AQUALAB

Best Water Activity Meters 2023

The Definitive Guide

WHO MAKES THE BEST WATER ACTIVITY METER?

Some people measure water activity because they have to. They’re simply looking for a number to write down – any number. Those people should head straight for Amazon, pay their $600, and pray that no one gets sick.

But if you’re a food, pharmaceutical, or personal care product manufacturer that takes safety seriously, a highly accurate water activity meter can be critical for your operation. And if you spend the time to pick the right instrument, you’ll enjoy the benefits for quite a while. The best instruments can last a decade or more.

IS IT AN INSTRUMENT OR A SENSOR?

There’s a confusing array of instruments to choose from when you’re shopping for a water activity meter. Essentially, you’re choosing between four sensor types: chilled mirror, capacitance, tunable diode laser, and resistive electrolytic.

It’s important to consider the sensor type carefully. The sensor determines the speed, accuracy, longevity, and reliability of your instrument. Sensors that measure water activity directly (chilled mirror and laser) are faster and more accurate than sensors that measure a secondary property like resistance or capacitance and convert it to water activity (resistive electrolytic and capacitance).

DO YOU NEED TO MEASURE VOLATILES?

If you're measuring chemicals or solvents, you probably know you'll have to look for a specialized sensor. But other ingredients that volatilize in air, such as ethanol, alcohol, vinegars, propylene glycol, and certain spices can also cause problems with a sensor.

The tunable diode laser is a sensor specifically made to deal with volatile ingredients. All other sensors struggle. Volatile ingredients can affect readings and reading speed for each of the other sensors, even when you use filters. Worse, electrolytic and capacitance sensors take readings by acting like a sponge, absorbing and desorbing the vapor over the sample. When they absorb volatile ingredients, it can change the response of your sensor and even destroy it.

Several instruments claim the ability to measure some volatiles with certain sensor/filter combinations. Our tests showed that the only instrument that can handle the tough stuff (we're not talking "bread aroma" here) is the laser sensor. It's not quite as fast as a chilled mirror and not quite as accurate overall, but if you measure many samples with volatiles, it's easily the best (some might say only) choice.

HOW LONG WILL YOUR INSTRUMENT LAST?

If you've just spent $10,000 for a lab instrument, you're probably hoping it's going to last you for a while. This is where build quality becomes a key consideration. We tested an instrument from Amazon, and while the initial price was quite attractive, it failed within the first week of testing. We were unable to get any support from the seller.

Aging can be an issue for some sensors. The sponge-like nature of resistive electrolytic and capacitance sensors makes them slower and less accurate as they absorb contaminants over time. This clearly impacted the older sensors in our tests. Novasina offers replacement sensors. Rotronic instruments require you to replace the entire sensor head.
The cost of these replacement parts is approximately the same (around $2,000).

Sensor age did not appear to have an impact on test time, accuracy, or stability of chilled mirror sensors, but should you need to have one replaced, it would cost about $950.

The oldest laser instrument we tested was 7 years old. Age did not impact the laser sensor readings (time or accuracy). If a laser sensor did fail, a replacement would cost approximately $1,850.

SPEED AND ACCURACY

If you need to read more than a few samples a day, a slow instrument can end up costing you money. On average, laser and chilled mirror sensors are nearly 10 times faster than resistive electrolytic or capacitance sensors. In our side by side testing, the speed differences caused bottlenecks as the slower instruments bogged our testers down.

