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Standard Test Method for Determination of Carbohydrates in Biomass by Gas Chromatography[1]

This standard is issued under the fixed designation E1821; 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.

INTRODUCTION

This test method gives a reproducible way to quantitatively determine in lignocellulosic materials the kind and amount of the structural carbohydrates made from arabinose, xylose, mannose, galactose, and glucose. This way is accomplished by first hydrolyzing the carbohydrates to their constituent monosaccharides. Subsequent derivatization produces the corresponding alditol acetates that are quantified using capillary gas chromatography.

1. Scope

1.1 This test method describes the determination of structural carbohydrates present in a biomass sample, expressed as the percent mass of an oven-dried sample basis of each anhydrosugar.

1.2 Sample materials suitable for this procedure include hard and softwoods, herbaceous materials, such as sericea and switchgrass, agricultural residues, such as corn stover, wheat straw, and bagasse, wastepaper, such as boxboard, office waste, and newsprint, acid or alkaline-pretreated biomass, washed free of any residual acid or alkali, and the solid fraction of fermentation residues.

1.3 The options for the types of samples to be analyzed in this procedure are:

1.3.1 *Prepared Biomass Samples:*

1.3.1.1 *Air Dried Material*—Results are reported as the percent by mass, based on the oven-dried mass of the air-dried sample.

1.3.1.2 *45°C Dried Material*—Results are reported as the percent by mass, based on the oven-dried mass of the 45°C dried sample.

1.3.1.3 *Freeze Dried Material*—Results are reported as the percent by mass, based on the oven-dried mass of the freeze dried sample.

1.3.2 *Extractives-Free Sample*—Results are reported as the percent by mass, based on the oven-dried mass of the extracted sample.

1.4 This standard method is generally not suitable for samples that contain soluble, nonstructural carbohydrates unless they are removed prior to analysis.

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

1.6 *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.* See Section 8 for specific hazards statements.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1193 Specification for Reagent Water

E1690 Test Method for Determination of Ethanol Extractives in Biomass

E1721 Test Method for Determination of Acid-Insoluble Residue in Biomass

E1756 Test Method for Determination of Total Solids in Biomass

E1757 Practice for Preparation of Biomass for Compositional Analysis

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *anhydrosugars, n*—the nominal repeating unit of a polysaccharide. When polysaccharides undergo acid

[1] This test method is under the jurisdiction of ASTM Committee E48 on Bioenergy and Industrial Chemicals from Biomass and is the direct responsibility of Subcommittee E48.05 on Biomass Conversion.

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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.

hydrolysis, each repeating unit adds a single molecule of water to form the free monosaccharide that is analyzed. The extra weight from this water of hydrolysis must be taken in to account whencalculating the actual mass percent of the polysaccharide in the original biomass sample.

3.1.2 *as received biomass, n*—material as it is received in its field or process collected state.

3.1.3 *extractives-free biomass*—air-dried solids left after biomass has been treated according to Test Method E1690.

3.1.4 *oven-dried mass, n*—the moisture-free mass of any biomass sample (as received, prepared, extractives-free, etc.) dried at 105°C as described in Test Method E1756.

3.1.5 *prepared biomass, n—as received biomass* material that has been treated according to Practice E1757 in order to raise the total solids content above 85 %, based on an oven-dried solids weight.

3.1.6 *structural carbohydrates, n*—polysaccharides that cannot be removed by extraction with solvents and are liberated from the biomass solids with dilute acid hydrolysis. For the purpose of this test method, the monosaccharides that are considered present are arabinose, xylose, mannose, galactose, and glucose.

3.2 *Abbreviations:*

3.2.1 $\%Anhydro_{ext}$—the percent by mass of the anhydrosugar on an extractives-free, oven-dried mass basis.

3.2.2 $\%Anhydro_{whole}$—the percent by mass of the anhydrosugar, on an oven-dried mass basis.

3.2.3 AR_c (Amount Ratio)—ratio of the concentration (amount) of monosaccharide *c* to the concentration (amount) of internal standard in the specimen.

3.2.4 $area_c$—reported area counts for the monosaccharide *c* peak in the chromatogram, as integrated by the electronic integrator.

3.2.5 $area_{IS}$—reported area counts for the internal standard peak in the chromatogram, as integrated by the electronic integrator.

3.2.6 C_{avg}—average concentration of monosaccharide *c* in specimen *s*, in mg/mL, averaged across multiple injections of specimen *s*.

