## Field Measurement of Dissolved Oxygen (DO)

##### Use in conjunction with:

###### FT 1000 General Field Testing and Measurement

###### FS 1000 General Sampling Procedures

###### FD 1000 Documentation Procedures

##### Equipment and Supplies

##### Field Instruments

##### Membrane-type polarographic or galvanic electrode DO sensor with dedicated meter or configured with multi-parameter sonde

##### Luminescence-based DO sensor with dedicated meter or configured with multi-parameter sonde (for informational purposes, see SM 4500-O H 2016 in Standard Methods for the Examination of Water and Wastewater (see Standard Methods Online, http://www.standardmethods.org).

##### Select instrument assemblies that provide minimum precision of +/- 0.2 mg DO/L and a minimum accuracy of +/- 0.2 mg DO/L.

##### Compensate for temperature dependence of DO measurements by using instruments employing automatic temperature compensation or by manually correcting measurements in accordance with method 4500-O, Oxygen (Dissolved) 2016.

##### Calibrate on-board temperature sensors as described in FT 1400.

##### Standards

##### NIST-traceable Celsius thermometer with a scale marked for every 0.1oC and a range of 0 to 100oC.

##### Access to an organization with capability to perform the Winkler titration procedure is recommended but not mandatory.

##### A “zero-DO standard”, prepared on-site or prior to site visit with an aliquot of site water or deionized or tap water. Prepare by adding excess sodium sulfite and a trace of cobalt chloride to bring the DO to zero, or follow manufacturer’s instructions for solution preparation. Pre-formulated zero-DO solutions can also be used.

##### Recordkeeping and Documentation Supplies:

###### Field notebook (waterproof paper is recommended) or forms

###### Indelible pens

##### Calibration and Use: The electrode method is predominantly used in situ for dissolved oxygen determinations.

##### General Concerns

##### Turbulence is necessary to keep a constant flow of water across the membrane-sample interface. Make sure the appropriate mechanism is working before using the probe.

##### Follow instrument manufacturer’s instructions for probe storage. For example, store the probe with a cover that creates a saturated atmosphere. A cap, with a wet sponge in it, will suffice for single-parameter probes. If the sensor is in a multi-probe device, keep the protective cap chamber moist during storage.

##### Before mobilizing, check to make sure there are no bubbles beneath the probe membrane, or any wrinkles or tears in the probe membrane. If so, replace the membrane and KCl solution. Follow manufacturers recommendation for conditioning newly installed membranes in order to ensure stable readings. Check the leads, contacts, etc., for corrosion and/or shorts if meter pointer remains off-scale, does not calibrate, or drifts.

##### Dissolved inorganic salts interfere with the performance of DO probes. For example, DO readings in salt water are affected by salinity and must be corrected. The DO meter may adjust automatically based on readings taken from the specific conductivity/salinity probe. If corrections are not automatic the appropriate calculations must be used to correct for salinity. If automatic adjustments are used the specific conductivity/salinity probe calibration must be verified or calibrated in accordance with FT 1200.

##### Reactive gases, which pass through the membrane, may interfere. For example, chlorine will depolarize the cathode and cause a high probe output. Long-term exposures to chlorine will coat the anode with the chloride of the anode metal and eventually desensitize the probe. Sulfide (from H2S) will undergo oxidation if high enough potential (voltage) is applied, creating current flow, yielding faulty readings. If such interferences are suspected, change the membrane electrode more frequently and calibrate at more frequent intervals.

##### Ensure that the temperature of the sensor and sample are stable. Unstable temperatures will produce erroneous calibrations, verifications or sample measurements.

##### Erroneous calibrations or verifications may result if the saturated air chamber is not vented to atmospheric pressure, properly humidified and protected from temperature fluctuations produced by common field conditions such as evaporation or fluctuation in sunlight intensity.

##### Barometric pressure interferes with the performance of DO probes. As a 100% air-saturated sample increases in altitude, the barometric pressure decreases and so does the saturation of oxygen in the sample. This effect of barometric pressure is corrected with proper sensor calibration. For most sensors, it is not necessary to correct for changes in barometric pressure after a proper calibration. DO readings in varying altitudes will need to be corrected based on the specific probe being used.

