An Insight Into Measuring Conductivity Of Solutions With Ease: A Review.

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ABSTRACT

In electrochemistry, it is very useful to measure the conductivity. However, there might be some difficulties with measuring conductivity owing to some technical restrictions. Herein, we present a summary of the most relevant conductivity measurement techniques of high and low concentrations. Additionally, a clear systematic and practical comparison between these techniques is made. Namely, the contacting and inductive conductivity measurements. We also highlight the main advantages and drawbacks of each techniques to allow researchers to have a clear understanding of the technical capabilities, limits and accuracy of each conductivity measurement technique.
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INTRODUCTION

Conductivity is the ability of a material to permit an electric current. In solutions, the current is carried by cations and anions. Electrical conductance is governed by several factors, namely, concentration, mobility of ions, valence of ions, and temperature [1]. Conductivity SI units are (Ω^{-1}. m^{-1}), otherwise called "Siemens" (S. m^{-1}). Solutions of ionic salts or of compounds that ionize in solution are often called "electrolytes" [2]. Ions formed in electrolytes carry the electric current in solution. Electrolytes might be strong or weak depending on the nature of cations and anions that make them up. Strong electrolytes dissociate completely in water. Upon imposing an electric field, ions of strong electrolyte can basically travel freely in aqueous solutions.

On the other hand, weak electrolytes do not fully dissociate in solution. For instance, acetic acid just partly dissociates into acetate ions and hydrogen ions. Hence, a solution of a weak electrolyte can conduct electricity, but only lower than strong electrolytes and that is mainly attributed to the partial dissociation of ions in solution [3-4].
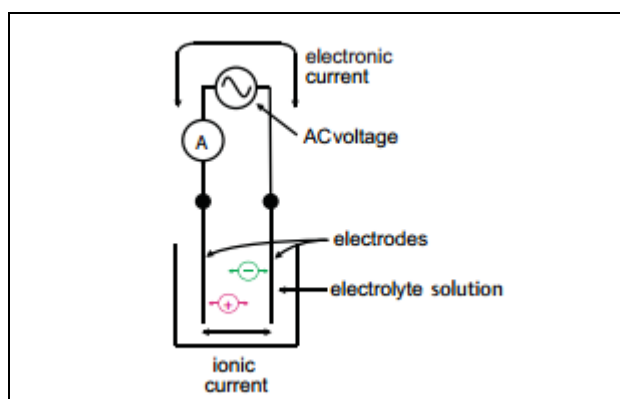
MEASUREMENT OF CONDUCTIVITY

In order to quantify the strength of electrolytes in aqueous solutions, the conductivity can be measured via implementing conductivity meters. Basically, There are two sorts of conductivity measurements: contacting and inductive. To specify which to use it depends mainly on the amount of conductivity, the corrosive strength of a liquid, and the amount of suspended solids. Generally speaking, the inductive method is highly recommended when the liquid is somehow corrosive in nature, the conductivity is relatively high, and there are some suspended solids exist in solution [5--10].

Contacting Conductivity

In general, the majority of conductivity sensors are composed of two metal electrodes, stainless steel or titanium, in contact with the electrolyte solution. See Figure 1. The analyzer applies an alternating voltage to the electrodes. The electric field causes the ions to move back and forth to generating a current. Because the charge carriers are ions, the current is called an ionic current. The analyzer measures the current using Ohm's law to calculate the resistance, and the reciprocal of resistance is equivalent to the conductivity.

The ionic current depends on the total concentration of ions in solution and on the length and area current flow (through solution). The current pathway is definite by the geometry of the sensor, or cell constant, which has units of cm^{-1}. Multiplying the conductance by the cell constant corrects for the effect of sensor geometry on the measurement. The result is the conductivity, which depends only on the concentration of ions.
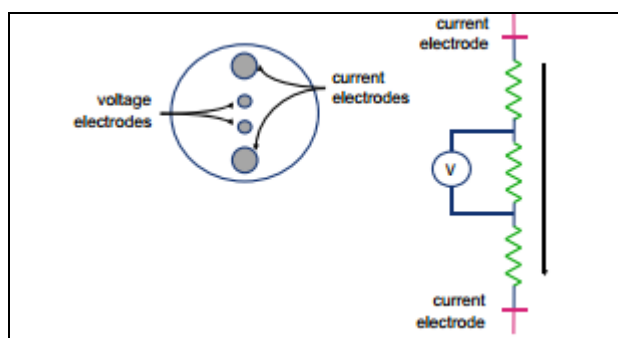

Figure 1: In the two electrode conductivity measurement the motion of ions in the electric field carries current through the solution. Coupling of the ionic and electronic current occurs at the interface between the metal electrode and the solution. The interface can be thought of as a capacitor with the metal electrode being one plate and the adjacent electrolyte being the other. The alternating voltage causes the capacitor to charge and discharge, allowing the current to cross the interface.