3.2.7 C_{LF}—original concentration of monosaccharide *c* in loss factor sample, in mg/mL.

3.2.8 C_{IS}—concentration of internal standard (inositol) in the calibration standards and specimen, in mg/mL.

3.2.9 C_s—concentration of monosaccharide *c* in specimen *s*, measured by gas chromatography (GC), in mg/mL.

3.2.10 C_{STD}—concentration of monosaccharide *c* in the calibration standard, in mg/mL.

3.2.11 *CV (coefficient of variation)*—the estimated standard deviation divided by the average value measured.

3.2.12 *%extractives*—the percentage by mass of extractives in the extracted specimen as described in Test Method E1690.

3.2.13 *k*—constant used to convert the mass of monosaccharide to the mass of anhydrosugar from which it is derived. For arabinose and xylose, $k = 0.88$ (m/z 132/150); for mannose, galactose and glucose, $k = 0.90$ (m/z 162/180).

3.2.14 *LF*—loss factor for monosaccharide *c*. Used to correct for the amount of monosaccharide lost through degradation during acid hydrolysis of biomass.

3.2.15 m_I—initial mass of the biomass specimen, in mg.

3.2.16 m_{corr}—mass of monosaccharide in solution, corrected for hydrolysis losses, in mg.

3.2.17 RR_{avg}—averaged response ratio of monosaccharide *c* to the internal standard (inositol) in the calibration standard. Derived from multiple injections of the same calibration standard.

3.2.18 RR_s—response ratio of monosaccharide *c* to the internal standard (inositol) in the specimen.

3.2.19 RR_{STD}—response ratio of monosaccharide *c* to the internal standard (inositol) in the calibration standard.

3.2.20 *RRF (Relative Response Factor of monosaccharide c)*—this is the ratio of the detector response for monosaccharide *c* versus the detector response for the internal standard (inositol) for a given injection of the specimen.

3.2.21 V_f—87 mL, volume of hydrolysis solution.

3.2.22 $\%T_{45}$—percentage by mass, of total solids of the specimen prepared by drying at 45°C, as described by Practice E1757.

3.2.23 $\%T_{105}$—percentage by mass, of total solids of the specimen, dried at 105°C, as determined by Test Method E1756.

3.2.24 $\%T_{ad}$—percentage by mass, of total solids of the air-dried specimen determined at 105°C as described by Test Method E1756.

3.2.25 $\%T_{ext}$—percentage by mass, of total solids of the extracted specimen determined at 105°C as described by Test Method E1756.

3.2.26 $\%T_{fd}$—percentage by mass, of total solids of the specimen prepared by freeze drying, as described by Practice E1757.

3.2.27 $\%T_{prep}$—percentage, by mass, of total solids of the specimen prepared by freeze drying,% T_{fd}, or by drying at 45°C, $\%T_{45}$, as determined by Practice E1757.

4. Significance and Use

4.1 The structural carbohydrate content is used in conjunction with other assays to determine the total composition of biomass samples.

5. Interferences

5.1 The results of structural carbohydrate analysis are affected by incomplete hydrolysis of biomass or hydrolysis conditions that are too severe. Incomplete hydrolysis will bias the results low because dimeric and oligomeric carbohydrates are not quantified. Hydrolysis conditions that are too severe degrade the liberated monosaccharides into materials that are not quantified by this procedure, again biasing the results low.

5.2 Incomplete neutralization and removal of acetic acid from the methylene chloride extract prior to GC analysis can

result in ghost peaks appearing in the chromatogram or carryover of monosaccharides from one injection to the next (owing to buildup of monosaccharides in the injection port), leading to erroneous quantitation.

5.3 Test specimens not suitable for analysis by this procedure include alkaline and acid-pretreated biomass samples that have not been washed. Unwashed pretreated biomass samples containing free acid or alkali may change visibly on heating.

5.4 Materials containing nonstructural carbohydrates also are unsuitable for this procedure since nonstructural carbohydrates may undergo degradation to materials that are not quantified in this procedure.

6. Apparatus

6.1 *Analytical Balance,* readable to 0.1 mg.

6.2 *Autoclave,* capable of maintaining 121 ± 3°C.

6.3 *Convection Ovens,* temperature controlled to 45 ± 3°C and 105 ± 3°C.

6.4 *Desiccator,* containing anhydrous calcium sulfate.

