



Standard Test Methods for Determination of Total Oxygen in Gasoline and Methanol Fuels by Reductive Pyrolysis¹

This standard is issued under the fixed designation D 5622; 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 These test methods cover the quantitative determination of total oxygen in gasoline and methanol fuels by reductive pyrolysis.

1.2 Precision data are provided for 1.0 to 5.0 mass % oxygen in gasoline and for 40 to 50 mass % oxygen in methanol fuels.

1.3 Several types of instruments can be satisfactory for these test methods. Instruments can differ in the way that the oxygen-containing species is detected and quantitated. However, these test methods are similar in that the fuel is pyrolyzed in a carbon-rich environment.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *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:

D 1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method²

D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter³

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products³

D 4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C₁ to C₄ Alcohols in Gasoline by Gas Chromatography⁴

2.2 Other Standard:

Clean Air Act (1992)⁵

3. Summary of Test Method

3.1 A fuel specimen of 1 to 10 μL is injected by syringe into a 950 to 1300°C high-temperature tube furnace that contains metallized carbon. Oxygen-containing compounds are pyrolyzed, and the oxygen is quantitatively converted into carbon monoxide.

3.2 A carrier gas, such as nitrogen, helium, or a helium/hydrogen mixture, sweeps the pyrolysis gases into any of four downstream systems of reactors, scrubbers, separators, and detectors for the determination of the carbon monoxide content, hence of the oxygen in the original fuel sample. The result is reported as mass % oxygen in the fuel.

4. Significance and Use

4.1 These test methods cover the determination of total oxygen in gasoline and methanol fuels, and they complement Test Method D 4815, which covers the determination of several specific oxygen-containing compounds in gasoline.

4.2 The presence of oxygen-containing compounds in gasoline can promote more complete combustion, which reduces carbon monoxide emissions. The Clean Air Act (1992) requires that gasoline sold within certain, specified geographical areas contain a minimum percent of oxygen by mass (presently 2.7 mass %) during certain portions of the year. The requirement can be met by blending compounds such as methyl tertiary butyl ether, ethyl tertiary butyl ether, and ethanol into the gasoline. These test methods cover the quantitative determination of total oxygen which is the regulated parameter.

5. Apparatus

5.1 *Oxygen Elemental Analyzer*^{6,7,8,9}—A variety of instrumentation can be satisfactory. However, the instrument must reductively pyrolyze the specimen and convert oxygen to carbon monoxide.

5.1.1 *Test Method A*⁶—Helium carrier gas transports the

¹ These test methods are under the jurisdiction of Committee D02 on Petroleum Products and Lubricants and are the direct responsibility of Subcommittee D02.03.0A on Chemical Methods.

Current edition approved Aug. 15, 1995. Published October 1995. Originally published as D 5622 – 94. Last previous edition D 5622 – 94.

² *Annual Book of ASTM Standards*, Vol 05.01.

³ *Annual Book of ASTM Standards*, Vol 05.02.

⁴ *Annual Book of ASTM Standards*, Vol 05.03.

⁵ Federal Register, Vol 57, No. 24, Feb. 5, 1992, p. 4408.

⁶ Carlo Erba Models 1106 and 1108 have been found satisfactory for these analyses. They are available from CE Elantech, Inc., 170 Oberlin Ave. N., Ste 5, Lakewood, NJ 08701.

⁷ Leco Model RO-478 has been found satisfactory for this analysis. It is available from Leco Corp., 3000 Lakeview Ave., St. Joseph, MI 49085.

⁸ Perkin-Elmer Series 2400 has been found satisfactory for this analysis. It is available from Perkin-Elmer Corp., 761 Main Ave., Norwalk, CT 06859.

⁹ UIC, Inc./Coulometrics Model 5012 CO₂ coulometer and Model 5220 autosampler-furnace have been found satisfactory for this analysis. They are available from UIC Inc., Box 863, Joliet, IL 60434.

pyrolysis products through a combination scrubber to remove acidic gases and water vapor. The products are then transported to a molecular sieve gas chromatographic column where the carbon monoxide is separated from the other pyrolysis products. A thermal conductivity detector generates a response that is proportional to the amount of carbon monoxide.

