

What is TDS?

by Randy Holmes-Farley

The use of "TDS" (total dissolved solids) meters for analyzing the purity of fresh water has become widespread in recent years. Many aquarists use them to determine if tap water purification systems such as reverse osmosis (RO) or reverse osmosis/deionization (RO/DI) are working properly, or if deionizing resins need to be replaced.

The use of such devices, however, is not without complications. Contrary to what the name might imply, for example, these devices do not measure all dissolved solids. There are also many different units of measure used with TDS meters. While all are referred to as ppm (parts per million), they are still different, just as degrees Celsius are different than degrees Fahrenheit.

This article describes how these meters work, what they detect and do not detect, and what the units mean. It also gives some tips on how to best use them.

How a TDS Meter Works

TDS meters are, in reality, conductivity meters. They work by applying a voltage between two or more electrodes. Positively charged ions (e.g., sodium, Na⁺; calcium, Ca⁺⁺; magnesium, Mg⁺⁺; hydrogen ion, H⁺; etc.) will move toward the negatively charged electrode, and negatively charged ions (e.g., chloride, Cl⁻; sulfate, SO₄⁻; bicarbonate, HCO₃⁻; etc.) will move toward the positively charged electrode (Figure 1). Because these ions are charged and moving, they constitute an electrical current. The meter then monitors how much current is passing between the electrodes as a gauge of how many ions are in solution. A detailed article from a high-end meter manufacturer on the theory of conductivity measurement can be found [here](#).