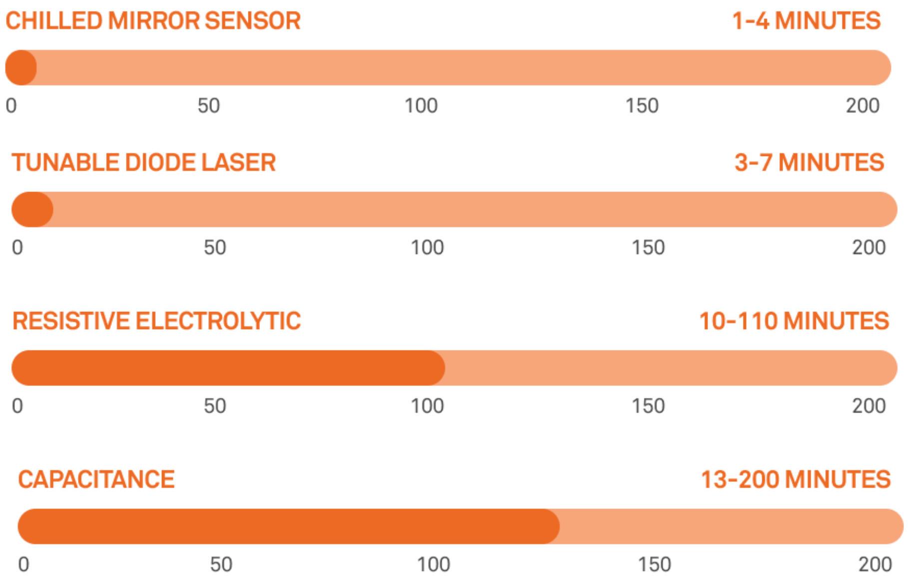
Many are tempted to sacrifice accuracy to save a few dollars. Remember that when it comes to safety equipment, if you don't pay up front, you'll pay in the end. It may be through lost profits—over-packaging and over-drying because you aren't confident about the safety of your product. Or it might be in waste from rejected shipments, recalls, or customer complaints. In any case, accurate sensors are expensive, but inaccurate sensors often cost far more.

SPEED

We measured eighteen different sample types. Three separate readings were taken with each instrument using the procedure specified by the manufacturer in user documentation. The instruments used were new, factory-calibrated equipment prepared for testing in the manner specified by the manufacturer.

All readings were made at 25 degrees C. The samples were pre-equilibrated to the reading temperature on a temperature equilibration tray. All readings are true water activity measurements made using equilibration mode, not estimated or "fast" mode.

The results: On average, chilled mirror and tunable diode laser sensors are nearly 10 times faster than resistive electrolytic and capacitance sensors when making true (fully equilibrated) measurements.



SAMPLE TYPE	CHILLED MIRROR	TUNABLE DIODE LASER	RESISTIVE ELECTROLYTIC	CAPACITANCE
Potato Chips	3.43	3.00	19.80	150.92
Infant Formula	3.18	3.00	14.38	63.42
Peanut Butter	4.38	3.00	25.00	30.92
Dog Kibble	2.62	3.00	10.00	14.42
Craisins	2.45	4.50	10.00	82.42
Honey	2.72	4.50	12.13	78.42
Beef Jerky	2.42	7.50	11.08	41.92
Chocolate Syrup	3.08	3.00	74.13	23.42
Grape Jelly	2.55	3.00	60.80	10.92
Pure Maple Syrup	2.15	7.50	69.47	18.92
Parmesan Cheese	2.42	3.00	17.47	13.42
Ketchup	2.28	3.00	11.57	44.42
Gluten-Free Panini Bread	2.03	7.50	63.87	26.92
Country Potato Bread	1.88	11.00	86.40	27.42
Unsatled Butter	6.72	10.00	109.20	62.42
Cream Cheese	2.03	15.50	74.27	20.42
Potato Gnocchi	2.12	16.50	78.13	40.42
Canned Pumpkin	2.20	12.00	74.67	61.42

THE COST OF SLOW SENSORS

- Need for faster throughput may require purchase of more instruments
- Long read times may slow down production when waiting for QA reading
- Inability to move to the next process step may cause product waste
- Slow measurement may hamper lab efficiency and increase staffing needs
- Slow measurements may delay shipments

ACCURACY

We measured 15 different salt standards with well defined water activity values in the literature (Greenspan, 1979). Six of the standards were unsaturated and nine were saturated. Three separate readings were taken with each instrument using the procedure specified by the manufacturer in user documentation. Instruments used were new, factory-calibrated equipment prepared for testing in the manner specified by the manufacturer.