##### Follow the quality control requirements for calibration (see activities in FT 1000, section 2.2). Sample readings must be chronologically bracketed by verifications performed under saturated conditions. Quantitative bracketing of sample measurements is not required. See section 2.5 below for additional verifications that may be performed.

##### Initial Calibration and Initial Calibration Verification

##### Air Calibration and Initial Calibration Verification (ICV): Calibrate the meter at 100% saturation. Before use, verify the meter calibration, in “read” or “run” mode, in water-saturated air to make sure it is properly calibrated and operating correctly. After sample measurement(s), perform a continuing calibration verification (CCV) as in section 2.4 below. Perform a CCV at no more than 24-hour intervals from the previous verification, or demonstrated as in FT 1000, sections 2.2.5.1 and 2.2.5.2. **Follow the manufacturer’s instructions for operation of a specific instrument.**

##### Allow an appropriate warm up period before initial calibration or verification.

##### Wet the inside of the calibration chamber with water, pour out the excess water (leave a few drops), wipe any droplets off the membrane/sensor and insert the sensor into the chamber (this ensures 100% humidity).

##### Allow adequate time for the DO sensor and the air inside the calibration chamber to equilibrate.

##### Once the probe/calibration chamber is stable at ambient temperature, check the air temperature and determine, from the oxygen solubility table, what the theoretical DO saturation value should be at the observed temperature (see Table FT 1500-1, below). A stable and accurate temperature is required for a valid calibration. The acceptance criterion for DO calibration verification is +/- 0.3 mg DO/L at the observed temperature of the verification.

##### Recalibrate the instrument if the acceptance criterion is not met.

##### Continuing Calibration Verification

##### After sample measurement(s), perform a continuing calibration verification (CCV) below. Perform a CCV at no more than 24-hour intervals from the previous verification, or at demonstrated intervals as in FT 1000, sections 2.2.5.1 and 2.2.5.2.

##### Air-Calibration Verification: DO sensor or instrument is calibrated against air that is saturated with water at a known temperature and ambient atmospheric pressure. Use Table FT 1500-1 below to verify calibration at specified temperature*,* while the instrument is in the “read” or “run”mode.

##### Wet the inside of the calibration chamber with water, pour out the excess water (leave a few drops) and insert the sensor into the chamber (this ensures 100-percent humidity)

##### Allow adequate time for the DO sensor and the air inside the calibration chamber to equilibrate.

##### Measure the temperature in the calibration chamber and observe the readings until the instrument stabilizes.

##### Use the oxygen solubility Table FT 1500-1 below to determine the theoretical DO saturation at a measured temperature and atmospheric pressure. Calculate values to the nearest tenth degree by interpolation or use an expanded version of this table found in FS 2200, which provides saturation data in 0.1ºC increments for a selected temperature range (see Table FS 2200-2).

##### Compare DO meter reading with value obtained from Table FT 1500-1 below to verify continuous calibration.

##### Additional Verifications: The following methods may be used as additional checks to verify calibration. These additional checks may be required as part of a specific permit.

##### Winkler method: This check is useful to assess the condition of the DO sensor (i.e., its degradation with time/use) and that the instrument can still maintain a valid calibration (see method SM 4500-O B 2016).

##### **Perform the Winkler method when required by permit or other regulation at the required calendar frequency.**

##### For an accuracy calibration verification using the Winkler method, followmethod SM 4500-O B 2016.

##### Fill a clean bucket with uncontaminated or de-ionized water and place the probe into the bucket (with stirrer or equivalent mechanism turned off). Fill at least two biological oxygen demand (BOD) bottles without entraining atmospheric oxygen into the bottles. Carefully submerge the bottom of the bottle (one at a time) into the water and allow the water to fill the bottle. Place the bottle on the bottom of the bucket and carefully place a stopper into it without adding atmospheric oxygen. Retrieve the bottles and determine their DO by the Winkler method (see method SM 4500-O-B 2016 for more details). Turn the stirrer or equivalent mechanism on and read the DO of the water in the bucket.

##### Adjust the DO meter according to manufacturer's instructions. Be sure to adjust the meter to the temperature of water in the bucket, and then calibrate the DO meter to read the average DO concentration of the two samples determined by the Winkler test.