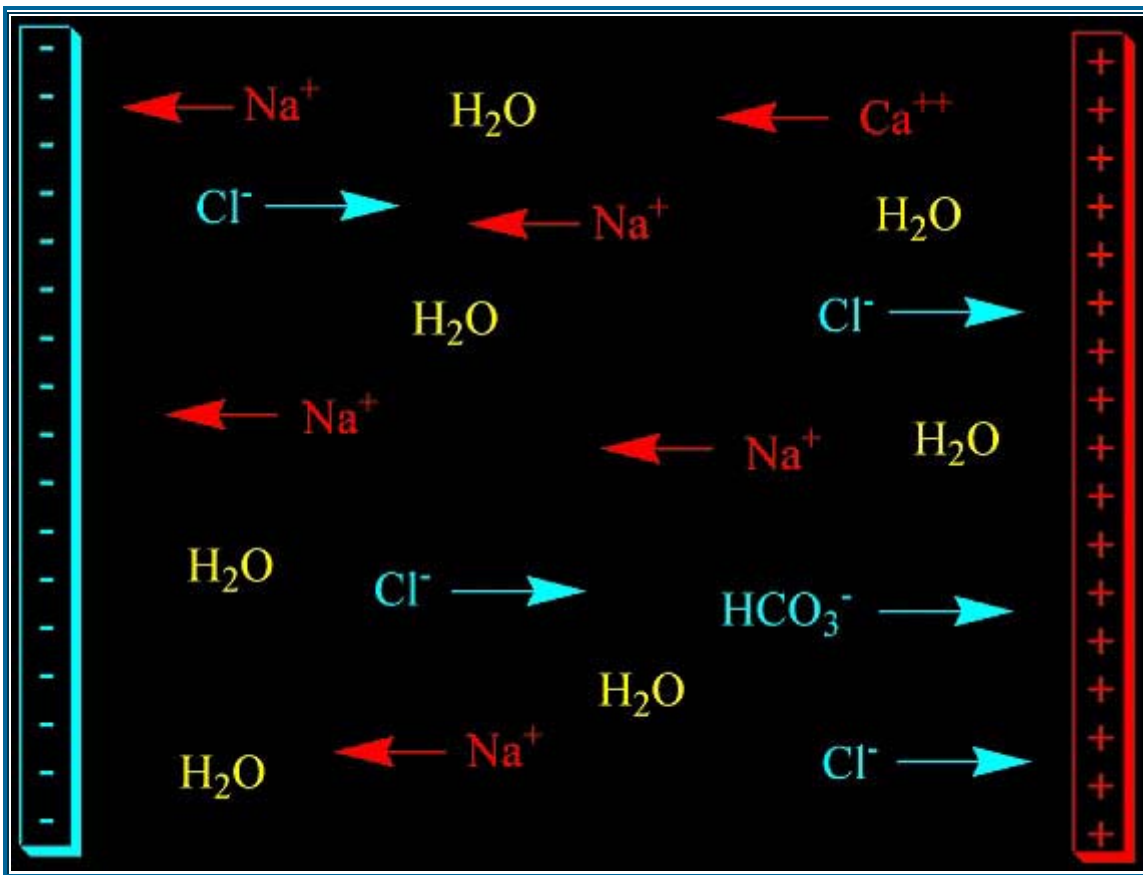


Figure 1. Schematic of a conductivity electrode, showing negatively-charged anions (blue) moving toward the positively charged electrode, positively-charged cations (red) moving toward the negatively charged electrode, and neutral molecules (yellow) not moving at all.

What Does a TDS Meter Actually Detect?

Since TDS meters are often used to test water "purity," it is important to understand what they do not detect. As conductivity meters in disguise, TDS meters will only detect mobile charged ions. They will not detect any neutral (uncharged) compounds. Such compounds include sugar, alcohol, many organics (including many pesticides and their residues), and unionized forms of silica, ammonia, and carbon dioxide. These meters also do not detect macroscopic particulates, as those are too large to move in the electric fields applied. So if you see "rusty" looking water from iron oxide particulates, that won't be measured. Neither will anything else that makes the water look cloudy. Bacteria and viruses also won't be detected.

Consequently, the term "total dissolved solids" is really quite a misnomer. "Total charged ions" is likely a much better term for what it measures. Fortunately, a measurement of total charged ions is good enough for many aquarium purposes.

In addition to how many ions are present, the measured conductivity of a solution is also a function of what ions are actually present. Table 1 shows the relative

water. There are differences between the conductivity of the different ions, and this fact becomes important in the discussion of the units that are used for conductivity in subsequent sections.

Ions with higher charges tend to have higher conductivity because they not only carry more charge but they respond more strongly to an electric field. Good examples of this are sulfate (SO_4^-) and calcium (Ca^{++}), which have higher conductivities than sodium (Na^+) or chloride (Cl^-). Another effect is that larger ions tend to have more "drag" as they move through the water, and thus have lower conductivity. In such comparisons one needs to take into account the tightly bound water molecules that get dragged along as well, so one cannot simply look at molecular weights or ionic radii. This drag due to the size of the hydrated ion is, for example, why lithium (Li^+) is so much less conductive than sodium, which in turn is less conductive than potassium (K^+).

Table 1. Relative conductivity of various ions.

Cations:	Relative Conductivity:	Anions:	Relative Conductivity:
H^+	7.0	OH^-	4.0
Li^+	0.8	Cl^-	1.5
Na^+	1.0	Br^-	1.6
K^+	1.5	I^-	1.5
Mg^{++}	2.1	NO_3^-	1.4
Ca^{++}	2.4	acetate	0.8
Zn^{++}	2.1	SO_4^{--}	3.2

"Can I Just Use a Multimeter to Measure Conductivity?"

No. Several factors make it impossible to accurately measure conductivity with a standard multimeter. The size and shape of the electrodes are significant, but more important is what happens at those electrodes. If a DC current is applied to seawater, numerous reactions take place when the ions hit the electrodes. Some ions will plate out on the electrodes, some may bubble off as gases, and the electrodes themselves may dissolve. These and other effects all serve to change the nature of the solution at the electrode, impacting the measured conductivity.

So how do conductivity probes get around this problem? They use an AC current rather than DC. Using fields that oscillate very rapidly, there is no overall movement of ions toward one electrode or the other. The ions move one way for a tiny fraction of a second, and then back the other direction for the second half of the cycle. Overall, the solution and electrodes stay unchanged and the conductivity is accurately measured. Modern conductivity meters use complex AC waveforms to minimize additional complications such as capacitance, which can interfere with simple conductivity measurements.

