



Designation: **D7039—13 D7039 – 15**

Standard Test Method for Sulfur in Gasoline, Diesel Fuel, Jet Fuel, Kerosine, Biodiesel, Biodiesel Blends, and Gasoline-Ethanol Blends by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry¹

This standard is issued under the fixed designation D7039; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope*

1.1 This test method covers the determination of total sulfur by monochromatic wavelength-dispersive X-ray fluorescence (MWDXRF) spectrometry in single-phase gasoline, diesel fuel, refinery process streams used to blend gasoline and diesel, jet fuel, kerosine, biodiesel, biodiesel blends, and gasoline-ethanol blends.

NOTE 1—Volatile samples such as high-vapor-pressure gasolines or light hydrocarbons might not meet the stated precision because of the evaporation of light components during the analysis.

1.2 The range of this test method is between the pooled limit of quantitation (PLOQ) value (calculated by procedures consistent with Practice **D6259**) of ~~3.23.2 mg/-mg/kg-kg~~ total sulfur and the highest level sample in the round robin, ~~28222822 mg/-mg/kg~~ kg total sulfur.

1.3 Samples containing oxygenates can be analyzed with this test method provided the matrix of the calibration standards is either matched to the sample matrices or the matrix correction described in Section 5 or **Annex A1** is applied to the results. The conditions for matrix matching and matrix correction are provided in the Interferences section (Section 5).

1.4 Samples with sulfur content above ~~28222822 mg/-mg/kg-kg~~ can be analyzed after dilution with appropriate solvent (see **5.4**). The precision and bias of sulfur determinations on diluted samples has not been determined and may not be the same as shown for neat samples (Section 15).

1.5 When the elemental composition of the samples differ significantly from the calibration standards used to prepare the calibration curve, the cautions and recommendation in Section 5 should be carefully observed.

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

1.7 *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 hazard information, see **3.1**.

2. Referenced Documents

2.1 *ASTM Standards:*²

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products

D6259 Practice for Determination of a Pooled Limit of Quantitation

D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance

D6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products and Lubricants

2.2 *EPA Documents:*³

40 CFR 80.584 Code of Federal Regulations; Title 40; Part 80; U.S. Environmental Agency, July 1, 2005

¹ This test method is under the jurisdiction of ASTM Committee **D02** on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee **D02.03** on Elemental Analysis.

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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 Available from U.S. Government Printing Office, 732 N. Capitol Street, NW, Washington, DC 20401.

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

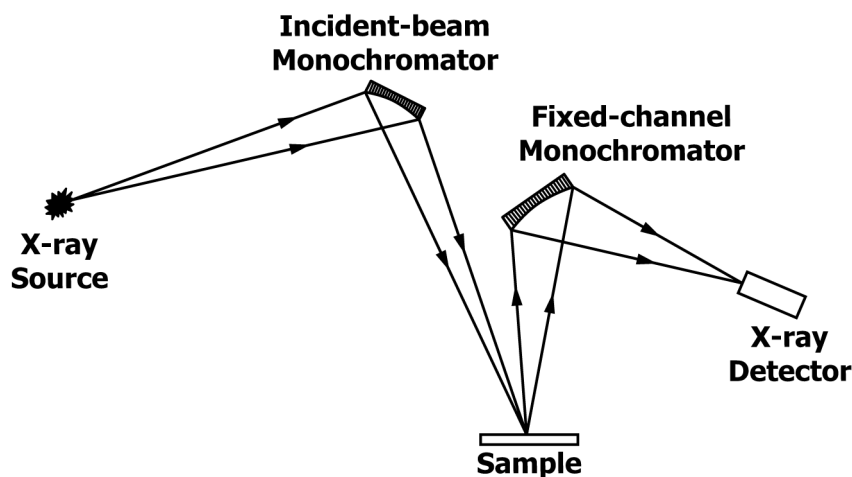


FIG. 1 Schematic of the MWDXRF Analyzer

3. Summary of Test Method

3.1 A monochromatic X-ray beam with a wavelength suitable to excite the K-shell electrons of sulfur is focused onto a test specimen contained in a sample cell (see Fig. 1). The fluorescent $K\alpha$ radiation at 0.5373 nm (5.373 Å) emitted by sulfur is collected by a fixed monochromator (analyzer). The intensity (counts per second) of the sulfur X rays is measured using a suitable detector and converted to the concentration of sulfur (mg/kg) in a test specimen using a calibration equation. Excitation by monochromatic X rays reduces background, simplifies matrix correction, and increases the signal/background ratio compared to polychromatic excitation used in conventional WDXRF techniques.⁴ (**Warning**—Exposure to excessive quantities of X-ray radiation is injurious to health. The operator needs to take appropriate actions to avoid exposing any part of his/her body, not only to primary X rays, but also to secondary or scattered radiation that might be present. The X-ray spectrometer should be operated in accordance with the regulations governing the use of ionizing radiation.)