6.5 *Gas Chromatograph,* equipped with electronic integrator, capillary split injection port, flame ionization detector with make-up gas, 250 µm × 15 m fused-silica capillary column coated with 50 % cyanopropylphenyl methylpolysiloxane, 0.25 µm film thickness (DB-225[3] or equivalent).

6.6 *Ice Bath.*

6.7 *Ultrasonic Bath.*

6.8 *Vortex Mixer,* or equivalent method to rapidly mix solutions in a test tube.

6.9 *Water Bath,* setable to 30 ± 1°C and 40 ± 1°C.

7. Reagents and Materials

7.1 *Chemicals:*

7.1.1 *Purity of Reagents*—Use reagent grade chemicals 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.[4] Monosaccharides used to prepare the monosaccharide stock solutions and loss factor standard solutions shall be 98+ mass % purity. Other chemical grades may be substituted, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.1.2 *Purity of Water*—Unless otherwise indicated, references to water mean reagent water as defined by Type 1 of Specification D1193.

7.1.3 *Acetic Acid* (CH_3COOH), glacial.

7.1.4 *Acetic Anhydride* ($(CH_3CO)_2O$).

7.1.5 *Ammonium Hydroxide,* (NH_4OH), concentrated (28–30 wt % NH_3).

7.1.6 *Ammonium Hydroxide Solution (~3 M)*—Dilute 5.0 ± 0.1 mL of concentrated ammonium hydroxide (NH_4OH) with 20.0± 0.1 mL of water. Prepare fresh before each use.

7.1.7 *Monosaccharide Stock A Solution*—Combine the following monosaccharides. Weigh each monosaccharide in the following nominal amounts (record each actual mass to the nearest 0.1 mg). Dissolve in water and dilute to 100 mL. Store at 4°C and discard after four weeks.

Arabinose ($C_5H_{10}O_5$)	90–110 mg
Xylose ($C_5H_{10}O_5$)	650–750 mg
Mannose ($C_6H_{12}O_6$)	90–110 mg
Galactose ($C_6H_{12}O_6$)	90–110 mg
Glucose ($C_6H_{12}O_6$)	1900–2100 mg

7.1.8 *Monosaccharide Stock B Solution*—Prepare in manner identical to monosaccharide stock A solution.

7.1.9 *Dichloromethane,* (CH_2Cl_2).

7.1.10 *Inositol Solution (20 mg/mL)*—Dissolve 5.000 ± 0.0025 g of inositol ($C_6H_{12}O_6$, 98 + wt %) in water and dilute to 250 mL. Store at 4°C and discard after one week.

7.1.11 *Loss Factor Standard Stock Solution*—Combine together each of the following monosaccharides. Weigh each monosaccharide in the following nominal amounts (record each actual weight to the nearest 0.1 mg). Dissolve in water and dilute to 100 mL. Store at 4°C and discard after four weeks.

Arabinose ($C_5H_{10}O_5$)	900–1100 mg
Mannose ($C_6H_{12}O_6$)	900–1100 mg
Galactose ($C_6H_{12}O_6$)	900–1100 mg
Xylose ($C_5H_{10}O_5$)	900–1100 mg
Glucose ($C_6H_{12}O_6$)	900–1100 mg

7.1.12 *1-Methylimidazole,* ($(C_3H_3N_2–)(CH_3)$).

7.1.13 *Potassium Borohydride Solution, (0.15 g/mL)*—Dissolve 7.50 ± 0.05 g potassium borohydride (KBH_4) in 40 mL of ~3 M ammonium hydroxide (NH_4OH) solution. Use an ultrasonic bath to get the salt to dissolve in a reasonable amount of time. Dilute to 50.0 ± 0.1 mL with ~3 M ammonium hydroxide (NH_4OH) solution. Prepare immediately before use. Discard after 6 h. This quantity is sufficient for 50 specimens and calibration standards.

7.1.14 *Potassium Hydroxide Solution (3.5 M)*—Dissolve 58.0± 0.5 g of potassium hydroxide (KOH, 85 wt %) in 200 mL water. Allow to cool to room temperature before diluting to 250 mL with water.

7.1.15 *Sulfuric Acid Solution (12 M)*—Slowly add 665 mL of 96 wt % sulfuric acid (H_2SO_4) to 300 mL of water cooled in an ice bath with stirring. Allow solution to come to room temperature and dilute to 1 L. Check the concentration by titration and adjust the concentration to 12.0 ± 0.1 M (24.0 ± 0.2 N).