In practice, commercial conductivity probes have either two or four electrodes,

that can cause degradation of the measurement. The electrodes are made of nonreactive materials such as epoxy/graphite, glass/platinum or stainless steel. The choice depends primarily on the nature of the solution to be tested, but nearly any commercial unit will be suitable for tap water.

Does Temperature Impact TDS Measurements?

One final complication is that the conductivity of ions in water depends upon temperature. There are a number of factors that cause this effect, but one big one is simply that the ions are naturally moving around faster as they get warmer. When the same numbers of ions are moving faster, the apparent conductivity is increased. The relationship between conductivity and temperature is complicated and dependent on the solution being tested.

Pure water responds fairly linearly with temperature, with its conductivity rising by 4.55% for every degree centigrade (2.5% per degree Fahrenheit). Sodium chloride solutions have a smaller change, about 2.12% per degree centigrade. Tap and other natural waters have many different ions in them, and such systems sometimes respond nonlinearly with temperature changes, but not typically to as great of an extent as does pure water.

For this reason, nearly all conductivity meters simultaneously measure the conductivity and the temperature. The internal electronics then take the temperature into account, and normally provide a value that is "corrected" to what the conductivity would be at a standard temperature (25°C). Some use a fixed correction (for example, one manufacturer uses 2.1% per degree centigrade, another uses 1.9% per degree centigrade). More expensive units often allow the user to select the temperature coefficient (I'd use about 2-3% per degree centigrade for tap water). Others even allow nonlinear corrections to be used. If your meter allows that, I'd pick that option as it is likely a fixed correction that is optimized for fresh water systems (often called nLF). Some very advanced meters also allow nonlinear correction for ultrapure water. If your meter uses either of these nonlinear corrections, it will clearly say so in the provided manual.

In short, since conductivity meters typically correct for temperature changes, the conductivity of the water sample can be measured regardless of the temperature of the sample.

What Do the Units "ppm" Mean?

The units of measurement that TDS meters use are even more confusing than the name TDS. Conductivity meters (including TDS meters) always work by first measuring conductivity. Conductivity in solutions always has units that relate to resistance. Often those units are $\mu\text{S}/\text{cm}$ (microsiemens per centimeter), but for solutions with higher conductivity, mS/cm (millisiemens per centimeter) is typically used (for example, normal seawater has a conductivity of about 53 mS/cm). For reference, the conductivity of totally pure water is 0.055 $\mu\text{S}/\text{cm}$.

[[**Aside:** Often the purity of very pure water is presented in units of resistance, or

Mohms (megaohms). In that case, totally pure water has a resistance of 18 Mohms, which is just $1/\text{conductivity}$ in $\mu\text{S}/\text{cm}$. Also, for curiosity, the highest known conductivity of an aqueous solution is that for 31% nitric acid, at 865 mS/cm.]]

Unfortunately, TDS meters do not typically provide a result in unambiguous conductivity units. They internally convert their conductivity measurement into a different unit: parts per million or ppm. Parts per million is the same as mg/kg. So these devices are somehow converting the conductivity unit into a weight based unit. The problem is that different users and different devices can define that conversion differently.

If you choose a meter that reads in mS/cm, then all of the concern about ppm units that is described below can be eliminated. The **Pinpoint Conductivity meter** is such a unit (Figure 2). Some devices allow either unit to be displayed, although these are usually more expensive, such as the **Oakton Con 200** (Figure 3).



Figure 2. The Pinpoint conductivity meter.