Despite the fact that the cell constant has a geometric understanding as mentioned earlier, it is seldom calculated from dimensional measurements. Most of designs the electric field is not restricted between the electrodes, so the realistic length and area are greater than the values from theoretical predictions. Practically speaking, the cell constant is measured against a solution of known conductivity. The cell constant is the ratio of the known conductivity (μS/cm) to the measured conductance (μS).

The usual conductivity range for a contacting sensor is 0.01 to 50,000 μS/cm. Because a given cell constant can be used only over a limited range, two, possibly three, cell constants are required to cover the entire range. Common cell constants are 0.01/cm, 0.10/cm, 1.0/cm, and 10/cm. higher conductivity samples require larger cell constants.

Cell constants change minimally during the life of the sensor. Yet, the cell constant should be regularly tested, and the sensor recalibrated if necessary.

Some contacting sensors have four electrodes as shown in figure 2. In in this case, the analyzer injects an alternating current through the exterior electrodes and measures the voltage through the interior electrodes. The analyzer consequently measures the conductance of the electrolyte solution from the current and voltage. Because the voltage measuring circuit draws very little current, charge transfer effects at the metal-liquid interface are actually marginal in four-electrode sensors. As a consequence, a single four-electrode sensor possess a considerably wider dynamic range than a two-electrode sensor, ca. 1 to 1,4000,000 μS/cm. Additionally, the four-electrode sensor has a cell constant, which depends on the area, spacing, and arrangement of the current and voltage electrodes. The cell constant is measured at the factory, and the user can setup the value in the analyzer at startup.


Figure 2: In the four electrode conductivity measurement, the analyzer injects current between the outer electrodes and measures the voltage drop caused by the resistance of the electrolyte between the inner electrodes.

Contacting conductivity measurements are very limited to applications where the conductivity is low (although four-electrode sensors have a higher end operating range). Two-electrode sensors are typical for measuring conductivity of high purity water in semiconductor, electricity generating, and pharmaceutical facilities.

Inductive Conductivity:

Inductive conductivity, otherwise called toroidal or electrodeless conductivity. An inductive sensor is composed of two wire-wound metal toroid wrapped in a plastic body. One toroid is the drive coil, the other is the receive coil. The sensor is dipped into a conductive solution. The analyzer applies an alternating voltage to the drive coil, which induces a voltage into the liquid in the vicinity of the coil. The voltage generates an ionic current to flow proportional to the conductance of the liquid. The ionic current induces an electric current in the receive coil, which the analyzer can measure. The induced current is proportional to the conductance of the solution. See Figure 3.
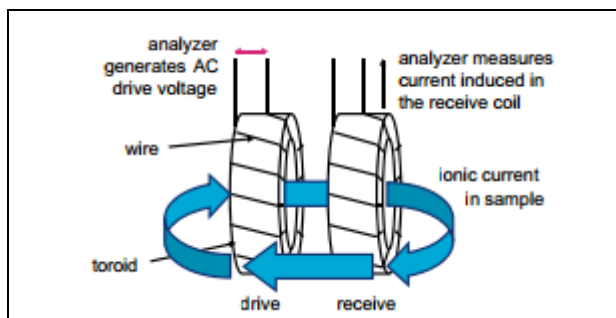
Figure 3: Both coils are encased in a single sensor body and over molded with plastic. The coils must be completely submerged in the process liquid.

The current in the receive coil depends on the number of windings in the drive and receive coils and the dimensions of the sensor, which describes the volume of sample through which the ionic current flows. The number of windings and the dimensions of the sensor are described by the cell constant. Similarly in the case of contacting sensors, the product of the cell constant and conductance is the conductivity.

The wall of the tank or pipe in which the sensor is installed also influence the cell constant—the so-called wall effect. A metal wall in the vicinity of the sensor boost the induced current which consequently increases conductance and decreases the cell constant. A plastic wall has an inverse effect, as wall effects vanish when the distance between the sensor and wall approaches three-fourths of the diameter of the sensor. See Figure 4.
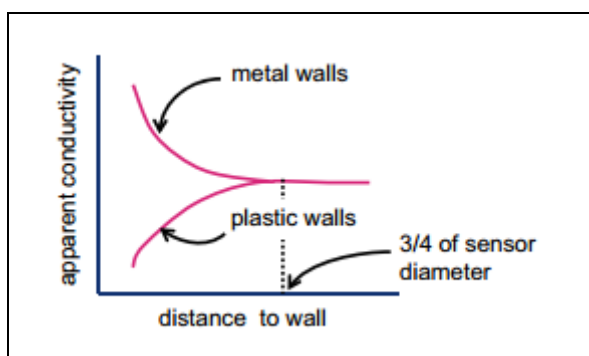
Figure 4: For typical sensors, wall affects disappear when the clearance between the sensor and wall is 1 − 1 ½ in (25 − 37 mm).

