# Application of gliding arc discharge plasma for the creation of plasma activated water

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## Introduction

Nowadays, plasma activated water (PAW) is widely used in different fields such as agriculture, medicine, biotechnology, the food industry, etc [1-5]. Performed research revealed that the unique physicochemical properties of the PAW or liquids are attributed to the existence of the nitrite ($NO_2^-$), nitrate ($NO_3^-$), and hydrogen peroxide ($H_2O_2$). It should be noted that the concentration of $NO_2^-$, $NO_3^-$, and $H_2O_2$ very strongly depends on the used plasma equipment, type of the gas, gas flow rate, treatment duration, volume of used water and etc. [1-8]. Once the PAW is produced, the treatment could be done in different ways: by immersing the samples, by washing the food or plants, and spraying on the plant, seeds or foods. Meanwhile, the effect of the plasma activated water on the seed germination or plant growth will depend not only on the physicochemical properties of used PAW, but also on the nature of the seeds or plants, as well as the treatment procedure [4-7]. The main aim of the study was to adopt the gliding arc discharge (GAD) plasma device for the creation of the plasma-activated water and to determine the relationship between the physicochemical properties of treated water and the composition of the produced PAW.

## Experimental setup

The gliding arc discharge plasma reactor was used to produce plasma activated water [5]. The composition of the air plasma was investigated using the flame-emission spectrometer Flame UV-VIS (Ocean Insight, Orlando, FL, USA), in a wavelength range of 200–1000 nm and acousto-optic emission spectrometer IFU AOS4 (in the range of 250–800 nm). The air was injected into the plasma reactor from the top of the electrodes, with a flow rate of 8.93 L/min, and tangentially, with a flow rate of 9.44 L/min. The output voltage was ranged from 90 V to 250 V. The tap water (TP), deionized water (DW), and deionized water supplemented by salts

($Ca^{2+}$, $Mg^{2+}$ and $Ca^{2+}$+$Mg^{2+}$) was used to produce the plasma activated water. The volume of the water was 200 ml, the plasma treatment time was 300 s, the output voltage was kept at 170 V. The specific electrical conductivity, pH values, concentration of nitrates and hydrogen peroxide in water before and after plasma treatment was determined.

**Results and discussions**

The typical optical emission spectrum of the air plasma obtained output voltage of 130 V is given in Figure 1. It was found that the main species in the emission spectrum of the air plasma were $N_2$, $N_2^+$, $N^+$, $NO_\gamma$ and O particles. The highest intensity peaks obtained at 316 nm, 337 nm, 353 nm, 358 nm, and 379 nm are related to the nitrogen molecule ($N_2$) vibrational modes, respectively. The lower intensity peaks at 391 nm and 419 nm, are related to the first negative band of the molecular nitrogen ion ($N_2^+$) [2]. The emission spectra lines at 200 nm to 300 nm range are attributed to the exited states of $NO_\gamma$ species in the air and nitrogen-oxygen plasma [3-6]. The very low intensity peaks in the emission spectrum at ~221 nm, ~399 nm, and ~434 nm is attributed to the atomic nitrogen ions. It should be noted that several emission lines related to the oxygen species were obtained. The emission lines detected at the 777 nm and 845 nm wavelengths are attributed to the existence of atomic oxygen (O). The emission peaks at 464 nm and 636 nm are due to the formation of the oxygen ions ($O^+$) and molecular oxygen ions ($O_2^+$), respectively.

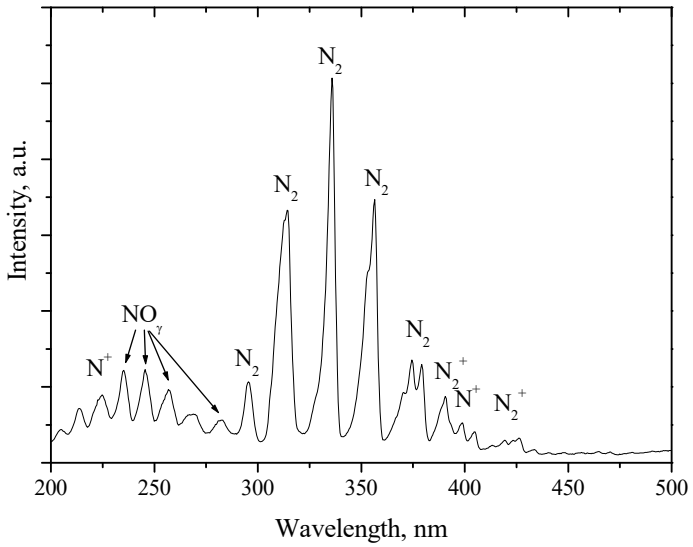


Fig. 1 Emission spectrum of the air plasma when output voltage was 130 V.

