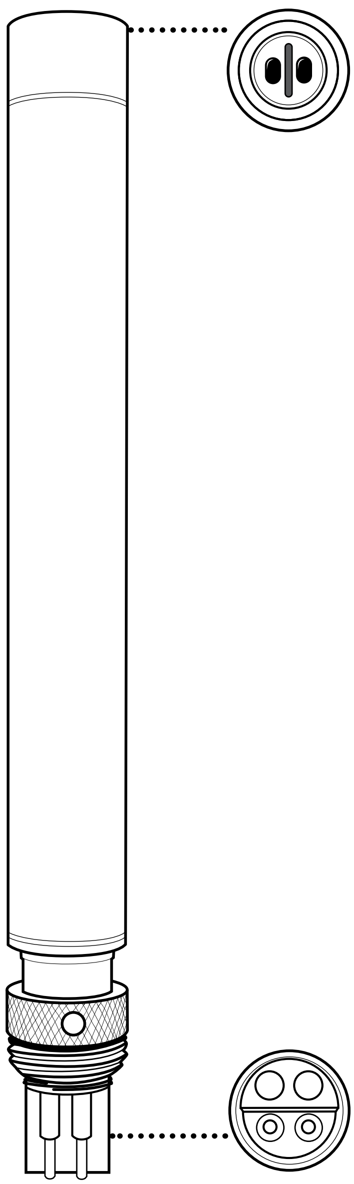
4.25 Turbidity

Sensor Overview

Turbidity is the indirect measurement of the suspended solid concentration in water and is typically determined by shining a light beam into the sample solution and then measuring the light that is scattered off of the suspended particles. Turbidity is an important water quality parameter and is a fundamental tool for monitoring environmental changes due to events like weather-induced runoff or illicit discharges. The source of the suspended solids varies (examples include silt, clay, sand, algae, and organic matter) but all particles will impact light transmittance and result in a turbidity signal.

(continued)



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Specifications

Default Units	FNU
Temperature *Operating* *Storage*	 -5 to +50°C -20 to +80°C
Range	0 to 4000 FNU
Accuracy	0-999 FNU: 0.3 FNU or ±2% of reading, whichever is greater; 1000-4000 FNU: ±5% of reading[2]
Response	T63<2 sec
Resolution	0-999 FNU: 0.01 FNU 1000-4000 FNU: 0.1 FNU
Sensor Type	Optical, 90° scatter
Optics: Excitation	 860±15 nm

1 *ASTM D7315-07a "Test Method for Determination of Turbidity Above 1 Turbidity Unit (TU) in Static Mode."*

2 *Performance based on 3-point calibration done with YSI AMCO-AEPA standards of 0, 124, and 1010 FNU. The same type of standard must be used for all calibration points.*

The EXO Turbidity sensor employs a near-infrared light source and has been characterized as a nephelometric near-IR, non-ratiometric sensor in accordance with ASTM Method D7315-07a.[1] This method calls for this sensor type to report values in formazin nephelometric units (FNU), which is the default calibration unit for the EXO sensor. Users are able to change calibration units to nephelometric turbidity units (NTU).

Turbidity is one of the most misunderstood measurements in environmental monitoring. In reality the turbidity sensor is not much different from other optical sensors: differences in outcomes with different standards, sensors and environments can be a result of differing optical components and geometries, and the impact of different environmental factors upon the measurement technologies themselves. Thus like many optical measurements, where a light beam is passing through a sample in an environment of changing temperature, etc., turbidity is best monitored with consistent use of standards, technology platforms, and practices to compare outcomes for scientific conclusions.

Among the many factors that can impact turbidity measurements, users should be aware of three over which they have some control. These are the use of recommended YSI standards, preventing fouling, and using sound and consistent calibration practices.

Turbidity Standards

Turbidity sensors of many types, from many manufacturers, are often calibrated with formazin. Considered the "gold standard" for turbidity calibration there is the perception that all turbidity sensors will read consistently in formazin. In practice this has led to the belief that two different sensors of different types (design or manufacturer, for instance), if calibrated in formazin, would yield the same FNU when used to measure a sample. When sensors are of the same fundamental design, using the same type of light source and with detection of scattering at the same angles of incident light, this is more likely to be true, especially if measuring an actual formazin solution. However, with field samples this rule does not always hold; different manufacturer's sensors calibrated with the same formazin solutions can yield slightly different readings from the same field samples. There can be a number of reasons for this, including how the raw data are post-processed.

Due to the challenges of preparation and disposal of formazin, polymer-based standards are now preferred as turbidity standards. As with formazin, it is the case that field readings will vary between different models of turbidity sensors even when they are calibrated with the same standards. This is true of the popular AMCO-AEPA standards upon which YSI's standards solutions are based, and which were used to determine the Specifications shown below.

