



**Designation: D5441–98 (Reapproved 2017) D5441 – 21**

## **Standard Test Method for Analysis of Methyl Tert-Butyl Ether (MTBE) by Gas Chromatography<sup>1</sup>**

This standard is issued under the fixed designation D5441; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### **1. Scope**<sup>\*</sup>

1.1 This test method covers the determination of the purity of methyl tert-butyl ether (MTBE) by gas chromatography. It also provides a procedure to measure impurities in MTBE such as C<sub>4</sub> to C<sub>12</sub> olefins, methyl, isopropyl and tert-butyl alcohols, methyl sec-butyl and methyl tert-amyl ethers, acetone, and methyl ethyl ketone. Impurities are determined to a minimum concentration of ~~0.02 mass %~~ 0.02 % by mass.

1.2 This test method is not applicable to the determination of MTBE in gasoline.

1.3 Water cannot be determined by this test method and must be measured by a procedure such as Test Method **D1364** and the result used to normalize the chromatographic values.

1.4 A majority of the impurities in MTBE is resolved by the test method, however, some co-elution is encountered.

1.5 This test method is inappropriate for impurities that boil at temperatures higher than 180 °C or for impurities that cause poor or no response in a flame ionization detector, such as water.

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1.6 The values stated in SI (metric) units of measurement are preferred and used throughout the standard.

1.6.1 *Exception*—Alternate units, in common usage, are also provided to improve clarity and aid the user of this test method.

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

1.8 *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:*<sup>2</sup>

<sup>1</sup> 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 **D02.04.01** on Gas Chromatography Methods.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

[D1364 Test Method for Water in Volatile Solvents \(Karl Fischer Reagent Titration Method\) \(Withdrawn 2021\)<sup>3</sup>](#)  
[D3700 Practice for Obtaining LPG Samples Using a Floating Piston Cylinder](#)  
[D4057 Practice for Manual Sampling of Petroleum and Petroleum Products](#)  
[D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants](#)  
[D4307 Practice for Preparation of Liquid Blends for Use as Analytical Standards](#)  
[D4626 Practice for Calculation of Gas Chromatographic Response Factors](#)  
[E355 Practice for Gas Chromatography Terms and Relationships](#)  
[E594 Practice for Testing Flame Ionization Detectors Used in Gas or Supercritical Fluid Chromatography](#)

### 3. Terminology

3.1 *Definitions*—This test method makes reference to many common gas chromatographic procedures, terms, and relationships. Detailed definitions of these and other terms used in this test method can be found in Practices [E355](#) and [E594](#), and Terminology [D4175](#).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1  $C_4$  to  $C_{12}$  ~~olefins~~—*olefins, n*—common olefin impurities in MTBE are unreacted feedstock and dimers or trimers of feed such as trimethylpentene or pentamethylheptene.

### 4. Summary of Test Method

4.1 A representative aliquot of the MTBE product sample is introduced into a gas chromatograph equipped with a methyl silicone bonded phase fused silica open tubular column. Helium carrier gas transports the vaporized aliquot through the column where the components are separated by the chromatographic process. Components are sensed by a flame ionization detector as they elute from the column.

4.2 The detector signal is processed by an electronic data acquisition system or integrating computer. Each eluting component is identified by comparing its retention time to those established by analyzing standards under identical conditions.

4.3 The concentration of each component in mass percent is determined by normalization of the peak areas after each peak area has been corrected by a detector response multiplication factor. The detector response factors are determined by analyzing prepared standards with concentrations similar to those encountered in the sample.

### 5. Significance and Use

5.1 The presence of impurities in MTBE product can have a deleterious effect upon the value of MTBE as a gasoline additive. Oxygenate and olefin contents are of primary concern. This test method provides a knowledge of the composition of MTBE product. This is useful in the evaluation of process operations control, in the valuation of the product, and for regulatory purposes.

5.2 Open tubular column gas chromatography with a flame ionization detector, used by the test method, is a technique that is sensitive to the contaminants commonly found in MTBE, and a technique that is widely used.

