



Standard Test Method for Oxidation-Reduction Potential of Water¹

This standard is issued under the fixed designation D1498; 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.

1. Scope

1.1 This test method covers the apparatus and procedure for the electrometric measurement of oxidation-reduction potential (ORP) in water. It does not deal with the manner in which the solutions are prepared, the theoretical interpretation of the oxidation-reduction potential, or the establishment of a standard oxidation-reduction potential for any given system. The test method described has been designed for the routine and process measurement of oxidation-reduction potential.

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

1.3 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*²

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

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *oxidation-reduction potential, n* —the electromotive force, E_m , developed between a noble metal electrode and a standard reference electrode.

¹ This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.03 on Sampling Water and Water-Formed Deposits, Analysis of Water for Power Generation and Process Use, On-Line Water Analysis, and Surveillance of Water.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1.1 *Discussion*—This oxidation-reduction potential (ORP) is related to the solution composition by:

$$E_m = E^o + 2.3 \frac{RT}{nF} \log[A_{ox}/A_{red}]$$

where:

E_m	= ORP,
E^o	= constant that depends on the choice of reference electrodes,
F	= Faraday constant,
R	= gas constant,
T	= absolute temperature, °C + 273.15,
n	= number of electrons involved in process reaction, and
A_{ox} and A_{red}	= activities of the reactants in the process.

4. Summary of Test Method

4.1 This is a test method designed to measure the ORP which is defined as the electromotive force between a noble metal electrode and a reference electrode when immersed in a solution. The test method describes the equipment available to make the measurement, the standardization of the equipment and the procedure to measure ORP. The ORP electrodes are inert and measure the ratio of the activities of the oxidized to the reduced species present.

5. Significance and Use

5.1 Various applications include monitoring the chlorination/dechlorination process of water, recognition of oxidants/reductants present in wastewater, monitoring the cycle chemistry in power plants, and controlling the processing of cyanide and chrome waste in metal plating baths.

5.2 The measurement of ORP has been found to be useful in the evaluation of soils, for evaluating treatment design data at sites contaminated with certain chemicals, and in evaluating solid wastes.

6. Interferences

6.1 The ORP electrodes reliably measure ORP in nearly all aqueous solutions and in general are not subject to solution interference from color, turbidity, colloidal matter, and suspended matter.

6.2 The ORP of an aqueous solution is sensitive to change in temperature of the solution, but temperature correction is

rarely done due to its minimal effect and complex reactions. Temperature corrections are usually applied only when it is desired to relate the ORP to the activity of an ion in the solutions.

6.3 The ORP of an aqueous solution is almost always sensitive to pH variations even to reactions that do not appear to involve hydrogen or hydroxyl ions. The ORP generally tends to increase with an increase in hydrogen ions and to decrease with an increase in hydroxyl ions during such reactions.

6.4 Reproducible oxidation-reduction potentials cannot be obtained for chemical systems that are not reversible. Most natural and ground waters do not contain reversible systems, or may contain systems that are shifted by the presence of air. The measurement of end point potential in oxidation-reduction titration is sometimes of this type.

6.5 If the metallic portion of the ORP electrode is sponge-like, materials absorbed from solutions may not be washed away, even by repeated rinsings. In such cases, the electrode may exhibit a memory effect, particularly if it is desired to detect a relatively low concentration of a particular species immediately after a measurement has been made in a relatively concentrated solution. A brightly polished metal electrode surface is required for accurate measurements.

6.6 The ORP resulting from interactions among several chemical systems present in mixed solutions may not be assignable to any single chemical.

7. Apparatus

7.1 *Meter*—Most laboratory pH meters can be used for measurements of ORP by substitution of an appropriate set of electrodes and meter scale. Readability to 1 mV is adequate. The choice will depend on the accuracy desired in the determination.

7.1.1 Most process pH meters can be used for measurement of ORP by substitution of an appropriate set of electrodes and meter scale. These instruments are generally much more rugged than those which are used for very accurate measurements in the laboratory. Usually, these more rugged instruments produce results that are somewhat less accurate and precise than those obtained from laboratory instruments. The choice of process ORP analyzer is generally based on how closely the characteristics of the analyzer match the requirements of the application. Typical factors which may be considered include, for example, the types of signals which the analyzer can produce to drive external devices, and the span ranges available.