Further, if YSI sensors are calibrated with the non-YSI standard AMCO-AEPA solutions, sensor specifications may differ from those shown in the Specification table, and thereby turbidity measurements may differ. For the best consistency, EXO users should use the YSI-labeled turbidity standards throughout the lifetime of their sensors, and use the FNU values on the labels of these standards during calibration.

While formazin can be used to calibrate YSI's EXO turbidity sensors, the specifications were determined with YSI-labeled AMCO-AEPA turbidity standards, and the factory-defined limits for the SmartQC tool were also determined with YSI standards.

Preventing Fouling

Turbidity measurements are vulnerable to both biofouling and non-biological fouling. This is because of the high sensitivity and resolution of measurements, which can be affected by any changes to the sensor face that light must pass through. Any obstruction of that light path will affect measurements, and even bubbles on the sensor's face can affect measurements. Low-range measurements (e.g. <100 FNU) are especially susceptible to these effects.

As such it is imperative in continuous monitoring applications that antifouling tools be employed. The central wiper on the EXO 2, 2^{S}, and 3 sondes is highly effective in combating fouling during continuous monitoring, and can be aided by strategies like C-spray and copper tape on the sensors. Even during spot-sampling applications such as with EXO 1 it is very important that users pay attention to the sensor faces so that they are not trapping bubbles during measurements.

Calibration Practices

The following section describes in detail how to calibrate EXO turbidity sensors. Before calibrating, be certain that the probe is very clean and free of debris. Solid particles, particularly those carried over from past deployments, will contaminate the standards and can cause either calibration errors and thereby errors in measurement.

The cleaning instructions in Section 5.6 should be helpful for preventing contamination, but another recommendation we make is to have a sonde guard and a calibration cup devoted solely to turbidity calibration.

Finally, never calibrate turbidity *without* the sonde guard. If one is using the copper antifouling guard for a deployment, then that is the guard that should be used during turbidity calibration (don't use the standard black guard).

4.26 Turbidity
Calibration

Tools and Practices

YSI Turbidity standards that are based upon AMCO-AEPA polymer are the basis of SmartQC and EXO turbidity sensor specifications, and therefore should be used for turbidity sensor calibration. Gallon bottles are available as follows:

Item No.	Description
608000	0 FNU
607200	12.4 FNU
607300	124 FNU
607400	1010 FNU

Standards should be selected based upon the range in which one is expected to work. For low-turbidity waters, one might use 0 and 12.4 for a two-point calibration. If turbidities might exceed the lower ranges 0 and 124 should be used for a two-point calibration (not 0 and 1010 for reasons described below), and 0, 124 and 1010 for a three-point calibration. There is not a calibration standard beyond 1010 FNU at this time.

The FNU of each bottle can change with production batches, and as such the label of the bottle should always be checked for the FNU that should be entered into the software or handheld during calibration.

In some cases it may be acceptable to use deionized or distilled water rather than YSI's 0 FNU standard. Beware, however, that distilled water from some sources has been shown to not be 0 FNU. Calibration with a non-zero standard can cause negative readings when the sensor is used in waters that actually are clear. Non-zero readings also can occur if the calibration equipment (e.g. sonde guard, calibration cup) is not sufficiently clean.

Some users will have a preference, if not a requirement, for use of formazin standards. Examples may be formazin prepared according to *Standard Methods for the Treatment of Water and Wastewater* (Section 2130 B), or Hach StablCal™ of various NTUs. These standards are acceptable for a two-point calibration. However, users who anticipate working in higher turbidities and who choose to use a formazin standard for the third point may see yellow SmartQC Scores during that calibration. The sensor can still be used, but since the algorithms for calibration were developed with YSI's polymer beads there may be less perfect alignment of the gain factors when using formazin.

Note also that if doing a three-point calibration, one should not use formazin for the second point, and polymer for the third point. Rather, one should only use the polymer for all points of a three point calibration (or water for 0 FNU and polymer for the second and third points), or formazin for all three points.

In all cases, due to the non-linear response of turbidity sensors and YSI's proprietary algorithms for post-processing of the data, the points of a two or three point calibration must be within the limits outlined here:

First Point	> 0 and ≤1 FNU
Second Point	>5 and ≤200 FNU
Third Point	>400 and ≤4200 FNU

The second calibration point, whether one is using formazin or YSI's polymer, should not be out of the 5-200 FNU range. If one tries to use a standard that is in the 400-4200 FNU range for the second calibration point, accuracy cannot be assured and often a yellow QC Score will result.