7.2 *Materials:*

7.2.1 *Glass Filtering Crucibles,* 50 mL, medium porosity, nominal pore size of 10 µm.

7.2.2 *Glass Serum Bottles,* 125 mL, crimp-top style with rubber stoppers and aluminum seals to fit.

7.2.3 *Vacuum Adaptor for Filtering Crucibles.*

[3] DB-225 is a trademark of Agilent Technologies, Inc., 5301 Stevens Creek Boulevard, Santa Clara CA 95051.

[4] *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.

7.2.4 *Vials,* 13 × 32 mm crimp-top style with polytetrafluoroethylene-faced rubber septum and aluminum crimp seals or equivalent.

8. Hazards

8.1 Do not permit sulfuric acid, glacial acetic acid, acetic anhydride, or potassium hydroxide to contact skin or clothing. They are corrosive. Wear protective clothing.

8.2 After the autoclave step, the glass bottles are hot and may be pressurized. Handle with caution.

8.3 Solutions of potassium borohydride will spontaneously evolve hydrogen gas on standing. To prevent pressurization, do not seal bottles. Ensure adequate ventilation around such solutions to avert the accumulation of flammable hydrogen gas. Wet potassium borohydride is highly flammable.

8.4 Methylene chloride is a very volatile solvent and is both toxic and a suspected carcinogen. Handle only with adequate ventilation.

9. Sampling, Test Specimens and Test Units

9.1 Test specimens suitable for analysis by this procedure are listed below:

9.1.1 *As-Received Biomass.*

9.1.2 *Biomass,* prepared according to Practice E1757.

9.1.3 *Extractives-Free Material,* prepared according to Test Method E1690.

10. Calibration and Standardization

10.1 GC Calibration Standards. Prepare one of each.

10.1.1 *GC Calibration Standard A Solution*—Measure 10.00 mL of monosaccharide stock A solution. Add 69.0 mL of water, 5.0 mL of Inositol solution and 3.0 mL of 12 M sulfuric acid. Mix. Store at 4°C and use within four weeks of preparation.

10.1.2 *GC Calibration Standard B Solution*—Measure 10.00 mL of monosaccharide stock B solution. Add 69.0 mL of water, 5.0 mL of Inositol solution and 3.0 mL of 12 M sulfuric acid. Mix. Store at 4°C and use within four weeks of preparation.

NOTE 1—If the analyst desires a multipoint calibration curve, differing amounts of the respective stock solution can be diluted to 10.00 mL and the calibration solutions made up as described in 10.1.1 or 10.1.2.

10.2 *Loss Factor Calibration Solution*—Prepare once. Measure 10.00 mL of loss factor standard stock solution. Add 69.0 mL of water, 5.0 mL of Inositol solution and 3.0 mL of 12 M sulfuric acid. Mix. Store at 4°C and use within one week of preparation.

10.3 *Loss Factor Sample Solution*—Prepare in duplicate. Measure 10.00 mL of loss factor standard stock solution. Add 69.0 mL of water, 5.0 mL of inositol solution and 3.0 mL of 12 M sulfuric acid. Mix. Store at 4°C and use within one week of preparation.

11. Procedure

11.1 An overview of the analytical sequence is as follows:

11.1.1 Pretreatment of specimens with 12 M sulfuric acid.

11.1.2 Dilution and autoclaving of specimens and loss factor sample solutions.

11.1.3 Filtration of insolubles from hydrolyzates and loss factor sample solutions.

11.1.4 Derivatization of monosaccharides in GC Calibration Standards, Loss Factor Calibration solution, Loss Factor Sample solutions and hydrolyzate specimens.

11.1.5 GC analysis of derivitized GC Calibration Standards, Loss Factor Calibration solution, Loss Factor Sample solutions, and hydrolyzate specimens.

11.1.6 Calculation of anhydrosugar contents.

11.2 For samples used as received (as received biomass), determine the total solids by Test Method E1756 and record the total solids value as $\%T_{105}$. The remainder of the specimen is treated according to Practice E1757 to produce a prepared biomass specimen. This prepared specimen should be stored in a manner to ensure that its moisture content remains constant prior to analysis.

