



# Standard Test Methods for Dissolved Oxygen in Water<sup>1</sup>

This standard is issued under the fixed designation D888; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

<sup>ε</sup><sup>1</sup> NOTE—Table X2.1 was corrected and the Summary of Changes was added editorially in July 2013.

## 1. Scope\*

1.1 These test methods cover the determination of dissolved oxygen in water. Three test methods are given as follows:

	Range, mg/L	Sections
Test Method A—Titrimetric Procedure—High Level	>1.0	8 to 15
Test Method B—Instrumental Probe Procedure—Electrochemical	0.05 to 20	16 to 25
Test Method C—Instrumental Probe Procedure—Luminescence-Based Sensor	0.05 to 20	26 to 29

1.2 The precision of Test Methods A and B was carried out using a saturated sample of reagent water. It is the user's responsibility to ensure the validity of the test methods for waters of untested matrices.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For a specific precautionary statement, see [Note 17](#).

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

[D1066 Practice for Sampling Steam](#)

<sup>1</sup> These test methods are under the jurisdiction of ASTM Committee D19 on Water and are the direct responsibility of Subcommittee D19.05 on Inorganic Constituents in Water.

Current edition approved March 1, 2012. Published March 2012. Originally approved in 1946. Last previous edition approved in 2009 as D888 – 09. DOI: 10.1520/D0888-12E01.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- [D1129 Terminology Relating to Water](#)
- [D1193 Specification for Reagent Water](#)
- [D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water](#)
- [D3370 Practices for Sampling Water from Closed Conduits](#)
- [D5847 Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis](#)
- [E200 Practice for Preparation, Standardization, and Storage of Standard and Reagent Solutions for Chemical Analysis](#)

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, refer to Terminology [D1129](#).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *amperometric systems, n*—those instrumental probes that involve the generation of an electrical current from which the final measurement is derived.

3.2.2 *instrumental probes, n*—devices used to penetrate and examine a system for the purpose of relaying information on its properties or composition.

3.2.2.1 *Discussion*—The term probe is used in these test methods to signify the entire sensor assembly, including electrodes, electrolyte, membrane, materials of fabrications, and so on.

3.2.3 *potentiometric systems, n*—those instrumental probes in which an electrical potential is generated and from which the final measurement is derived.

## 4. Significance and Use

4.1 Dissolved oxygen is required for the survival and growth of many aquatic organisms, including fish. The concentration of dissolved oxygen may also be associated with corrosivity and photosynthetic activity. The absence of oxygen may permit anaerobic decay of organic matter and the production of toxic and undesirable esthetic materials in the water.

\*A Summary of Changes section appears at the end of this standard

## 5. Purity of Reagents

5.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society.<sup>3</sup> Other grades may be used if it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.1.1 Reagent grade chemicals, as defined in Practice E200, shall be used unless otherwise indicated. It is intended that all reagents conform to this standard.

5.2 Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specification D1193, Type I. Other reagent water types may be used provided it is first ascertained that the water is of sufficiently high purity to permit its use without adversely affecting the bias and precision of the test method. Type II water was specified at the time of round robin testing of this test method.

## 6. Sampling

6.1 Collect the samples in accordance with Practices D1066 and D3370.

6.2 For higher concentration of dissolved oxygen, collect the samples in narrow mouth glass-stoppered bottles of 300-mL capacity, taking care to prevent entrainment or solution of atmospheric oxygen.

6.3 With water under pressure, connect a tube of inert material to the inlet and extend the tube outlet to the bottom of the sample bottle. Use stainless steel, Type 304 or 316, or glass tubing with short neoprene connections. Do not use copper tubing, long sections of neoprene tubing, or other types of polymeric materials. The sample line shall contain a suitable cooling coil if the water being sampled is above room temperature, in which case cool the sample to 16 to 18°C. When a cooling coil is used, the valve for cooling water adjustment shall be at the inlet to the cooling coil, and the overflow shall be to a point of lower elevation. The valve for adjusting the flow of sample shall be at the outlet from the cooling coil. The sample flow shall be adjusted to a rate that will fill the sampling vessel or vessels in 40 to 60 s and flow long enough to provide a minimum of ten changes of water in the sample vessel. If the sampling line is used intermittently, flush the sample line and cooling coil adequately before using.

6.4 Where samples are collected at varying depths from the surface, a special sample bottle holder or weighted sampler with a removable air tight cover should be used. This unit may be designed to collect several 250 or 300 mL samples at the same time. Inlet tubes extending to the bottom of each bottle and the water after passing through the sample bottle or bottles displaces air from the container. When bubbles stop rising from

the sampler, the unit is filled. Water temperature is measured in the excess water in the sampler.

6.5 For depths greater than 2 m, use a Kemmerer-type sampler. Bleed the sample from the bottom of the sampler through a tube extending to the bottom of a 250 to 300 mL biological oxygen demand (BOD) bottle. Fill the bottle to overflowing and prevent turbulence and the formation of bubbles while filling the bottle.

## 7. Preservation of Samples

7.1 Do not delay the determination of dissolved oxygen. Samples for Test Method A may be preserved 4 to 8 h by adding 0.7 mL of concentrated sulfuric acid (sp gr 1.84) and 1.0 mL of sodium azide solution (20 g/L) to the bottle containing the sample in which dissolved oxygen is to be determined. Biological activity will be inhibited and the dissolved oxygen retained by storing at the temperature of collection or by water sealing (inverting bottle in water) and maintaining at a temperature of 10 to 20°C. Complete the determination as soon as possible, using the appropriate procedure for determining the concentration of dissolved oxygen.

### TEST METHOD A TITRIMETRIC PROCEDURE—HIGH LEVEL

## 8. Scope

8.1 This test method is applicable to waters containing more than 1000 µg/L of dissolved oxygen such as stream and sewage samples. It is the user's responsibility to ensure the validity of the test method for waters of untested matrices.

8.2 This test method, with the appropriate agent, is usable with a wide variety of interferences. It is a combination of the Winkler Method, the Alsterberg (Azide) Procedure, the Rideal-Stewart (permanganate) modification, and the Pomeroy-Kirshman-Alsterberg modification.

8.3 The precision of the test method was carried out using a saturated sample of reagent water.

## 9. Interferences

9.1 Nitrite interferences are eliminated by routine use of sodium azide. Ferric iron interferes unless 1 mL of potassium fluoride solution is used, in which case 100 to 200 mg/L can be tolerated. Ferrous iron interferes, but that interference is eliminated by the use of potassium permanganate solution. High levels of organic material or dissolved oxygen can be accommodated by use of the concentrated iodide-azide solution.

## 10. Apparatus

10.1 *Sample Bottles*, 250 or 300 mL capacity with tapered ground-glass stoppers. Special bottles with pointed stoppers and flared mouths are available from supply houses, but regular types (tall or low form) are satisfactory.

10.2 *Pipettes*, 10-mL capacity, graduated in 0.1-mL divisions for adding all reagents except sulfuric acid. These pipettes should have elongated tips of approximately 10 mm

<sup>3</sup> *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

for adding reagents well below the surface in the sample bottle. Only the sulfuric acid used in the final step is allowed to run down the neck of the bottle into the sample.

## 11. Reagents

### 11.1 Alkaline Iodide Solutions:

11.1.1 *Alkaline Iodide Solution*—Dissolve 500 g of sodium hydroxide or 700 g of potassium hydroxide and 135 g of sodium iodide or 150 g of potassium iodide (KI) in water and dilute to 1 L. Chemically equivalent potassium and sodium salts may be used interchangeably. The solution should not give a color with starch indicator when diluted and acidified. Store the solution in a dark rubber-stoppered bottle. This solution may be used if nitrite is known to be absent and must be used if adjustments are made for ferrous ion interference.

