



Standard Test Method for On-Line Measurement of Low-Level Dissolved Oxygen in Water¹

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1. Scope

1.1 This test method covers the on-line determination of dissolved oxygen (DO) in water samples primarily in ranges from 0 to 500 $\mu\text{g/L}$ (ppb), although higher ranges may be used for calibration. On-line instrumentation is used for continuous measurements of DO in samples that are brought through sample lines and conditioned from high-temperature and high-pressure sources when necessary.

1.2 *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 specific hazards statements, see 6.5.

2. Referenced Documents

2.1 ASTM Standards:

- D 1066 Practice for Sampling Steam²
- D 1129 Terminology Relating to Water²
- D 1192 Specification for Equipment for Sampling Water and Steam in Closed Conduits²
- D 1193 Specification for Reagent Water²
- D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water²
- D 3370 Practices for Sampling Water from Closed Conduits²
- D 3864 Practice for Continual On-Line Monitoring Systems for Water Analysis²

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *diffusion-type probes*—galvanic or polarographic sensors that depend on the continuous influx of oxygen through the membrane to develop the measurement signal.

3.2.2 *equilibrium-type probes*—modified polarographic sensing probes that have a negligible influx of oxygen through the membrane except during changes of sample DO concen-

tration. Oxygen consumption and regeneration balance each other within the probes under stable conditions, and the net flux through the membrane is insignificant.

3.2.3 *galvanic systems*—sensing probes and measuring instruments that develop an electrical current from two electrodes inside the probe from which the final measurement is derived.

3.2.4 *partial pressure (of oxygen)*—the volume fraction of oxygen multiplied by the total pressure. The partial pressure of oxygen is the actual parameter detected by DO probes, whether in air or dissolved in water.

3.2.5 *polarographic systems*—sensing probes and measuring instruments that include circuitry to control the operating voltage of the system, usually using a third (reference) electrode in the probe.

4. Summary of Test Method

4.1 Dissolved oxygen is measured by means of an electrochemical cell separated from the sample by a gas-permeable membrane. Behind the membrane and inside the probe, electrodes immersed in an electrolyte develop an electrical current proportional to the oxygen partial pressure of the sample.

4.2 The partial pressure signal is temperature compensated automatically to account for variations with temperature of the following: oxygen solubility in water; electrochemical cell output; and, when necessary, diffusion rate of oxygen through the membrane. This yields a direct readout in concentration of $\mu\text{g/L}$ (ppb) or mg/L (ppm).

4.3 Diffusion-type probes rely on a continuous diffusion of oxygen through the membrane. Immediately inside the membrane, oxygen is reduced at the noble metal cathode, usually platinum or gold. An electrical current is developed that is directly proportional to the arrival rate of oxygen molecules at the cathode, which is in turn dependent on the diffusion rate through the membrane. The less noble anode, usually silver or lead, completes the circuit and is oxidized in proportion to the current flow. At steady state, the resulting current signal is then proportional to the oxygen partial pressure of the sample. Thorough descriptions of diffusion-type probes are given by Hitchman (1)³ and Fatt (2).

4.4 Equilibrium-type probes rely on oxygen diffusion

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² *Annual Book of ASTM Standards*, Vol 11.01.

³ The boldface numbers in parentheses refer to the list of references at the end of this test method.

through the membrane only until equilibrium between the inside and outside is achieved. Oxygen is reduced at the noble metal cathode, as with diffusion-type probes. However, the measuring circuit forces electrical current to flow through the noble metal anode equal and opposite to that at the cathode, and the resulting oxidation reaction produces oxygen. This is the exact reverse of the reaction at the cathode, so there is no net consumption of oxygen by the probe. It reaches equilibrium in constant DO samples, and no net oxygen diffuses through the membrane. Accuracy is not dependent on membrane surface condition or sample flow-rate.⁴

5. Significance and Use

5.1 DO may be either a corrosive or passivating agent in boiler/steam cycles and is therefore controlled to specific concentrations that are low relative to environmental and wastewater treatment samples. Out-of-specification DO concentrations may cause corrosion in boiler systems, which leads to corrosion fatigue and corrosion products—all detrimental to the life and efficient operation of a power unit. The efficiency of DO removal from boiler feedwater by mechanical or chemical means, or both, may be monitored by continuously measuring the DO concentration before and after the removal process with on-line instrumentation. DO measurement is also a check for air leakage into the boiler water cycle.