4. Significance and Use

4.1 This test method provides for the precise measurement of the total sulfur content of samples within the scope of this test method with minimal sample preparation and analyst involvement. The typical time for each analysis is five minutes.

4.2 Knowledge of the sulfur content of diesel fuels, gasolines, and refinery process streams used to blend gasolines is important for process control as well as the prediction and control of operational problems such as unit corrosion and catalyst poisoning, and in the blending of products to commodity specifications.

4.3 Various federal, state, and local agencies regulate the sulfur content of some petroleum products, including gasoline and diesel fuel. Unbiased and precise determination of sulfur in these products is critical to compliance with regulatory standards.

5. Interferences

5.1 Differences between the elemental composition of test samples and the calibration standards can result in biased sulfur determinations. For samples within the scope of this test method, elements contributing to bias resulting from differences in the matrices of calibrants and test samples are hydrogen, carbon, and oxygen. A matrix-correction factor (C) can be used to correct this bias; the calculation is described in Annex A1. For general analytical purposes, the matrices of test samples and the calibrants are considered to be matched when the calculated correction factor C is within 0.98 to 1.04. No matrix correction is required within this range. A matrix correction is required when the value of C is outside the range of 0.98 to 1.04. For most testing, matrix correction can be avoided with a proper choice of calibrants. For example, based on the example graph in Annex A1 (Fig. 2), a calibrant with 86 mass % carbon and 14 mass % hydrogen can cover non-oxygen containing samples with C/H ratios from 5.4 to 8.5. For gasolines with oxygenates, up to 2.3 mass % oxygen (12 mass % MTBE) can be tolerated for test samples with the same C/H ratio as the calibrants.

5.2 Fuels containing large quantities of oxygenates, such as biodiesel, biodiesel blends, and gasoline-ethanol blends, can have a high oxygen content leading to significant absorption of sulfur $K\alpha$ radiation and low sulfur results.

5.2.1 Biodiesel and biodiesel blends may be analyzed using this test method by applying correction factors to the results or using calibration standards that are matrix-matched to the test sample (see Table 1). Correction factors may be calculated (see Annex A1), or obtained from Table 2 if the sample has been measured on a mineral oil calibration curve.

⁴ Bertin, E. P., *Principles and Practices of X-ray Spectrometric Analysis*, Plenum Press, New York, 1975, pp. 115–118; Bertin, E. P., *Principles and Practices of X-ray Spectrometric Analysis*, Plenum Press, New York, 1975, pp. 115–118.