7.1.2 For remote ORP measurements the potential generated can be transmitted to an external indicating meter. Special shielded cable is required to transmit the signal.

7.2 *Reference Electrode*—A calomel, silver-silver chloride, or other reference electrode of constant potential shall be used. If a saturated calomel electrode is used, some potassium chloride crystals shall be contained in the saturated potassium chloride solution. If the reference electrode is of the flowing junction type, a slow outward flow of the reference-electrode solution is desired. To achieve this, the solution pressure inside the liquid junction should be somewhat in excess of that

TABLE 1 National Institute of Standards and Technology (NIST) Materials for Reference Buffer Solutions

NIST Standard Sample Designation ^A	Buffer Salt	Drying Procedure
186-II-e	disodium hydrogen phosphate	2 h in oven at 130°C
186-I-e	potassium dihydrogen phosphate	2 h in oven at 130°C
185-g	potassium hydrogen phthalate	drying not necessary

^A The buffer salts listed can be purchased from the Office of Standard Reference Materials, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

outside the junction. In nonpressurized applications this requirement can be met by maintaining the inside solution level higher than the outside solution level. If the reference electrode is of the nonflowing junction type, these outward flow and pressurization considerations shall not apply. The reference electrode and junction shall perform satisfactorily as required in the procedure for checking sensitivity described in 11.2.

7.3 *Oxidation-Reduction Electrode*—A noble metal is used in the construction of oxidation-reduction electrodes. The most common metals employed are platinum and gold; silver is rarely used. It is important to select a metal that is not attacked by the test solution. The construction of the electrode shall be such that only the noble metal comes in contact with the test solution. The area of the noble metal in contact with the test solution should be approximately 1 cm².

7.4 *Electrode Assembly*—A conventional electrode holder or support can be employed for laboratory measurements. Many different styles of electrode holders are suitable for various process applications such as measurements in an open tank, process pipe line, pressure vessel, or a high pressure sample line.

8. Reagents and Materials

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.³ 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*—References to water that is used for reagent preparation, rinsing, or dilution shall be understood to mean water that conforms to the quantitative specifications for type I or II reagent water of Specification D1193.

8.3 *Aqua Regia*—Mix 1 volume of concentrated nitric acid (HNO₃, sp gr 1.42) with 3 volumes of concentrated hydrochloric acid (HCl, sp gr 1.18). It is recommended that only enough solution be prepared for immediate requirements.

8.4 *Buffer Standard Salts*—Table 1 lists the buffer salts

³ *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 the *United States Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

TABLE 2 Potential of the Platinum Electrode for Several Reference Electrodes at 25°C in Ferrous-Ferric Reference Solution

Reference Electrode	Potential EMF, mV
Hg, Hg ₂ Cl ₂ , satd KCl	+ 430
Ag, AgCl, 1.00 M KCl	+ 439
Ag, AgCl, 4.00 M KCl	+ 475
Ag, AgCl, satd KCl	+ 476
Pt, H ₂ (p = 1), H (a = 1)	+ 675

available from the National Institute of Standards and Technology specifically for the preparation of standard buffer solutions. The NIST includes numbers and drying procedures.

8.4.1 *Phthalate Reference Buffer Solution* (pH_s = 4.00 at 25°C)—Dissolve 10.12 g of potassium hydrogen phthalate (KHC₈H₄O₄) in water and dilute to 1 L.

8.4.2 *Phosphate Reference Buffer Solution* (pH_s = 6.86 at 25°C)—Dissolve 3.39 g of potassium dihydrogen phosphate (KH₂PO₄) and 3.53 g of anhydrous disodium hydrogen phosphate (Na₂HPO₄) in water and dilute to 1 L.

8.5 *Chromic Acid Cleaning Solution*—Dissolve about 5 g of potassium dichromate (K₂Cr₂O₇) in 500 mL of concentrated sulfuric acid (H₂SO₄, sp gr 1.84).

8.6 *Detergent*—Use any commercially available “low-suds” liquid or solid detergent.

8.7 *Nitric Acid* (1 + 1)—Mix equal volumes of concentrated nitric acid (HNO₃, sp gr 1.42) and water.