### 6. Interferences

6.1 Cyclopentane and 2,3-dimethylbutane have been observed to co-elute with MTBE. However, these are not commonly found impurities in MTBE.

### 7. Apparatus

7.1 *Gas Chromatograph*—Instrumentation capable of operating at the conditions listed in [Table 1](#). A heated flash vaporizing injector designed to provide a linear sample split injection (that is, 200:1) is required for proper sample introduction. Carrier gas controls must be of adequate precision to provide reproducible column flows and split ratios in order to maintain analytical integrity. Pressure control devices and gauges must be designed to attain the linear velocity required in the column used (for

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

**TABLE 1 Typical Operating Conditions**

|                            |                       |           |           |
|----------------------------|-----------------------|-----------|-----------|
| Column Temperature Program |                       |           |           |
| Column length              | 50 m                  | 100 m     | 150 m     |
| Initial temperature        | 40 °C                 | 50 °C     | 60 °C     |
| Initial hold time          | 13 min                | 13 min    | 13 min    |
| Program rate               | 10 °C/min             | 10 °C/min | 10 °C/min |
| Final temperature          | 180 °C                | 180 °C    | 180 °C    |
| Final hold time            | 3 min                 | 7 min     | 20 min    |
| Injector                   |                       |           |           |
| Temperature                | 200 °C                |           |           |
| Split ratio                | 200:1                 |           |           |
| Sample size                | 0.1 to 0.5 µL         |           |           |
| Detector                   |                       |           |           |
| Type                       | flame ionization      |           |           |
| Temperature                | 250 °C                |           |           |
| Fuel gas                   | hydrogen (≈30 mL/min) |           |           |
| Oxidizing gas              | air (≈300 mL/min)     |           |           |
| Make-up gas                | nitrogen (≈30 mL/min) |           |           |
| Carrier Gas                |                       |           |           |
| Type                       | helium                |           |           |
| Average linear velocity    | 20 cm/s to 24 cm/s    |           |           |

example, if a 150 m column is used, a pressure of approximately 550 kPa (80 psig) is required). A hydrogen flame ionization detector with associated gas controls and electronics, designed for optimum response with open tubular columns, is required.

**7.2 Sample Introduction**—Manual or automatic liquid syringe sample injection to the splitting injector is employed. Devices capable of 0.1 µL to 0.5 µL injections are suitable. It should be noted that inadequate splitter design, or poor injection technique, or both can result in poor resolution. Overloading of the column can also cause loss of resolution for some components and, since overloaded peaks are skewed, variation in retention times. Watch for any skewed peaks that indicate overloading during column evaluation. Observe the component size and where possible, avoid conditions leading to this problem during the analyses.

**7.3 Open Tubular Column**<sup>4</sup>—This test method utilizes a fused silica open tubular column with non-polar methyl silicone bonded (cross-linked) phase internal coating such as one of the following:

|                   |         |         |         |
|-------------------|---------|---------|---------|
| Column length     | 50 m    | 100 m   | 150 m   |
| Film thickness    | 0.5 µm  | 0.5 µm  | 1.0 µm  |
| Internal diameter | 0.20 mm | 0.25 mm | 0.25 mm |

Other columns with equal or greater resolving power may be used. A minimum resolution between trans-2-pentene and tert-butanol, and between cis-2-pentene and tert-butanol of 1.3 is required. The 150 m column is expected to decrease the likelihood of co-elution of impurities.

**7.4 Electronic Data Acquisition System**—Any data acquisition and integration device used for quantification of these analyses must meet or exceed these minimum requirements:

- 7.4.1 Capacity for at least 50 peaks per analysis,
- 7.4.2 Normalized area percent calculations with response factors,
- 7.4.3 Identification of individual components based on retention time,
- 7.4.4 Noise and spike rejection capability,
- 7.4.5 Sampling rate for fast (<1 s) peaks,
- 7.4.6 Positive and negative sloping baseline correction,
- 7.4.7 Peak detection sensitivity compensation for narrow and broad peaks, and

<sup>4</sup> Petrocol DH series columns from Supelco, Inc., Bellefonte, PA were used to obtain the retention data and example chromatogram shown in this standard. Other suitable columns are available commercially.