Matrix Correction vs. C/H for total oxygen wt.%

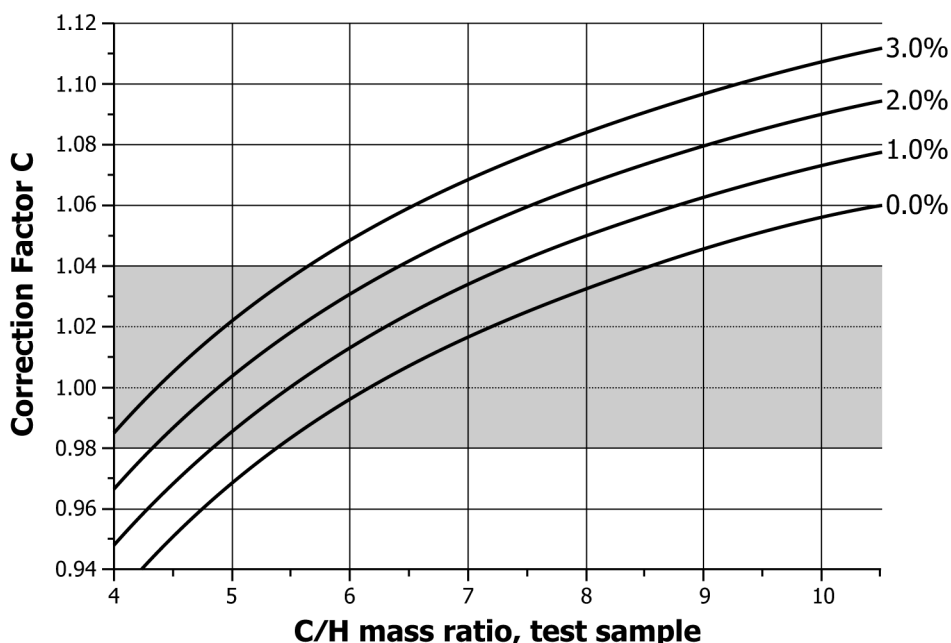


FIG. 2 Matrix Correction for a Test Sample vs. C/H and Total Oxygen Content Using Chromium K α for the Excitation Beam

TABLE 1 Methods for Interference Correction by Sample Type

Sample Type	Correction Tables (Table 2, Table 3, Table 4, or N/A)	Correction Calculation (Annex A1)	Matrix Matching
Biodiesel and Biodiesel Blends	2	Yes	Yes
Gasoline-ethanol Blends	3 or 4	Yes	Yes
All Other Sample Types	N/A	Yes	Yes

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5.2.2 Gasoline-ethanol blends may be analyzed using this test method by applying correction factors to the results or using calibration standards that are matrix matched to the test sample (see Table 1). Correction factors may be calculated (see Annex A1), or obtained from the correction tables. Use Table 3 if the sample has been measured on a mineral oil calibration curve, or use Table 4 if the sample has been measured on an ethanol calibration curve. Ethanol-based calibrants can be used for gasoline-ethanol blends. Ethanol-based calibrants are recommended for gasoline-ethanol blends containing more than 50 % (by volume) ethanol.

5.3 Other samples having interferences as described in 5.1 may be analyzed using this test method by applying correction factors to the results or by using calibration standards that are matrix matched to the test sample (see Table 1). Correction factors may be calculated as described in Annex A1.

5.4 To minimize any bias in the results, use calibration standards prepared from sulfur-free base materials of the same or similar elemental composition as the test samples. When diluting samples, use a diluent with an elemental composition the same or similar to the base material used for preparing the calibration standards.

5.4.1 A base material for gasoline can be approximately simulated by mixing 2,2,4-trimethylpentane (*isooctane*) and toluene in a ratio that approximates the expected aromatic content of the samples to be analyzed.

6. Apparatus

6.1 *Monochromatic Wavelength Dispersive X-ray Fluorescence (MWDXRF) Spectrometer*⁵, equipped for X-ray detection at 0.5373 nm (5.373Å). Any spectrometer of this type can be used if it includes the following features, and the precision and bias of test results are in accordance with the values described in Section 15.

⁵ The sole source of this apparatus known to the committee at this time is X-ray Optical Systems, Inc., 15 Tech Valley Drive, East Greenbush, NY 12061. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

TABLE 2 Correction Factors for Biodiesel Blends Measured on a Mineral Oil Calibration Curve

NOTE 1—Determine the correction factor in the table below by finding the known oxygen content of the test specimen (for example, 11 wt %) as the sum of the value in the first column and the value in the first row (for example, 11 = 10+1). The intersection of these two values is the correction factor (for example, 1.1914). Apply the correction according to 12.5.

Oxygen, wt %	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %
0 %	1.0000	1.0174	1.0348	1.0522	1.0696	1.0870	1.1044	1.1218	1.1392	1.1566
10 %	1.1740	1.1914	1.2088	1.2262	1.2436	1.2610	1.2784	1.2958	1.3132	1.3306

TABLE 3 Correction Factors for Gasoline-ethanol Blends Measured on a Mineral Oil Calibration Curve

NOTE 1—Determine the correction factor in the table below by finding the known ethanol content of the test specimen (for example, 15 vol %) as the sum of the value in the first column and the value in the first row (for example, 15 = 10+5). The intersection of these two values is the correction factor (for example, 1.0881). Apply the correction according to 12.5.

