

Conductivity/TDS Meters Introduction

Definition of Conductivity

Electrical Conductivity is the ability of a solution to conduct an electrical current. Current flow in liquids carried by ions is different from metals, where is carried by free electrons. Ions are formed when a solid such as salt is dissolved in a liquid to form electrical components having opposite electrical charges. The sodium chloride separates to form Na^+ and Cl^- ions. All ions present in the solutions contribute to the current flowing through the sensor and therefore, contribute to the conductivity measurement. Conductivity can be used as a measure of the concentration of ions present in the sample.

Conductivity Units

Electrical conductivity is the reciprocal of electrical resistivity. Electrical resistivity uses the unit of ohm meter or $\Omega \times \text{m}$. Rather than use the units $\Omega^{-1} \times \text{m}^{-1}$, in 1971 the unit "Siemens" (symbolized by the capital letter S) was adopted by the General Conference on Weights and Measures as an SI derived unit.

The unit for electrical conductivity becomes siemens per meter. The siemens unit is named after Werner von Siemens, the 19th century German inventor and entrepreneur in the area of electrical engineering. Previously to the siemens per meter unit, mho/cm was used to measure conductivity, where the unit "mho" is a reciprocal ohm. The "mho" is the "ohm" spelled backwards. Because of the history of conductivity, micromho/cm and millimho/cm is commonly translated to microsiemens/cm and millisiemens/cm because they correspond one-to-one.

The unit of measurement commonly used is one millionth of a Siemens per centimeter (micro-Siemens per centimeter or $\mu\text{S}/\text{cm}$). When measuring more concentrated solutions, the units are expressed as milli-Siemens/cm (mS/cm). For ease of expression, 1000 $\mu\text{S}/\text{cm}$ are equal to 1 mS/cm . Often times conductivity is expressed simply as either micro or milli Siemens.

Table of Aqueous Conductivity/TDS/Resistivity

Solution	$\mu\text{S}/\text{cm}$	mS/cm	ppm	$\text{M}\Omega \times \text{cm}$
Pure water	0.055			18.18
Typical DI water	0.1			10
Distilled water	0.5			2
Rain water	50-100		25-50	0.02 - 0.01
Drinking water	500-800	0.5-0.8	250-400	2.0-1.25 [$\text{K}\Omega \times \text{cm}$]
Potable water (max)	1 055	1.055	528	0.95 [$\text{K}\Omega \times \text{cm}$]
Sea water	56 000	56	28 000	
1 mol/L NaCl	85 000	85	42.5 [ppt]	
1 mol/L HCl	332 000	332	166 [ppt]	

TDS

Total dissolved solids (TDS) is a gravimetric measurement, but because the solids in a solution are predominately present in ionic form, they can be approximated with conductivity. The TDS scale uses $2 \mu\text{S}/\text{cm} = 1 \text{ ppm}$ (part per million as CaCO_3), expressed as 1 mg/L TDS. The method of measurement is the same, the conductivity meters make the conversion and express the results of a measurement in TDS units.

Resistivity

For low and very low ionic concentration, the measured conductivity becomes difficult and not accurate. Therefore, the resistivity scale is used to express the results as opposed to fractions. The numbers are exactly the inverse of each other. The reciprocal of $0.10 \mu\text{S}/\text{cm}$ or $1/(0.10 \times 10^{-6} \text{ S}/\text{cm})$ is then $10 \times 10^6 \text{ ohms} \times \text{cm}$ ($10 \text{ M}\Omega \times \text{cm}$). This is also commonly referred to as "mega-ohms". Either unit of measurement can be used to state exactly the same value.

Salinity

Salinity is a measurement without the unit corresponding to the weight of dissolved salts in seawater. The salinity is calculated from an empirical relationship between the conductivity and the salinity of a seawater sample. Oceanographic Tables and Standards endorsed by UNESCO/SCOR/ICES/IAPSO are used for the calculation.

Salinity measurements are performed with no direct temperature correction. The salinity range is calibrated using a standard sea water solution.

Temperature effect

Conductivity is temperature sensitive as ionic activity increases with increasing temperature. Commonly, conductivity is referred to 25°C such as in the reference temperature of some standards. The coefficient used to correct for changes in temperature, β is expressed as a percentage of reading per degree Celsius. In order to establish the true value of beta, the solution is measured at high temperature (without temperature compensation = actual conductivity), then the solution is cooled and re-measured. β can then be calculated for that solution. HANNA conductivity meters allow for custom reference temperatures and adjustable β temperature correction factor. The β temperature correction factor can be in the following ranges according with the solution class: Acids: $(1.0 \div 1.6\%)/^\circ\text{C}$; Bases: $(1.8 \div 2.2\%)/^\circ\text{C}$; Salts: $(2.2 \div 3.0\%)/^\circ\text{C}$; Drinking water: $2.0\%)/^\circ\text{C}$; Ultrapure water: $5.2\%)/^\circ\text{C}$.

