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CHANGES IN WATER SURFACE TENSION INDUCED BY PLASMA TREATMENT

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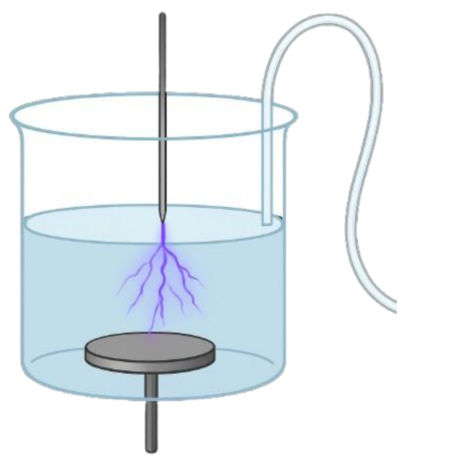
INTRODUCTION

High voltage electrical discharge plasma (HVED) has emerged as a promising, non-thermal technology for modifying the physicochemical properties of liquids, including water. This research examines how HVED treatment, resulting in plasma-activated water, influences the surface tension (SFT) of water, with particular focus on the mechanisms responsible for its reduction. The interaction of plasma with the water surface generates reactive oxygen and nitrogen species, which can alter molecular interactions at the air–liquid interface. These changes may disrupt hydrogen bonding networks, leading to a measurable decrease in surface tension. Understanding these effects provides valuable insight into the potential applications of plasma-activated water in fields such as food processing, agriculture, and environmental decontamination. Furthermore, investigating the relationship between plasma parameters and the resulting surface tension change may help optimize treatment conditions for target applications.



MATERIALS AND METHODS

Plasma was generated under ambient conditions with argon, nitrogen and oxygen being used as working gases, and demineralized water samples were exposed for varying treatment voltages (20 and 30 kV) with fixed duration (7 min). Two types of high voltage electrodes were used: titanium and silver made electrodes. Also, two different configurations of reactors were used – gaseous and liquid plasma reactor. Measurements of surface tension were conducted using the pendant drop method after plasma exposure. The surface tension is calculated using image analysis software.
For each sample after each treatment pH, concentration of H_2O_2 and NO_2^-, and oxidation-reduction potential was measured.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RESULTS

Table 1. PAW samples treated for 7 minutes with Ag electrode used in process

SAMPLE	U (kV)	Gas	Plasma type	pH	c (H_2O_2) mg/L	c (NO_2^-) mg/L
P_Ag_Ar_20	20	Ar	Gas	6.26	5.25	0.35
P_Ag_Ar_30	30	Ar	Gas	4.44	21.42	0.99
T_Ag_Ar_20	20	Ar	Liquid	5.85	6.44	0.16
T_Ag_Ar_30	30	Ar	Liquid	5.80	8.25	0.11
P_Ag_N2_20	20	N2	Gas	4.55	3.91	3.03
P_Ag_N2_30	30	N2	Gas	3.73	5.30	3.99
T_Ag_N2_20	20	N2	Liquid	5.67	4.00	0.06
T_Ag_N2_30	30	N2	Liquid	5.77	9.00	0.11
P_Ag_O2_20	20	O2	Gas	6.32	3.84	0.01
P_Ag_O2_30	30	O2	Gas	6.14	11.52	0.01
T_Ag_O2_20	20	O2	Liquid	6.36	5.20	0.10
T_Ag_O2_30	30	O2	Liquid	6.28	9.15	0.14

In table 1 there is visible influence of treatment voltage on formation of H_2O_2 molecules. For all types of NTP reactors and all gases used, amount of formed H_2O_2 molecules is significantly higher in process with 30 kV than in 20 kV. Same trend follows the concentration of NO_2^-.
In accordance with literature, formation of H_2O_2 is generally highest in Ar gas-phase plasma and lowest in N_2 gas-phase plasma.
During the process of plasma in PAW happens formation of radicals, e.g. •OH, H_2O_2, NO_2^- and NO_3^- which we see as a mild acidification of PAW with pH values dropping under 6.5.