All readings were made at 25 degrees C. Samples were pre-equilibrated to the reading temperature on a temperature equilibration tray. Readings are true water activities made using equilibration mode, not estimated or “fast” mode.

Sensors were graded by taking into account the average accuracy, accuracy range, and accuracy distribution of each sensor. Details of the absolute accuracy of each sensor over each standard are included after the summary.

CHILLED MIRROR sensors earned an accuracy score of 98/100 (excellent)

Average accuracy ±0.001
Accuracy range ±0.00 - ±0.005
No (0/15) standards measured with an inaccuracy greater than ±0.01.

TUNABLE DIODE LASER sensors earned an accuracy score of 92/100 (excellent)

Average accuracy ±0.002
Accuracy range ±0.00 - ±0.009
No (3/15) standards measured with an inaccuracy greater than ±0.01.

RESISTIVE ELECTROLYTIC sensors earned an accuracy score of 78/100 (acceptable)

Average accuracy ±0.005
Accuracy range ±0.001 - ±0.020
One fifth (3/15) of all standards measured with an inaccuracy greater than ±0.01.

CAPACITANCE SENSORS earned an accuracy score of 64/100 (unacceptable for some applications)

Average accuracy ±0.007
Accuracy range ±0 - ±0.022
One third (5/15) of all standards measured with an inaccuracy greater than ±0.01.

ABSOLUTE ACCURACY OVER ALL STANDARDS

WATER ACTIVITY STANDARD	CHILLED MIRROR	TUNABLE DIODE LASER	RESISTIVE ELECTROLYTIC	CAPACITANCE
Sat LiCl - 0.113	0.001	0.005	0.001	0.006
17.8 mol/kg LiCl - 0.150	0.001	0.003	0.002	0.007
13.41 mol/kg LiCl - 0.250	0.000	0.003	0.001	0.009
Sat MgCl2 - 0.328	0.001	0.005	0.001	0.009
8.57 mol/kg LiCl - 0.500	0.001	0.004	0.007	0.008
Sat Mg(NO3)2 - 0.529	0.001	0.004	0.001	0.014
Sat NaBr - 0.576	0.003	0.006	0.000	0.015
Sat NaCl - 0.753	0.004	0.000	0.002	0.000
6.00 mol/kg NaCl - 0.760	0.000	0.005	0.005	0.000

Sat KCl - 0.843	0.003	0.003	0.003	0.003
2.33 mol/kg NaCl - 0.920	0.001	0.005	0.004	0.002
Sat KNO3 - 0.936	0.005*	0.003	0.01*	0.007*
0.50 mol/kg KCl - 0.984	0.001	0.002	0.018	0.015
Steam Distilled Water - 1.00	0.000	0.002	0.020	0.022

THE COST OF INACCURACY

- Inaccuracy may lead to shipment of defective product (product appears to pass when it should have failed)
- Inaccuracy may cause unnecessary rework (product appears to fail when it actually passes)
- Slow, less accurate measurements limit or prevent use of water activity for continuous improvement and process control

ISSUES WITH “FAST MODE”

We evaluated fast mode measurements of resistive electrolytic and capacitance sensors by measuring the same product on the same instrument, with exactly the same conditions in both fast and fully equilibrated mode. We then evaluated the difference between the water activity value reported for fast mode and the one reported for equilibrated mode.

Our testing found “Fast” mode to have unacceptable variation between the predicted and actual readings for both resistive electrolytic sensors and capacitance sensors. At very high or very low water activity levels, these problems can be even more profound.

Fast mode is not significantly faster for resistive electrolytic sensor instruments (25-60+ min. for a true measurement vs. 8-30 min. in estimating mode) and we found significant differences between measurements in true vs. predictive mode.

The brand-new resistive electrolytic sensor we tested had differences between the predicted and actual readings from 0.001 at best to 0.121 at worst (an average of 0.024), with 7 of 12 readings outside the acceptability limit of ±0.01 aw. In every case, fast mode gave a water activity that was too low.