11.2.1 If Method A of Practice E1757 is used (air drying), determine the total solids of this prepared specimen by Test Method E1756 and record the total solids value as $\%T_{ad}$.

11.2.2 If Method B of Practice E1757 is used (drying at 45°C), record the total solids calculated in this practice, $\%T_{45}$, as $\%T_{prep}$.

11.2.3 If Method C of Practice E1757 is used (freeze drying), record the total solids calculated in this practice, $\%T_{fd}$, as$\%\ T_{prep}$.

11.3 If extractives-free material is used, determine the total solids of the extractive-free material by Test Method E1756 and record this value as $\%T_{ext}$.

11.4 Weigh 300 ± 10 mg of the prepared or extractive-free specimen to the nearest 0.1 mg and place in 16 × 100 mm test tube. Record as m_1, the initial mass.

11.5 Add 3.00 ± 0.01 mL (4.92 ± 0.01 g) of 12 M H_2SO_4 and stir with a clean glass rod for 1 min or until thoroughly mixed. Leave the glass rod in the test tube.

NOTE 2—**Warning:** 12 M sulfuric acid is very corrosive and should be handled only by trained personnel.

NOTE 3—Incomplete mixing of the acid-biomass slurry during the primary acid hydrolysis can produce very erratic results. Ensure that all of the material is thoroughly wetted by the acid.

11.6 Place the test tube in the water bath controlled to 30 ± 1°C and hydrolyze for 2 h. Stir the specimen with the glass rod every 15 min to assure complete mixing and wetting.

NOTE 4—The hydrolysis time may be reduced to 1 h if the dried specimen has been milled previously and sieved to pass through a 20 mesh sieve and be retained on a 80 mesh sieve.

11.7 Transfer the hydrolyzate to a glass serum bottle by adding 79.00 ± 0.04 mL water. Carefully rinse all the residual solids from the glass rod and the test tube, and transfer these solids along with the hydrolysis liquor to the serum bottle.

11.8 Add 5.00 ± 0.02 mL of inositol solution to the serum bottle.

11.9 Process the duplicate loss factor sample solutions beginning at this point by transferring the entire volume of each loss factor sample (87 mL) into their respective serum bottles.

11.10 Stopper each of the serum bottles and crimp the aluminum seals into place.

11.11 Set the autoclave to a liquid vent cycle to prevent loss of specimen from the bottles in the event of loose crimp seals. Autoclave the specimens in their sealed bottles for 1 h at 121 ± 3°C.

NOTE 5—**Warning:** Handle sealed bottles with caution after the autoclave step as they may be pressurized.

11.12 After completion of the autoclave cycle, allow the specimen to cool for about 20 min at room temperature before removing the seals and stoppers.

11.13 Vacuum filter the hydrolysis solution through a filtering crucible and collect the hydrolyzate in the vacuum flask.

NOTE 6—If acid-insoluble residue or acid-soluble lignin determinations are to be conducted on the specimen, the residual solids must be collected by filtering the hydrolyzates through an ashed and weighed filtering crucible prior to removing an aliquot for carbohydrate analysis. Refer to Test Method E1721 for details. If an acid-soluble lignin determination is to be conducted, an aliquot of the filtrate must be reserved for analysis. Acid-soluble lignin should be analyzed within 24 h, and preferably within 6 h, of hydrolysis.

NOTE 7—Because of the length and complexity of the following sections of this test method for the derivatization of monosaccharides, it is recommended that all hydrolyzates be run in duplicate to ensure that a valid specimen for GC analysis is produced.

11.14 Transfer 1000 ± 1 µ÷L (1.000 mL) of each hydrolyzate solution into their respective 18 × 150 mm glass test tubes. Also, transfer 1000 ± 1 µ÷L (1.000 mL) each of GC Calibration Standard A and B solutions and the Loss Factor Calibration solution to their respective glass test tubes.

11.15 Add 250 ± 1 µ÷L of concentrated ammonium hydroxide to each specimen in the test tubes. Immediately mix the solution with a vortex mixer for 5 s after the vortex appears.

NOTE 8—The solution should have a pH equal to or greater than 10.3. This pH can be verified with wide range pH papers. Values for pH less than this indicate either that the 12 M sulfuric acid used for hydrolysis is too strong, unacceptable evaporation of the hydrolysis solution occurred during the autoclave or the transfer step or that the concentrated ammonium hydroxide has evaporated and is less than 28 % mass ammonia. Solutions with a pH of less than 10.3 will show irreproducible reduction reactions with potassium borohydride.