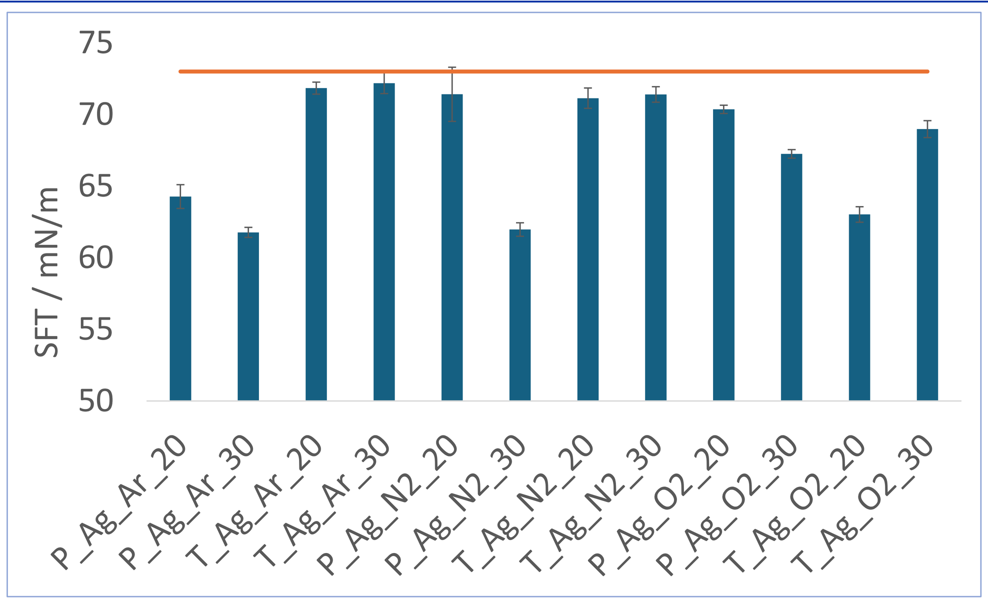

Figure 1. Surface tension of samples treated with Ag electrode

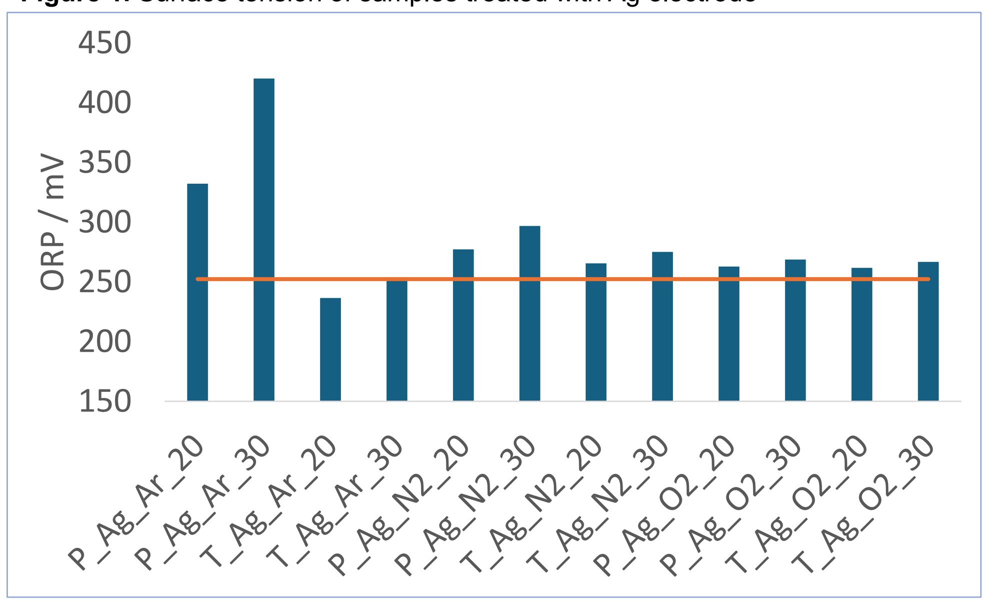

Figure 2. Oxidation-reduction potential of samples treated with Ag electrode

Figure 1 shows drop in surface tension with plasma treatment. Red line represents surface tension of demineralized water of 73 mN/m. With acidification of PAW and formation of different chemical species we see a considerable influence on SFT. The biggest drop of SFT value is for PAW samples treated in Ar atmosphere which complies with table 1 results where formation of H_2O_2 and NO_2^- combined has the highest values. The lowest decrease of value generally for liquid-phase plasma process.
Oxidation-reduction potential, Fig. 2, shows that the biggest increase is for samples treated in Ar atmosphere and gas-phase plasma process.

Table 2. PAW samples treated for 7 minutes with Ti electrode used in process

SAMPLE	U (kV)	Gas	Plasma type	pH	c (H_2O_2) mg/L	c (NO_2^-) mg/L