5.1.2 *Test Method B*⁷—Nitrogen carrier gas transports the pyrolysis products through a scrubber to remove water vapor. The pyrolysis products then flow through tandem infrared detectors that measure carbon monoxide and carbon dioxide, respectively.

5.1.3 *Test Method C*⁸—A mixture of helium and hydrogen (95:5 %), helium, or argon transports the pyrolysis products through two reactors in series. The first reactor contains heated copper which removes sulfur-containing products. The second reactor contains a scrubber which removes acidic gases and a reactant which oxidizes carbon monoxide to carbon dioxide (optional). The product gases are then homogenized in a mixing chamber, which maintains the reaction products at absolute conditions of temperature, pressure, and volume. The mixing chamber is subsequently depressurized through a column that separates carbon monoxide (or carbon dioxide, if operating in the oxidation mode) from interfering compounds. A thermal conductivity detector measures a response proportional to the amount of carbon monoxide or carbon dioxide.

5.1.4 *Test Method D*⁹—Nitrogen carrier gas transports the pyrolysis products through scrubbers to remove acidic gases and water vapor. A reactor containing cupric oxide at 325°C oxidizes the carbon monoxide to carbon dioxide, which in turn is transported into a coulometric carbon dioxide detector. Coulometrically generated base titrates the acid formed by reacting carbon dioxide with monoethanolamine.

5.2 A technique must be established to make a quantitative introduction of the test specimen into the analyzer. Specimen vials and transfer labware must be clean and dry.

5.3 For instruments that measure carbon monoxide only, pyrolysis conditions must be established to quantitatively convert oxygen to carbon monoxide.

5.4 A system of scrubbers and separators must be established to effectively remove pyrolysis products that interfere with the detection of carbon monoxide or carbon dioxide, or both.

5.5 The detector responses must be linear with respect to concentration, or nonlinear responses must be detectable and accurately related to concentration.

5.6 Selected items are available from the instrument manufacturer.

5.6.1 *Pyrolysis Tubes,*

5.6.2 *Scrubber Tubes, and*

5.6.3 *Absorber Tubes.*

6. Reagents

6.1 *Purity of Reagents*¹⁰—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available. 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.

6.2 *Calibration Standards:*

6.2.1 NIST SRM 1837¹¹, which contains certified concentrations of methanol and *t*-butanol in reference fuel, can be used to calibrate the instrument for the analysis of oxygenates in gasoline.

6.2.2 Anhydrous methanol, 99.8 % minimum assay, can be used to calibrate the instrument for the analysis of methanol fuels.

6.2.3 *Iso*—octane, or other hydrocarbons, can be used as the blank provided the purity is satisfactory.

6.3 *Quality Control Standard*—NIST SRM 1838¹¹ can be used to check the accuracy of the calibration.

6.4 The instrument manufacturers require additional reagents.

6.4.1 *Test Method A:*⁶

6.4.1.1 Anhydron (anhydrous magnesium perchlorate),

6.4.1.2 Ascarite II (sodium hydroxide on silica),

6.4.1.3 Helium carrier gas, 99.995 % pure,

6.4.1.4 Molecular sieve, 5Å, 60 to 80 mesh,

6.4.1.5 Nickel wool,

6.4.1.6 Nickelized carbon, 20 % loading,

6.4.1.7 Quartz chips, and

6.4.1.8 Quartz wool.

6.4.2 *Test Method B:*⁷

6.4.2.1 Anhydron (anhydrous magnesium perchlorate),

6.4.2.2 Carbon pyrolysis pellets, and

6.4.2.3 Nitrogen carrier gas, 99.99 % pure.

6.4.3 *Test Method C:*⁸

6.4.3.1 Anhydron (anhydrous magnesium perchlorate),

6.4.3.2 Ascarite II (sodium hydroxide on silica),

6.4.3.3 Carrier gas, either helium (95 %)/hydrogen (5 %), mixture, 99.99 % pure; helium, 99.995 % pure; or argon, 99.98 % pure,

6.4.3.4 Copper plus, wire form, and

6.4.3.5 Platinized carbon.

6.4.4 *Test Method D:*⁹

6.4.4.1 Anhydron (anhydrous magnesium perchlorate),

6.4.4.2 Ascarite II (sodium hydroxide on silica),

6.4.4.3 Copper (II) oxide,

6.4.4.4 Coulometric cell solutions, including a cathode solution of monoethanolamine in dimethyl sulfoxide and an

¹⁰ *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 Pharmacopoeia and National Formulary*, U.S. Pharmacopoeial Convention, Inc. (USPC), Rockville, MD.