11.16 Add 500 ± 5 µ÷L of fresh 0.15 g/mL potassium borohydride solution to each test tube and immediately vortex mix for 5 s after the vortex appears.

11.17 Place the test tube in a water bath at 40 ± 1°C for 90 min to allow reduction of the monosaccharides to their respective alditols (sugar alcohols).

11.18 Remove the test tubes from the water bath and stop the reduction reaction by adding 500 ± 25 µL of glacial acetic acid, dropwise. Allow the effervescence to subside before adding a subsequent drop of acid. As soon as the addition is complete, mix on the vortex mixer for 5 s after the vortex appears and allow to cool to room temperature (about 10 min).

11.19 Pipet 400 ± 1 µ÷L of each reduced specimen to a new 18 × 150 mm glass test tube.

11.20 Add 500 ± 5 µ÷L of 1-methylimidazole to each test tube. Mix on the vortex mixer for 5 s.

11.21 Add 2.0 ± 0.1 mL of acetic anhydride dropwise. Use care as the initial reaction can be quite vigorous and the tube will become quite warm. Mix on the vortex mixer for 5 s after the vortex appears, and allow the reaction to proceed for 30 min without special cooling.

11.22 Decompose the excess acetic anhydride by adding 5.0 ± 0.1 mL of water. Vortex mix the specimens for 5 s after the vortex appears, and allow to cool to room temperature (about 10 min). An ice bath may be used to hasten the cooling.

11.23 Add 2.0 ± 0.1 mL of dichloromethane, vortex mix for 15 s after the vortex appears, and allow the phases to completely separate so that little or no haziness is present in either phase (allow at least 15 min).

11.24 Pipet off the top 5.0 mL of the aqueous phase and discard.

11.25 Cool the test tube in an ice bath. Add 5.0 ± 0.1 mL of 3.5 M potassium hydroxide, dropwise, while cooling. When the addition is complete, vortex mix for 5 s after the vortex appears, and allow the phases to completely separate so that no haziness is present in either phase (again allow at least 15 min).

11.26 Pipet 1.0 to 1.5 mL of the lower phase (dichloromethane solution of alditol acetates) into a 13 × 32 mm vial. Use care to ensure that none of the upper aqueous layer is transferred with the dichloromethane. Cap the vial with a crimp septum cap. Store the specimen in a refrigerator at 4°C if it is not analyzed immediately by gas chromatography.

11.27 *Gas Chromatographic Instrument Conditions:*

11.27.1 The recommended conditions for gas chromatography are as follows:

11.27.1.1 GC equipped with flame ionization detector, capillary split injection port and electronic integrator.

11.27.1.2 Column: DB-225,[3] 15 m × 250 µm ID, 0.25 µm film thickness.

11.27.1.3 Alternative column: SPB-225,[5] Rtx™-225[6] or equivalent.

11.27.1.4 Alternative detector: Mass spectrometer, select ion monitoring mass 43.

11.27.1.5 Temperature Programmed GC run:

	190°C for 1.0 min
	10°C/min to 220°C
	Hold for 10 min
	Total run time: 14 min
Injection volume	: 2 µL
Injector temp.	: 200°C
Detector temp.	: 250°C
Carrier gas	: Helium, velocity of 40 cm/s
Split ratio	: 1:30

NOTE 9—Relative retention times of alditol acetates of respective monosaccharides:

Arabinose	0.45
Xylose	0.53
Mannose	0.82
Galactose	0.88
Glucose	0.95
Inositol	1.00—Internal Standard

[5] SPB-225 is a trademark of Sigma-Aldrich, P.O. 14508, St. Louis, MO 63178.

[6] Rtx-225 is a trademark of Restek Corporation, 110 Benner Circle, Bellefonte, PA 16823-8812.

11.28 Inject each of the specimen, calibration standards, and loss factor samples in triplicate. Determine the peak area for each respective monosaccharide and the internal standard.

12. Calculations

12.1 Calibration of the GC is done by calculating relative response factors (RRFs). Repeat for each monosaccharide in each injection of each calibration standard and loss factor calibration solution.

12.1.1 First calculate the amount ratio (AR_c) for each monosaccharide in each standard:

$$AR_c = \frac{C_{STD}}{C_{IS}} \quad (1)$$

where:

AR_c = amount ratio of monosaccharide c,
C_{STD} = known concentration of monosaccharide c in the standard, in mg/mL, and
C_{IS} = concentration of internal standard (inositol) in standard, in mg/mL.