8.8 *Redox Standard Solution; Ferrous-Ferric Reference Solution*⁴—Dissolve 39.21 g of ferrous ammonium sulfate (Fe(NH₄)₂(SO₄)₂·6H₂O), 48.22 g of ferric ammonium sulfate (FeNH₄(SO₄)₂·12H₂O) and 56.2 mL of sulfuric acid (H₂SO₄, sp gr 1.84) in water and dilute to 1 L. It is necessary to prepare the solution using reagent grade chemicals that have an assay confirming them to be within 1% of the nominal composition. The solution should be stored in a closed glass or plastic container.

8.8.1 The ferrous-ferric reference solution is a reasonably stable solution with a measurable oxidation-reduction potential. Table 2 presents the potential of the platinum electrode for various reference electrodes at 25°C in the standard ferrous-ferric solution.

8.9 *Redox Reference Quinhydrone Solutions*—Mix 1 L of pH 4 buffer solution, (see 8.4.1), with 10 g of quinhydrone. Mix 1 L of pH 7 buffer solution, (see 8.4.2), with 10 g of quinhydrone. Be sure that excess quinhydrone is used in each solution so that solid crystals are always present. These reference solutions are stable for only 8 h. Table 3 lists the nominal millivolt redox readings for the quinhydrone reference solutions at temperatures of 20°C, 25°C, and 30°C.

8.10 *Redox Standard Solution; Iodide/Triiodide*—Dissolve 664.04 g of potassium iodide (KI), 1.751 g of resublimed I₂, 12.616 g of boric acid (H₃BO₃), and 20 ml of 1 M potassium hydroxide (KOH) in water and dilute to 1 L. Mix solution. This

solution is stable at least one year. Solution can be stored in a closed glass or plastic container. Table 4 provides the potential of the platinum electrode for various reference electrodes at various temperatures in the standard Iodide/Triiodide solution.

9. Sampling

9.1 Collect the samples in accordance with Practices D3370.

10. Preparation

10.1 *Electrode Treatment*—Condition and maintain ORP electrodes as recommended by the manufacturer. If the assembly is in intermittent use, the immersible ends of the electrode should be kept in water between measurements. Cover the junctions and fill-holes of reference electrodes to reduce evaporation during prolonged storage.

10.2 *ORP Electrode Cleaning*—It is desirable to clean the electrode daily. Remove foreign matter by a preliminary treatment with a detergent or mild abrasive, such as toothpaste. If this is insufficient, use 1 + 1 nitric acid. Rinse the electrode in water several times. An alternative cleaning procedure is to immerse the electrode in chromic acid cleaning mixture at room temperature for several minutes, then rinse with dilute hydrochloric acid, and then thoroughly rinse with water. If these steps are insufficient, immerse the ORP electrode in warm (70°C) aqua regia and allow to stand for 1 min. This solution dissolves noble metal and should not be used longer than the time specified. In these cleaning operations, particular care must be exercised to protect glass-metal seals from sudden changes of temperature, which might crack them.

11. Standardization

11.1 Turn on meter according to manufacturer’s instructions. Check zero on meter by shorting the input connection. The reading should be less than ±0.5 mV.

11.2 *Checking the Response of the Electrode to Standard Redox Solutions* (see 8.8, 8.9 and 8.10)—Wash the electrodes with three changes of water or by means of a flowing stream from a wash bottle. Use one or more of the solutions from 8.8, 8.9, and 8.10 to check the response of the electrode. Fill the sample container with fresh redox standard solution and immerse the electrodes. The reading should be within 30 mV of the value expected for the standard solution. Repeat the measurement with fresh solution. The second reading should not differ from the first by more than 10 mV.

12. Procedure

12.1 After the electrode/meter assembly has been standardized as described in 11, wash the electrodes with three changes of water or by means of a flowing stream from a wash bottle. Place the sample in a clean glass beaker or sample cup and insert the electrodes. Provide adequate agitation throughout the measurement period. Read the millivolt potential of the solution allowing sufficient time for the system to stabilize. Measure successive portions of the sample until readings on two successive portions differ by no more than 10 mV. A system that is very slow to stabilize probably will not yield a meaningful ORP.

⁴ “Standard Solution for Redox Potential Measurements,” *Analytical Chemistry*, Vol 44, 1972, p. 1038.

