times 10^{-6}$ (cm)	$\omega_{pe} \times 10^{11}$ (rad/sec)	$n_e \times 10^{17}$ (cm^{-3})	T_e (eV)	Food slat weight (mg)
8	**1.6342**	**377.1176**	**4.4519**	**2.1537**	**300**
7	**1.7278**	**332.3521**	**3.1577**	**1.8698**	**400**
7	**1.93989**	**279.1951**	**2.4401**	**1.6633**	**500**

5. Conclusion

A DC discharge in atmospheric pressure air in a pin with one electrode submerged in water at different NaCl concentrations was investigated. The influence of added NaCl to the distilled water on the air discharge was investigated in more detail. The results shown that the parameters of the air discharge conductivity are strongly influenced by the conductivity of the electrode liquid that formed in the gap between the pin and electrode and distilled water surface. Finally, salts in water can increase its conductivity, which may not lead to increased electrical discharge and potentially create safety hazards. High salt concentrations can also cause corrosion and damage to electrical equipment. Therefore, it is not recommended to increase the concentration of salts in water to improve electrical discharge characteristics..

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7. References

[1] Anas, A.A., Sabre, J.M. and Ghuson, H.M. (2019). Spectroscopic Diagnostics of Plasma parameter in Laser Induced Plasma using PbO Lines. Tikrit Journal of Pure Science, 24(2):63-67.

[2] Bo, J. et al. (2014). Review on electrical discharge plasma technology for wastewater remediation. Chemical Engineering Journal, 236:348-368.

[3] Bruggeman, P.J. et al. (2016). Plasma–liquid interactions: a review and roadmap. Plasma Sources Science and Technology, 25(053002):1-59.

[4] Kolb, J.F., Joshi, R.P., Xiao, S. and Schoenbach, K.H. (2008). Streamers in water and other dielectric liquids. Journal of Physics D: Applied Physics, 41(23):234007.

[5] Bruggeman, P. et al. (2009). OPTICAL EMISSION SPECTROSCOPY OF PLASMAS IN AND IN CONTACT WITH LIQUIDS. III Central European Symposium On Plasma Chemistry,23-27 Aug 2009, Kyiv, Ukraine.

[6] Ahmed, A.I. and Hamdoon, N.A. (2022). Electronic transport study for SF6 Plasma. Tikrit Journal of Pure Science, 27 (3):59-66.

[7] Chih, W.C., How, M.L. and Moo, B.C. (2008). Inactivation of Aquatic Microorganisms by Low-Frequency AC Discharges. IEEE Transactions on Plasma Science, 36(1):215-219,

[8] Vesna, V.K. et al. (2017). Measurement of reactive species generated by dielectric barrier discharge in direct contact with water in different atmospheres. Journal of Physics D: Applied Physics, 50(15):155205.

[9] Oehmigen, K. et al. (2010). The Role of Acidification for Antimicrobial Activity of Atmospheric Pressure Plasma in Liquids. Plasma Process. Polym., 7:187-352.

[10] Radu, B., Michael, J., Kirkpatrick, B. and Lockeb, R. (2006). Formation of reactive species in gliding arc discharges with liquid water. Journal of Electrostatics, 64(1):35-43.

[11] Fuxiang, L. et al. (2009). Inactivation of Bacteria in an Aqueous Environment by a Direct-Current, Cold-Atmospheric-Pressure Air Plasma Micro jet. Plasma Process Polym., 7:231-236.

[12] Monica, M., Nicolae, B.M. and Vasile, I.P. (2007). Degradation of organic dyes in water by electrical discharges. Plasma Chemistry and Plasma Processing, 27:589-598.

[13] Zdenko, M., Lenka, C. and Michal, P. (2010). Plasma agents in bio-decontamination by dc discharges in atmospheric air. Journal of Physics D: Applied Physics, 43(22).

[14] Ma, M., Duan, J., Lu, X. and He, G. (2019). Genotoxic and mutagenic properties of atmospheric pressure plasma jet on human liver cell line L02. Physics of Plasmas, 26(023523).

[15] Shiqiang, Z. and Thierry, D. (2018). Self-organized patterns by a DC pin liquid anode discharge in ambient air: Effect of liquid types on formation. Physics of Plasmas, 25(7):073502.

https://doi.org/10.25130/tjps.v29i2.1514

[16] Foster, J.E. (2017). Plasma-based water purification. Challenges and prospects for the future. Physics of Plasmas, 24(5):055501.

[17] Ercolini, D. (2004). PCR-DGGE fingerprinting: Novel strategies for detection of microbes in food. Journal of Microbiological Methods, 56(5):297-314.

[18] Schmidt, M., et al. (2017). AC-driven pin-to-liquid discharge: Characterization and application. In Proceedings of the ISPC 23 Montreal QC. Available online: https://www.ispc-conference.org/ispcproc/ispc23/190.pdf.

[19] Frantisek, K., Zdenka, K., Vera, M. and Thierry B. (2018). Characterization of novel pin-hole based plasma source for the generation of discharge in liquids supplied by DC non-pulsing voltage. Plasma Sources Science and Technology, 27(6).

[20] Zdenka, K. et al. (2015). Generation of dc pin-hole discharges in liquids: comparison of discharge breakdown in the diaphragm and capillary configuration. The European Physical Journal D., 69 (100).

[21] Rond, C. et al. (2018). Influence of applied voltage and electrical conductivity on underwater pin-to-pin pulsed discharge. Journal of Physics D: Applied Physics, 52(2).

[22] Ahmad, H., James, D. and Antoine, H. (2021). Dynamics of a pulsed negative nanosecond discharge on the water surface and comparison with the positive discharge. Journal of Physics Communications, 5(3).

[23] Jungmi, H. (2013). Atmospheric Pressure Plasma Chemical Deposition by Using Dielectric Barrier Discharge System. Thesis, University of Illinois at Urbana-Champaign.

[24] Garrett, E.M. (2012). Characterization Of A Plasma Reactor Device For Photovoltaic Applications. Ph.D. Thesis Colorado State University.

[25] Sadeghzadeh, E.L. et al. (2019). Calculation of electron density and temperature of plasmas by using new Stark broadening formula of helium lines. Physics of Plasmas, 26(2):023519.

[26] Bard, A.K. and Qusay, A. (2022) Influence of Cylindrical Electrode Configuration on Plasma Parameters in a Sputtering System. Iraqi journal of Science, 63(8):412-3423.

[27] Kadhim, M.M., Qusay, A.A. and Mohammed, R.A. (2022). Study of some plasma characteristics in dielectric barrier discharge (DBD) system. Iraqi Journal of Science, 63(5):2048-2056.

[28] Mazhir, S.N. (2018). Spectroscopic Study of $(TiO2)_{1-x}$ $(CuO)_x$ Plasma Generated by Nd: YAG Laser. ARPN Journal of Engineering and Applied Sciences, 13(3):864-869.

[29] Krčma, F. (2018). Characterization of novel pin-hole based plasma source for generation of discharge in liquids supplied by DC non-pulsing voltage. Plasma Sources Science and Technology, 27(6).