5.2 Guidelines for feedwater to high-pressure boilers with all volatile treatment generally require a feedwater DO concentration below 5 µg/L (3).

5.3 Boiler feedwater with oxygenated treatment is maintained in a range of 50 to 300 µg/L DO (4).

5.4 In microelectronics production, DO can be detrimental in some manufacturing processes, for example, causing undesirable oxidation on silicon wafers.

6. Interferences

6.1 The leakage of atmospheric air into samples is sometimes difficult to avoid and detect. Although sample line fittings and connections to flow chambers may be water tight, it is still possible for air to diffuse through the water film of a joint to contaminate a low-µg/L sample. Section 9 provides further details on this non-obvious interference.

6.2 Diffusion-type probes consume oxygen and will deplete it from the sample in immediate contact with the membrane surface unless an adequate, turbulent sample flow is maintained. The manufacturer's minimum flowrate recommendations must be met or exceeded in order to prevent erroneously low readings.

6.3 Diffusion-type probes are subject to negative errors from the buildup of coatings such as iron oxides, which impede the diffusion rate of oxygen. (Equilibrium-type probes are not subject to errors from flowrate or coating.)

6.4 Calibration must be corrected for barometric pressure according to the manufacturer's recommendations at atmo-

spheric conditions that deviate from a nominal range of 745 to 775 mmHg. See Table 1 for altitude corrections. Calibration under low-pressure conditions without compensation would result in positive measurement errors.

6.5 The growth of bacteria in sample lines and flow chambers and on probe membranes can consume oxygen and cause negative errors. Chemical sterilization with hydrochloric acid (1 + 44) or sodium hypochlorite solution (10 mg/L) should be performed if errors from bacteria growth are suspected.

NOTE 1—Warning: Do not mix hydrochloric acid and sodium hypochlorite since hazardous chlorine gas would be released rapidly.

6.6 The passage of high-temperature samples containing both DO and an oxygen scavenger through hot sample lines can allow continued reaction of the two. With long sample lines, the DO measured at the probe may be significantly below that at the sample point. Short sample lines and cooling near the source are recommended.

6.7 Volatile oxygen scavengers or suppressants, such as hydrazine, amines, and hydrogen, that pass through the probe membrane may cause unwanted reactions at the electrodes and negative errors. The magnitude of errors depends on the relative concentrations of DO and the oxygen scavenger or suppressant as well as the type of electrochemical cell used. The probe manufacturer's cautions and limitations should be considered.

6.8 New sample lines require conditioning to achieve equilibrium conditions. See Practices D 3370 to avoid sampling interferences.

6.9 Iron oxides and other deposits accumulate in slow-flowing horizontal sample lines and can develop chromatograph-like retention of dissolved species, resulting in very long delay times. Precautions are described in Section 9.

6.10 The response time can be slow for large decreases in DO. This is especially true of measurements below 10 µg/L following air calibration, which corresponds to a concentration

TABLE 1 Solubility of Oxygen (mg/L) at Various Temperatures and Elevations (Based on Sea Level Barometric Pressure of 760 mmHg) (5)

Temperature, °C	Elevation, ft 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

⁴ Leeds & Northrup, North Wales, PA, Model 7931 dissolved oxygen analyzer and probe have been found to provide satisfactory equilibrium-type probe performance.

decrease of 3 to 4 orders of magnitude. Hours may be required for all traces of oxygen to diffuse out of the probe and to achieve accurate measurements at low $\mu\text{g/L}$ levels.

7. Apparatus

7.1 Measuring Instrument:

7.1.1 The instrument should have both $\mu\text{g/L}$ (ppb) and mg/L (ppm) range capability. It must have a span calibration adjustment to match the readout to the sensitivity of a particular probe.

7.1.2 The direct readout of DO concentration requires temperature compensation for effects of the following: (1) oxygen solubility in water; (2) electrochemical cell output; and (3) when necessary, diffusion rate of oxygen through the membrane. During air calibration, the instrument must disable the oxygen solubility portion of the compensation to respond only to partial pressure.