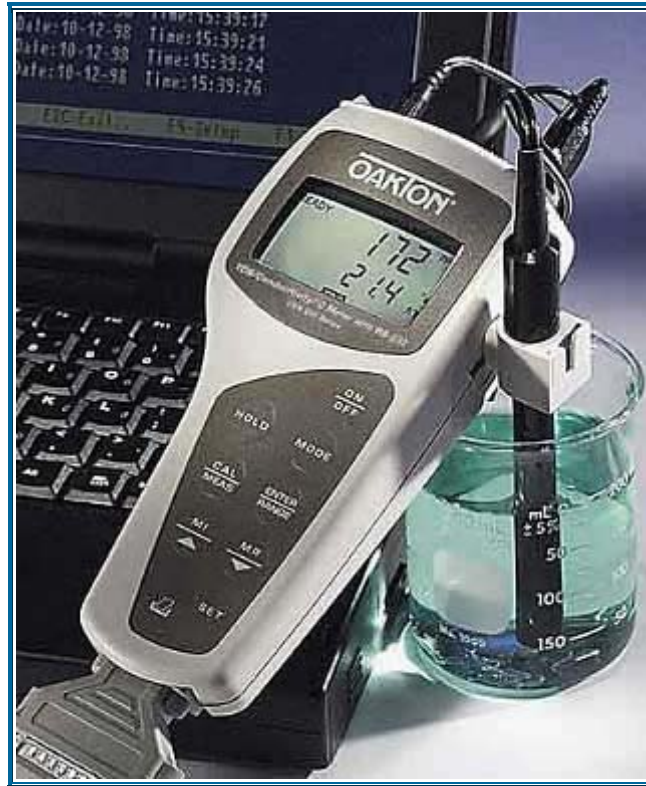


Figure 3. The Oakton Con 200 conductivity meter.

True TDS meters (that only give output in TDS units, such as the **Oakton TDS Tester** shown in Figure 4) typically convert the conductivity reading into the ppm concentration of some salt that would give the same measured conductivity. For example, it might be set to give as its output the concentration of sodium chloride (NaCl) that would give that same conductivity. So if the device detected $447 \mu\text{S}/\text{cm}$, it might display that as 215.5 ppm, as that is the concentration of sodium chloride that gives that same conductivity.



Figure 4. The Oakton TDS Tester.

Unfortunately, there is no single exact conversion between conductivity and ppm NaCl as the conductivity of a sodium chloride solution is not linear with concentration (that is, 20 ppm NaCl is slightly less conductive than twice that of 10 ppm NaCl, the reasons for which are beyond this article, but in a sense, the more ions there are in solution, the more they interfere with each other in terms of sensing the voltage, and in terms of moving in response to it). Nevertheless, for values in the range sensed by most TDS meters, a rough conversion is that 1 ppm NaCl = 2.1 $\mu\text{S}/\text{cm}$.

Now the fun really begins. The problem with such devices, at least when not carefully calibrated, is that it is not clear whether it is referring to ppm of sodium chloride equivalents, or to something else. **Potassium chloride** (KCl) is actually used as the standard more often than sodium chloride. Additionally, researchers often use something called **442**, which is a mixture of sodium sulfate (40%), sodium bicarbonate (40%) and sodium chloride (20%). The 442 mixture is designed to mimic the ions often present in natural fresh water systems.

These systems all have slightly different relationships between concentration (in ppm) and conductivity (in $\mu\text{S}/\text{cm}$). Table 2 shows this relationship for some commercial conductivity standards made by **Oakton**. For many aquarium purposes, it may make little difference whether the true value corresponds to 10 ppm NaCl or 10 ppm 442, but there is a 30-70% difference in the measured conductivity and hence in the total ions present. **Consequently, two aquarists using different meters (which may use different standards) may get substantially different results on the same water.** Of course, if you calibrate the meter yourself (if that is possible, not all meters can be calibrated), instead of accepting a factory calibration, then you eliminate this concern since

you know exactly what you calibrated with.