For capacitance-based meters, the time savings for fast mode (~5 min.) to an equilibrated reading was better (30-60 min), but produced a larger discrepancy in accuracy.

The brand-new capacitance sensor had differences between the predicted and actual readings from 0.002 at best to 0.061 at worst (an average of 0.023), with 9 of 12 readings outside the acceptability limit of ±0.01 aw. We judged the capacitance sensor to be slightly less predictable, because predicted values were higher and sometimes lower than the true measurements.

The reason these predicted fast mode readings are so far from their equilibrated values is that the method of prediction does not consider the sample in any way. All products have a unique vapor equilibration rate. To accurately predict a fast reading, this rate needs to be determined. Fast mode prediction methods are applied in the same way for all sample types – which means they simply can't do a good job.

*AQUALAB provides options for product specific 60 second readings which are accurate to +/-0.02aw or better.

ABSOLUTE DIFFERENCES BETWEEN FAST AND TRUE (FULLY EQUILIBRATED) READINGS

	POTATO CHIPS	INFANT FORMULA	PEANUT BUTTER	DOG KIBBLE	CRAISINS	HONEY	BEEF JERKY	GRAPE JELLY	PARM CHEESE	KETCHUP	GF PANINI BREAD	POTATO GNOCCHI
Resistive Electrolytic	0.019	0.036	0.040	0.121	0.015	0.005	0.020	0.006	0.001	0.005	0.016	0.004
Capacitance	0.061	0.052	0.028	0.010	0.006	0.002	0.013	0.021	0.019	0.028	0.013	0.020

*note : all chilled mirror and laser readings are fully equilibrated direct measurements, so fast mode is not necessary

WHEN INSTRUMENTS GET DIRTY

In the course of testing food products, instruments can get contaminated with food and greasy or sticky substances. Only one of the manufacturers (AQUALAB) instructs users to clean their instrument frequently.

But how – if at all – are sensors affected by contamination? To test this, we contaminated the sample chambers of each instrument with ground up dog kibble, milk powder, bacon grease, and marshmallow fluff, then measured the water activity of salt standards.

The best performer? Chilled mirror sensors. A dirty chamber brought the chilled mirror accuracy score from an A (98%) to a B+ (88%). Our brand new resistive electrolytic sensor also dropped 10 points from a C+ to a D+. Dirty chambers affected the other sensors more severely. The capacitive sensor dropped 16 points from a D to an F. And the laser sensor dropped a whopping 28 points from a B+ to an F.

Dirty chambers made Fast Mode on both electrical properties sensors even worse. Contamination caused the Rotronic instrument's accuracy to drop 40 accuracy points, from a barely- passing score of 60 to an unacceptable score of 20. The Novasina instrument did better, but its Fast Mode performance with a dirty chamber still dropped 16 points to finish at a D- (63).

SENSOR HYSTERESIS

WHAT HAPPENS WHEN TESTING A LOW AW SAMPLE AFTER A HIGH AW SAMPLE?

Sensor hysteresis is when the sensor retains the moisture from the previous sample and is unable to release it when testing the next sample, especially one with a lower water activity. This is a particular problem for resistive electrolytic and capacitance sensors. These sensors hold onto moisture and cause the subsequent water activity readings to be falsely elevated.