Ethanol, vol %	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %
0 %	0.9895	0.9962	1.0029	1.0095	1.0161	1.0228	1.0294	1.0360	1.0425	1.0491
10 %	1.0556	1.0621	1.0686	1.0751	1.0816	1.0881	1.0945	1.1009	1.1073	1.1137
20 %	1.1201	1.1265	1.1328	1.1391	1.1455	1.1518	1.1580	1.1643	1.1706	1.1768
30 %	1.1830	1.1892	1.1954	1.2016	1.2077	1.2139	1.2200	1.2261	1.2322	1.2383
40 %	1.2444	1.2504	1.2565	1.2625	1.2685	1.2745	1.2805	1.2865	1.2924	1.2984
50 %	1.3043	1.3102	1.3161	1.3220	1.3279	1.3337	1.3396	1.3454	1.3512	1.3570
60 %	1.3628	1.3686	1.3743	1.3801	1.3858	1.3915	1.3972	1.4029	1.4086	1.4143
70 %	1.4199	1.4256	1.4312	1.4368	1.4424	1.4480	1.4536	1.4591	1.4647	1.4702
80 %	1.4757	1.4813	1.4868	1.4922	1.4977	1.5032	1.5086	1.5141	1.5195	1.5249
90 %	1.5303	1.5357	1.5410	1.5464	1.5518	1.5571	1.5624	1.5677	1.5730	1.5783

TABLE 4 Correction Factors for Gasoline-ethanol Blends Measured on an Ethanol Calibration Curve

NOTE 1—Determine the correction factor in the table below by finding the known ethanol content of the test specimen (for example, 85 vol %) as the sum of the value in the first column and the value in the first row (for example, 85 = 80+5). The intersection of these two values is the correction factor (for example, 0.9492). Apply the correction according to 12.5. Refer to 7.8 and 10.1 for ethanol calibration.

Ethanol, vol %	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %
0 %	0.6248	0.6291	0.6333	0.6375	0.6417	0.6459	0.6500	0.6542	0.6583	0.6625
10 %	0.6666	0.6707	0.6748	0.6789	0.6830	0.6871	0.6912	0.6952	0.6993	0.7033
20 %	0.7073	0.7113	0.7153	0.7193	0.7233	0.7273	0.7313	0.7352	0.7392	0.7431
30 %	0.7470	0.7510	0.7549	0.7588	0.7627	0.7665	0.7704	0.7743	0.7781	0.7820
40 %	0.7858	0.7896	0.7934	0.7972	0.8010	0.8048	0.8086	0.8124	0.8161	0.8199
50 %	0.8236	0.8274	0.8311	0.8348	0.8385	0.8422	0.8459	0.8496	0.8533	0.8569
60 %	0.8606	0.8642	0.8679	0.8715	0.8751	0.8787	0.8823	0.8859	0.8895	0.8931
70 %	0.8967	0.9002	0.9038	0.9073	0.9108	0.9144	0.9179	0.9214	0.9249	0.9284
80 %	0.9319	0.9354	0.9388	0.9423	0.9458	0.9492	0.9527	0.9561	0.9595	0.9629
90 %	0.9663	0.9697	0.9731	0.9765	0.9799	0.9833	0.9866	0.9900	0.9933	0.9967

6.1.1 *X-ray Source*, capable of producing X rays to excite sulfur. X-ray tubes with a power >25W capable of producing Rh L α , Pd L α , Ag L α , Ti K α , Sc K α , and Cr K α radiation are recommended for this purpose.

6.1.2 *Incident-beam Monochromator*, capable of focusing and selecting a single wavelength of characteristic X rays from the source onto the specimen.

6.1.3 *Optical Path*, designed to minimize the absorption along the path of the excitation and fluorescent beams using a vacuum or a helium atmosphere. A vacuum of < 2.7 kPa (<20 Torr) is recommended. The calibration and test measurements must be done with identical optical paths, including vacuum or helium pressure.

6.1.4 *Fixed-channel Monochromator*, suitable for dispersing sulfur K α X rays.

6.1.5 *Detector*, designed for efficient detection of sulfur K α X rays.

6.1.6 *Single-Channel Analyzer*, an energy discriminator to monitor only sulfur radiation.

6.1.7 *Removable Sample Cell*, an open-ended specimen holder compatible with the geometry of the MWDXRF spectrometer and designed to use replaceable X-ray transparent film (see 6.1.8) to hold a liquid specimen with a minimum depth of 5 mm. The sample cell must not leak when fitted with X-ray transparent film. A disposable cell is recommended.

