

# Detection of reactive species in plasma-treated water using Electrochemical Impedance Spectroscopy

S. Khosravi<sup>1</sup>, G. Zarate Segura<sup>1,2</sup>, L. Zampieri<sup>1</sup>, C. Riccardi<sup>1</sup> and E. Martinez<sup>1</sup>

<sup>1</sup> Department of Physics “Giuseppe Occhialini”, University of Milano-Bicocca, 20126 Milano, Italy

<sup>2</sup> Physics Section, Pontificia Universidad Católica del Perú, 15088 Lima, Perú

Measuring reactive species produced in water by the action of cold atmospheric plasmas with selective and non-invasive techniques is a problem of interest for the design and characterization of plasma sources in biomedical and agricultural applications. Here we propose a novel approach based on electrochemical impedance spectroscopy. After demonstrating that this technique can be used to characterize saline solutions, both regarding salt concentration and salt type, we show its application to water treated with different cold plasma sources and discuss the reliability and effectiveness of the technique.

## 1 Introduction

Cold atmospheric plasma (CAP) treatments of water generate complex mixtures of reactive oxygen and nitrogen species (RONS), playing important roles in emerging applications across biomedicine and agriculture [1]. The characterization of these species presents an analytical challenge due to their varying concentrations. Most of the techniques nowadays used require the use of reagents, and therefore the loss of the sample.

Electrochemical impedance spectroscopy (EIS) is a powerful analytical technique for characterizing the electrical properties of solutions and interfaces [2]. By applying a sinusoidal voltage perturbation across a range of frequencies and measuring the current response, EIS provides information about ion concentrations, charge transfer processes, diffusion phenomena, and interfacial properties. As a fast and non-destructive method, EIS is an innovative candidate for real-time characterization of plasma-treated water (PAW) samples, offering distinct advantages for probing multi-ion systems without perturbing the original chemical environment.

## 2 Materials and methods

EIS measurements were performed using a digital impedance analyser (MFIA, Zurich Instruments). The instrument was configured to measure impedance in the frequency range of 10 Hz to 100 kHz, with a test voltage of 300 mV. A custom measurement cell was designed. In a non-conductive container, holding the liquid samples, two parallel stainless steel cylindrical electrodes with a diameter of 2 mm were positioned at 22 mm distance.

Saline solutions of varying concentrations were prepared using three different salts. The impedance was measured, and the results were summarized as a point in the plane defined by amplitude and position

of the peak of the imaginary part of the admittance [3]. The measurements were then repeated using ultrapure water treated with different plasma sources, varying the treatment time.

## 3 Results

The points in the plane cited above were found to be aligned along a straight line for different salt concentrations. Furthermore, different lines were found for different salts, showing the potential of species detection. The data obtained from the plasma-treated water were also plotted in this plane, showing a tendency to align according to the reached concentration of reactive species, quantified by the treatment time. An attempt of calibration against nitrite and nitrate ion concentrations was made. While further studies are still required to develop a calibration method and optimize the salt discrimination in multi-ion solutions, the preliminary results show the potential of this technique.

## References

- [1] P. J. Bruggemann *et al.*, J. Appl. Phys. **130**, 200401 (2021).
- [2] B-Y Chang *et al.*, Annu. Rev. Anal. Chem. **3**, 207–229 (2010).
- [3] M. Grossi *et al.*, Eng. Sci. Technol. Int. J. **22**, 102-108 (2019).

This work was funded by the National Plan for NRRP Complementary Investments (PNC, established with the decree-law 6 May 2021, n. 59, converted by law n. 101 of 2021) in the call for the funding of research initiatives for technologies and innovative trajectories in the health and care sectors (Directorial Decree n. 931 of 06-06-2022) - project n. PNC0000003 - AdvANced Technologies for Human-centrEd Medicine (project acronym: ANTHEM). This work reflects only the authors' views and opinions, neither the Ministry for University and Research nor the European Commission can be considered responsible for them.