11.1.2 *Alkaline Iodide-Sodium Azide Solution I*—This solution may be used in all of these submethods except when adjustment is made for ferrous ion. Dissolve 500 g of sodium hydroxide or 700 g of potassium hydroxide and 135 g of sodium iodide or 150 g of potassium iodide in water and dilute to 950 mL. To the cooled solution add 10 g of sodium azide dissolved in 40 mL of water. Add the  $\text{NaN}_3$  solution slowly with constant stirring. Chemically equivalent potassium and sodium salts may be used interchangeably. The solution should not give a color with starch indicator solution when diluted and acidified. Store the solution in a dark rubber-stoppered bottle.

11.1.3 *Alkaline Iodide-Sodium Azide Solution II*—This solution is useful when high concentrations of organic matter are found or when the dissolved oxygen concentration exceeds 15 mg/L. Dissolve 400 g of sodium hydroxide in 500 mL of freshly boiled and cooled water. Cool the water slightly and dissolve 900 g of sodium iodide. Dissolve 10 g of sodium azide in 40 mL of water. Slowly add, with stirring, the azide solution to the alkaline iodide solution, bringing the total volume to 1 L.

11.2 *Manganous Sulfate Solution*—Dissolve 364 g of manganous sulfate in water, filter, and dilute to 1 L. No more than a trace of iodine should be liberated when the solution is added to an acidified potassium iodide solution.

11.3 *Potassium Biiodate Solution (0.025 N)*—Dissolve 0.8125 g of potassium biiodate in water and dilute to 1 L in a volumetric flask.

NOTE 1—If the bottle technique is used, dissolve 1.2188 g of biiodate in water and dilute to 1 L to make 0.0375 N.

11.4 *Phenylarsine Oxide Solution (0.025 N)*—Dissolve 2.6005 g of phenylarsine oxide in 110 mL of NaOH solution (12 g/L). Add 800 mL of water to the solution and bring to a pH of 9.0 by adding HCl (1 + 1). This should require about 2 mL of HCl. Continue acidification with HCl (1 + 1) until a pH of 6 to 7 is reached, as indicated by a glass-electrode system. Dilute to 1 L. Add 1 mL of chloroform for preservation. Standardize against potassium biiodate solution.

NOTE 2—Phenylarsine oxide is more stable than sodium thiosulfate. However, sodium thiosulfate may be used. The analyst should specify which titrant is used. For a stock solution (0.1 N), dissolve 24.82 g of  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$  in boiled and cooled water and dilute to 1 L. Preserve by adding 5 mL of chloroform. For a dilute standard titrating solution (0.005 N) transfer 25.00 mL of 0.1 N  $\text{Na}_2\text{S}_2\text{O}_3$  to a 500-mL volumetric flask. Dilute to the mark with water and mix completely. Do not prepare more

than 12 to 15 h before use.

NOTE 3—If the full bottle technique is used, 3.9007 g must be used to make 0.0375 N.

NOTE 4—If sodium thiosulfate is used, prepare and preserve a 0.1 N solution as described in Note 1. Determine the exact normality by titration against 0.025 N potassium biiodate solution. Dilute the appropriate volume (nominally 250 mL) of standardized 0.1 N  $\text{Na}_2\text{S}_2\text{O}_3$  solution to 1 L. One millilitre of 0.025 N thiosulfate solution is equivalent to 0.2 mg of oxygen. If the full bottle technique is followed, use 37.5 mL of sodium thiosulfate solution and standardize to 0.0375 N.

11.5 *Starch Solution*—Make a paste of 6 g of arrowroot starch or soluble iodometric starch with cold water. Pour the paste into 1 L of boiling water. Then add 20 g of potassium hydroxide, mix thoroughly, and allow to stand for 2 h. Add 6 mL of glacial acetic acid (99.5 %). Mix thoroughly and then add sufficient HCl (sp gr 1.19) to adjust the pH value of the solution to 4.0. Store in a glass-stoppered bottle. Starch solution prepared in this manner will remain chemically stable for one year.

NOTE 5—Powdered starches such as thyodene have been found adequate. Some commercial laundry starches have also been found to be usable.

NOTE 6—If the indicator is not prepared as specified or a proprietary starch indicator preparation is used, the report of analysis shall state this deviation.

11.6 *Sulfuric Acid (sp gr 1.84)*—Concentrated sulfuric acid. One millilitre neutralizes about 3 mL of the alkaline iodide reagent.

NOTE 7—Sulfamic acid (3 g) may be substituted.

11.7 *Potassium Fluoride Solution (400 g/L)*—Dissolve 40 g of potassium fluoride in water and dilute to 100 mL. This solution is used in the procedure for eliminating ferric ion interference. Store this solution in a plastic bottle.

11.8 *Potassium Oxalate Solution (20 g/L)*—Dissolve 2 g of potassium oxalate in 100 mL of water. One millilitre of this solution will reduce 1.1 mL of the  $\text{KMnO}_4$  solution. This solution is used in the procedure for eliminating ferrous ion interference.

11.9 *Potassium Permanganate Solution (6.3 g/L)*—Dissolve 6.3 g of potassium permanganate in water and dilute to 1 L. With very high ferrous iron concentrations, solution of  $\text{KMnO}_4$  should be stronger so that 1 mL will satisfy the demand. This solution is used in the procedure for eliminating ferrous ion interference.

## 12. Procedure

### 12.1 Elimination of Ferrous Ion Interference, If Necessary:

12.1.1 Add to the sample (collected as in 6.2) 0.70 mL of  $\text{H}_2\text{SO}_4$ , followed by 1.0 mL of  $\text{KMnO}_4$  solution. Where high iron is present, also add 1.0 mL of KF solution. Stopper and mix by inversion. The acid should be added with a 1-mL pipette graduated in 0.1-mL divisions. Add sufficient  $\text{KMnO}_4$  solution to maintain a violet tinge for 5 min. If the color does not persist for 5 min, add more  $\text{KMnO}_4$  solution, but avoid excess. In those cases where more than 5 mL of  $\text{KMnO}_4$  solution is required, a stronger solution of this reagent may be used to avoid dilution of the sample.

12.1.2 After 5 min, completely destroy the permanganate color by adding 0.5 to 1.0 mL of  $\text{K}_2\text{C}_2\text{O}_4$  solution. Mix the

sample well, and allow it to stand in the dark. Low results are caused by excess oxalate so it is essential to add only sufficient oxalate to completely decolorize the permanganate without having an excess of more than 0.5 mL. Complete decolorization should be obtained in 2 to 10 min. If the sample cannot be decolorized without a large excess of oxalate, the dissolved oxygen results will be of doubtful value.

12.2 Add 2.0 mL of  $\text{MnSO}_4$  solution to the sample as collected in a sample bottle, followed by 2.0 mL of alkaline iodide-sodium azide solution well below the surface of the liquid (see [Note 8](#) and [Note 9](#)). Be sure the solution temperature is below  $30^\circ\text{C}$  to prevent loss due to volatility of iodine. Carefully replace the stopper to exclude air bubbles and mix by inverting the bottle several times. Repeat the mixing a second time after the floc has settled, leaving a clear supernatant solution. Water high in chloride requires a 10-min contact period with the precipitate. When the floc has settled, leaving at least 100 mL of clear supernatant solution, remove the stopper, and add 2.0 mL of  $\text{H}_2\text{SO}_4$ , allowing the acid to run down the neck of the bottle. Restopper and mix by inversion until the iodine is uniformly distributed throughout the bottle. Titrate without delay 203 mL of original sample. A correction is necessary for the 4 mL of reagents added (2 mL of  $\text{MnSO}_4$  solution and 2 mL of alkaline iodide-sodium azide solution:  $200 \times [300/(300 - 4)] = 203$  mL (see [Note 10](#))).