In the case of natural water, the temperature correction is no longer linear, in this case, a non linear characteristic has to be used. Many HANNA meters offer the ability to apply this temperature correction curve.

Amperometric

The first solution to measure conductivity was originally an amperometric probe based on two electrodes at a distance of 1 cm. The amperometric method applies a known potential (voltage, V) to

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the pair of electrodes and measures the current (I) that is established in the solution. Current is proportional with the conductivity. Construction for these types of probes can use either graphite or stainless steel pin electrodes. HANNA offers probes and instruments using either constructed solutions. The resistance can be precisely calculated but is not constant, the major perturbation is generated by the deposits and polarization effect that appear on the electrodes based on the electrolysis effect which appears in the solution during the measurements. For low to medium levels of conductivity ($< 2 \text{ mS/cm}$) the effect is not significant and this may be acceptable if the voltage that is applied is alternated. For higher values the accuracy of reading will be affected, and in this case, the potentiometric method is recommended.

Potentiometric

The potentiometric method employs four rings: two outer rings apply an alternating voltage and induce a current loop in the solution, while the remaining inner rings measure the voltage drop induced by the current loop. The voltage drop measured is directly dependent to solution conductivity. All of the probes utilize a sleeve during the measurement to control the influence of the external elements over the inducted field. The range in which these kinds of probes can be used is higher than the limits imposed to the amperometric methods by the electrolysis effect. Stainless steel or platinum rings can be used in the construction of this type of probe. HANNA offers both solutions for these types of probes. The selection has to be chosen based on criteria in which the resistance to corrosion and cleaning are important factors.

Inductive or Toroidal

For industrial process control systems, another method of conductivity measurement is available using an inductive or toroidal sensor. The advantage of this technology is measurement without any electrical contact between the electrode and the process fluid. The probe uses two toroidal transformers which are inductively coupled side by side and encased in a plastic sheath.

The controller supplies a high frequency reference voltage to the first toroid or drive coil which generates a strong magnetic field. The liquid containing conductive ions close the magnetic field that induces in the second toroidal current. A clear relation between the measured current and the conductivity of solution in which the probe is immersed can be established. The magnetic field is not disturbed if a minimum distance from the wall or pipe is respected.

Calibration

The calibration of conductivity meters is performed using a conductivity standard, by example $1413 \mu\text{S/cm}$. The scope of the calibration is to determine the precise value of cell constant of the probe. The meters allow the user to select from a range of pre-selected standard values according with the range where solution will be measured and expected to be. Many HANNA meters allow up to five point calibration for improved accuracy over a wider range of measured values. It is recommended to calibrate the probes a minimum of one time per week.

US Pharmacopoeia

USP <645> with Stage 1, 2 and 3 compliance is required for purified water and WFI (water for injection). HANNA offers instruments that are able to perform all three stages required by this standard. Some of these requirements are: Resolution of $0.1 \mu\text{S/cm}$ or better, accuracy at $1.3 \mu\text{S/cm}$ of $0.1 \mu\text{S/cm}$, to be able to read with or without automatic temperature compensation, the cell constant be known with an uncertainty better than $\pm 2\%$.

Conductivity partly depends on other factors such as the pH, the temperature, and the amount of atmospheric carbon dioxide which has been dissolved in the water to form ions (intrinsic conductivity). Conductivity also depends on the chloride, sodium and ammonium ions considered as water impurities (extraneous conductivity). The conductivity (intrinsic and extraneous) of the water is measured and compared to values listed in a table to evaluate if the studied water is suitable or not for use in pharmaceutical applications. If the sample fails Stage 1, additional tests have to be performed (Stages 2 and 3) in order to determine if the excessive conductivity value is due to intrinsic factors or extraneous ions.



HI 4321

Research Grade Conductivity/TDS/ Resistivity/Salinity/Temperature Meter with USP <645>

HI 4321 is a research-grade EC/Resistivity/TDS/Salinity benchtop meter with a large, color, graphic LCD with backlight capable of millesimal measuring resolution of conductivity with an extended range from $0.001 \mu\text{S/cm}$ to 1 S/cm .

HI 4321 can be used to perform all 3 stages of USP <645> method required for conductivity measurement of pure and ultra pure water. The instrument provides clear directions on how to perform each testing stage and automatically monitors the temperature, conductivity and stability during testing and determines whether a sample is within USP limits.