TABLE 3 Nominal ORP of Reference Quinhydrone Solutions

	ORP, mV								
	4			7			9		
Buffer solution, nominal pH	20	25	30	20	25	30	20	25	30
Temperature, °C									
Reference Electrode									
Silver/silver chloride	268	263	258	92	86	79	−23	−32	−41
Calomel	223	218	213	47	41	34	−68	−77	−86
Hydrogen	470	462	454	295	285	275	180	167	155

TABLE 4 Nominal Potential in mV of Platinum Electrode in Iodide/Triiodide Standard Solution

Reference Electrode	Temperature, °C		
	20	25	30
Silver/silver chloride Ag, AgCl, sat'd KCl	220	221	222
Standard Hydrogen Pt, H ₂ (p=1), H (a=1)	424	420	415
Calomel Hg, Hg ₂ Cl ₂ , sat'd KCl	176	176	175

12.2 Continuous Determination of the ORP of Flowing Streams or Batch Systems—Process ORP analyzers with their rugged electrodes and electrode chambers provide continuous measurements which are the basis for fully automatic control. Make selection of the electrodes and electrode chamber to suit the physical and chemical characteristics of the process material. Locate the submersion-style electrode chamber so that fresh solution representative of the process stream or batch continuously passes across the electrodes. Agitation may be employed in order to make the stream or batch more nearly homogeneous. The ORP value is usually displayed continuously and can be noted at any specific time. Frequently, the pH value is continuously recorded, yielding a permanent record.

13. Calculation

13.1 Report the oxidation-reduction potential in millivolts directly from the meter. The electrode system employed must also be reported.

13.2 If it is desired to report the oxidation-reduction potential referred to the hydrogen electrode, calculate as follows:

$$E_h = E_{obs} + E_{ref}$$

where:

- E_h = oxidation-reduction potential referred to the hydrogen scale, mV,
- E_{obs} = observed oxidation-reduction potential of the noble metal-reference electrode employed, mV, and
- E_{ref} = oxidation-reduction potential of the reference electrode as related to the hydrogen electrode, mV.

14. Report

14.1 Report the oxidation-reduction potential to the nearest 1 mV, interpolating the meter scale as required. When considered appropriate, the temperature at which the measurement was made and the pH at the time of measurement, may also be reported.

15. Precision and Bias

15.1 The collaborative test data were obtained on standard solutions for bias data and a range of samples including distilled water, spiked distilled water, tap water, chlorinated tap

water, and a standard buffer for single operator precision data. Interlaboratory precision was not directly determined by this round robin because of the inherent instability of ORP samples.

15.2 Precision—The single operator standard deviation (S_o) and total standard deviation (S_T) determined in this round-robin are shown in Table 5. The data for distilled water was not included because it was determined that distilled water does not have a sufficient redox couple present to give a stable and meaningful reading. Distilled water measurements ranged from 170 to 547 mV. The data for tap water was not included because it was determined that the method of sample collection did not account for the changing ORP value in the tap water. Tap water measurements ranged from 166 to 504 mV.

15.3 Bias—Measured bias data in known standards determined in this round-robin is shown in Table 6.

15.4 In accordance with Section 1.3 of Practice D2777, the Executive Committee of D19 granted this test method an exemption from the full collaborative study requirements of Practice D2777 due to the nature of the test method. The actual study design used consisted of duplicate measurements from eight analysts on each of two different instruments. Single operator standard deviation was calculated from the variance within each instrument among all operators. Total standard deviation was calculated from the sum of between-operator and between-instruments variance components added to the single-operator variance to reflect total standard deviation expected among multiple laboratories.

16. Quality Control

16.1 In order to be certain that analytical values obtained using this test method are valid and accurate within the confidence limits of the test, the following QC procedures must be followed when running the test:

16.2 Initial Calibration Verification:

16.2.1 The ORP meter zero is checked by shorting out the input connections. The reading should be less than ± 0.5 mV.

16.2.2 The response of the electrode to standard redox solutions should be checked in accordance with 11.2.

16.3 Subsequent Calibration Verification, Each Day Measurements are Made:

16.3.1 The ORP meter zero is checked by shorting out the input connections. The reading should be less than ± 0.5 mV.

16.3.2 The response of the electrode to standard redox solutions should be checked in accordance with 11.2.

16.3.3 If the response of the electrode does not meet the 11.2 requirements, then the electrode should be cleaned in accordance with the 10.2 requirements.

