Application Note AN-EC-038

Measuring ionic conductivity using screen-printing technology

Study of potable waters analyzed with the 11COND screen-printed electrode

Ionic conductivity (σ) is a key factor when evaluating different liquid solutions. For instance, this parameter is directly related to water salinity, and may also indicate the amount of pollution present [1]. Therefore, it is extremely important to properly calculate σ. However, when using standard conductivity probes, large liquid volumes are usually required which might not always be available. Furthermore, contamination problems might arise with certain types of samples, damaging the probe. Considering these drawbacks, a disposable screen-printed based solution is presented in this Application Note. The 11COND screen-printed electrode (SPE) is used to obtain the σ value of different potable water samples using only 100 µL of each type. The results are compared with those obtained using a standard conductivity probe, demonstrating the suitability and reproducibility of this disposable solution.

Metrohm

FUNDAMENTAL CONCEPTS

Measuring σ is directly linked to the movement of ions (polarization) when an electric field is applied. Under this condition, ions move while experiencing a resistance which is employed to calculate the solution's conductivity.

Experimentally, electrochemical impedance spectroscopy (EIS) is usually employed since a DC potential with a certain AC oscillation is applied, generating the ions' movement. If the chosen frequency is high enough to just consider the resistive part of the solution (i.e., ohmic behavior), the impedance module ($|Z|$) is basically the solution resistance [2].

Aside from this value, the cell dimensions, represented by the cell constant (K_{cell}), must also be considered. For standard probes, this parameter represents the length/area relationship of the cell where σ is measured.

Figure 1 shows the formula that must be employed when using the 11COND SPEs.

$$\sigma\ (\mu S \cdot cm^{-1}) = \left(\frac{1}{|Z| - r_0}\right) \cdot K_{cell} \cdot 10^6$$

Figure 1. Equation employed for the ionic conductivity calculation in this Application Note.

The basal (internal) electrode's resistance is represented by the term r_o. Note that the temperature must be considered constant at 25 °C for this equation to be strictly valid. The range of conductivities for the use of this electrode spans from 84 $\mu S \cdot cm^{-1}$ to 111.8 $mS \cdot cm^{-1}$.

INSTRUMENTATION AND SOFTWARE

In this Application Note, eight different samples of drinking water were analyzed, including tap water and seven commercial mineral bottled water brands. The experimental setup includes 11COND electrodes (Figure 2). These electrodes are comprised of a ceramic substrate with two screen-printed carbon circles surrounded by dielectric ink.

The µStat-i M8One multi-potentiostat (Figure 3) with impedance technology was employed for all measurements. This setup allowed all the EIS experiments to be performed simultaneously for all the mentioned water samples.

Figure 2. An 11COND screen-printed electrode.

Figure 3. The µStat-i M8One multi-channel potentiostat.

The software configuration used in this study is shown in Figure 4. Notice that both freqBegin and freqEnd have the same value (10 kHz), since only the $|Z|$ value at this frequency is needed. Furthermore, the experiment is carried out at the open-circuit potential (OCP) value.

First, the liquids must be tempered at 25 °C before starting the experiment. Then, after completing both setup and software configuration, a 100 µL drop of each sample is placed on the electrodes, covering both circles.

Once the EIS assay is finished, $|Z|$ is extracted from the impedance data. Using that value, r_o and K_{cell} (which are given in the SPE box), along with the equation shown in Figure 1, the different conductivities can be calculated in $\mu S \cdot cm^{-1}$.