P_Ti_Ar_20	20	Ar	Gas	6.26	8.35	0.17
P_Ti_Ar_30	30	Ar	Gas	5.63	18.75	0.70
T_Ti_Ar_20	20	Ar	Liquid	6.18	3.03	0.08
T_Ti_Ar_30	30	Ar	Liquid	6.37	7.40	0.09
P_Ti_N2_20	20	N2	Gas	5.76	3.07	1.25
P_Ti_N2_30	30	N2	Gas	4.19	4.71	3.12
T_Ti_N2_20	20	N2	Liquid	5.98	2.68	0.03
T_Ti_N2_30	30	N2	Liquid	6.01	5.63	0.11
P_Ti_O2_20	20	O2	Gas	6.5	2.83	0.00
P_Ti_O2_30	30	O2	Gas	6.09	14.84	0.03
T_Ti_O2_20	20	O2	Liquid	6.31	4.54	0.34
T_Ti_O2_30	30	O2	Liquid	6.17	6.12	0.67

Table 2 shows slightly different concentrations of H_2O_2 and NO_2^- formed because this process used Ti electrode as high voltage electrode.
Again, same trend is observable, with the biggest formation of H_2O_2 molecules occurring in Ar gas-phase plasma, with smaller difference to the second-best results in O2 gas-phase process. NO_2^- formation keeps the trend with the highest concentration measured in N_2 gas-phase plasma treatment. Acidification of samples is present with slightly lower value compared to the process with Ag electrode.