**NOTE 8**—Take care to use the correct alkaline iodide solution ([11.1.1](#)) if no nitrite is present or ferrous ion was oxidized, ([11.1.2](#)) for normal use, or ([11.1.3](#)) if there is a high organic or dissolved oxygen concentration.

**NOTE 9**—Two millilitres of the alkaline iodide-sodium azide solution are used to ensure better contact of the iodide-azide solution and sample with less agitation. With 250-mL bottles, 1 mL of the iodide-azide solution may be used if desired. In this procedure, as in the succeeding ones, all reagents except the  $\text{H}_2\text{SO}_4$  are added well below the surface of the liquid.

**NOTE 10**—In the case where ferrous ion interference has been eliminated, a total of 6.7 mL of reagents were added (0.7 mL of acid, 1 mL of  $\text{KMnO}_4$  solution, 2 mL of  $\text{MnSO}_4$  solution, and 3 mL of alkaline iodide solution). The volume of sample for titration is 203 mL. A slight error occurs due to the dissolved oxygen of the  $\text{KMnO}_4$  solution, but rather than complicate the correction further, this error is ignored.

12.3 Rapidly titrate the 203 mL of sample with 0.025 *N* titrating solution to a pale, straw yellow color. Add 1 to 2 mL of starch indicator. Continue the titration to the disappearance of the blue color.

**NOTE 11**—If the full bottle technique is used, transfer the entire contents of the bottle,  $300 \pm 3$  mL, to a 500-mL Erlenmeyer flask and titrate with 0.0375 *N* titrating solution.

**NOTE 12**—At the correct end point, one drop of 0.025 *N*  $\text{KH}(\text{IO}_3)_2$  solution will cause the return of the blue color. If the end point is overrun, continue adding 0.025 *N*  $\text{KH}(\text{IO}_3)_2$  solution until it reappears, noting the volume required. Subtract this value, minus the last drop of  $\text{KH}(\text{IO}_3)_2$  (0.04 mL) from the volume of 0.025 *N* titrating solution used. Disregard the late reappearance of the blue color, which may be due to the catalytic effect of organic material or traces of uncomplexed metal salts.

### 13. Calculation

13.1 Calculate the dissolved oxygen content of the sample as follows:

$$\text{Dissolved oxygen, mg/L} = \frac{T \times 0.2}{200} \times 1000 \quad (1)$$

where:

$T$  = 0.025 *N* titrating solution required for titration of the sample, mL.

13.2 Use [Eq 2](#) to convert to a standard temperature and pressure measurement.

$$\text{Dissolved oxygen, mg/L} = \frac{A}{0.698} \quad (2)$$

where:

$A$  = oxygen at  $0^\circ\text{C}$  and 760 mm Hg, mL.

**NOTE 13**—Each millilitre of 0.0375 *N* titrant is equivalent to 1 mg/L  $\text{O}_2$  when the full bottle technique is used.

**NOTE 14**—If the percentage of saturation at 760-mm atmospheric pressure is desired, the dissolved oxygen found is compared with solubility data from standard solubility tables,<sup>4</sup> making corrections for barometric pressure and the aqueous vapor pressure, when necessary. See [Appendix X1](#).

### 14. Precision and Bias<sup>5</sup>

14.1 The precision of the test method was determined by six operators in three laboratories, running three duplicates each (not six laboratories as required by [Practice D2777](#)) using a saturated sample of reagent water. The mean concentration was 9.0 mg/L, and the pooled single operator precision in these samples was 0.052 mg/L.

14.2 Precision and bias for this test method conforms to [Practice D2777 – 77](#), which was in place at the time of collaborative testing. Under the allowances made in 1.4 of [Practice D2777 – 08](#), these precision and bias data do meet existing requirements for interlaboratory studies of Committee D19 test methods.

### 15. Quality Control

15.1 In order to be certain that analytical values obtained using these test methods are valid and accurate within the confidence limits of the test, the following QC procedures must be followed when analyzing dissolved oxygen.

15.2 *Calibration and Calibration Verification:*

15.2.1 Standardize the titrating solution against the potassium biiodate solution.

15.2.2 Verify titrating solution by analyzing a sample with a known amount of the dissolved oxygen, if possible. The amount of the sample should fall within  $\pm 15\%$  of the known concentration.

15.2.3 If standardization cannot be verified, restandardize the solution.

15.3 *Initial Demonstration of Laboratory Capability:*

15.3.1 If a laboratory has not performed the test before, or if there has been a major change in the measurement system, for example, new analyst, new instrument, and so forth, a precision and bias study must be performed to demonstrate laboratory capability.

<sup>4</sup> Carpenter, J. H., "New Measurement of Oxygen Solubility in Pure and Natural Water," *Limnology and Oceanography*, Vol 11, No. 2, April 1966, pp. 264–277.

<sup>5</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D19-1070.



15.3.2 Analyze seven replicates of the same solution. Each replicate must be taken through the complete analytical test method including any sample preservation and pretreatment steps.

15.3.3 Calculate the mean and standard deviation of the seven values and compare to the acceptable ranges of bias in 14.1. This study should be repeated until the recoveries are within the limits given in 14.1. If an amount other than the recommended amount is used, refer to Practice D5847 for information on applying the *F* test and *t* test in evaluating the acceptability of the mean and standard deviation.

#### 15.4 Laboratory Control Sample (LCS):

15.4.1 Air-saturated reference water samples may be used for laboratory control samples. The value obtained must fall within the control limits established by the laboratory.

#### 15.5 Method Blank:

15.5.1 Analyze a reagent water test blank with each batch. The amount of dissolved oxygen found in the blank should be less than the analytical reporting limit. If the amount of dissolved oxygen is found above this level, analysis of samples is halted until the contamination is eliminated, and a blank shows no contamination at or above this level, or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

#### 15.6 Matrix Spike (MS):

15.6.1 Dissolved oxygen is not an analyte that can be feasibly spiked into samples.

#### 15.7 Duplicate:

15.7.1 To check the precision of sample analyses, analyze a sample in duplicate with each batch. The value obtained must fall within the control limits established by the laboratory.

15.7.2 Calculate the standard deviation of the duplicate values and compare to the precision determined by the laboratory or in the collaborative study using an *F* test. Refer to 6.4.4 of Practice D5847 for information on applying the *F* test.

15.7.3 If the result exceeds the precision limit, the batch must be reanalyzed or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

#### 15.8 Independent Reference Material (IRM):

15.8.1 Independent reference water samples may be obtained from commercial sources. The value obtained from these samples must fall within the control limits established by the laboratory.

## TEST METHOD B INSTRUMENTAL PROBE PROCEDURE— ELECTROCHEMICAL

### 16. Scope

16.1 This test method is applicable to waters containing dissolved oxygen in the range from 50 to 20 000 µg/L. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

16.2 This test method describes procedures that utilize electrochemical probes for the determination of dissolved oxygen in fresh water and in brackish and marine waters that

may contain dissolved or suspended solids. Samples can be analyzed in situ in bodies of water or in streams, or samples can be collected and analyzed subsequent to collection. The electrochemical probe method is especially useful in the monitoring of water systems in which it is desired to obtain a continuous record of the dissolved oxygen content.

