Using Correct Conductivity Temperature Compensation

by Lori L. McPherson

Conductivity measurements are normally used to interpret the quantity of ions contained in the solution. The temperature of the solution can have a large affect on the reading. Most conductivity instruments will "compensate" for this conductivity affect, allowing the reading to be standardized to an estimated value at 25° C. For water solutions, a temperature compensation factor, or coefficient of 2 percent per degree centigrade, is normally used. This compensation is reasonably accurate in accounting for the affect of temperature on the conductivity measurement. However, in solutions other than water the actual coefficient may be significantly different, and if not programmed correctly can result in very large measurement errors.

The Conductivity Measurement

The conductivity measurement is literally a measurement of the solution's ability to conduct electricity. It is directly affected by the number of dissolved ions in the solution. As the number of dissolved ions increases, the ability to conduct electricity also increases. The measurement value is generally considered to be a measurement of the actual number of ions contained in the sample, while in fact, this is only inferred.

The conductivity measurement unit is the inverse of the resistivity measurement. Resistivity measures the solution's ability to resist electrical current flow. This is measured in Ohms*cm. Therefore, conductivity is mhos/cm, with mhos being defined as Ohms^{-1}. This unit has been renamed by the International Standards Organization to be Siemen (S). However, both mhos/cm and S/cm are considered correct terms. In clean water (surface water, well water, etc.), the order of magnitude is in the range of 10^{-6} S/cm, or µS/cm.

The Affect of Temperature on Conductivity

The solution's ability to conduct electricity is related to the concentration and specific conductivity of the ions in the solution, and the temperature of the solution. Increased temperature provides increased activity or ionic movement that enables more electricity to be carried through the solution from one electrode to another.

In order to better correlate the electrical conductivity to the concentration of ions, the affect of temperature on the solution's ability to conduct electricity is subtracted from the actual conductivity. For example, a solution at 25° C may conduct 200 µS. This same solu-

Table 1. Temperature Coefficients of Solutions of Inorganic Electrolytes at 18° C[1,2]

Electrolyte	*Concentration (Wgt. percent)*	*Temperature Coefficient*
$AgNO_3$	5	.0218
	10	.0217
	20	.0212
	40	.0205
	80	.0209
HCl	5	.0158
	10	.0156
	20	.0154
	30	.0154
	40	.0152
HF	1.50	.0720
	4.80	.0666
	24.5	.0583
HNO_3	6.2	.0147
	12.4	.0142
	31.0	.0139
	62.0	.0157
H_2SO_4	10	.0128
	20	.0145
	40	.0178
	80	.0349
	90	.0295
	96	.0286
KCl	5	.0201
	10	.0188
	15	.0179
	20	.0168
$KHSO_4$	5	.0085
	10	.0086
	20	.0088
	27	.0093
NaCl	5	.0217
	10	.0214
	20	.0216
	25	.0227

[1] *Electrochemical Data: A Handbook for Electrochemists in Industry and Universities*, D. Dobos, Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York, 1975.

[2] Data presented is as published to a reference of 18° C. U.S. standard is to reference to 25° C.

tion at 35° C would conduct 240 µS. Since the primary purpose of the measurement is to correlate to the purity of the solution, the affect of temperature is subtracted (compensated), with a displayed, compensated value shown of 200 µS. This provides a means of standardizing the conductivity reading to the concentration of ions at 25° C.

Applications with Coefficients Different from Water

Many solutions other than water are effectively controlled using conductivity. Some of these include offset printing fountain solutions, water soluble lubricants used in metal machining and quenching solutions. Many of these solutions have been tested to determine their temperature coefficients, and have been found to have coefficients significantly different than the 2.0 percent per degree centigrade used for water solutions. If the coefficient used is incorrect, when the temperature of the solution changes, the conductivity value will be seen to change. However, in reality, the concentration in the solution remains the same.

Other solutions, such as acids or bases, can also have temperature coefficients significantly different than that of water. In many cases, each concentration range of a solution will have its own temperature coefficient. For example, 10 percent sulfuric acid will have a much different temperature coefficient than 50 percent, and those values will be different than sulfuric acid at 90 percent. To maintain the highest level of accuracy across temperature changes, it is recommended to check the temperature response of the solution, and program the instrument accordingly.

Applications that Should Not be Temperature Compensated

In some applications, the measurement of the true or actual electrical conductivity is important, without any standardization back to the conductivity level at 25° C. One example of this type of application is the salt solution used to shock poultry prior to processing. The salt content of this solution is monitored using conductivity, to ensure that it can carry sufficient current to effectively stun the chicken. In this case, the temperature compensation program should be deactivated (generally by introducing a coefficient of 0.0 per degree centigrade). This activity guarantees that the measurement is a true measurement of the electrical current the solution will pass, and the process will operate as needed.

A second example is the reionization of pure water to prevent carona discharge across high pressure nozzles. In the semiconductor industry, the water used in rinsing wafers must be free of any impurities. In this state, the water generally has a resistivity associated with it of 18.3 MΩ. Unfortunately, water this resistive can cause a static, or carona discharge when the water passes through a high pressure spray nozzle. This discharge, or sparking, can badly damage the water being washed. By re-ionizing the water with carbon dioxide, the water regains some ability to conduct electricity, without salt contamination, and the discharge is prevented. In this case, the electrical property of the solution is the important property, not its inference to the content of carbon dioxide. Therefore, temperature compensation should not be used for optimum process control.

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Depth filter

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Using Correct Conductivity...

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Determining the Temperature Coefficient

For many chemicals, the temperature coefficient may be obtained from published data such as that found in Table 1 from Dobos' *Electrochemical Data*. If the data is not available, it can be determined experimentally quite easily.

It is important to realize that the function of temperature compensation is to normalize the reading back to that which would occur at 25° C. This is the reference point for the determination of the temperature coefficient. In other words, the coefficient defines the change in conductivity per each degree centigrade change in temperature, from the reference or starting point of 25° C. Using water as an example, with a 2 percent per degree centigrade coefficient (TC = .02), the coefficient defines the conductivity increase as 2 percent of the reading at 25° C. A 1000 μS solution at 25° C would increase 20 μS in conductivity with each one degree centigrade temperature change. If the temperature range is 40 to 50° C, the relationship to temperature must be linearized back to give a conductivity reading at 25° C to establish a correct temperature coefficient. This is the basis for the calculation below for determining the coefficient from conductivity values at two different temperatures:

$$C1 = C_{25} * (1+(TC*(T1-25))$$

Using two data points at temperatures other than 25° C (for ease of experimentation), and solving the two equations for C_{25}, enables the determination of the TC to be simplified to the following equation:

$$TC = \frac{(C1-C2)}{C2\,(T1-25)-C1(T2-25)}$$

where C_{25} is the conductivity (reference) at 25° C, C1 is the conductivity at temperature T1, and C2 is the conductivity at temperature T2.

When obtaining values for C1 (@T1) and C2 (@T2), it is critical to disable any temperature compensation in the instrument. This is normally accomplished by setting the coefficient to 0.0 percent per degree C. Once this has been done, the readings taken at the two temperatures will be raw conductivity values, and can be used in the calculation. It is recommended that the two points used represent the maximum range of temperature for the application being tested. Furthermore, allowing time for the temperature to stabilize, and taking several readings for statistical averaging will greatly increase the accuracy of this determination.

Non-linear Temperature Compensation

In some situations, temperature compensation does not follow a clean, linear relationship as defined above. The most common of these applications is pure water, in the resistivity range of 1 to 18.3 MΩ*cm. For this application, resistivity instruments are pre-programmed for the exponential response to temperature that can occur. A linear compensation program would be highly inaccurate for this application, especially in temperatures below 25° C.

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