¹¹ Available from the National Institute of Standards and Technology, Gaithersburg, MD 20899.

anode solution of water and potassium iodide in dimethyl sulfoxide,

6.4.4.5 Nickelized carbon, 20 % loading, and

6.4.4.6 Nitrogen carrier gas, 99.99 % pure.

7. Sampling

7.1 Take samples in accordance with the instructions in Practice D 4057.

7.2 Visually inspect the samples, and when there is evidence of nonuniformity, take fresh samples.

7.3 Store the samples in a cold room or a laboratory refrigerator designed for storage of chemicals.

8. Preparation of Apparatus

8.1 Prepare the instrument in accordance with the manufacturer's recommendations. These test methods require that correct operating procedures are followed for the model used. Instrument design differences make it impractical to specify all of the required operating conditions.

8.2 The carrier gas can be scrubbed to remove traces of oxygen and oxygen-containing compounds.

9. Calibration and Standardization

9.1 *Calibration for Test Methods A, B, and C, Oxygenates in Gasoline:*

9.1.1 Use a syringe to introduce 1 to 10 μL , or 1 to 10 mg, of the blank. The amount of specimen must be precisely known. Measure the response. Repeat the introduction and measurement until stable readings are observed.

9.1.2 In similar fashion, introduce 1 to 10 μL , or 1 to 10 mg, of SRM 1837 and measure the response. Repeat two times with the same quantity of the SRM. If the blank corrected responses do not agree within 2 % relative, take corrective action and repeat the calibration.

9.1.3 Calculate the K -factor as follows:

$$K = \frac{C_{\text{std}} \times M_{\text{std}}}{R_{\text{avg}}} \quad (1)$$

where:

C_{std} = mass % oxygen in the SRM,

M_{std} = mass of the SRM, mg,

= volume of the SRM (μL) \times density of the SRM (g/mL), and

R_{avg} = average of the blank corrected responses.

NOTE 1—Density can be determined by Test Method D 1298 or Test Method D 4052.

9.2 *Calibration for Test Methods A, B, and C, Methanol Fuels*—Repeat procedure 9.1; however, substitute anhydrous methanol for the SRM. For methanol fuels, a unique K -factor can be necessary.

9.3 *Calibration for Test Method D*—This test method does not require calibration; however, a quality control standard must be analyzed to ensure proper operation of the instrument. A blank must also be analyzed periodically to ensure consistent responses.

9.4 *Quality Control (QC):*

9.4.1 Introduce the QC standard SRM 1838 in the same manner as the calibration standards. Calculate the percent oxygen (m/m) as described in Section 10.

9.4.2 When results obtained on the QC standard do not agree with the certified values within 2 % relative, take corrective action and repeat the calibration and quality control.

9.4.3 For Test Method D, when the recovery of oxygen from the QC SRM is less than 0.85 (that is, 85 %), take corrective action and repeat the quality control. Recoveries that are greater than 0.85 but less than unity can be used to correct the calculated result (refer to the r parameter in Section 10).

9.5 *Procedure:*

9.5.1 Introduce the samples, and record the instrument response. Calculate the results as described in Section 10. Use the appropriate K -factor for oxygenates in gasoline and methanol fuels.

9.5.2 Recalibrate the instrument with the appropriate calibration standard after each set of ten samples.

10. Calculation and Report

10.1 Calculate the mass % oxygen for the QC standard and samples as follows:

$$\text{Mass \% Oxygen} = \frac{R \times K}{M \times r} \quad (2)$$

where:

R = blank corrected instrument response,

K = K -factor, refer to Eq 1, assume unity for Test Method D,

M = mass of sample, mg,

= volume (μL) \times density (g/mL), and

r = recovery, refer to 9.4.3, assume unity for Test Methods A, B, and C.

10.2 For instruments with computer data systems, the calculation of the K -factor (Eq 1) and the calculation of mass % oxygen (Eq 2) can be automatic with a digital readout provided.

10.3 Report mass % oxygen to the nearest 0.01 %.

11. Precision and Bias ¹²

11.1 *Precision*—The precision of these test methods was determined by statistical analysis of interlaboratory test results. Twelve laboratories analyzed in duplicate eight different samples, providing a total of thirteen data sets. One laboratory used two different test methods. The breakdown on data sets by test method is: Test Method A, three; Test Method B, two; Test Method C, three; Test Method D, five. The statistical analysis was performed on the set of 13 data sets because the reductive pyrolysis technique is common to all four test methods. Separate statistics were not determined for individual test methods. The sample set included anhydrous methanol and gasoline stocks that were spiked with one or more of the following: isobutanol, *n*-butanol, *sec*-butanol, *tert*-butanol, diisopropyl ether, ethanol, ethyl *tert*-butyl ether, methanol, methyl *tert*-butyl ether, *n*-propanol, isopropanol, *tert*-amyl methyl ether.

11.1.1 *Repeatability*—The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test materials

¹² Interlaboratory study data are available from ASTM by requesting RR:D02-1338.

would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty.

Mass % Oxygen Range	Repeatability, Mass % Oxygen
1.0 to 5.0 %	0.06 %
40 to 50 %	0.81 %

11.1.2 *Reproducibility*—The difference between two single and independent results, obtained by different operators working in different laboratories on identical test materials, would in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty.

Mass % Oxygen Range	Reproducibility, Mass % Oxygen
1.0 to 5.0 %	0.26 %
40 to 50 %	0.81 %

11.2 *Bias*—Bias was determined from interlaboratory results obtained on NIST SRM 1838, which contains ethanol. The null hypothesis that was tested was that the true difference between the grand average result and the NIST certified value is zero. The result of the hypothesis testing was that if the true difference was zero, the determined difference would occur by chance approximately 50 % of the time. Hence, the null hypothesis of *no difference* or *no bias* is accepted.

12. Keywords

12.1 carbon dioxide; carbon monoxide; di-isopropyl ether; ethanol; ethyl *tert*-butyl ether; isobutanol; isopropanol; methanol; methyl *tert*-butyl ether; *n*-butanol; *n*-propanol; oxygen; reductive pyrolysis; *sec*-butanol; *tert*-butanol; *tert*-amyl methyl ether

APPENDIX

(Nonmandatory Information)

X1. EFFECT OF WATER IN GASOLINE CONTAINING OXYGENATES

X1.1 The Clean Air Act (1992) requirement for oxygenates in gasoline implicitly excludes water-borne oxygen from the specification for total oxygen. Experimental evidence indicates that for typical oxygenated gasolines, the maximum amount of soluble water is approximately 0.1 mass %. This corresponds to 0.09 mass % oxygen which is very close to the repeatability of these test methods. When oxygen from dissolved water must be excluded from the analysis, the gasoline can be pretreated with potassium carbonate or Molecular Sieve 3A prior to analysis by these test methods.

X1.2 According to the patent literature¹³, gasoline can be treated with potassium carbonate to remove dissolved water. Test Method B was used to analyze five different gasolines that were spiked with 0.1 mass % water. These gasolines contained one or more of the following oxygenates at concentrations typical of gasolines: *tert*-amyl methyl ether, ethanol, ethyl *tert*-butyl ether, *sec*-butanol, *n*-butanol, methanol, di-isopropyl

ether, *n*-propanol. A few millilitres of each water-spiked gasoline were treated with 200 mg of potassium carbonate prior to analysis. The results obtained on the treated, spiked samples did not differ from the results obtained on the neat gasolines by more than 0.02 mass % oxygen, which is within the repeatability of these test methods.

X1.3 The literature¹⁴ describes an alternative technique for removing water from gasoline, namely, treatment of the gasoline with Molecular Sieve 3A. In an experiment similar to that described in X1.2, water-spiked, oxygenated gasolines were pretreated with Sieve 3A prior to analysis by Test Method B. The results obtained on the sieve treated, spiked samples did not differ from the results obtained on the neat gasolines by more than the repeatability of these test methods.

¹³ U.S. Patent No. 4 539 013, Sep. 3, 1985.

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¹⁴ Burfield, D. R., and Smithers, R. H., "Desiccant Efficiency in Solvent and Reagent Drying," *Journal of Organic Chemistry*, Vol 48, No. 14, 1983, pp. 2420–2422.