TABLE 5 Precision

Sample	DI H ₂ O sat. with quinhydrone	Iodide/triiodide standard	Pool water
Average, mV	172.8	214.8	593.0
Single operator standard deviation, (S _o)	14.3	3.8	16.5
Total standard deviation, (S _T)	24.4	6.3	57.7

TABLE 6 Bias

Sample	pH 7 buffer sat. with quinhydrone	Iodide/triiodide standard	pH 4 buffer sat. with quinhydrone
Average, mV	86.4	213.8	259.8
Bias, mV	–2.6	–6.2	–5.2
Significant	no	yes	no

16.3.4 If after cleaning, the electrode does not meet the 11.2 requirements, then the electrode should be replaced.

16.4 *Method Blank*—A blank sample on reagent water is meaningless as there is no redox couple present to give a stable reading.

16.5 *Matrix Spike*—A matrix spike may be attempted using a known quantity of oxidizing or reducing agent, but this is expected to be extremely difficult to accomplish and is not required for routine ORP measurements.

16.6 *Duplicate*—Duplicate analyses may be performed to determine individual or laboratory precision.

17. Keywords

17.1 electrodes; ferrous-ferric reference solutions; iodide/triiodide; noble metal electrodes; ORP; oxidation-reduction potential; quinhydrone; redox; redox standards; reference electrodes; reference solutions

APPENDIX

(Nonmandatory Information)

X1. OXIDATION REDUCTION POTENTIAL

X1.1 *Meaning of the Term ORP*—The ORP measurement establishes the ratio of oxidants and reductants prevailing within a solution of water or waste water. The measurement is nonspecific in contrast, for example, to the pH measurement. The ORP electrode pair senses the prevailing net potential of a solution. By this measurement, the ability to oxidize or reduce species in the solution may be determined.

X1.2 Use of ORP Control of Waste Processes

X1.2.1 ORP measurements are used in industrial process control to monitor the treatment of unwanted materials which are amenable to oxidation or reduction. Frequently, only one species in solution is to be treated, in which case the oxidation-reduction profile of the process can be predicted with some accuracy. Two examples in this category are found in the plating industry: Waste cyanide is oxidized to cyanate and then (if required) to carbon dioxide and nitrogen, and waste hexavalent-chromium is reduced to the trivalent state. ORP measurements are useful for process control in both instances if the pH is constant and controlled.

X1.2.2 In addition to control of processes in which a specific material is treated, ORP measurements can be used to control nonspecific processes if a correlation can be established between prevailing ORP and the reaction in the process. An example is the use of ORP measurements in odor control of municipal waste by chlorination. In some cases, the extent of odor production correlates with ORP. Also, sewage treatment plants may be protected from unwanted oxidizing or reducing agents which might harm treatment materials if the ORP of the influent is monitored.

X1.3 Temperature Effects on ORP Measurements

X1.3.1 The effect of temperature on ORP measurements can be understood by considering the Nernst equation:

$$E = E^{\circ} + 2.3 \frac{RT}{nF} \log Q$$

where:

- E = measured potential,
- E° = potential when all components involved in the reaction are at unit activity and 25°C,
- R = gas constant,
- T = absolute temperature, $t^{\circ}\text{C} + 273.15$,
- F = Faraday,
- n = number of electrons involved in the reaction, and
- Q = product of the activities of the oxidants divided by the product of the activities of the reductants, each activity raised to that power whose exponent is the coefficient of the substance in the applicable chemical reaction.

Changes in E° with temperature produce the same changes in E . Further, the slope of the curve that relates E and T depends directly on T . Finally, changes in activity with temperature will produce changes in E .

X1.3.2 Automatic temperature compensation is seldom attempted in ORP measurements, due to the appearance of n in the prelogarithmic factor of the Nernst equation. The slope of the plot of E versus T thus depends not only on T , but on n as well, so that different amounts of compensation are required, depending on the value of n . If the process under study is well characterized and the value of n known, automatic temperature compensation is possible. However, if the value of n is unknown or variable (see X1.2.1), then compensation is not possible.

X1.4 Polarity Check—The polarity of the input of the analyzer may also be determined by connecting a battery of known polarity and observing the deflection of the meter. A resistive voltage divider may be connected between the battery and analyzer, if necessary, to prevent the meter from being driven off-scale due to application of an excessively high potential.

X1.5 Increase Precision of Measurement—If the system is electrochemically reversible, and a precision of better than ± 5 mV is desired, control the temperature of the assembly to within $\pm 1^\circ\text{C}$. Use silver/silver chloride reference electrodes with a flowing junction to avoid temperature hysteresis.

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