16.2.1 This test method is recommended for measuring dissolved oxygen in waters containing materials that interfere with the chemical methods, such as sulfite, thiosulfate, polythionate, mercaptans, oxidizing metal ions, hypochlorite, and organic substances readily hydrolyzable in alkaline solutions.

16.3 Electrochemical dissolved oxygen probes are practical for the continuous monitoring of dissolved oxygen content in natural waters, process streams, biological processes, and so on, when the probe output is conditioned by a suitably stable electronic circuit and recorded. The probe must be standardized before use on samples free of interfering materials, preferably with the azide modification of Test Method A.

### 17. Summary of Test Method

17.1 The most common instrumental probes for determination of oxygen dissolved in water are dependent upon electrochemical reactions. Under steady-state conditions, the current or potential can be correlated with dissolved oxygen concentrations.

NOTE 15—Steady-state conditions necessitate the probe being in thermal equilibrium with the solution, this typically taking 20 min for nonlaboratory conditions.<sup>6</sup>

17.1.1 Probes that employ membranes normally involve metals of different nobility immersed in an electrolyte that is retained by the membrane. The metal of highest nobility (the cathode) is positioned at the membrane. When a suitable potential exists between the two metals, reduction of oxygen to hydroxide ion occurs at the cathode surface. An electrical current is developed that is directly proportional to the rate of arrival of oxygen molecules at the cathode.

17.1.2 The thallium probe, which does not utilize a membrane, exposes a thallium electrode to the water sample. Reaction of oxygen with the thallium establishes a potential between the thallium electrode and a reference electrode. The potential is related logarithmically to dissolved oxygen concentration. The cell output decreases (theoretically 59 mV/decade at 25°C) with increased oxygen concentration.

NOTE 16—The thallium probe has utility in waste treatment monitoring systems; it has limited application under conditions of high dissolved oxygen (>8 mg/L) and low temperature (<10°C).

17.1.3 The electronic readout meter for the output from dissolved oxygen probes is normally calibrated in convenient scales (0 to 10, 0 to 15, or 0 to 20 mg/L) with a sensitivity of approximately 0.05 mg/L. More sensitive dissolved oxygen ranges are practical through amplification in the electronic readout (including µg/L readings in boiler feed waters).

<sup>6</sup> D'Aoust, B. G., Clark, M. J. R., "Analysis of Supersaturated Air in Natural Waters and Reservoirs," *Transactions of the American Fisheries Society*, Vol 109, 1980, pp. 708–724.

17.2 Interfacial dynamics at the probe-sample interface are a factor in probe response. Turbulence should be constant or above some minimum level as recommended by the instrument manufacturer.

17.3 Response rates of dissolved oxygen probes are relatively rapid, often as fast as 99 % in 15 s. Probe outputs may be recorded for continual monitoring or utilized for process control (see [Note 15](#)).

## 18. Interferences

18.1 Dissolved organic materials normally encountered in water are not known to interfere in the output from dissolved oxygen probes.

18.2 Dissolved inorganic salts are a factor in the calibration of dissolved oxygen probe.

18.2.1 Solubility of oxygen in water at a given oxygen partial pressure changes with the kind and concentration of dissolved inorganic salts. Conversion factors for seawater and brackish waters may be calculated from dissolved oxygen saturation versus salinity data if internal compensation is not included in the instrument. Conversion factors for specific inorganic salts may be developed experimentally. Broad variations in the kinds and concentrations of salts in samples can make the use of a membrane probe difficult.

18.2.2 The thallium probe measures ionic activity instead of concentration as do all ion selective electrodes. Gross changes in the concentration of dissolved salts will affect the activity coefficient of the thallos ion and thus shift the span (see [20.2.1](#)). The thallium probe may be calibrated and operated in water of any conductivity above 100  $\mu\text{S}$ , but a ten-fold change in conductivity will produce an error of approximately 20 %. Since the thallium requires a conducting path through the sample to the reference electrode, the response will become sluggish at very low conductivity. It is therefore desirable to calibrate the sensor in solutions having a conductivity greater than 100  $\mu\text{S}$ .

18.3 Reactive compounds can interfere with the output or the performance of dissolved oxygen probes.

18.3.1 Membrane probes are sensitive to reactive gases that may pass through the membrane. Chlorine will depolarize the cathode and cause a high probe output. Long-term exposure to chlorine can coat the anode with the chloride of the anode metal and may eventually desensitize the probe. Hydrogen sulfide will interfere with membrane probes if the applied potential is greater than the half-wave potential of the sulfide ion. If the applied potential is less than the half-wave potential, an interfering reaction will not occur, but coating of the anode metal can occur.

18.3.2 The thallium probe is affected by interference from soluble sulfur compounds, such as hydrogen sulfide or mercaptans. Ten milligrams of hydrogen sulfide per litre of water will produce a negative error corresponding to approximately 1 mg/L of dissolved oxygen. Free halogens also will interfere with the thallium probe if present in appreciable concentrations, such as above 2 mg of chlorine per litre of water.

18.4 At dissolved oxygen concentrations below 2 mg/L, pH variation below 4 and above 10 interfere with the performance

of the thallium probe (approximately  $\pm 0.05$  mg/L dissolved oxygen per pH unit). The performance of membrane probes is not affected by pH changes.

18.5 Dissolved oxygen probes are temperature sensitive and temperature compensation is normally provided by the manufacturer. The thallium probe has a temperature coefficient of 1.0 mV/ $^{\circ}\text{C}$ , membrane probes have a temperature coefficient of 4 to 6 %/ $^{\circ}\text{C}$  dependent upon the membrane employed.

18.6 Insoluble organic or inorganic materials that can coat the surface of dissolved oxygen probes will affect the performance of either the thallium or membrane probes.

## 19. Apparatus

19.1 *Amperometric Probes*—Oxygen-sensitive probes of the amperometric type are normally composed of two solid metal electrodes of different nobility in contact with a supporting electrolyte that is separated from the test solution by a selective membrane. The current generated by the reduction of oxygen at the cathode is measured through an electronic circuit and displayed on a meter. Typically, the anode is constructed of metallic silver or lead and the cathode of gold or platinum. Probes are generally not affected by hydraulic pressure and can be used in the temperature range from 0 to 50 $^{\circ}\text{C}$ .

19.1.1 *Semipermeable Membranes of Polyethylene or TFE-fluorocarbon* permit satisfactory oxygen diffusion and limit interference from most materials.

19.1.2 *Accessory Equipment* may involve apparatus to move the sample past the probe and to provide suitable turbulence at the membrane-sample interface.

19.2 *Potentiometric Probes*—The commonly used potentiometric probe employs a thallium-measuring electrode and a suitable reference half cell such as a saturated calomel. At 25 $^{\circ}\text{C}$  and 0.1 mg/L of dissolved oxygen, the cell establishes a negative potential of approximately 817 mV. The potential decreases logarithmically in absolute value with increased dissolved oxygen concentration (theoretically, 59 mV/decade change in dissolved oxygen concentration) to approximately 688 mV at 15 mg/L of dissolved oxygen. An external millivoltage source that opposes the output of the electrometer is used to adjust the net readout of output to the desired range.

NOTE 17—Thallium and its salts are toxic. Avoid contact with the skin.