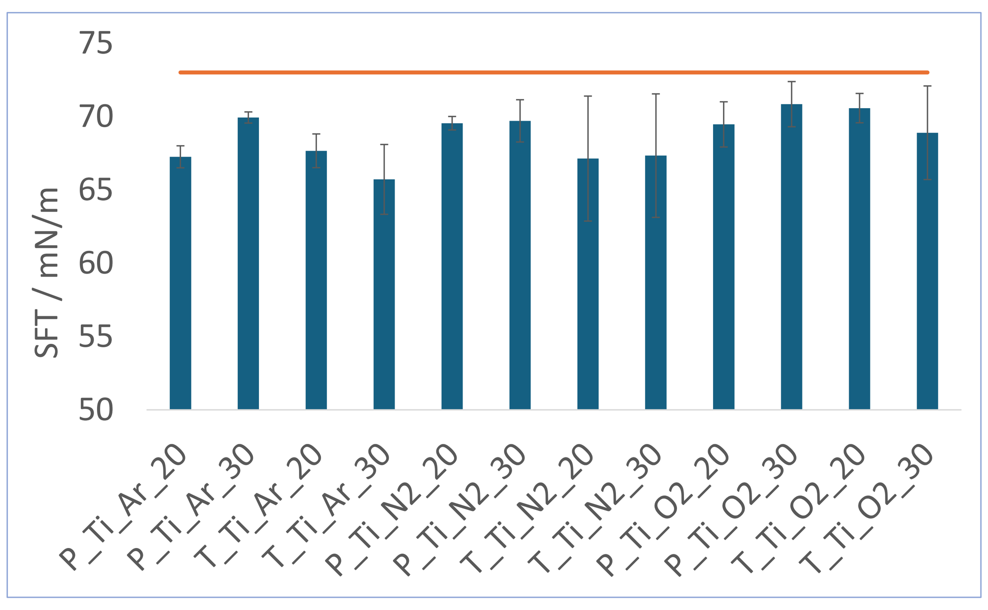

Figure 3. Surface tension of samples treated with Ti electrode

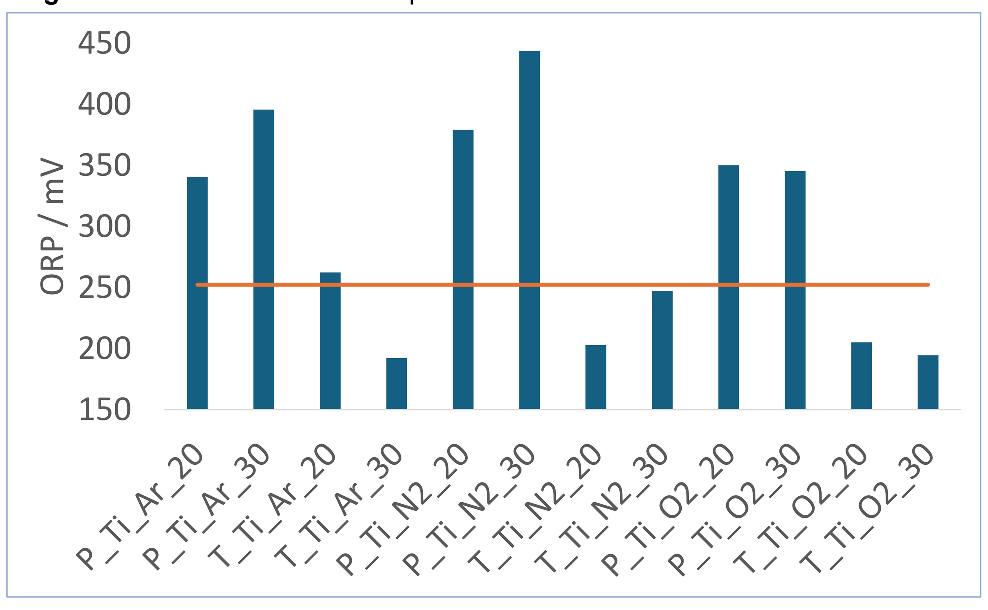

Figure 4. Oxidation-reduction potential of samples treated with Ti electrode

Figure 3 depicts decrease in surface tension values for all plasma treatments. Compared to process with Ag electrode, Fig. 1, decrease is value is slightly smaller, and values are in the 5 mN/m interval (~65 – 70 mN/m). When gas-phase plasma is compared to liquid-phase plasma values of SFT measurement, samples treated in liquid-phase plasma show slightly bigger decrease of value, even though formation of H_2O_2 and NO_2^- is generally lower compared to gas-phase plasma process.
In Fig. 4 oxidation-reduction potential show trend of significant increase of ORP value for gas-phase plasma treatment. Samples treated in liquid-phase plasma process show decrease in ORP value or samples (T_Ti_Ar_20 and T_Ti_N2_30) keep approximately same value as demineralized H_2O (252,3 mV).

CONCLUSSION

The biggest decrease in surface tension value and the biggest increase in oxidation-reduction potential are for sample treated with Ag electrode, 7 min treatment, Ar atmosphere and gas-phase plasma process. This sample shows potential for applications for different food treatments or surface treatments. The results demonstrate that high-voltage electrical discharge (HVED) treatment effectively reduces the surface tension of water without inducing significant thermal effects. This indicates the potential of HVED for diverse applications in surface engineering, sterilization, and chemical processing. The reduction in surface tension facilitates improved wettability, allowing water to spread and flow more readily across and within porous materials, thereby enhancing surface coverage and penetration.

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