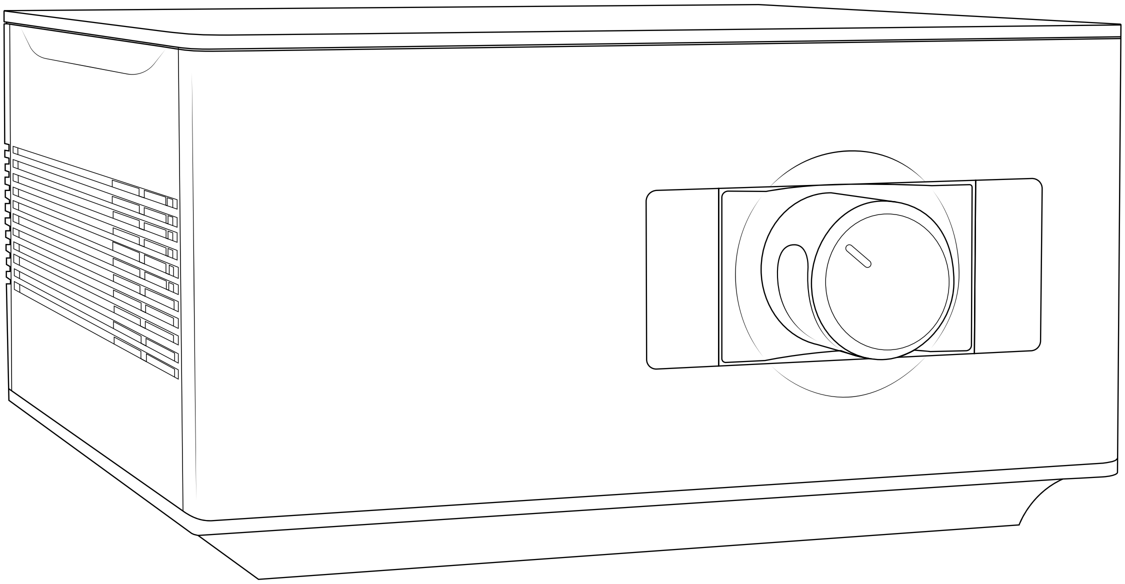
Our test set-up was simple, and all instruments were set to read in equilibration mode. First, a baseline water activity reading for a sample of flour was taken. All sensors read close to 0.33 aw, with the capacitance reading slightly lower at 0.32 aw. Since there was good agreement between the sensors, a water activity of 0.33 aw was taken as the true, equilibrated value for the flour. Next, a 0.92 aw standard solution was read. Immediately after that reading was finished, a sample of flour was re-tested.

The chilled mirror and tunable diode laser sensors read the flour the same before and after the 0.92 aw standard was read. They displayed no sensor hysteresis at all. However, the resistive electrolytic and capacitance sensors both showed significant sensor hysteresis. The electrolytic solution displayed the worst hysteresis with an aw increase of +0.046 and the capacitance sensor had a hysteresis of +0.020 aw from the flour's true water activity.

What is also important to point out is how long it took to make this final equilibrated water activity reading of the flour. The chilled mirror and tunable diode laser sensors made the reading in 3 minutes or less. The resistive electrolytic sensor took over 50 minutes to complete and still could not read the true water activity of the flour. The capacitance sensor completed the reading in 17 minutes and also did not read the true water activity value.

SENSOR TYPE	A_W FLOUR (Before)	0.92 STD	A_W FLOUR (After)	SENSOR HYSTERESIS	FLOUR (AFTER) TIME (MIN)
Chilled Mirror	0.330	0.922	0.331	0.001	2.53
Tunable Diode Laser	0.330	0.916	0.330	0.000	3.00
Resistive Electrolytic	0.328	0.928	0.374	0.046	50.96
Capacitance	0.322	0.929	0.342	0.020	17.00