## 20. Apparatus Standardization

20.1 Under equilibrium conditions, the partial pressure of oxygen in air-saturated water is equal to that of the oxygen in the water-saturated air. Consequently, a probe may be calibrated in air as well as water. Consider carefully the manufacturer's recommended procedure. If it is necessary to zero the instrument, immerse the probe in water containing 1 g of sodium sulfite and two drops of saturated cobalt chloride solution (as deoxygenation catalyst) per litre of water and adjust the instrument to read zero. If a water-saturated air calibration is necessary, follow the manufacturer's directions for its preparation.

20.2 To calibrate the probe in water, carefully obtain approximately 1 L of the type of water to be tested and saturate it with oxygen from the atmosphere by passing clean air

through it. Carefully draw three replicate samples from the well-mixed sample and immediately determine the dissolved oxygen concentration by Test Method A in duplicate. In the third replicate sample, immerse the probe and provide for suitable turbulence in the sample. Standardize the probe by adjusting the meter reading to the dissolved oxygen value as determined by the chemical procedure. If substances that interfere with the chemical method are present in the natural water or wastewater sample, standardize the probe using reagent water or a synthetic sample as indicated below.

**20.2.1 Fresh Water Samples** (less than 1000 mg/L of dissolved salts)—If chemical interferences are absent, use a test sample as indicated above. If interferences are present, use reagent water for membrane probes. With thallium probes, the greatest accuracy can be obtained from calibrating in a sample of the water to be tested or a synthetic sample similar to the test sample.

**20.2.2 Salt Water Samples and Membrane Probes** (greater than 1000 mg/L of dissolved salts)—Use a sample of clean water having the same salt content as the test material. If a sample free from substances that interfere with the azide method is not available, prepare a synthetic standardization sample by adding the same salts contained in the sample until the two solutions have the same electrical conductance within 5 %. High concentrations of dissolved salts are not a problem with the thallium probe.

**20.3 Temperature Coefficient**—Systems are available with automatic temperature compensation that permit direct measurements in milligrams per litre of dissolved oxygen. The temperature compensation of membrane probes corrects for changes in membrane characteristics including boundary-layer effects at the membrane-water interface and the changes in solubility of oxygen in water. The temperature compensation of thallium probes corrects for the changes characteristic of oxidation/reduction systems (see [Note 15](#)). It is necessary that the probe is in thermal equilibrium with the solution to be measured for satisfactory temperature correction.

**20.3.1** For those instrumental systems using membrane probes that are not temperature-compensated, the following procedure is recommended to obtain the temperature coefficient. Measure the oxygen content in water samples for five temperatures over a  $\pm 10^\circ\text{C}$  range greater and less than the expected sample temperature. By a least-squares procedure, or graphically in a semilog plot of  $Y$  versus  $T$ , calculate the slope and intercept constant as follows:

$$\text{Log } y = B/T + A \quad (3)$$

where:

- $y$  = scale factor, milligrams of dissolved oxygen per litre per microampere of electrode current,
- $B$  = slope constant,
- $T$  = temperature,  $^\circ\text{C}$ , and
- $A$  = intercept constant.

This relationship is linear on a semilog plot only over a range of  $\pm 10^\circ\text{C}$ . Over larger ranges an equation of higher degree is necessary to reflect the curvature of the relationship.

**20.3.2** If the thallium probe is utilized in a circuit without temperature compensation, the observed output in millivolts

must be corrected for the temperature sensitivity of the measuring cell that has a temperature coefficient of  $1.0 \text{ mV}/^\circ\text{C}$ . The measuring cell's output will increase (apparent dissolved oxygen concentration decrease) with an increase in temperature,

$$MV_R = MV_0 - 1.0 (T_o - T_R) \quad (4)$$

where:

- $MV_R$  = millivolts of output at reference temperature,
- $MV_0$  = millivolts of output observed,
- $T_R$  = reference temperature,  $^\circ\text{C}$ , and
- $T_o$  = temperature at the observed output,  $^\circ\text{C}$ .

**20.4 Correction for Content of Dissolved Salts**—If the concentration of salts is above 1000 mg/L, it will be necessary to correct for the effect of the salts in the relationship between oxygen partial pressure and concentration and also for the activity of thallium ion. For any given salt, a series of experimental data should be obtained in which solutions are prepared by dissolving varying weights of the salt in reagent water in the range of interest. The solutions plus a reagent water control are aerated at constant temperature until oxygen saturation is achieved. Determine the oxygen concentration of each solution by the chemical method and, at the same time, obtain probe readings. Determine the ratio  $A$  for each solution as follows:

$$A = O/R \quad (5)$$

where:

- $O$  = actual dissolved oxygen concentration, mg/L, as determined by Test Method A, and
- $R$  = reading of the probe meter.

For the reagent water control to which the probe is calibrated, the value of  $A$  is 1.0. Prepare a plot with salt concentration as abscissa and the ratio  $A$  as ordinate. Use the developed curve for calculation of the dissolved oxygen content of salt waters.

## 21. Sampling

**21.1 Bottle Samples**—Collect a bottle sample by the procedure described in Practice [D1066](#) or Practices [D3370](#). Collect the samples in 300-mL BOD bottles or other suitable glass-stoppered bottles, preventing entrainment or solution of atmospheric oxygen. If analysis is delayed beyond 15 min, cool the sample below  $5^\circ\text{C}$  and hold at this temperature until analyzed. Make the dissolved oxygen determination without further temperature adjustment using the appropriate temperature coefficient. It will be necessary to have the probe at the temperature of the sample or otherwise compensate for instability due to heat flow from probe to sample.

**21.2 In Situ Samples**—An effective use of the instrumental probes is for the direct, in situ determination of dissolved oxygen. By this means, sample handling problems are avoided, and data may be obtained quickly at various locations in a body of water without concern for the change in oxygen during storage or handling.



## 22. Procedure

22.1 Consider carefully the manufacturer's recommendations on the use of equipment to obtain satisfactory operation.

22.2 Provide for suitable turbulent flow past the membrane of membrane probes or past the thallium probe. This may, under some circumstances, be achieved adequately in flowing streams. However, in large bodies of water, it may be necessary to employ mechanical stirring or pumping of water past the probe. For accurate results, it is important that comparable degrees of turbulence be employed both for calibration and utilization.

22.3 If the probe is not automatically compensated for temperature changes, record the temperature of the water at the sample probe at the time of dissolved oxygen measurement. To avoid heat-flow effects, it is important that temperature equilibrium be established between sample and probe.

22.4 Recalibrate the probe whenever the comparison with reference samples (20.2) indicates an absolute error of more than  $\pm 0.2$  mg/L of dissolved oxygen or other value that is compatible with the desired accuracy.

22.4.1 Careful handling is required with membrane probes to avoid rupturing the thin membrane.

22.4.2 Recalibrate the probe after replacing the membrane or cleaning the probe in accordance with the manufacturer's directions. For a period of a few hours after a membrane replacement, the probe output may drift, and frequent recalibration may be required.

22.5 Probes can become fouled by oil, grease, biological growths, and so on, and cleaning may be required. Some of the techniques currently in use include air-blasting, brush cleaning, and ultrasonic cleaning systems.

22.6 The probe may be utilized in situ or the sample may be transferred to a sampling station that houses the probe and associated equipment.

22.6.1 In situ placement of the probe is preferable from the consideration that sample handling is not involved. However, in situ installations may be impractical because of problems with vandalism, severe climate conditions (freezing, and so on), and difficulty in probe recovery for maintenance.

22.6.2 The use of sample transfer systems is practical when proper consideration is given to design features such as line size, rates of transfer, kind of pump and location, practicality for cleaning the transfer system, and other maintenance.