12.1.2 Next calculate the response ratio (RR_{STD}) for each monosaccharide in each standard:

$$RR_{STD} = \frac{area_c}{area_{IS}} \quad (2)$$

where:

RR_{STD} = response ratio of monosaccharide c to the internal standard (inositol) in the calibration standard,
$area_c$ = reported area counts for the monosaccharide c peak, as integrated by electronic integrator, and
$area_{IS}$ = reported area counts for the internal standard peak, as integrated by electronic integrator.

12.1.3 Average the response ratios for the triplicate injections for use in subsequent calculations.

$$RR_{avg} = \frac{\sum_{s=1}^{3} RR_{STD}}{3} \quad (3)$$

where:

RR_{avg} = average response ratio of monosaccharide c in the standard, and
RR_{STD} = response ratio of monosaccharide c to the internal standard (inositol) in the calibration standard, Eq 2.

12.1.4 Calculate the relative response factor (RRF) for each monosaccharide in each standard:

$$RRF = \frac{AR_c}{RR_{AVG}} \quad (4)$$

where:

RRF = relative response factor of monosaccharide c,
AR_c = amount ratio of monosaccharide c, Eq 1, and
RR_{AVG} = response ratio of monosaccharide c, Eq 3.

NOTE 10—If multipoint calibration curve is desired (see Note 1), an alternative to Eq 4 is to calculate a linear regression curve, using AR_c as the independent variable and RR_{STD} as the dependent variable. The slope of the curve is equal to the RRF. Details on the calculation of linear regression curves can be found in most elementary statistical analysis texts.

12.2 Calculate the actual concentration of monosaccharides, both in hydrolyzates and loss factor samples. Repeat for each monosaccharide in each injection.

12.2.1 First calculate the response ratio (RR_s) for each monosaccharide in each standard:

$$RR_s = \frac{area_c}{area_{IS}} \quad (5)$$

where:

RR_s = response ratio of monosaccharide c to the internal standard (inositol) in the specimen,
$area_c$ = reported area counts for the monosaccharide c peak, as integrated by electronic integrator, and
$area_{IS}$ = reported area counts for the internal standard peak, as integrated by electronic integrator.

12.2.2 Calculate the concentration (C_s) for each monosaccharide in each specimen:

$$C_s = RR_s \times C_{IS} \times RRF \quad (6)$$

where:

C_s = concentration of monosaccharide c in specimen s, measured by GC, in mg/mL,
RR_s = response ratio of monosaccharide c to the internal standard (inositol) in the specimen,
C_{IS} = concentration of internal standard (inositol) in specimen, in mg/mL, and
RRF = relative response factor for monosaccharide c, Eq 3. The appropriate RRF to use is the one calculated from the standard with the RR_{AVG} closest to the RR_s of the specimen being calculated.

NOTE 11—If a multipoint calibration curve is calculated (see Note 10), use the RRF calculated from the slope of the curve.

12.2.3 Average the results for the triplicate injections for use in subsequent calculations.

$$C_{avg} = \frac{\sum_{s=1}^{3} C_s}{3} \quad (7)$$

where:

C_{avg} = average concentration of monosaccharide c in specimen s, in mg/mL, and
C_s = concentration of monosaccharide c in specimen s, in mg/mL.

12.3 The loss factor is a correction factor to adjust for losses of monosaccharides that occur during acid hydrolysis and is calculated as follows:

$$LF = C_{LF}/C_{avg} \quad (8)$$

where:

LF = loss factor for monosaccharide c,
C_{LF} = original concentration of monosaccharide c in loss factor sample, in mg/mL, and
C_{avg} = average concentration of monosaccharide c in the loss factor sample, in mg/mL, Eq 7.

12.4 The calculation of original monosaccharide mass in solution, corrected for hydrolysis losses, is as follows:

$$m_{corr} = C_{avg} \times LF \times V_F \quad (9)$$

where:

m_{corr} = corrected mass of monosaccharide c in solution, in mg,
C_{avg} = average concentration of monosaccharide c in specimen s, in mg/mL, Eq 7,
LF = loss factor for monosaccharide c, Eq 8, and
V_f = 87 mL, volume of hydrolysis solution.