##### Air-Saturated Water: Calibrate the DO sensor or instrument system against water that is saturated with oxygen at a known temperature and ambient atmospheric pressure. Air-saturated water calibration can be used in place of air calibration discussed above in sections 2.3 and 2.4.Before use, verify the meter calibration, in “read” or “run” mode, in air-saturated water to make sure it is properly calibrated and operating correctly. Make a similar verification at the end of the day, sampling event or at other appropriate intervals.

##### The temperature and conductivity of water used for calibration should be about the same as the temperature and conductivity of the water to be measured.

##### Place DO sensor and calibration water in a large beaker or open-mouth container.

##### Aerate the water for an adequate amount of time.

##### Determine if the water is 100% saturated with oxygen, and take a temperature reading. The temperature probe must be verified per FT 1400 before DO calibration.

##### Use Table FT 1500-1 to determine the theoretical DO saturation value at the measured water temperature and atmospheric pressure used in calibrating the DO sensor or instrument. A stable and accurate temperature is required for valid calibration. The acceptance criterion for DO calibration verification is +/-0.3 mg DO/L at the observed temperature of the verification.

##### Zero-DO Verification: The air calibration and the interfering effects of the sample can be further checked in the field by means of a “zero-DO standard” (see method SM 4500-O G).

##### Prepare this standard on-site or prior to site visit with an aliquot of site water (sample water), deionized or tap water by adding excess sodium sulfite and a trace of cobalt chloride to bring the DO to zero, or follow manufacturer’s instructions for solution preparation. Pre-formulated zero-DO solutions can also be used. Prepare this zero-DO standard in a beaker or a large-mouth sample container of appropriate size to insert the DO probe.

##### After adding the chemicals, gently swirl the water and let it sit for about 30 seconds before inserting the probe.

##### Read the DO of the sample. If the reading is outside the acceptance interval of ≤0.3 mg/L DO, the instrument must be recalibrated and/or zero-adjusted if the meter allows for this adjustment.

##### Measuring DO in Samples:

Insert or place the DO probe in situ at a measuring location representative of the sampling source. Do not measure dissolved oxygen from an intermediate container containing static sample.

##### Take the DO of an effluent just before it enters the receiving water. If the effluent is aerated prior to entering the surface water, take the DO reading in the receiving water right where it enters.

##### For well mixed surface waters, e.g., fast flowing streams, take the DO reading at approximately 1-2 feet below the surface or at mid-depth.

##### For still or sluggish surface waters, take a reading at one foot below the surface, one foot above the bottom, and at mid-depth.

##### For shallow surface waters, (less than two feet) take the reading at mid-depth.

##### Do not take a reading in frothy or aerated water unless required by the sampling plan.

##### Groundwater samples must be measured *in situ* with a downhole probe or in a flow-through container. Do not measure bailed or pumped samples in an intermediate container containing static sample.

##### Rinse probe with de-ionized water and keep the probe in the saturated atmosphere (see 2.1.2 above) between sites and events.

##### If the readings show distinct, unexplainable changes in DO levels, or when the probe has been in waters with high sulfides, recalibrate or perform maintenance per manufacturer’s instructions. While taking a reading, if it is very low (e.g., below 1.0 mg/L), allow the meter to stabilize, record it and then, remove and rinse the probe, as the environment is very likely anoxic and may contain hydrogen sulfide, which can damage the probe.

##### Salinity and temperature corrections may be necessary. Follow manufacturer instructions for automatic corrections or perform manual calculations (see method SM 4500-O G 2016).

##### Preventive Maintenance: Refer to FT 1000, section 3.

##### Documentation

##### Standard and Reagent Documentation: Document information about standards and reagents used for verifications.

##### Note the date of receipt, expiration date and date of first use for all standards and reagents. Document acceptable verification of any standard used after its expiration date.

##### Record the concentration or other value for the standard in the appropriate measurement units.

##### Note vendor catalog number and description for pre-formulated solutions as well as for neat liquids and powdered standards.

##### Retain vendor assay specifications for standards as part of the calibration record.

##### Record the grade of standard or reagent used.

##### When formulated in-house, document all calculations used to formulate calibration standards. Record the date of preparation of all in-house formulations.