22.6.3 Examine unattended probes at least once per week and recalibrate when required depending upon condition and service. Recalibration may be accomplished by using a portable probe that has been placed into position next to the unattended probe and that has been properly calibrated as outlined in 20.2.

## 23. Calculation

23.1 For uncompensated probes, correct the observed meter reading for the difference of the observed temperature from the standardization temperature by the factors developed in 20.3.

23.2 For wastewaters with varying salt contents, make corrections utilizing the data developed in 20.4.

## 24. Precision and Bias

24.1 The precision of this test method was determined by six operators in three laboratories running three duplicates each (not six laboratories as required by Practice D2777) using a saturated sample of reagent water. The mean concentration was 9.0 mg/L, and the pooled single-operator precision in these samples was 0.029 mg/L.

24.2 Precision and bias for this test method conforms to Practice D2777 – 77, which was in place at the time of collaborative testing. Under the allowances made in 1.4 of Practice D2777 – 08, these precision and bias data do meet existing requirements for interlaboratory studies of Committee D19 test methods.

## 25. Quality Control

25.1 In order to be certain that analytical values obtained using these test methods are valid and accurate within the confidence limits of the test, the following QC procedures must be followed when analyzing dissolved oxygen.

### 25.2 Calibration and Calibration Verification:

25.2.1 Standardize the titrating solution against the potassium biiodate solution.

25.2.2 Verify titrating solution by analyzing a sample with a known amount of the dissolved oxygen, if possible. The amount of the sample should fall within  $\pm 15$  % of the known concentration.

25.2.3 If standardization cannot be verified, restandardize the solution.

### 25.3 Initial Demonstration of Laboratory Capability:

25.3.1 If a laboratory has not performed the test before, or if there has been a major change in the measurement system, for example, new analyst, new instrument, and so forth, a precision and bias study must be performed to demonstrate laboratory capability.

25.3.2 Analyze seven replicates of the same solution. Each replicate must be taken through the complete analytical test method including any sample preservation and pretreatment steps.

25.3.3 Calculate the mean and standard deviation of the seven values and compare to the acceptable ranges of bias in 24.1. This study should be repeated until the recoveries are within the limits given in 24.1. If an amount other than the recommended amount is used, refer to Practice D5847 for information on applying the *F* test and *t* test in evaluating the acceptability of the mean and standard deviation.

### 25.4 Laboratory Control Sample (LCS):

25.4.1 Air-saturated reference water samples may be used for laboratory control samples. The value obtained must fall within the control limits established by the laboratory.

### 25.5 Method Blank:

25.5.1 Analyze a reagent water test blank with each batch. The amount of dissolved oxygen found in the blank should be less than the analytical reporting limit. If the amount of dissolved oxygen is found above this level, analysis of samples is halted until the contamination is eliminated, and a blank shows no contamination at or above this level, or the results



must be qualified with an indication that they do not fall within the performance criteria of the test method.

25.6 *Matrix Spike (MS):*

25.6.1 Dissolved oxygen is not an analyte that can be feasibly spiked into samples.

25.7 *Duplicate:*

25.7.1 To check the precision of sample analyses, analyze a sample in duplicate with each batch. The value obtained must fall within the control limits established by the laboratory.

25.7.2 Calculate the standard deviation of the duplicate values and compare to the precision determined by the laboratory or in the collaborative study using an *F* test. Refer to 6.4.4 of Practice D5847 for information on applying the *F* test.

25.7.3 If the result exceeds the precision limit, the batch must be reanalyzed or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

25.8 *Independent Reference Material (IRM):*

25.8.1 Independent reference water samples may be obtained from commercial sources. The value obtained from these samples must fall within the control limits established by the laboratory.

**TEST METHOD C  
INSTRUMENTAL PROBE PROCEDURE—  
LUMINESCENCE-BASED SENSOR**

**26. Scope**

26.1 This test method is applicable to waters containing dissolved oxygen in the range from 50 to 20 000 µg/L. It is the user’s responsibility to ensure the validity of this test method for waters of untested matrices.

26.2 This test method is for an instrumental probe-luminescence-based sensor using the technology of frequency-domain lifetime-based luminescence quenching and signal processing for analysis of dissolved oxygen. This test method is amenable to all water and wastewater matrices that are free from interferences at normal water and influent-to-treatment and final effluent wastewater concentrations.

26.3 Sustained periods of sensor immersion in water containing high levels of chlorine dioxide may degrade sensor performance. Refer to manufacturer’s guidelines for specific instrument interferences.

26.4 Instrumental probe-luminescence-based sensors for dissolved oxygen are practical for the continuous monitoring of dissolved oxygen content in natural water, process streams and biological processes, and so on.

**27. Summary of Test Method**

27.1 The most common method is Frequency Domain Lifetime-Based Luminescence Quenching of Dissolved Oxygen.

**28. Apparatus**

28.1 *Lifetime Luminescence-Based Probe*—Luminescence-based sensor probes that measure luminescence lifetime are normally composed of a luminophore embedded sensing foil, an emitter (Light Emitting Diode - LED) and a photodetector. The pulsed or modulated emitter causes excitation of the luminophore, which is quenched in the presence of oxygen. The photodetector converts the luminescence emission into an electrical signal that can be sampled and processed to compute the luminescence phase shift or luminescence lifetime. This phase shift or lifetime is used to quantify dissolved oxygen concentrations.

28.2 Probe designs vary in the emitter wavelength and luminophore that is used in the sensing foil.

**29. Calibration and Calibration Verification**

29.1 *Calibration*—Some luminescence-based sensors have a built-in multipoint calibration and therefore requires no initial multipoint calibration.

29.2 Calibration verification of the sensor is recommended as part of the laboratories’ quality control program to ensure the internal calibration; point calibration is constant and invariant during DO measurements.

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

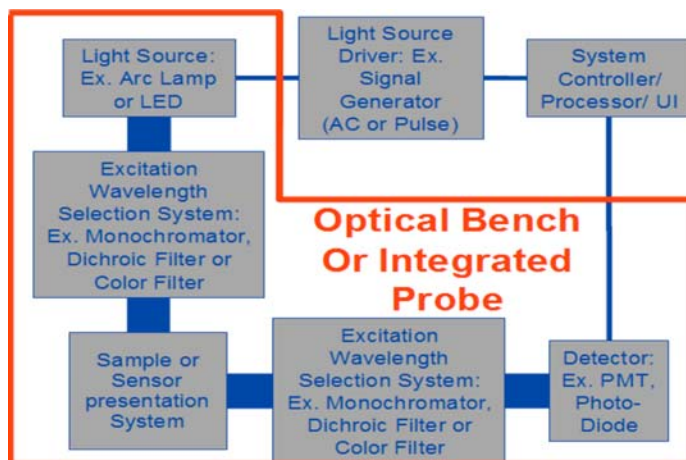


FIG. 1 Optical Bench or Integrated Probe

water-saturated air. Consequently, the calibration and verification of the instrumental probe-luminescence based sensor may be performed in air as well as water. The data presented in this test method was based on instruments with a single-point calibration.

**29.4 Preparation of Water-Saturated Air Sample:**

29.4.1 Add ¼ in. of reagent water to a clean 300-mL BOD bottle and seal with stopper.

29.4.2 Shake vigorously for approximately 30 seconds.

29.4.3 Allow 30 minutes for the BOD bottle and its contents to equilibrate to room temperature.

29.4.4 The water-saturated air sample is now ready to use for calibration purposes.

**29.5 Preparation of Air-Saturated Water:**

29.5.1 Add approximately 1500 mL of reagent water to a 2-L beaker.

29.5.2 Allow the water to equilibrate to room temperature ( $\pm 2^\circ\text{C}$ ).

29.5.3 Using a steady stream of clean compressed air (approximately 10 to 40 mL per minute flow rate) aerate the water for a minimum of 30 minutes.