12.5 The final calculation of anhydrosugar originally present in the specimen, as percent mass of an oven-dried specimen, depends on the method of preparation of the specimen.

12.5.1 If the biomass was prepared in accordance with Practice E1757, calculate the percent by mass of each anhydrosugar in the as received sample, on a oven-dried mass basis, as follows:

$$\%Anhydro_{whole} = \frac{m_{corr} \times k}{m_1 \times \frac{\%T_{ad}}{100\,\%}} \times 100\,\% \quad (10)$$

where:

$\%Anhydro_{whole}$ = the percent by mass, of the anhydrosugar in the sample, on a oven-dried mass basis,
m_{corr} = corrected mass of monosaccharide c in solution, in mg,
k = constant used to convert the mass of monosaccharide to the weight of anhydrosugar. For arabinose and xylose, $k = 0.88$ (132/150); for mannose, galactose and glucose, $k = 0.90$ (162/180),
m_i = initial mass of specimen, in mg, and
$\%T_{ad}$ = percent by mass, of total solids of the air-dried specimen determined by Test Method E1756.

12.5.2 If the biomass was prepared in accordance with Practice E1757, calculate the percent by mass of each anhydrosugar in the as received sample, on an oven-dried mass basis, as follows:

$$\%Anhydro_{whole} = \frac{m_{corr} \times k}{m_1 \times \frac{\%T_{105}}{\%T_{prep}}} \times 100\,\% \quad (11)$$

where:

$\%Anhydro_{whole}$ = the percent by mass, of the anhydrosugar in the sample, on an oven-dried mass basis,
m_{corr} = corrected mass of monosaccharide c in solution, in mg,
k = constant used to convert the mass of monosaccharide to the weight of anhydrosugar. For arabinose and xylose, $k = 0.88$ (132/150); for mannose, galactose and glucose, $k = 0.90$ (162/180),
m_i = initial mass of specimen, in mg,
$\%T_{105}$ = percent by mass of total solids of the specimen dried at 105°C as described in Test Method E1756,
$\%T_{prep}$ = percent by mass, of total solids of the specimen prepared by freeze-drying, and

$\%T_{fd}$, or by drying at 45°C,% T_{45}, as described in Practice E1757.

12.5.3 If the biomass was prepared according to Test Method E1690, first calculate the percent by mass of each anhydrosugar in the extractives-free sample, on an oven-dried mass basis, and then correct this value to an as received (whole sample) oven-dried mass basis.

12.5.3.1 Calculate the percent by mass of each anhydrosugar present on an extractives-free basis as follows:

$$\%Anhydro_{ext} = \frac{m_{corr} \times k}{m_1 \times \frac{\%T_{ext}}{100\,\%}} \times 100\,\% \quad (12)$$

where:

$\%Anhydro_{ext}$ = the percent by mass of the anhydrosugar on an extractives-free, oven-dried mass basis,
m_{corr} = corrected mass of monosaccharide c in solution, in mg,
k = constant used to convert the mass of monosaccharide to the weight of anhydrosugar. For arabinose and xylose, $k = 0.88$ (132/150); for mannose, galactose and glucose, $k = 0.90$ (162/180),
m_i = initial mass of specimen, in mg, and
$\%T_{ext}$ = percent by mass of total solids of the ethanol-extracted specimen determined at 105°C as described in Test Method E1756.

12.5.3.2 Correct the percent by mass of the anhydrosugar value on an extractives-free basis, to an as received (whole sample) oven-dried mass basis as follows:

$$\%Anhydro_{whole} = \%Anhydro_{ext} \times \frac{100\,\% - \%extractives}{100\,\%} \quad (13)$$

where:

$\%Anhydro_{whole}$ = the percent by mass of the anhydrosugar in the sample, on an oven-dried mass basis,
$\%Anhydro_{ext}$ = the percent by mass of the anhydrosugar on an extractives-free, oven-dried mass basis, as determined in Eq 12, and
$\%extractives$ = the percent by mass of extractives in the extracted specimen as described in Test Method E1690.

13. Report

13.1 Report the percent by mass of anhydrosugar present in the sample to two decimal places, on an oven-dried mass basis.

14. Precision and Bias

14.1 *Summary*—Precision and bias data are not complete at this time.

15. Keywords

15.1 agricultural residue; biomass; carbohydrates; fermentation residue; herbaceous; monosaccharide; wastepaper; wood