##### Describe or cite the procedure(s) used to prepare any standards in-house (DEP SOP or internal SOP).

##### Field Instrument Calibration Documentation: Document acceptable calibration and calibration verification for each instrument unit and field test or analysis, linking this record with affected sample measurements.

##### Retain vendor certifications of all factory-calibrated instrumentation.

##### Designate the identity of specific instrumentation in the documentation with a unique description or code for each instrument unit used. Record the manufacturer name, model number and identifying number such as a serial number for each instrument unit.

##### Record the time and date of all initial calibrations and all calibration verifications.

##### Record the instrument reading (value in appropriate measurement units) of all calibration verifications to the level of resolution stated by the sensor manufacturer.

##### Record the temperature associated with all calibration verifications.

##### Record the name of the analyst(s) performing the calibration.

##### Document the specific standards used to calibrate or verify the instrument or field test with the following information:

##### Type of standard or standard name (e.g., saturation)

##### Value of standard, including correct units (e.g., mg/L at oC)

##### Link to information recorded according to section 4.1 above

##### Retain manufacturers’ instrument specifications.

##### Document whether successful initial calibration occurred.

##### Document whether each calibration verification passed or failed.

##### Document any corrective actions taken to correct instrument performance according to records requirements of FD 3000.

##### Document the date and time of any corrective action.

##### Note any incidence of discontinuation of use of the instrument due to calibration failure.

##### Describe or cite the specific calibration or verification procedure performed (DEP SOP or internal SOP).

##### Record all field-testing measurement data, to include the following:

###### Project name

###### Date and time of measurement or test (including time zone, if applicable)

###### Source and location of the measurement or test sample (e.g., monitoring well identification number, outfall number, station number or other description)

* + Latitude and longitude of sampling source location (if required)

###### Analyte or parameter measured

###### Measurement or test sample value to the level of resolution stated by the sensor manufacturer

###### Reporting units

###### “J” qualifier code and explanatory comment if the sample measurement is not chronologically bracketed by acceptable verifications