29.5.4 Allow the water to re-equilibrate to room temperature ( $\pm 2^\circ\text{C}$ ) for 45 to 60 minutes.

29.5.5 Transfer aerated water to clean BOD bottles until overflowing, then seal with stopper.

29.5.6 Note the laboratory barometric pressure and sample temperature and use values from **Table X1.1** to calculate the theoretical dissolved oxygen concentration.

29.5.7 Analyze within 4 hours of preparation.

29.6 Provide for suitable turbulent flow past the sensor cap.

29.7 Verify calibration with water-saturated air or air-saturated water and the completion of matrix samples.

29.7.1 Calibration verification should be within 97 to 104 % of theoretical dissolved oxygen concentration.

29.7.2 If calibration verification is outside of theoretical recovery range, re-calibrate sensor and re-analyze matrix samples.

29.8 Two-point calibrations are acceptable; however, inter-laboratory data included in this standard was collected using a single-point calibration.

29.8.1 It is the users responsibility to demonstrate acceptability of calibration. Data must meet the method requirements in **Table 1** and **Table 2**.

29.8.2 Steps and supporting data for a two-point calibration can be found in **Appendix X2**.

**29.9 Preparation of Nitrogen-Saturated Water (for 0 Point of a Two-Point Calibration):**

29.9.1 Add approximately 1500 mL of reagent water to a 2-L beaker.

29.9.2 Using a steady stream of clean compressed nitrogen (approximately 10 to 40 mL per minutes flow rate) aerate the water for a minimum of 30 minutes.

**29.10 Preparation of Saturated Sodium Sulfite Solution:**

29.10.1 Add approximately 252.08 g/L of sodium sulfite ( $\text{Na}_2\text{SO}_3$ ) to reagent water for a 2 M solution. Alternatively, add approximately 50 g of anhydrous sodium sulfite ( $\text{Na}_2\text{SO}_3$ ) to 1L of reagent water for a solution of about 0.4 M.

29.10.2 The sodium sulfite sample is now ready to use for calibration purposes.

**30. Precision and Bias**

30.1 The precision of the test method was determined by eight laboratories using four saturated samples of reagent water at a reference dissolved oxygen concentration of 1.74 mg/L. The mean concentration was 1.73 mg/L, and the pooled single operator precision in these samples was 0.02 mg/L.

30.2 Precision and bias for this test method conform to Practice **D2777 – 03**, which was in place at the time of collaborative testing. Under the allowances made in Section 1.4 of **D2777 – 08**, these precision and bias data do meet existing requirements for interlaboratory studies of Committee D19 test methods.

NOTE 18—The data presented in this test method was based on instruments with a single-point calibration. The calibration was performed in air and verified in water.

**31. Quality Control**

31.1 In order to be certain that analytical values obtained using these test methods are valid and accurate within the confidence limits of the test, the following QC procedures must be followed when analyzing dissolved oxygen.

**31.2 Calibration and Calibration Verification:**

31.2.1 Use water-saturated air and air-saturated water reference samples described in **29.4** and **29.5**. Calibration values should fall within values in **Table 1**.

**31.3 Initial Demonstration of Laboratory Capability:**

31.3.1 If a laboratory has not performed the test before, or if there has been a major change in the measurement system, for example, new analyst, new instrument, and so forth, a precision and bias study must be performed to demonstrate laboratory capability.

31.3.2 Analyze four replicates of air-saturated water.

31.3.3 Calculate the mean and standard deviation of the seven values and compare to the acceptable ranges of bias in **30.1** and recovery and precision in **Table 1**. This study should be repeated until the recoveries are within the limits given in **30.1**.

**TABLE 1 Pooled Round Robin Recovery and Precision Criteria for Luminescence-Based Sensor**

Reference Water DO Range	DO Conc. (mg/L)	97.5 % Lower Limit of Recovery (%)	97.5 % Upper Limit of Recovery (%)	95 % Upper Limit of Precision (%)
Low	1.72 – 1.74	95.4	104.0	1.75
High	7.22 – 9.23	96.2	104.0	1.10

**TABLE 2 Method Performance of DO Measurements from Air-Saturated Water Reference Samples**

Lab No.	Data Set 1			Data Set 2		
	Method A Winkler % Rec.	Method B Membrane % Rec.	Method C LDO % Rec.	Method A Winkler % Rec.	Method B Membrane % Rec.	Method C LDO % Rec.
1	88.2	95.7	96.7	96.1	99.4	96.0
2	97.5	98.9	98.2	97.5	98.9	98.9
3	97.9	99.0	101.0	98.7	98.9	99.2
5	99.9	98.1	99.2	97.4	97.7	99.5
6	96.7	96.6	100.0	91.0	90.6	101.0
7	94.3	94.3	101.0	94.5	94.5	98.4
8	95.0	96.1	101.0	96.2	96.2	99.6
9	109.0	104.0	107.0	106.0	105.0	104.0
10	93.2	90.8	98.6	93.8	94.8	94.8
11	104.0	104.0	102.0	105.0	97.9	102.0
Average	97.5	97.7	101.0	97.6	97.4	99.3
Stdev	5.6	4.0	2.9	4.7	3.8	2.7
%RSD	5.8	4.1	2.9	4.8	3.9	2.7
Pooled Data Sets						
Average	97.6	97.5	100.0			
Stdev	5.0	3.8	2.7			
%RSD	5.2	3.9	2.7			

### 31.4 Laboratory Control Sample (LCS):

31.4.1 Air-saturated reference water samples may be used for laboratory control samples. The value obtained must fall within the control limits established by the laboratory.

### 31.5 Matrix Spike (MS):

31.5.1 Dissolved oxygen is not an analyte that can be feasibly spiked into matrix samples.

### 31.6 Duplicate:

31.6.1 To check the precision of sample analyses, analyze an air-saturated water reference sample in duplicate with each batch. The value obtained must fall within the control limits established by the laboratory.

31.6.2 Calculate the standard deviation of the duplicate values and compare to the precision determined by the laboratory or in the collaborative study.

31.6.3 If the result exceeds the precision limit, the batch must be reanalyzed or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

### 31.7 Independent Reference Material (IRM):

31.7.1 Independent reference water samples may be obtained from commercial sources. The value obtained from these samples must fall within the control limits established by the commercial source.

31.8 **Tables 1 and 2** reflect round robin results that a typical user of this test method should achieve.

## 32. Keywords

32.1 analysis; dissolved oxygen; frequency domain; lifetime-based; luminescence; probe; titrimetric; water

## APPENDIXES

### (Nonmandatory Information)

#### X1. OXYGEN SATURATION VALUES

X1.1 *Oxygen Saturation Values in Water and Elevations*—The solubility of oxygen in water at various temperatures and elevations under an atmospheric pressure of 760 mm is shown in **Table X1.1**.

X1.2 *Oxygen Saturation Values in Water and Salt Waters*—The solubility of oxygen in water exposed to water saturated

air under an atmospheric pressure of 760 mm is shown in **Table X1.2** at several temperatures and concentrations of sea water to illustrate the effects of salt concentration and temperature. The solubility versus dissolved salt concentration can vary considerably with the nature of the salts in solution.