6.1.8 *X-Ray Transparent Film*, for containing and supporting the test specimen in the sample cell (see 6.1.7) while providing a low-absorption window for X rays to pass to and from the sample. Any film resistant to chemical attack by the sample, free of sulfur, and X-ray transparent can be used, for example, polyester, polypropylene, polycarbonate, and polyimide. However, samples of high aromatic content can dissolve polyester and polycarbonate films.

7. Reagents and Materials

7.1 *Purity of Reagents*—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.⁶ 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.

7.2 *Calibration-Check Samples*, for verifying the accuracy of a calibration. The check samples shall have known sulfur content and not be used in determining the calibration curve. A standard from the same reliable and consistent source of calibration standards used to determine the calibration curve is convenient to check the calibration.

7.3 *Di-n-butyl Sulfide*, a high-purity liquid with a certified sulfur concentration. Use the certified sulfur concentration when calculating the exact concentrations of sulfur in calibration standards. (**Warning**—Di-n-butyl sulfide is flammable and toxic. Prepared solutions may not be stable several months after preparation.)

NOTE 2—It is essential to know the concentration of sulfur in the di-n-butyl sulfide, not only the purity, since impurities can also be sulfur-containing compounds. The sulfur content may be determined via mass dilution in sulfur-free white oil followed by a direct comparison analysis against NIST (or other primary standards body) reference materials.

7.4 *Drift-Monitor Sample (Optional)*, to determine and correct instrument drift over time (see 10.4, 11.1, and 12.1). Various forms of stable sulfur-containing materials are suitable drift-correction samples, for example, liquid petroleum, solid, pressed powder, metal alloy, and fused glass. The count rate displayed by the monitor sample, in combination with a convenient count time (T), shall be sufficient to give a relative standard deviation (RSD) of < 1 % (see Appendix X1).

NOTE 3—Calibration standards may be used as drift-monitor samples. Because it is desirable to discard test specimens after each determination, a lower cost material is suggested for daily use. Any stable material can be used for daily monitoring of drift.

NOTE 4—The effect of drift correction on the precision and bias of this test method has not been studied.

7.4.1 Drift correction can be done automatically if the instrument embodies this option, although the calculation can be readily done by conventional methods of data reduction and processing.

7.5 *Quality-Control (QC) Samples*, for use in establishing and monitoring the stability and precision of an analytical measurement system (see Section 14). Use homogeneous materials, similar to samples of interest and available in sufficient quantity to be analyzed regularly for a long period of time

NOTE 5—Verification of system control through the use of QC samples and control charting is highly recommended.

NOTE 6—Suitable QC samples can be prepared by combining retains of typical samples.

7.6 *White Oil*, use a high purity mineral oil and account for its sulfur content when calculating the sulfur concentrations of the calibration standards.

7.7 *Helium*, minimum purity 99.9 %, for use as an optical path.

7.8 *Ethanol*, use a high purity grade and account for its sulfur content when calculating the sulfur concentrations of the calibration standards. (**Warning**—Ethanol is flammable and harmful if swallowed or inhaled. It is an eye irritant and may cause skin irritation.)

7.9 *2,2,4-Trimethylpentane (Isooctane)*, use a high purity grade and account for its sulfur content when calculating the sulfur concentration of the calibration standards. (**Warning**—Isooctane is flammable and harmful if swallowed or inhaled. It is an eye irritant and may cause skin irritation.)

7.10 *Toluene*, use a high purity grade and account for its sulfur content when calculating the sulfur concentration of the calibration standards. (**Warning**—Toluene is flammable and harmful if swallowed or inhaled. It is an eye irritant and may cause skin irritation.)

7.11 *Polysulfide Oil*, generally nonylpolysulfides containing a known percentage of sulfur diluted in a hydrocarbon matrix. (**Warning**—May cause allergic skin reactions.)

NOTE 7—Polysulfide oils are high molecular weight oils that contain high concentrations of sulfur, as high as 50 weight percent.

8. Sampling and Sample Handling

8.1 Sample fuel according to the procedures in Practices D4057 or D4177

8.2 Use the utmost care in sampling and handling gasoline to prevent evaporation of light ends which could change the concentration of sulfur in the sample. Store gasoline in a leak tight container at 0°C to 4°C until ready for analysis. If possible, maintain at this temperature throughout any transfer and handling processes. Allow specimens maintained at 0°C to 4°C to reach room temperature before testing, and expose these materials to ambient conditions only as long as necessary to obtain a sample for analysis. Analyze test specimens as soon as possible after sub-sampling from bulk container. Do not allow bulk container to remain uncovered any longer than is needed to obtain desired sub-samples.