Table 2. Conductivity and ppm values for various commercial standards made by Oakton.				
Model # (bottles)	Conductivity (µS/cm)	TDS ppm KCl	TDS ppm NaCl	TDS ppm 442
WD-00653-23	23	11.6	10.7	14.74
WD-00653-16	84	40.38	38.04	50.50
WD-00653-47	447	225.6	215.5	300.0
WD-00653-18	1413	744.7	702.1	1000
WD-00653-15	1500	757.1	737.1	1050
WD-00653-27	2070	1045	1041	1500
WD-00653-20	2764	1382	1414.8	2062.7
WD-00653-89	8974	5101	4487	7608
WD-00606-10	12,880	7447	7230	11,367
WD-00653-50	15,000	8759	8532	13,455
WD-00653-32	80,000	52,168	48,384	79,688
Model # (pouches)				
WD-35653-09	10	4.7	4.8	7.0
WD-35653-10	447	225.6	215.5	300.0
WD-35653-11	1413	744.7	702.1	1000
WD-35653-12	2764	1382	1414.8	2062.7
WD-35653-13	15,000	8759	8532	13,455

Tips for Using TDS Meters

1. Always rinse the business end of TDS and conductivity meters before and after each use with as clean fresh water as you have available. The buildup of salts will interfere with proper operation, and the carryover of salts from one solution to another can skew the readings.
2. Do not touch or otherwise abrade the electrode surfaces, except with a soft, nonabrasive cloth.
3. Clean the electrodes, when necessary, by soaking the tip in acid (e.g., vinegar or diluted hydrochloric acid (muriatic acid)) and then rinsing well in water. If it is heavily fouled with organic material, soaking the tip in alcohol or bleach may help. Gentle wiping with a soft, nonabrasive cloth may also be acceptable.
4. If you care what the exact readings mean, be sure to calibrate the meter using a commercial standard. Some meters may require an exact standard, or any of several standards with a preset value, so get the meter first and see what you need. One standard is adequate. If all you care about is whether the reading is zero or not (for testing water purification systems), then calibration may not be

important.

5. Nearly all conductivity (TDS) meters have automatic temperature compensation over the range from 0 to 50°C. Even the least expensive units usually do this. If for some reason yours does not, the standard temperature for taking readings is 25°C. Just be aware that readings in cooler temperatures will be artificially low if it is not corrected (about 2-4% per degree centigrade).

6. Only very expensive meters have cell constant adjustment. The "cell constant" is another word for calibration, but is somewhat more sophisticated as some units allow you to use different electrode assemblies optimized for different types of solutions. For example, some are optimized for low, medium, or high conductivities in the solutions to be tested. The meter would have to know what kind of electrode assembly it was attached to, if it were allowed to be changed. Most TDS meters will not permit this change.

7. If you are using a TDS or conductivity meter to monitor the performance of an RO membrane, then the measured value should drop by at least a factor of 10 from the starting tap water. So, for example, if the tap water reads 231 ppm, then the RO water should be less than 23 ppm. In many cases, it will drop much more than that. Less of a drop than a factor of 10 indicates a problem with the RO membrane.

8. If you are using a TDS or conductivity meter to monitor the performance of an RO/DI system, then the measured value should drop to near zero. Maybe 0-1 ppm. Higher values indicate that something is not functioning properly, or that the DI resin is becoming saturated and needs replacement. However, that does not necessarily mean that 2 ppm water is not OK to use. But beware that it may begin to rise fairly sharply when the resin becomes saturated. Do not agonize over 1 ppm vs. zero ppm. While pure water has a TDS well below 1 ppm, uncertainties from carbon dioxide in the air (which gets into the water and ionizes to provide some conductivity) and the TDS meter itself may yield results of 1 or 2 ppm even from pure water.

9. If you are using a TDS or conductivity meter to monitor the saturation of limewater, then it will have to be able to read as high as 10.5 mS/cm (about 9300 ppm of 442 equivalents). This [linked article](#) describes how that is done.

10. If you are using a TDS or conductivity meter to monitor the salinity of a marine aquarium, you will have to be able to read up to about 53 mS/cm (about 53,000 ppm of 442 equivalents). I do not suggest trying to determine salinity from diluted samples, as the conductivity of seawater does not drop linearly with dilution.

11. You can measure the TDS of a water sample in any way that is convenient given the water and the meter being used. The primary consideration is that the entire electrode assembly must be submerged in the sample without a lot of bubbles or solids present between the electrodes. So, for example, you cannot

often gets between the electrodes that way (resulting in an artificially low reading).

I hope this information proves useful in using your TDS meter successfully!

Happy Reefing!