

## Understanding Low Conductivity / High Resistivity Measurements

There are a growing number of laboratory and industrial processes that require low-conductivity / high-resistivity water. Maintaining high-purity water is crucial for many of these applications, yet many assigned with the task of monitoring their water fail to grasp the challenges involved. In order to verify acceptable water quality levels, it is important to gain an understanding of the measuring principles involved and to select the right instrumentation for the job.

Conductivity and resistivity are both measures of the ability of a fluid to conduct electrical current. Conductivity is simply the reciprocal of resistivity:  $\text{conductivity} = 1/\text{resistivity}$  (See Table 1). In practice, conductivity units are typically used when referring to water ranging from drinking water to sea water, while resistivity units are reserved for ultra pure water such as deionized or reverse-osmosis water.

**Table 1**

Conductivity	Resistivity
0.01 uS	100 MΩ
0.055 uS	18.0 MΩ
0.1 uS	10 MΩ
1 uS	1 MΩ
10 uS	0.1 MΩ
100 uS	0.01 MΩ
1 mS	1 kΩ

The unit of conductivity is the Siemen (S). A millisiemen (mS) = 1/1,000 S, a microsiemen (uS) = 1/1,000,000 S. Conductivity is also referred to as electrical conductivity (EC) or specific conductance.

Resistivity units are expressed in Ohms (Ω). A kilohm (kΩ) = 1,000Ω, a megaohm (MΩ) = 1,000,000Ω.

Since conductivity and resistivity relate to an area between which current is measured it is common to see the units expressed per volume such as MΩ-cm or uS-cm or umhos-cm. Few realize that “mho” is ohm spelled backwards to indicate the reverse relationship to Ohm’s law! A “mho” is equivalent to a Siemen and is used interchangeably.

**TEMPERATURE COMPENSATION AND COEFFICIENT:** *“I don’t care about the temperature, I just want to measure conductivity”*

Conductivity is greatly influenced by temperature. Most fluids increase in conductivity as temperature increases. Most ionic solutions will increase about 2% for each 1°C increase. Unfortunately, this temperature coefficient (TC) is not linear. In the case of high resistance water it can be closer to 5% or so per °C.

Many instruments adjust the conductivity value based on a TC and display a value that is said to be corrected or normalized to 25°C. The meter will automatically make corrections to the reading and display a value as if the sample was 25°C, no matter what the actual temperature is. Some instruments use a fixed TC of 2.0% per °C. Let us consider a meter that uses 2.0% TC to measure a 1413uS standard at 25°C (77°F). If the standard is warmed to 30°C (86°F), the meter applies a correction of 5 degrees x 0.02% x 1413uS = 141.3. Without correction (0.0% TC) the actual value of a 1413uS standard of KCl at 30°C(86°F) is 1548uS. As the meter corrects for temperature, it displays a value of 1548 minus 141.3 = 1407uS. When the sample cools to 25°C, it will again read 1413uS as no correction is applied. Although conductivity cell response is immediate, temperature corrected values will fluctuate as the temperature measurement stabilizes.

Advanced meters offer adjustable TCs, usually from 0.0% to as much as 10% per °C. This is a beneficial feature for two reasons. First, by adjusting the coefficient to zero, non-compensated measurements can be recorded. This eliminates the possibility of using an incorrect TC. Methods such as United States Pharmacopeia 23 specifically call for non-compensated measurements. Second, by using a TC of zero, the ideal TC for a sample can be determined by performing tests of the conductivity values at various temperatures. Once the TC of the sample fluid is established, it can be entered into the meter for automatic temperature correction.

TC labels on conductivity calibration standards often provide a temperature table listing conductivity values at different temperatures. Conductivity meters with a fixed TC should be calibrated to the conductivity value at the meters normalization temperature, usually 25°C. Calibration to values other than the normalization temperature would only be appropriate if the meter did not utilize temperature correction, or if the TC was adjusted to 0.0%. As a general rule it is

always best to calibrate and measure as close to 25°C as possible when a TC is applied. Recording the temperature during calibration and measurement is good practice.

Another feature of advanced meters is a selectable normalization temperature. This allows temperature compensated readings to be adjusted either to 25°C (77°F) or another value, usually 20°C (68°F). The advantage here is that 20°C (68°F) is often closer to the actual sample temperatures than 25°C (77°F). When using a normalization temperature other than 25°C it is important to calibrate to the appropriate value of the conductivity standard at the specified normalization temperature. For example, a 1413uS standard at 25°C should be calibrated to its value at 20°C which is 1278uS.

While emphasis is given to the conductivity accuracy, it is important not to neglect the temperature accuracy. Although temperature is directly related to conductivity measurement it is often overlooked. Meter temperature accuracy should be verified and calibrated if necessary prior to conductivity calibration.

**CELL CONSTANT & CELL SELECTION:** *“I thought I had a 1.0 cell-- it keeps changing each time I recalibrate”*

It's best to think of cell constant as the "cell efficiency". It's a factor that the meter uses to make the standard value agree with the measured value. Conductivity cells are offered with nominal values such as k=1.0. In reality, the effective cell constant may deviate several percent of the nominal value and is determined only after calibration. A nominal 1.0 cell may have a 0.97 constant after calibration and correction by the meter which had to make a 3% correction to the calibration value. Each time the meter and cell are recalibrated, this cell efficiency may change. A cell can change slowly over time from physical changes taking place such as chemical oxidization, scratches, coating, bending, stripping, etc.

It's important to choose a cell constant based on the anticipated measuring range (see table below). If a cell constant other than 1.0 is required, a meter with a selectable cell constant will be necessary.

Cell Constant	Optimal Range
0.01 uS	<1 uS
0.1 uS	0.5 to 200 uS
1.0	10 to 2,000 uS
10	1 to 200 mS

It is also necessary to choose between a 2-cell or a 4-cell. Skipping much of theory, 4-cells are more expensive but considered better as they resist polarization effects and fouling, however for clean water applications, this advantage may be small.

**LOW CONDUCTIVITY/HIGH RESISTIVITY STANDARDS:** *“Don't you have anything lower? I need a liquid standard that is less than 1 microsiemen”*

High resistivity calibration standards are not commercially feasible. Precision resistors can be used in place of the conductivity/resistivity probe to verify response and accuracy meter, but this practice will not account for differences in efficiency of the sensing cells or bands in individual probes.

Conductivity standards in the 10 to 100 uS range are available commercially. Prolonged exposure to air as well as contamination from glassware and the cell itself can significantly increase the value of your standard. Individual single-use pouches are often preferred over bottled standards, as they do not have to be poured into a sample container and are not subject to contamination thru reuse. It is vital to maintain a clean cell at all times and use good laboratory techniques for accurate and reproducible results.

**CONDUCTIVITY vs TDS:** *“I have no idea what the conductivity level is, but I know my TDS is about 15 ppm. What factor should I use?”*

Meters that use total dissolved (ionic) solids (TDS) measure conductivity and multiply the reading by a fixed or adjustable “TDS factor” to determine TDS. TDS values are usually expressed as parts per million (ppm) or ppt (parts per thousand). There are many limitations when using TDS. First, the TDS factor used is salt specific so if there are multiple or unknown salts in solution, its nearly impossible to determine the correct factor to use. Second, since ionic concentrations are not linear, the TDS factor changes with concentration. TDS values are generally not considered with low conductivity values.