Performing a 2-point calibration

Pour the 0 FNU standard (or deionized or distilled water) into the clean calibration cup and immerse the probe end of the sonde into the standard. The sonde should have the sonde guard on, and if one will deploy with the copper antifouling guard that is likewise the guard that should be used during calibration. Pay careful attention while submersing the sensors to not trap bubbles on the face of the turbidity sensor(s).

In either KorEXO Software or the handheld's Calibration menu, select Turbidity to calibrate.

Enter 0.0 (or some offset value between 0.0 and 1.0) as the first calibration value. While the sensor is still stabilizing one may wipe the sensors (using the button in the software or menu option on the handheld) to remove any bubbles. When the data are Stable, select the option to "Apply calibration" for this point.

It is advised at this point that the sensors, sonde guard, and calibration cup be rinsed with a small amount of the standard that will be used for the second calibration point. Discard this rinse, and then fill the cup with the second calibration standard. Click Add Another Cal Point in the software.

Place the sensors into the second calibration standard, and follow the same steps to wipe and obtain a stable reading. Use the value on the label of the YSI standard bottle for the FNU of the second calibration point.

When the data are Stable, select the option to "Apply calibration" for this point. Select the option to complete the calibration and observe the SmartQC Score in the calibration worksheet. In KorEXO Software, color indicators will also make the QC Score apparent.

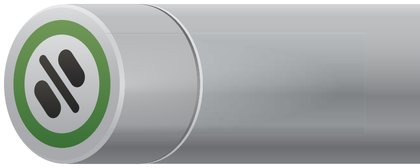
Rinse the sonde with water and discard all used turbidity standards.

Performing a 3-point calibration

The steps for a three-point calibration are the same as describe above, but note that:

- The first point must always be 0 FNU, followed by the second standard (5-200 FNU) and then third (400-4200 FNU).
- Always use the same type of standard for the two non-zero points. Both must be YSI polymer, or both must be formazin.
- It is critically important, between the second and third calibration points, to rinse the sensors, sonde guard, and calibration cup with water, blot them dry with a lint-free material, and then do a rinse (at least once) with the standard for the third calibration point.

SmartQC for Turbidity Sensors



The turbidity response is nonlinear across the sensor's range, and a proprietary algorithm that employs up to five terms is used during calibration and for generation of the SmartQC Score. Three of those terms are the actual calibration points, and those calibration points must read within an absolute range set within the sensor (this is slightly different than the concept of an offset that is used for SmartQC on most sensors). Two of the terms are calculated from the ratios of the calibration points, and likewise must be within an absolute range set within the sensor. The result is that the SmartQC calculation for turbidity is slightly different depending upon whether one does a 1, 2, or 3 point calibration. Since each individual term used by the algorithm must fall within an absolute range SmartQC is most reliable when the YSI standards, upon which these algorithms were built, are used.

Guidance on interpretation of the SmartQC Score for this sensor is as follows:

Green: A green SmartQC Score means that the point for a single-point calibration is within the specified range. For a two-point calibration a green SmartQC Score means that both calibration points, as well as the slope between them, is within the specified range for each term. For a three-point calibration a Green SmartQC Score means that all three calibration points, as well as the slope between the first two points and the slope between the second two points, are within the specified ranges for each term.

Yellow: A yellow SmartQC Score can result if any one of the five terms of interest is outside of the factory-specified range. If a user calibration results in a yellow QC Score, perform the following actions:

1. Perform a Factory Reset Calibration and re-do the calibration.
2. If a two-point calibration was performed, make sure that the second point is between 5-200 FNU.
3. If a three point calibration was performed with formazin, make sure that each calibration point was within the specified ranges of 0-1 FNU, 5-200 FNU, and 400-4200 FNU.
4. If a three point calibration was performed with YSI's polymer standards, make sure the correct values from the bottles were entered during calibration. For example, make sure the EXO values, and not the 6-Series values, were entered from the label.
5. Make sure you are using YSI's polymer standards. Difficulties in calibration may occur if AMCO-AEPA standards that were not produced for YSI instruments are used. These will not have a YSI label on them.
6. It is imperative that the sensors, calibration cup, and sonde guard are all very clean when calibrating turbidity.
7. Customers who use the 12.4 NTU standard to calibrate will often see a yellow QC Score, even with a perfect calibration.
8. Always use an EXO calibration cup and EXO probe guard with bottom plate during the turbidity calibration.

Red: Any of the five terms of interest may be outside of the factory-set specifications. If a user calibration results in a red QC Score, follow the same steps described above for a yellow QC Score.

If the QC Score remains red, please contact YSI Technical Support for further assistance.