As a matter of fact, inductive measurement has few advantages. Firstly, the toroid does not need to touch the sample. So, they can be covered in plastic, to permit the sensor to be used in solutions that might corrode metal electrode sensors. Secondly, inductive sensors can endure high levels of fouling, and that is why they can be used in solutions containing high levels of suspended solids. As long as the fouling does not significantly change the area of the toroid opening, readings would be reasonably accurate. Conversely, even a light coating onto a contacting sensor may cause an error with measurement. Last but not least, inductive sensors are perfect for measuring conductivity of solutions of high conductivity.

Nonetheless, Inductive sensors might have some defects, e.g. they are very suited to be used for samples which have conductivity higher than ~15 µS/cm [11-14].

CONCLUSION

In this review, we presented a clear idea about measuring conductivity of various types of solutions depending on their corrosiveness, presence of some suspended solids, and their concentration. The two techniques which we discussed with elaboration explains the benefits and the defects of each one in terms of the accuracy, restrictions, and robustness. In electrochemistry, it is very useful to measure the conductivity.

However, there might be some difficulties with measuring conductivity owing to some technical restrictions. Herein, we present a summary of the most relevant conductivity measurement techniques of high and low concentrations. Additionally, a clear systematic and practical comparison between these techniques is made. Namely, the contacting and inductive conductivity measurements. We also highlight the main advantages and drawbacks of each techniques to allow researchers to have a clear understanding of the technical capabilities, limits and accuracy of each conductivity measurement technique.

CONCLUSIONS

To sum up, the review highlighted the common techniques for probing conductivity in different kinds of solutions depending on their chemical nature. It also covered almost all challenges that encounter technicians to measure the conductivity of a given solution with high precision and accuracy.

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REFERENCES

[1] Rosenthal R, and Kidder J, Beckman Instruments 1969; 26-27.
[2] Luo J, Hu J, Saak W, Beckhaus R, Wittstock G, Vankelecom I, Agert C, and Conrad O, Journal of Materials Chemistry 2011; 21: 10426–10436.
[3] Estevez J, Baquero E, Mora-Rodriguez R, Applied Physiology Nutrition and Metabolism 2008; 33: 290–298.
[4] Al Taay W, Salloom H, Ameer A, Ahmed A, Witwit N, and Yousif A, Journal of Chemical and Pharmaceutical Research 2015; 7: 513-521.
[5] Liu W, and Asheghi M, J. Heat Transfer 2006; 128: 75–83.
[6] Jang W, Chen Z, Bao W, Lau C, and Dames C, Nano Lett 2010; 10: 3909–3913.
[7] Zhang X, Xie H, Fujii M, Ago H, Takahashi K, Ikuta T, Abe H, and Shimizu T, Appl. Phys. Lett 2005; 86: 171912-171914.
[8] Brinkmann F, Dam N, Deák E, Durbiano F, Ferrara E, Főkő J, Jensen H, Máriássy M, Shreiner R, Spitzer P, Sudmeier U, Surdu M, Vyskočil L, Journal for Quality, Comparability and Reliability in Chemical Measurement, springer 2003; 8: 346–353.
[9] Lee H, Grossman C, Reed J, and Galli G, Appl. Phys. Lett 2007; 91: 223110-223111.
[10] Chung S, and Chiang Y, The Electrochemical Society 2003; 6: A278-A281.
[11] Luo J, Jensen A, Brooks N, Sniekers J, Knipper M, Aili D, Li Q, Vanroy B, Wübbenhorst M, Yan F, Meervelt L, Shao Z, Fang J, Luo Z, De Vos D, Binnemans K, and Fransaer J, Energy & Environmental Science 2015; 8: 1276-1291.
[12] Yousif E, Abdallh M, Hashim H, Salih N, Salimon J, Abdullah B, and Win Y, International Journal of Industrial Chemistry 2013; 4: 4-7.
[13] Oboudi S, Abdul Nabi M, Al-Taa'y W, Yusop R, Derawi D, Yousif E, Int. J. Electrochem. Sci 2015; 10: 1555 – 1562.
[14] Schwamb T, Burg B, Schirmer N, and Poulikakos D, Nanotechnology 2009; 20: 1- 5.