# Characterization and optimization of 3-pin atmospheric pressure plasma jet system for water treatment

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Cold plasma-based treatment processes are eco-friendly because they operate without any additional chemicals at atmospheric conditions. Contact of plasma with water generates a rich mixture of Reactive Oxygen and Nitrogen Species (RONS) (e.g. $HO^{\cdot}$, $O^{\cdot}$, $O_3$, $H_2O_2$, $NO^{\cdot}$, ONOOH, $NO_3^-$, $NO_2^-$, …) that are deposited in the water making Plasma Activated Water (PAW). Treatment of water for production of PAW has been studied extensively in the last decade [1]. This led to development of various electrode geometries for atmospheric pressure plasma sources and new generation of power supply units. Increase number of investigations of different plasma systems led to a discovery of some new phenomena like Pulsed Atmospheric Plasma Streamer (PAPS) [2]. But still the biggest obstacle in the field is the volume of these discharges i.e. their upscaling so that they can be used in water treatments for industry, agriculture, medicine etc. Usually the water treatment is done by atmospheric discharge positioned above the water surface or with discharge inside the water sample. In case of discharge positioned above the water the effective surface that is in direct contact with the discharge is small. The increase of contact surface can be done by increasing the plasma area or by introducing recirculation of water in the system.

In this work we present the results of water treatment by 3-pin Atmospheric Pressure Plasma Jet (APPJ) (shown in Fig. 1) which was utilized in a system for PAW production. Two options of the system were investigated: without and with the recirculation system for water samples [3]. 3-pin APPJ was made by using syringe needles as powered electrodes connected to a high voltage power supply. The inner diameter of needles is 1 mm and the outer diameter 1.8 mm. Each needle is placed in the glass tube and the distance between the tip of the needle and the edge of the tube is 5 mm. During treatments the water sample was positioned at the distance of 20 mm from the needle tips. The plasma was driven by an RF power supply with a frequency of 320 kHz. Argon gas with a total flow rate of 2 slm was used as a feed gas throughout the experiments.

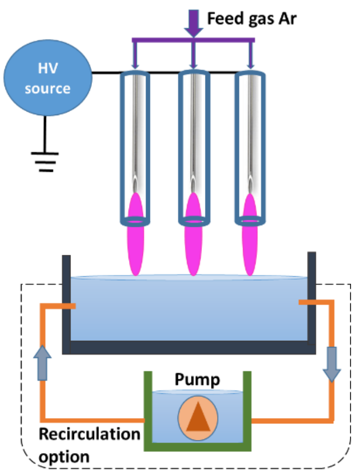


Figure 1. Experimental setup of the 3-pin APPJ for water treatments

A dielectric vessel holding a water sample was placed under the plasma source. Water in the vessel could be stationary (in case of smaller sample volumes) or it could be connected in a recirculation loop with an additional vessel, increasing the total volume of the water sample up to 600 ml. The idea was to test if we could increase the volume of obtained PAW while keeping similar properties, i.e. pH and RONS concentrations. In case of sample recirculation, a water pump (Atman AT-300) in the external vessel was used to run the water sample under the plasma jet and to adjust the flow of the sample in the system. Due to the capacity of the pump in some cases we had to use additional chokers to additionally reduce the water flow. In our experiments we have used volumes from 100 ml up to 600 ml of water.

The treatment times were from 10 min up to 90 min depending on the volume and if the water recirculation was used. After treatments, we measured pH using a probe while the presence of RONS was measured by using strips and spectrophotometrically.

For stationary water sample case we treated volume of $V_0$=100 ml of distilled water. After the treatment time of 20 mins we measured pH of 3.5 while concentrations of $H_2O_2$, $NO_2^-$, and $NO_3^-$ were around 10 mg/l, 20 mg/l and 10 mg/l respectively. By addition of the recirculation system we were able to treat volumes of 400 ml and 600 ml of distilled water. For these measurements the input power to the pin-jet was kept the same as for the stationary case.

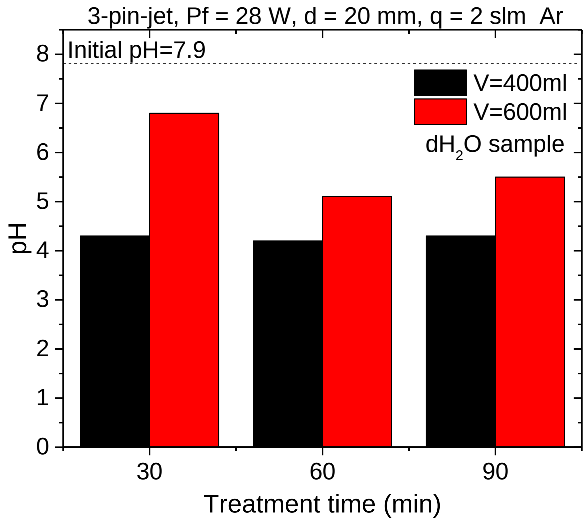


Figure 2. Measurements of pH of water samples treated for 30 mins, 60 mins and 90 mins using the recirculation system for two sample treatment volumes.

Since the volume sample was increased, we increased also the treatment time. In Figure 2 we show measurements of pH values after 30 mins, 60 mins and 90 mins of treatment. In case of $V_0$=400 ml pH values were almost constant despite the increased duration of treatment and stayed around 4. For $V_0$=600 ml of sample, pH was reducing more slowly in time with respect to 400 ml case. After 60 mins of treatment pH was further reduced and the final value stayed around 5. However, increased sample volume affected creation of reactive species. So even after 90 mins of treatment concentrations of $H_2O_2$, $NO_2^-$, and $NO_3^-$ were not reaching the values obtained with 100 ml of sample and were below 5 mg/l, 10 mg/l and 5 mg/l respectively for 400 ml volume and all below 5 mg/l for 600 ml of water sample.

So, on one side we obtained smaller reduction of pH by increasing the amount of the water sample treated. Generating PAW with less acidic conditions can be beneficiary for some applications where low pH can induce negative effects (e.g. application related to seeds and plants). Nevertheless, increasing the amount of the water sample reduces production of long-lived reactive species in PAW. This reduction cannot be compensated by just increasing the treatment time even if going to extreme duration such as 90 minutes. Therefore, when scaling up the system keeping target RONS concentration and their tuning has to involve changing more parameters so the optimization presents a complex and entangled task.

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References

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