7.1.3 If included, electrical output signal(s) from the instrument must be isolated from the probe measuring circuit and from earth ground in order to prevent ground loop problems when the instrument is connected to grounded external devices.

7.2 Probe:

7.2.1 Diffusion-type probes use galvanic or polarographic systems, with a noble metal cathode and oxidizable anode immersed in an electrolyte and separated from the sample with a polyethylene or fluorocarbon gas-permeable membrane.

7.2.2 Equilibrium-type probes are similar to polarographic probes, except that both the anode and cathode are platinum and the anode is not oxidized.

7.2.3 A sealed flow-through probe configuration must be used to prevent contamination from the atmosphere, as described in 6.1. The flowrate must be maintained within the manufacturer's recommendations. The probe must be capable of withstanding the flowrate, temperature, and pressure conditions of the installation. The probe must incorporate an integral precision temperature sensor to ensure that it senses the sample temperature at which the DO is being detected in order to ensure accurate temperature compensation with fast response.

7.2.4 Diffusion-type probes must have their electrodes, electrolyte, and membrane serviced or replaced according to the manufacturer's recommendations. Equilibrium-type probes do not require internal maintenance.

7.2.5 Probe membranes must be cleaned per the manufacturer's recommendations. The cleaning frequency is determined by experience with the particular sample and must be sufficient to maintain acceptable accuracy with diffusion-type probes (see 6.3). The cleaning of equilibrium-type probes is not necessary unless a heavy coating increases response time or becomes biologically active (see 6.5).

8. Reagents

8.1 *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,

where such specifications are available.⁵ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*— Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type I of Specification D 1193.

8.3 *Hydrochloric Acid* (1 + 44)—Add 1 volume of concentrated HCl (sp gr 1.19) to 44 volumes of water and mix.

8.4 *Sodium Hypochlorite* (10 mg/L)—Add approximately 0.05 mL (1 drop) of 5 % NaOCl solution (commercial bleach is satisfactory for this purpose) to 250 mL of water.

8.5 *Cobalt Chloride Solution, Saturated*—Dissolve 4.5 g of cobalt chloride (CoCl_2) in 10 mL of water.

8.6 *Sodium Sulfite Zero Solution* (10 g/200 mL)—Dissolve 10 g of sodium sulfite (Na_2SO_3) in 200 mL of water.

NOTE 2—To attain zero DO more rapidly, add two drops of saturated cobalt chloride solution to the sodium sulfite zero solution.

9. Sampling

9.1 Design and operate the sample lines to maintain sample integrity and fast response. Follow the applicable sampling precautions in Practices D 1066, D 3370, and D 3864 and Specification D 1192.

9.2 Use sample lines of compatible materials. Do not use copper because it can oxidize and consume oxygen. Do not use plastic or rubber since they are gas permeable and would allow air contamination.

9.3 Maintain a continuous, stable flowrate to enable the sample line to reach equilibrium with the sample conditions. Measurements following changes to the sample flowrate or temperature may not represent actual process conditions during the period of time required to recover from transient effects.

9.4 Seal the sample from the atmosphere to prevent oxygen absorption. Leakage of the equivalent of only one 2-mm-diameter air bubble/min into a sample flowing at 100 mL/min adds approximately 11 $\mu\text{g/L}$ oxygen to the sample. Test the sample line integrity by observing the measurement under steady state conditions of DO and increasing the sample flowrate approximately 50 %, but not exceeding the manufacturer's recommendations. A significant decrease in DO reading is usually an indication of air leakage since the higher flowrate dilutes the leak. (An increase in DO reading could be observed with a diffusion-type probe and indicates that the original flowrate was too low, as described in 6.2. The flowrate must then be increased until a stable plateau of response is reached.)

9.5 In power plant installations in which iron oxide and other solids occur in pure water samples, control flowrates to minimize the accumulation of deposits, which could delay the transport of dissolved materials greatly. A water sample flow velocity of 1.8 m/s (6 ft/s) in sample lines has been found optimum. Additional sample line design criteria have been documented in Refs (6-8).

⁵ "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., 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, UK, and the "United States Pharmacopeia."