The increase of the output voltage from 90 V up to 250 V led to the increase in intensities of the emission lines related to the molecular nitrogen ion, atomic oxygen and $NO_\gamma$ species.

Meanwhile, the intensities of the emission lines related to the nitrogen molecule vibrational modes firstly increased with the increase of the voltage to 170 V, and when was slightly reduced with the increase of the output voltage to 250 V. The obtained results shows that the ionization degree of the air plasma was increased [2, 4, 8].

Based on the optical emission spectrometry results it was decided to choose the output voltage of the 170 V for the creation of the plasma activated water. The pH values of the different types of deionized waters and tap water before and after plasma activation is presented in Figure 2.

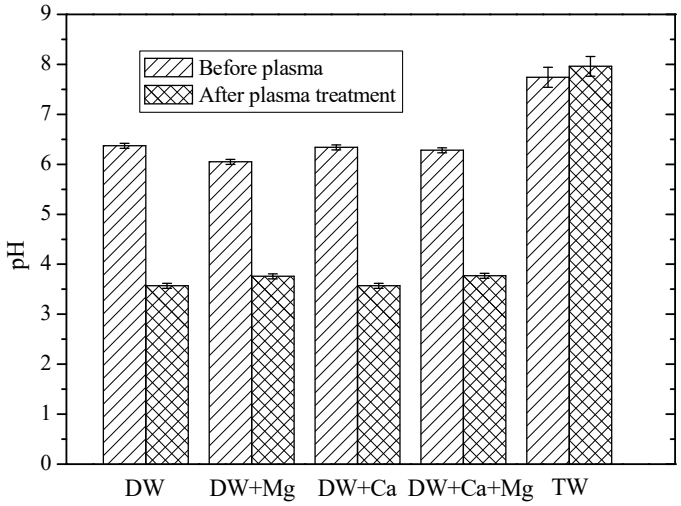


Fig. 2 Changes of the pH values after 5 min of plasma treatment (DW - deionized water, TP – tap water)

The pH of the deionize water was ~6.4, while after the plasma activation for 5 minutes, the pH of DW was reduced to ~3.61. The addition of known concentrations of $Ca^{2+}$, $Mg^{2+}$ and $Ca^{2+}$+$Mg^{2+}$ salts to the deionized water only slightly changed the initial pH values. Meanwhile, the pH values of plasma activated DW with calcium, DW with magnesium and DW containing Ca and Mg salts were drastically reduced to 3.57, 3.76 and 3.77, respectively. The pH value of the tap water was enhanced from 7.74 the 7.96 after the plasma treatment (Fig. 2).

The concentration of the hydrogen peroxide in the tap water was ~0.27 mM, which was similar (0.26 mM) to the hydrogen peroxide concentration observed in the plasma activated deionized water. The concentration of the nitrate ions in the DW with the various metal salts was very similar and changed from ~19 mg/l to ~22 mg/l. It should be mentioned that the $NO_3^-$ concentration in the deionized water was slightly lower. The highest concentration (~150 mg/L) of the $NO_3^-$ was observed in the plasma activated tap water. It should be noted that the specific electrical conductivity of the tap water after the plasma treatment was only very slightly enhanced (2-3 %). The increase in the plasma treatment duration from 150 to 600 s (at a voltage

of 170 V), increased the pH values, electrical conductivity of the tap water, and hydrogen peroxide concentration. Such increase is related to the higher ionization degree of air plasma. As the ionization degree of the plasma was increased more reactive oxygen and nitrogen species were formed [2, 8]. Additionally, it will result in a higher acidity of the plasma activated water. It should be noted that the concentrations of the nitrates in the plasma activated deionized water increased up to 4 times after one week after plasma treatment. The results indicate that the type of the used water is very important and could drastically affect to the final physicochemical properties of the plasma activated waters. Additionally, it was observed that the concentrations of the nitrates and hydrogen peroxide in plasma activated tap water and deionized water variated versus storage duration. Therefore, the results of the estimation of the PAW effects on the plants are hardly reproducible when using PAW obtained from the tap water.

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## References

1. F.S. Miranda et al., *Water* 2023, *15*, 4045.
2. Z. Machala et al., *J. Mol. Spectrosc.* 2007, *243*, 194–201.
3. S. Herianto et al. *Science of the Total Environment*, 2023, 874, 162235.
4. E. H. Choi et al., *J. Korean Phys. Soc.* 2022, *80*, 817–851.
5. M. Gharagozalian et al., *J. Theor. Appl. Phys.* 2017, *11*, 171–180.
6. S. Pandey, R. Jangra, K. Ahlawat et al. *Physics Letters A*, 2023, 474, 128832.
7. A. Patra et al. *Food Control*, 2022, 142, 109268.
8. L. Marcinauskas et al., *Appl. Sci.* 2024, *14*, 2135.