###### Initials or name of analyst performing the measurement

###### Unique identification of the specific instrument unit(s) used for the test(s)

Appendix FT 1500

Tables, Figures and Forms

**Table FT 1500-1: Solubility of Oxygen in Water at Atmospheric Pressure 1,2**

| **Temp (°C)** | **100% sat. (mg/L)** |
| --- | --- |
| 15.0 | 10.084 |
| 15.1 | 10.062 |
| 15.2 | 10.040 |
| 15.3 | 10.019 |
| 15.4 | 9.997 |
| 15.5 | 9.976 |
| 15.6 | 9.955 |
| 15.7 | 9.934 |
| 15.8 | 9.912 |
| 15.9 | 9.891 |
| 16.0 | 9.870 |
| 16.1 | 9.849 |
| 16.2 | 9.829 |
| 16.3 | 9.808 |
| 16.4 | 9.787 |
| 16.5 | 9.767 |
| 16.6 | 9.746 |
| 16.7 | 9.726 |
| 16.8 | 9.705 |
| 16.9 | 9.685 |
| 17.0 | 9.665 |
| 17.1 | 9.645 |
| 17.2 | 9.625 |
| 17.3 | 9.605 |
| 17.4 | 9.585 |
| 17.5 | 9.565 |
| 17.6 | 9.545 |
| 17.7 | 9.526 |
| 17.8 | 9.506 |
| 17.9 | 9.486 |
| 18.0 | 9.467 |
| 18.1 | 9.448 |
| 18.2 | 9.428 |
| 18.3 | 9.409 |
| 18.4 | 9.390 |
| 18.5 | 9.371 |
| 18.6 | 9.352 |
| 18.7 | 9.333 |
| 18.8 | 9.314 |
| 18.9 | 9.295 |
| 19.0 | 9.276 |
| 19.1 | 9.258 |
| 19.2 | 9.239 |
| 19.3 | 9.220 |
| 19.4 | 9.202 |
| 19.5 | 9.184 |
| 19.6 | 9.165 |
| 19.7 | 9.147 |
| 19.8 | 9.129 |
| 19.9 | 9.111 |
| 20.0 | 9.092 |
| 20.1 | 9.074 |
| 20.2 | 9.056 |
| 20.3 | 9.039 |
| 20.4 | 9.021 |
| 20.5 | 9.003 |
| 20.6 | 8.985 |
| 20.7 | 8.968 |
| 20.8 | 8.950 |
| 20.9 | 8.932 |
| 21.0 | 8.915 |
| 21.1 | 8.898 |
| 21.2 | 8.880 |
| 21.3 | 8.863 |
| 21.4 | 8.846 |
| 21.5 | 8.829 |
| 21.6 | 8.812 |
| 21.7 | 8.794 |
| 21.8 | 8.777 |
| 21.9 | 8.761 |
| 22.0 | 8.744 |
| 22.1 | 8.727 |
| 22.2 | 8.710 |
| 22.3 | 8.693 |
| 22.4 | 8.677 |
| 22.5 | 8.660 |
| 22.6 | 8.644 |
| 22.7 | 8.627 |
| 22.8 | 8.611 |
| 22.9 | 8.595 |
| 23.0 | 8.578 |
| 23.1 | 8.562 |
| 23.2 | 8.546 |
| 23.3 | 8.530 |
| 23.4 | 8.514 |
| 23.5 | 8.498 |
| 23.6 | 8.482 |
| 23.7 | 8.466 |
| 23.8 | 8.450 |
| 23.9 | 8.434 |
| 24.0 | 8.418 |
| 24.1 | 8.403 |
| 24.2 | 8.387 |
| 24.3 | 8.371 |
| 24.4 | 8.356 |
| 24.5 | 8.340 |
| 24.6 | 8.325 |
| 24.7 | 8.309 |
| 24.8 | 8.294 |
| 24.9 | 8.279 |
| 25.0 | 8.263 |
| 25.1 | 8.248 |
| 25.2 | 8.233 |
| 25.3 | 8.218 |
| 25.4 | 8.203 |
| 25.5 | 8.188 |
| 25.6 | 8.173 |
| 25.7 | 8.158 |
| 25.8 | 8.143 |
| 25.9 | 8.128 |
| 26.0 | 8.114 |
| 26.1 | 8.099 |
| 26.2 | 8.084 |
| 26.3 | 8.070 |
| 26.4 | 8.055 |
| 26.5 | 8.040 |
| 26.6 | 8.026 |
| 26.7 | 8.012 |
| 26.8 | 7.997 |
| 26.9 | 7.983 |
| 27.0 | 7.968 |
| 27.1 | 7.954 |
| 27.2 | 7.940 |
| 27.3 | 7.926 |
| 27.4 | 7.912 |
| 27.5 | 7.898 |
| 27.6 | 7.884 |
| 27.7 | 7.870 |
| 27.8 | 7.856 |
| 27.9 | 7.842 |
| 28.0 | 7.828 |
| 28.1 | 7.814 |
| 28.2 | 7.800 |
| 28.3 | 7.786 |
| 28.4 | 7.773 |
| 28.5 | 7.759 |
| 28.6 | 7.745 |
| 28.7 | 7.732 |
| 28.8 | 7.718 |
| 28.9 | 7.705 |
| 29.0 | 7.691 |
| 29.1 | 7.678 |
| 29.2 | 7.664 |
| 29.3 | 7.651 |
| 29.4 | 7.638 |
| 29.5 | 7.625 |
| 29.6 | 7.611 |
| 29.7 | 7.598 |
| 29.8 | 7.585 |
| 29.9 | 7.572 |
| 30.0 | 7.559 |
| 30.1 | 7.546 |
| 30.2 | 7.533 |
| 30.3 | 7.520 |
| 30.4 | 7.507 |
| 30.5 | 7.494 |
| 30.6 | 7.481 |
| 30.7 | 7.468 |
| 30.8 | 7.456 |
| 30.9 | 7.443 |

Derived using the formula in Standard Methods for the Examination of Water and Wastewater, Page 4, 101, 18th Edition, 1992.

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**1. The table provides three decimal places to aid interpolation.**

**2. Under equilibrium conditions, the partial pressure of oxygen in air-saturated water is equal to that of the oxygen in water-saturated air.**