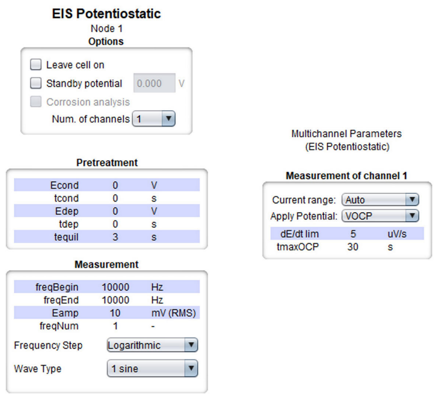

Figure 4. DropView 8400M software configuration needed to perform the described EIS experiment

RESULTS

Figure 5 shows the results of this study along with the associated error bars for each sample type. The values from the 11COND electrode and the standard conductivity probe are very similar, proving the suitability of using the SPE. Each water sample was analyzed with three different SPEs to ensure that the results are reproducible.

Considering the small volume required for the experiment and the disposability of the electrodes, the 11COND offers an easy and practical alternative to measure the ionic conductivity in moderately concentrated solutions.

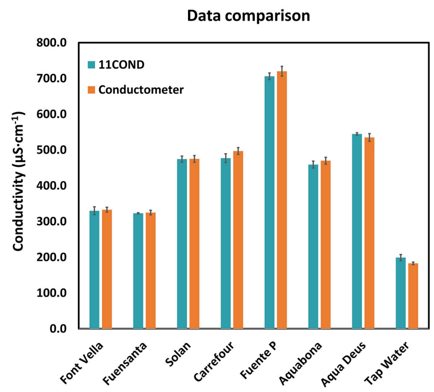

Figure 5. Data comparison obtained with the 11COND electrode from Metrohm DropSens (green) and with a standard conductivity probe (orange).

CONCLUSION

This Application Note demonstrates how the 11COND screen-printed electrode effectively measures the ionic conductivity values from different potable waters. This study includes seven commercial mineral bottled water brands along with tap water, obtaining nearly indistinguishable results between the 11COND SPE and a standard conductivity probe. These results serve as proof of concept demonstrating the reliability and practicality of the 11COND electrode for conductivity measurements, especially for small sample volumes, offering a clear advantage over conventional conductometers that require significantly larger volumes.

REFERENCES

1. R.B. Baird; E.W. Rice; A.D. Eaton. *Standard Methods for the Examination of Water and Wastewater, 23rd Edition*, 23rd ed.; American Public Health Association: Washington DC.
2. Lazanas, A. Ch.; Prodromidis, M. I. Electrochemical Impedance Spectroscopy – A Tutorial. *ACS Meas. Sci. Au* 2023, *3* (3), 162–193. https://doi.org/10.1021/acsmeasuresciau.2c00070.

RELATED APPLICATION NOTES

AN-T-076 Conductivity, pH value, alkalinity, hardness and chloride in tap water

AN-I-032 Dissolved oxygen, conductivity, and pH value in liquid dairy products

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µStat-i MXONE multichannel impedance analyzer

Multichannel impedance analyzer for multi-user and multidisciplinary electrochemical research that can be designed according to your needs

Screen-printed carbon electrode for conductivity measurements

Disposable screen-printed electrodes designed to measure conductivity aqueous media in a typical range of 84 µS cm^{-1} to 111.8 mS cm^{-1}. Conductivity sensors are recommended for working with microvolumes and are ideal for decentralized and 'in situ' assays.

Recommended instuctions to work with these SPEs:

- Let the sample temper at 25 ºC to obtain accurate measurements
- Place 100 µL onto the cell with the aid of a micropipette
- Measure |Z| in ohm at 10 kHz with an EIS potentiostat
- Subtract resistance value, r_0, in ohm to the |Z| to correct contribution of the electrodes

If $|Z| = 3638\ \Omega$ and $r_0 = 100\ \Omega$ then
$|Z| – r_0 = 3638\ \Omega – 100\ \Omega = 3538\ \Omega$

- Calculate inverted value and multiply by one million to achieve conductivity in µS

(1/3538 Ω) x 1000000 = 283 µS

- Multiply the value by the K_{cell} to obtain final result in µS·cm-1

If $K_{cell} = 5\ cm^{-1}$ then
283 µS x 5 cm^{-1} = 1413 µS cm^{-1}