⁶ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, D.C. 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. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

TABLE 5 Recommended Sulfur Standard Concentration Ranges

NOTE 1—Use the calibration range that brackets the expected sample concentration range. For example, it is not necessary to calibrate 0 to 3000 mg/kg unless the expected sample concentration range exceeds 500 mg/kg.

0 to 3000 mg/kg	0 to 500 mg/kg
0.0 ^A	0.0 ^A
25	5
100	15
500	50
1000	250
3000	500

^A Base material.

8.3 For each sample, an unused piece of X-ray film is required for the sample cell. Avoid touching the inside of the sample cell, any portion of the film exposed to the liquid or the X-ray beam, and also avoid touching the instrument window. (It is highly recommended that clean, disposable rubber or plastic gloves be used when preparing test specimens.) Oil from fingerprints on the film and wrinkles in the film can generate errors in the analysis of sulfur. Therefore, make sure the film is taut and clean to ensure reliable results. Use calibration-check samples (see 7.2) to verify calibration integrity if the type and thickness of the window film is changed. After the sample cell is filled, provide a vent above the sample to prevent bowing of the film by accumulating vapors. When reusable sample cells are used, thoroughly clean and dry cells before each use. Disposable sample cells shall not be reused.

8.4 Because impurities and thickness variations can occur in commercially available transparent films and vary from lot to lot, use calibration-check samples (see 7.2) to verify calibration integrity after starting each new batch of film.

9. Preparation of Apparatus and Specimens for Analysis

9.1 *Analyzer Preparation*—Ensure that the MWDXRF analyzer has been installed and put into operation according to manufacturer’s instructions. Allow sufficient time for instrument electronics to stabilize. Perform any instrument checkout procedures required. When possible, the instrument should be run continuously to maintain optimum stability.

9.1.1 Use the count time (T) recommended by the instrument manufacturer for the lowest sulfur concentration expected. The typical time for each measurement is two to three minutes.

9.1.2 Alternatively, determine T expected for a desired count precision by following the procedure in Appendix X1.

9.2 *Specimen Preparation*—Prepare a specimen of a test sample or a calibration standard as follows:

9.2.1 Carefully transfer a sufficient portion of the liquid to fill an open-ended sample cell above a minimum depth of 5 mm, beyond which additional liquid does not affect the count rate. Filling the sample cell to three-fourths of the cell’s depth is generally adequate.

9.2.2 Fit an unused piece of X-ray-transparent film over the sample-cell opening and attach securely. ~~Use~~ When available, use the same batch of film for the analysis of test samples and the calibration standards used for constructing the calibration curve; otherwise follow 8.4 to verify the calibration integrity when switching to a new batch of film, and recalibrate using the new batch of film when results obtained on the calibration-check sample(s) fall outside acceptance criteria (see 10). Avoid touching the inside of the sample cell, any portion of the film exposed to the liquid or the X-ray beam, and also avoid touching the instrument window. (It is highly recommended that clean, disposable rubber or plastic gloves be used when preparing test specimens.) Ensure the film is taut, wrinkle-free, and not leaking.

9.2.3 Provide a small vent to prevent bowing of the window film caused by the accumulating vapor. Many commercially available sample cells provide a means to vent the space above the liquid.

9.2.4 Perform the analysis of the specimen promptly after preparing the specimen. Do not let the specimen remain in the sample cell any longer than necessary before collecting the data.

10. Calibration

10.1 Obtain or prepare a set of calibration standards bracketing the expected concentration range (up to 3000 mg/kg sulfur) in the samples by careful mass dilution of di-n-butyl sulfide (DBS) with a suitable base material (BM) (see Section 5). Two suitable base materials include mineral oil (see 7.6) for use with the correction factors in Table 3 and ethanol (see 7.8) for use with the correction factors in Table 4. All standards used in the analysis must be from a reliable and consistent source, which can include commercially available standards. Recommended nominal sulfur concentration standards are listed in Table 5.

10.1.1 Take into account any sulfur in the base materials when calculating the sulfur content (mg/kg) in each of the calibration standards as shown in Eq 1:

$$S = [(D B S \cdot S_{DBS}) + (B M \cdot S_{BM})] / (D B S + B M) \quad (1)$$

where: