



Designation: D6414 – 23

Standard Test Methods for Total Mercury in Coal and Coal Combustion Residues by Acid Extraction or Wet Oxidation/Cold Vapor Atomic Absorption¹

This standard is issued under the fixed designation D6414; 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 procedures to determine the total mercury content in a sample of coal or coal combustion residue.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 **Warning:** *Mercury has been designated by many regulatory agencies as a hazardous material that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury and/or mercury containing products into your state or country may be prohibited by law.*

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

[D121 Terminology of Coal and Coke](#)

¹ These test methods are under the jurisdiction of ASTM Committee D05 on Coal and Coke and are the direct responsibility of Subcommittee D05.29 on Major Elements in Ash and Trace Elements of Coal.

Current edition approved Jan. 1, 2023. Published January 2023. Originally approved in 1999. Last previous edition approved in 2014 as D6414 – 14. DOI: 10.1520/D6414-23.

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.

[D1193 Specification for Reagent Water](#)

[D2013 Practice for Preparing Coal Samples for Analysis](#)

[D3173 Test Method for Moisture in the Analysis Sample of Coal and Coke](#)

[D3180 Practice for Calculating Coal and Coke Analyses from As-Determined to Different Bases](#)

[D7582 Test Methods for Proximate Analysis of Coal and Coke by Macro Thermogravimetric Analysis](#)

[E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method](#)

[IEEE/ASTM SI 10 Standard for Use of the International System of Units \(SI\): The Modern Metric System](#)

2.2 [ISO Standards:](#)³

[ISO 5725-6:1994 Accuracy of measurement methods and results-Part 6](#)

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology [D121](#).

4. Summary of Test Method

4.1 *Test Method A*—Mercury in the analysis sample is solubilized by heating the test sample at a specified temperature in a mixture of nitric and hydrochloric acids. The acid solutions produced are transferred into a vessel in which the mercury is reduced to elemental mercury. The mercury vapor is determined by flameless cold-vapor atomic absorption spectrometry.

4.2 *Test Method B*—Mercury in the analysis sample is solubilized by heating the test sample in a mixture of nitric and sulfuric acids with vanadium pentoxide.⁴ The acid solutions produced are transferred into a vessel in which the mercury is reduced to elemental mercury. The mercury vapor is determined by flameless cold-vapor atomic absorption spectrometry.

NOTE 1—Mercury and mercury salts can be volatilized at low temperatures. Precautions against inadvertent mercury loss should be taken when using this method.

³ Available from International Organization for Standardization (ISO), 1 rue de Varembe, Case postale 56, CH-1211, Geneva 20, Switzerland.

⁴ Crock, J. G., *Open-File Report*, U.S. Geological Survey, 87–84, p.19.

5. Significance and Use

5.1 The emission of mercury during coal combustion can be an environmental concern.

5.2 When representative test specimens are analyzed according to one of these procedures, the total mercury is representative of concentrations in the sample.

6. Apparatus

6.1 *Apparatus for Test Method A:*

6.1.1 *Analytical Balance*, with a sensitivity of 0.1 mg.

6.1.2 *Atomic Absorption Spectrometer*, with a flameless cold-vapor mercury analysis system.

6.1.3 *Digestion Vessels*, 100 mL to 250 mL bottles with an O-ring seal and screw cap. Bottle must be compatible for use with aqua regia. Polycarbonate and high density polyethylene (HDPE) are acceptable. Bottles and cap assemblies shall be washed in 1+1 hydrochloric acid (HCl) then dried before each use.

NOTE 2—Other bottle and cap assemblies may be used provided they are compatible for use with aqua regia at a temperature of 80 °C.

6.1.4 *Heat Source*, a water bath capable of maintaining a temperature of 80 °C.

6.1.5 *Syringe and Filter*, a 20 cm³ syringe and a 1 μm pore size polytetrafluoroethylene (PTFE) filter to fit syringe.

6.2 *Apparatus for Test Method B:*

6.2.1 *Analytical Balance*, with a sensitivity of 0.1 mg.

6.2.2 *Atomic Absorption Spectrometer*, with a flameless cold-vapor mercury analysis system.

6.2.3 *Digestion Vessels*, 16 mm by 150 mm disposable glass test tubes.

6.2.4 *Heat Source*, an aluminum block with 18-mm holes to accommodate the disposable test tubes. The block shall be capable of slowly reaching and maintaining a final temperature of 150 °C. The block can be heated by placing it on a hot plate or it can contain its own internal heating elements.

7. Sample

7.1 Prepare the analysis sample in accordance with Practice **D2013** by pulverizing the material to pass a 250 μm (No. 60 U.S. standard sieve).

7.2 Analyze separate test specimens for moisture in accordance with Test Method **D3173** or Test Method **D7582**.

Test Method A for the Analysis of Mercury by Using Acid Extraction

8. Reagents

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used. 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 can 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 Acids*—Use trace metal purity grade acids or equivalent. Redistilled acids are acceptable.

8.3 *Purity of Water*—Use water equivalent to ASTM Type II reagent water of Specification **D1193**.

8.4 *Mercury Standard Stock Solution [1000 μg/mL (1000 ppm)]*—Dissolve 1.0800 g of mercury (II) oxide (HgO) in a minimum volume of HCl (1+1) and dilute to 1 L with water. Alternatively, use a commercially available stock solution specifically prepared for atomic absorption spectrometry.

8.5 *Mercury Standard Solution (100 ng/mL)*—Prepare the mercury standard solution fresh daily. Dilute 5 mL of the mercury standard stock solution to 500 mL with deionized water. Further dilute 10 mL of this intermediate solution to 1 L with deionized water.

8.6 *Nitric Acid*—Concentrated (HNO₃, sp. gr. 1.42).

8.7 *Hydrochloric Acid*—Concentrated (HCl, sp. gr. 1.19).

8.8 *Sodium Chloride/Hydroxylamine Sulfate Solution*—Dissolve 12 g ± 0.01 g of sodium chloride and 12 g ± 0.01 g of hydroxylamine sulfate in water and dilute to 100 mL.

8.9 *Potassium Permanganate Solution (5 %)*—Dissolve 5 g of potassium permanganate (KMnO₄) in water and dilute to 100 mL.

8.10 *Stannous Chloride Solution (100 g/L)*—Dissolve 100 g of stannous chloride dihydrate (SnCl₂·2 H₂O) in 300 mL of concentrated hydrochloric acid (HCl, sp. gr. 1.19) and CAUTIOUSLY dilute to 1 L with water. This solution is stable for approximately one week if refrigerated.

8.11 *Certified Reference Material (CRM)*—Use Certified Reference Material (CRM) coals with dry-basis mercury values for which confidence limits are issued by a recognized certifying agency such as the National Institute of Standards and Technology (NIST). It is recommended that the user verify the value with the certifying agency before using the CRM coal for quality control purposes.

9. Procedure

9.1 *Preparation of Test Solution A (Extraction Step):*

9.1.1 Determine the mass of a test specimen of approximately 1 g of the sample into a digestion bottle. Record the mass (*m_s*) to the nearest 0.0001 g.

9.1.2 Quantitatively add 2 mL of concentrated nitric acid (8.6) and 6 mL of concentrated hydrochloric acid (8.7) to the digestion bottle and secure the cap.

⁵ *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.

9.1.3 Transfer the digestion bottle and contents to a water bath that has been heated to 80 °C and heat for 1 h. Secure the digestion bottle in such a way as to keep the contents below the surface of the water.

9.1.4 After 1 h, remove the digestion bottle and allow to cool to room temperature.

NOTE 3—**Caution:** Carefully relieve the pressure by slowly removing the cap.

9.1.5 Add 36.5 mL of water and mix the contents.

9.1.6 Add 5 mL of 5 % potassium permanganate solution (8.9). Allow the mixture to stand for 10 min.

9.1.7 Add 0.5 mL of the sodium chloride/hydroxylamine sulfate solution (8.8) and mix. If a pink color persists for more than 1 min, add an additional 0.5 mL of the sodium chloride/hydroxylamine sulfate solution (8.8) and mix. Note the total volume and record this volume (*V*) for use in the final calculations.

9.2 *Preparation of Reagent Blank*—Prepare a reagent blank by repeating the procedure in 9.1 but without the test specimen of the sample.

9.3 *Preparation of Control Sample:*

9.3.1 Prepare a test specimen of a CRM coal for analysis using the procedure described in 9.1. Record the expected value of mercury, the certified value in the coal, as CRME.

9.3.2 Alternatively, determine the mass of a test specimen of 1 g of a CRM. After the addition of the nitric and hydrochloric acids to the digestion bottle, add mercury standard solution (8.5). The volume of mercury standard solution to be added should yield an amount of mercury approximately equivalent to that in the CRM coal (Note 4).

9.3.3 Calculate the expected value of mercury CRME as follows

$$CRME = (m_{CRM} \times Val_{CRM} + V_{std} \times 0.1) / m_{CRM} \quad (1)$$

where:

m_{CRM} = dry mass of the CRM coal used for preparation of the quality control sample, g,

Val_{CRM} = certified value of mercury in the quality control sample,

V_{std} = volume of mercury standard solution added to the digestion bottle, mL, and

0.1 = the mass concentration of the mercury standard solution, µg/mL.

NOTE 4—A test specimen of 0.9 g dry mass of a CRM coal with 0.11 g/g (110 ng/g) of mercury is measured out as a quality control sample. To yield an amount approximately equivalent to that present in the CRM coal, 0.9 mL of the mercury standard solution is added to the digestion bottle after the addition of the nitric and hydrochloric acids. CRME calculates to 0.21 µg/g.

9.4 *Atomic Absorption Analyses:*

9.4.1 *Instrument Conditions*—Follow the instrument manufacturers recommended procedure to align the optical cell in the beam path of the atomic absorption spectrometer and optimize the performance of the instrument and the flameless cold-vapor apparatus.

9.4.2 *Instrument Calibration:*

9.4.2.1 Prepare 50 mL of (0.5, 1, 3, 5, and 10) ng/mL (ppb) of mercury calibration standards in a solution of 10 % HCl by serial dilution of the mercury standard solution.

9.4.2.2 Add a specified volume (*V_{cal}*) of a calibration solution to the reduction flask or reduction system.

NOTE 5—If an autosampler equipped with a peristaltic pump is used for delivery of both calibration and analyses sample solutions to the reduction system, a specific volume is not required.

9.4.2.3 Either manually or by means of an autosampling device begin the analyses of the calibration solution by adding enough stannous chloride solution so as to ensure complete reduction of the mercury in the calibration solution.

9.4.2.4 Record the absorbance of the calibration standard. Repeat for each calibration standard.

9.4.3 *Analysis of Test Solution A:*

9.4.3.1 Using the 20 cm³ syringe, draw Test Solution A into the syringe.

9.4.3.2 Fit the syringe with a 1 µm filter.

9.4.3.3 Filter a volume equivalent to *V_{cal}* of Test Solution A into the reduction flask or reduction system.

NOTE 6—A laboratory centrifuge may also be used to separate the solids from the test solution.

9.4.3.4 Determine the absorbance (*A_s*) of the Test Solution A using the procedure described in 9.4.2.

9.4.3.5 Using 10 % HCl, dilute test solutions with mercury absorbances greater than the highest calibration standard to give an estimated absorbance equivalent to the 3 ng/mL calibration standard and reanalyze.

9.4.3.6 Record the dilution factor as DF.

9.4.4 *Analysis of the Reagent Blank*—Determine the absorbance (*A_b*) of the reagent blank using the procedure described in 9.4.3.

9.4.5 *Analysis of the Quality Control Sample*—Determine the absorbance (*A_{qs}*) of the quality control sample using the procedure described in 9.4.3.

Test Method B for the Analysis of Mercury by Using Wet Oxidation Extraction

10. Reagents

10.1 *Purity of Reagents*—Reagent grade chemicals shall be used. 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 can 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.

10.2 *Purity of Acids*—Use trace metal purity grade acids or equivalent. Redistilled acids are acceptable.

10.3 *Purity of Water*—Use water equivalent to ASTM Type II reagent water of Specification D1193.

10.4 *Mercury Standard Stock Solution [1000 µg/mL (1000 ppm)]*—Dissolve 1.0800 g of mercury (II) oxide (HgO) in a minimum volume of HCl (1+1) and dilute to 1 L with water. Alternatively, use a commercially available stock solution specifically prepared for atomic absorption spectrometry.

10.5 *Mercury Standard Solution (100 ng/mL)*—Prepare the mercury standard solution fresh daily. Dilute 5 mL of the

mercury standard stock solution to 500 mL with deionized water. Further dilute 10 mL of this intermediate solution to 1 L with deionized water.

10.6 *Nitric Acid*—Concentrated (HNO_3 , sp. gr. 1.42).

10.7 *Hydrochloric Acid*—Concentrated (HCl , sp. gr. 1.19).

10.8 *Sulfuric Acid*—(H_2SO_4 , sp. gr. 1.83).

10.9 *Vanadium Pentoxide*, V_2O_5 —Remove traces of mercury by roasting the V_2O_5 in a fume hood at a temperature below 690 °C, the melting point of V_2O_5 , in a porcelain dish using a muffle furnace or a Fisher burner.

NOTE 7—**Warning:** V_2O_5 is highly toxic, an irritant, and a possible mutagen.

10.10 *Stannous Chloride Solution (100 g/L)*—Dissolve 100 g of stannous chloride dihydrate ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) in 300 mL of concentrated hydrochloric acid and CAUTIOUSLY dilute to 1 L with water. This solution is stable for approximately one week if refrigerated.

10.11 *Sodium Dichromate, Solution, (25 % mass concentration)*—Dissolve 25 g of $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ in water and dilute to 100 mL.

10.12 *Complex Reducing Solution*—Dissolve 30 g of hydroxylamine hydrochloride and 30 g of sodium chloride (NaCl) in approximately 500 mL of water. Slowly add 100 mL of concentrated sulfuric acid. Allow the solution to cool, then dilute to 1 L with water.

10.13 *Certified Reference Material (CRM)*—Use Certified Reference Material (CRM) coals with dry-basis mercury values for which confidence limits issued by a recognized certifying agency such as the National Institute of Standards and Technology (NIST). It is recommended that the user verify the value with the certifying agency before using the CRM coal for quality control purposes.

11. Procedure

11.1 Preparation of Test Solution B:

11.1.1 Determine the mass of a test specimen of 0.15 g of the test sample into a 16 mm by 150 mm disposable test tube. Record the mass (m_s) to the nearest 0.0001 g.

11.1.2 Add approximately 0.1 g of V_2O_5 (10.9), 3.5 mL of concentrated HNO_3 (10.6), and 1.5 mL of concentrated H_2SO_4 (10.8). Swirl to mix the contents. Place the test tube in the aluminum heating block and cover with a watch glass.

11.1.3 Adjust the temperature of the heating block so that it gradually reaches a temperature of 150 °C in 4 h. Maintain heating at this temperature for 16 h.

11.1.4 After heating, carefully remove the test tube from the aluminum heating block, allow to cool, and dilute the solution to a final volume of 15 mL (V) with water. Securely cap the test tube and mix the contents. Centrifuge the test tube and its contents for 5 min at 1000 rpm.

11.2 *Reagent Blank*—Prepare a reagent blank by repeating the procedure in 11.1 but without the test specimen of the sample.

11.3 Quality Control Sample:

11.3.1 Prepare a CRM coal for analysis using the procedure described in 11.1. Record the certified value as CRM.

11.3.2 Alternatively, determine the mass of a test specimen of 0.15 g of a CRM. After the addition of the nitric acid (10.6), add mercury standard solution (10.5) to the test tube. The volume of the mercury standard solution to be added should yield an amount of mercury approximately equivalent to that in the CRM coal (Note 8). Calculate the expected value CRME of mercury using Eq 1.

NOTE 8—A test specimen of 0.15 g of a CRM coal with 0.11 $\mu\text{g/g}$ (110 ng/g) of mercury is measured out as a quality control sample. To yield an amount approximately equivalent to that present in the CRM coal, 0.15 mL of the mercury standard solution is added to the test tube after the addition of the nitric acid. CRME calculates to 0.21 $\mu\text{g/g}$.

11.4 Atomic Absorption Analyses:

11.4.1 *Instrument Conditions*—Follow the instrument manufacturers' recommended procedure to align the optical cell in the beam path of the atomic absorption spectrometer and optimize the performance of the instrument and the flameless cold vapor apparatus.

11.4.2 Instrument Calibration:

11.4.2.1 Prepare 500 mL calibration standards of (0.5, 1, 3, 5, and 10) ng/mL (ppb) of mercury by diluting in water aliquots of the mercury standard solution (10.4) in 115 mL of concentrated HNO_3 (10.6), 50 mL of concentrated H_2SO_4 (10.8), and 10 mL of the sodium dichromate solution (10.11). Prepare fresh calibration standards every three months.

11.4.2.2 Prepare a 500 mL dilution solution by mixing 115 mL of concentrated HNO_3 (10.6), 50 mL of concentrated H_2SO_4 (10.8), and 10 mL of the sodium dichromate solution (10.11) and diluting to the mark with water. Prepare dilution solution every three months.

11.4.2.3 Add a specified volume, V_{cal} , not to exceed 15 mL of a calibration solution to the reduction flask or reduction system.

11.4.2.4 Either manually or by means of an autosampling device begin the analyses of the calibration solution by adding enough complex reducing solution (10.12) and stannous chloride (10.10) solution to ensure complete reduction of the mercury in the calibration solution.

11.4.2.5 Record the absorbance of the calibration standard (Note 9). Repeat for each calibration standard.

NOTE 9—Automated flow injection systems may have to be modified to include mixing loops when analyzing samples digested by Method B. Typical over-the-counter mixing loops are made using 4 mm outer diameter glass tubing wrapped around a 14 mm diameter mandrel. Without the mixing loops, foaming in the gas-phase separator may occur. The foaming interferes with the transfer of mercury vapor from the gas-phase separator to the absorption cell of the cold-vapor atomic absorption spectrometer. Descriptions and diagrams of a manifold used for the automated generation of mercury vapor from samples digested according to Method B are given by J. G. Crock and others.⁴ Automated flow injection systems that have been modified to include mixing loops can also be used to analyze samples digested by Test Method A.

11.4.3 Analysis of Test Solution B:

11.4.3.1 Add a volume equivalent to V_{cal} of Test Solution B into the reduction flask or reduction system.

11.4.3.2 Determine the absorbance (A_s) of the Test Solution B using the procedure described in 11.4.2.