RECOMMENDATIONS



CHILLED MIRROR SENSORS

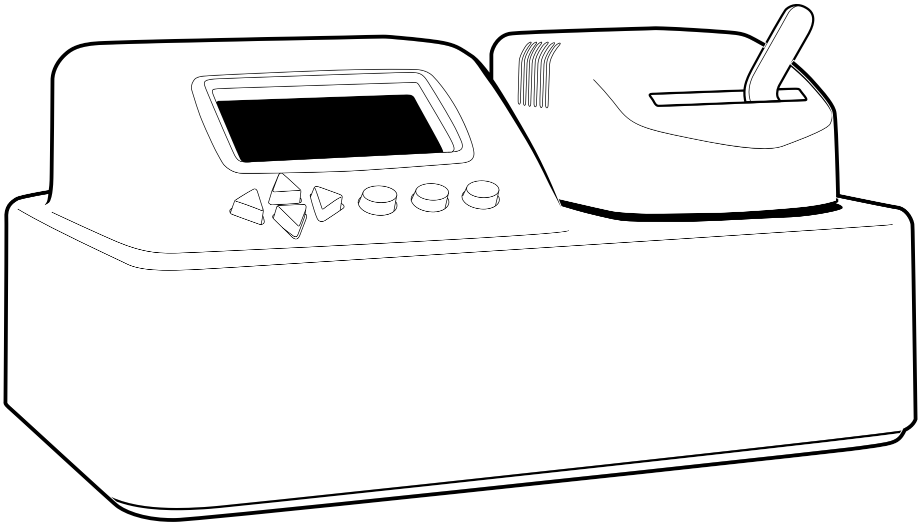
Pros: Nailed every standard from low to high with impressive accuracy and precision, typically in three minutes or less—half to one tenth the time of the competition. The standard knock on chilled mirror is that you have to keep the sensor clean, but these sensors were actually the top performers in our dirty sensor testing. Older sensors performed as well as brand new ones.

Cons: Can't read certain volatiles—check the manufacturer's guidelines here.

Bottom line: Chilled mirror sensors offer terrific accuracy, long sensor life, solid performance even when dirty, and the fastest read time of any water activity device you can buy.

LEARN MORE

RECOMMENDATIONS



LASER SENSORS

Pros: Can measure any sample, including alcohols, organic solvents, and propylene glycol. Accuracy and speed were both very good, though not as good as a chilled mirror. Should not experience any degradation in performance over time.

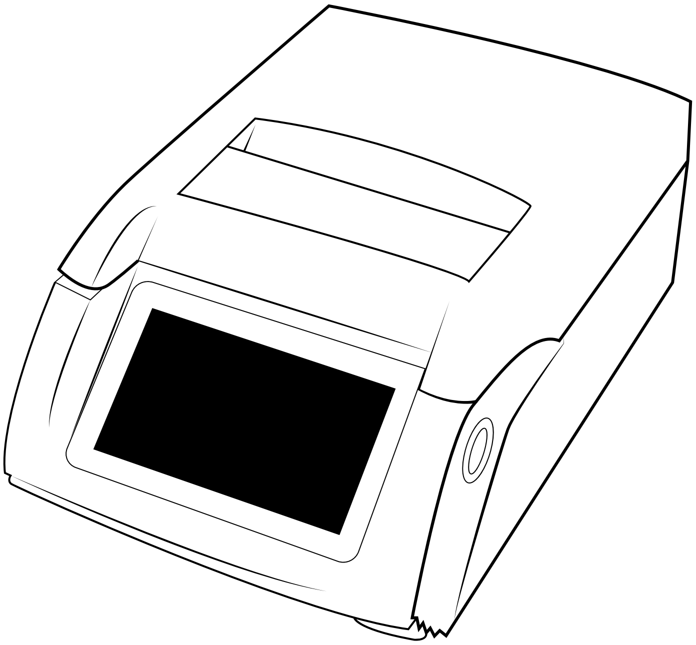
Cons: Less accurate than a chilled mirror and slightly slower. A dirty chamber disproportionately affects this sensor.

Bottom line: If you have to read the water activity of volatile samples, this is your sensor, but it must be used in an environment where you can keep it clean.

How it works: The sensor emits a finely tuned infrared laser beam across the headspace above the sample. The beam of the laser, which is less than one nanometer wide, is specific for the commonly occurring isotope of water. Other vapor molecules – including those from alcohols, gasoline, organic solvents, and propylene glycol – do not affect the reading. Attenuation of the beam is measured by the laser receiver and the concentration of water molecules in the air is determined directly from this value. The laser sensor is the only sensor that can accurately measure water activity in samples that contain significant concentrations of volatiles.

LEARN MORE

RECOMMENDATIONS



RESISTIVE ELECTROLYTIC SENSORS

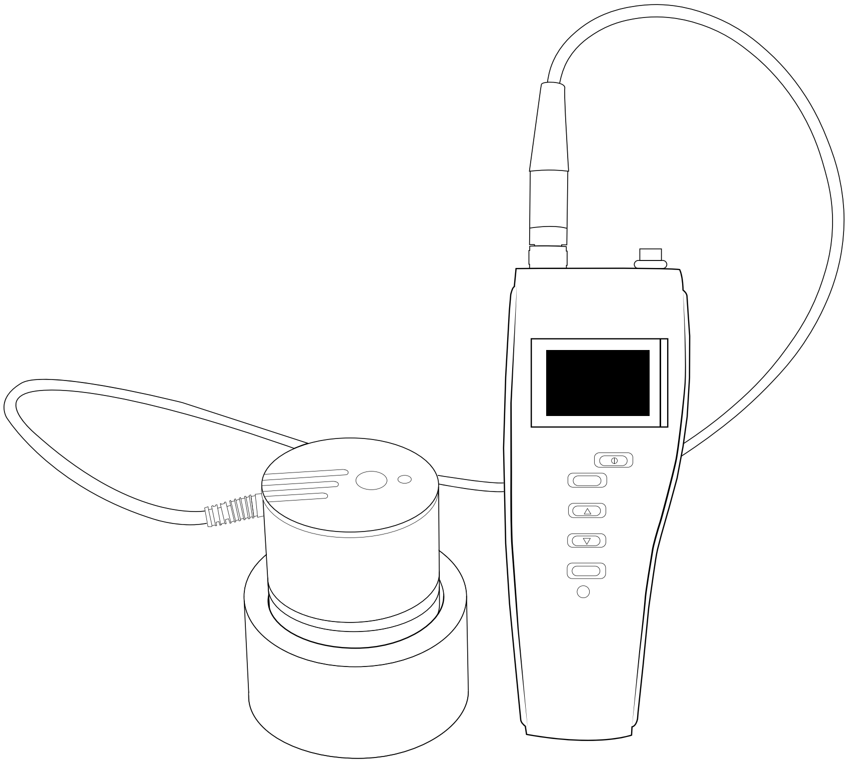
Pros: Solid (C+) accuracy in equilibration mode.

Cons: Slow, even in “Fast” mode. A dirty chamber makes accuracy unacceptable for water activities above 0.7. Sensors degrade over time. Not acceptable/practical for measuring most true volatiles. Lower cost models have limited accuracy and capabilities.

Bottom line: Resistive electrolytic sensors are solid performers backed by a quality company. But they can’t compete with the top-performing chilled mirror sensors on speed or accuracy, and their ability to measure volatiles is overstated.

How it works: Two extremely fine glass rods are held together at each end by a bead of glass. Metal electrodes are sandwiched between the rods, and an electrolytic solution is held in the trough between them. As the sensor absorbs water vapor, ionic functional groups are dissociated, and the resulting changes in impedance are correlated to changes in relative humidity.

RECOMMENDATIONS



CAPACITANCE SENSORS

Pros: Inexpensive. Less affected by volatiles than chilled mirror or resistive electrolytic sensors.

Cons: Slow. Significantly lower accuracy than other sensors. Sensors degrade over time. Not acceptable/practical for measuring most true volatiles. Disproportionately affected by a dirty chamber. Fast mode has unacceptable performance, especially in the presence of contaminants.

Bottom line: These sensors look like a good budget option, but the cost adds up over time. They are slow in equilibration mode and are not accurate enough for most applications, even if you're willing to wait for a reading. "Fast" mode has unacceptable accuracy and should not be considered an option by any serious user.

How it works: Capacitive sensors use a hygroscopic dielectric material sandwiched between a pair of electrodes forming a small capacitor. Most capacitive sensors are simply capacitors—two electrodes sandwiching a dielectric material, typically a plastic or polymer. The dielectric constant of the polymer or plastic is typically in the single digits, much lower than the dielectric constant of water vapor (80). As water vapor is absorbed by the dielectric material, the sensor capacitance increases. By relating this change in capacitance to the change in relative humidity, an instrument can calculate relative humidity from a capacitance reading.