**TABLE X1.1 Solubility of Oxygen (mg/L) at Various Temperatures and Elevations (Based on Sea Level Barometric Pressure of 760 mm Hg)<sup>12</sup>**

Temperature, ° C	Elevation, Feet above Sea Level						
	0	1000	2000	3000	4000	5000	6000
0	14.6	14.1	13.6	13.2	12.7	12.3	11.8
2	13.8	13.3	12.9	12.4	12.0	11.6	11.2
4	13.1	12.7	12.2	11.9	11.4	11.0	10.6
6	12.4	12.0	11.6	11.2	10.8	10.4	10.1
8	11.8	11.4	11.0	10.6	10.3	9.9	9.6
10	11.3	10.9	10.5	10.2	9.8	9.5	9.2
12	10.8	10.4	10.1	9.7	9.4	9.1	8.8
14	10.3	9.9	9.6	9.3	9.0	8.7	8.3
16	9.9	9.7	9.2	8.9	8.6	8.3	8.0
18	9.5	9.2	8.7	8.6	8.3	8.0	7.7
20	9.1	8.8	8.5	8.2	7.9	7.7	7.4
22	8.7	8.4	8.1	7.8	7.7	7.3	7.1
24	8.4	8.1	7.8	7.6	7.3	7.1	6.8
26	8.1	7.8	7.6	7.3	7.0	6.8	6.6
28	7.8	7.5	7.3	7.0	6.8	6.6	6.3
30	7.5	7.2	7.0	6.8	6.5	6.3	6.1
32	7.3	7.1	6.8	6.6	6.4	6.1	5.9
34	7.1	6.9	6.6	6.4	6.2	6.0	5.8
36	6.8	6.6	6.3	6.1	5.9	5.7	5.5
38	6.6	6.4	6.2	5.9	5.7	5.6	5.4
40	6.4	6.2	6.0	5.8	5.6	5.4	5.2

**TABLE X1.2 Solubility of Oxygen (mg/L) at Various Temperatures and Chlorinity (Based on Sea Level Barometric Pressure of 760 mm Hg)<sup>12</sup>**

Temperature, ° C	Chlorinity, %					
	0	4.0	8.0	12.0	16.0	20.0
0	14.6	13.9	13.2	12.5	11.9	11.3
2	13.8	13.2	12.5	11.9	11.4	10.8
4	13.1	12.5	11.9	11.3	10.8	10.3
6	12.4	11.8	11.3	10.8	10.3	9.8
8	11.8	11.3	10.8	10.3	9.8	9.4
10	11.3	10.8	10.3	9.8	9.4	9.0
12	10.8	10.3	9.8	9.4	9.0	8.6
14	10.3	9.9	9.4	9.0	8.6	8.3
16	9.9	9.4	9.0	8.6	8.3	8.0
18	9.5	9.1	8.7	8.3	8.0	7.6
20	9.1	8.7	8.3	8.0	7.7	7.4
22	8.7	8.4	8.0	7.7	7.4	7.1
24	8.4	8.1	7.7	7.4	7.1	6.9
26	8.1	7.8	7.5	7.2	6.9	6.6
28	7.8	7.5	7.2	6.9	6.6	6.4
30	7.5	7.2	7.0	6.7	6.4	6.2
32	7.3	7.0	6.7	6.5	6.2	6.0
34	7.1	6.8	6.5	6.3	6.0	5.8
36	6.8	6.6	6.3	6.1	5.8	5.6
38	6.6	6.4	6.1	5.9	5.6	5.4
40	6.4	6.2	5.9	5.7	5.4	5.2

## X2. TWO-POINT CALIBRATION ZERO POINT STEPS

X2.1 Prepare water saturated air as described in 29.4.

X2.2 Prepare nitrogen-saturated air as described in 29.9.2.

X2.3 Prepare 0.4 M sodium sulfite solution as described in 29.10.

**TABLE X2.1 Single Operator Recovery and Precision Criteria for Luminescence-Based Sensor – Two-Point Calibration**

<b>Key</b>				
ASW (BOD)		Single Point Calibration in Air Saturated Water (Saturated solution placed in BOD bottles and capped)		
ASW (BOD) / N <sub>2</sub>		Two Point Calibration in Air Saturated Water (BOD) and Nitrogen Saturated Water		
ASW (BOD) / Na <sub>2</sub> SO <sub>3</sub>		Two Point Calibration in Air Saturated Water (BOD) and Sodium Sulfite		
ASW (Bubbler)		Single Point Calibration in Air Saturated Water (Saturated solution in a bubbler)		
ASW (Bubbler) / N <sub>2</sub>		Two Point Calibration in Air Saturated Water (Bubbler) and Nitrogen Saturated Water		
ASW (Bubbler) / Na <sub>2</sub> SO <sub>3</sub>		Two Point Calibration in Air Saturated Water (Bubbler) and Sodium Sulfite		
WSA		Single Point Calibration in Water Saturated Air		
WSA / N <sub>2</sub>		Two Point Calibration in Water Saturated Air and Nitrogen Saturated Water		
WSA / Na <sub>2</sub> SO <sub>3</sub>		Two Point Calibration in Water Saturated Air and Sodium Sulfite		
<b>Pooled Data Set<sup>4</sup></b>				
Calibration Method		ASW (BOD)	ASW (BOD) / N <sub>2</sub>	ASW (BOD) / Na <sub>2</sub> SO <sub>3</sub>
Test point	Temp	100.0 %	100.0 %	100.0 %
Average RDO reading	26.83	99.46 %	99.34 %	99.27 %
Stdev		1.05 %	1.02 %	1.03 %
% RSD		1.05 %	1.03 %	1.04 %
Calibration Method		ASW (BOD)	ASW (BOD) / N <sub>2</sub>	ASW (BOD) / Na <sub>2</sub> SO <sub>3</sub>
Test point	Temp	100.0 %	100.0 %	100.0 %
Average RDO reading	26.83	99.46 %	99.34 %	99.27 %
Stdev		1.05 %	1.02 %	1.03 %
% RSD		1.05 %	1.03 %	1.04 %
Calibration Method		ASW (Bubbler)	ASW (Bubbler) / N <sub>2</sub>	ASW (Bubbler) / Na <sub>2</sub> SO <sub>3</sub>
Test point	Temp	100.0 %	100.0 %	100.0 %
Average RDO reading	26.83	99.21 %	99.17 %	99.18 %
Stdev		1.02 %	1.03 %	1.03 %
% RSD		1.03 %	1.04 %	1.04 %
Calibration Method		WSA	WSA / N <sub>2</sub>	WSA / Na <sub>2</sub> SO <sub>3</sub>
Test point	Temp	100.0 %	100.0 %	100.0 %
Average RDO reading	26.83	99.18 %	99.20 %	99.22 %
Stdev		1.04 %	1.04 %	1.02 %
% RSD		1.05 %	1.05 %	1.03 %

<sup>4</sup> Data collected from the In-Situ Inc. Research and Development Laboratory, Fort Collins, CO.

## SUMMARY OF CHANGES

Committee D19 has identified the location of selected changes to this standard since the last issue (D888 – 09) that may impact the use of this standard. (Approved March 1, 2012.)

- (1) Clarified **29.5.6**.
- (2) Modified **29.8** to clarify the interlaboratory process and the two-point calibration option.
- (3) Added **Note 18** to **30.2** to address the interlaboratory study.
- (4) Moved the single-point interlaboratory study data, **Table 1** and **Table 2**, from the appendix, which is non-mandatory, to the main test method.
- (5) Added **Appendix X2** on the two-point calibration process and the single laboratory supporting data.

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