7.4.8 Non-resolved peaks separated by perpendicular drop or tangential skimming as needed.

## 8. Reagents and Materials

8.1 *Carrier Gas*, helium, 99.99 % pure. (**Warning**—Compressed gas under high pressure.)

8.2 *Fuel Gas*, hydrogen, 99.99 % pure. (**Warning**—Extremely flammable gas under pressure.)

8.3 *Oxidant*, air, oil free. (**Warning**—Compressed gas under high pressure.)

8.4 *Make-Up Gas*, nitrogen, 99.99 % pure. (**Warning**—Compressed gas under high pressure.)

8.5 *Reference Standards*:

8.5.1 *tert-Amyl methyl ether*,<sup>5,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.2 *Butane*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.3 *tert-Butanol*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.4 *sec-Butyl methyl ether*,<sup>7,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.5 *4,4-Dimethyl-2-neopentyl-1-pentene*,<sup>8,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.6 *Isobutylene*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.7 *Methanol*, (**Warning**—See **Note 1**.)

NOTE 1—**Warning**: Toxic Flammable Liquid. Harmful if inhaled or ingested.

8.5.8 *2-Methyl-2-butene*,<sup>8,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.9 *Methyl tert-butyl ether*, 99 + % pure,<sup>9,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.10 *2,2,4,6,6-Pentamethyl-3-heptene*,<sup>8,6</sup> (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.11 *n-Pentane*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.12 *cis-2-Pentene*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.13 *trans-2-Pentene*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.14 *2,4,4-Trimethyl-1-pentene*, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.15 *2,4,4-Trimethyl-2-pentene*, (**Warning**—Flammable liquid. Harmful if inhaled.)

<sup>5</sup> The sole source of supply of the apparatus known to the committee at this time is Aldrich-Sigma-Aldrich Chemical Company, Inc., Milwaukee, WI. A 96 % pure sample obtained from Aldrich-Sigma-Aldrich was the highest purity found.

<sup>6</sup> 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,<sup>1</sup> which you may attend.

<sup>7</sup> The sole source of supply of the apparatus known to the committee at this time is Farcham Laboratories, Gainesville, FL.

<sup>8</sup> The sole source of supply of the apparatus known to the committee at this time is Organic Technologies (formerly Wiley Organics), P.O. Box 640, 1245 S. 6th St., Coshocton, OH 43812.

<sup>9</sup> The sole source of supply of the apparatus, HPLC grade MTBE, known to the committee at this time is from Aldrich Chemical Company, Inc., Milwaukee, WI.

8.5.16 *1 % Contaminant Standard*, <sup>10,6</sup> contains 1.0 % of some of the contaminants in MTBE, (**Warning**—Flammable liquid. Harmful if inhaled.)

8.5.17 *0.1 % Contaminant Standard*, <sup>10,6</sup> contains 0.1 % of some of the contaminants in MTBE, (**Warning**—Flammable liquid. Harmful if inhaled.)

## 9. Sampling

9.1 MTBE can be sampled either in a floating piston cylinder or into an open container since vapor pressures less than 70 kPa (10 psi) are expected.

9.1.1 *Cylinder Sampling*—Refer to Practice **D3700** for instructions on transferring a representative sample from a source into a floating piston cylinder. Add inert gas to the ballast side of the piston to achieve a pressure of 310 kPa (45 psi) above the vapor pressure of the sample.

9.1.2 *Open Container Sampling*—Refer to Practice **D4057** for instructions on manual sampling from bulk storage into open containers. Stopper container immediately after drawing sample.

9.2 Preserve the sample by cooling to approximately 4 °C and by maintaining that temperature until immediately prior to analysis.

9.3 Transfer an aliquot of the cooled sample into a precooled septum vial, then seal appropriately. Obtain the test specimen for analysis directly from the sealed septum vial, for either manual or automatic syringe injection.

## 10. Preparation of Apparatus

10.1 Install and condition column in accordance with manufacturer's or supplier's instructions. After conditioning, attach column outlet to flame ionization detector inlet and check for leaks throughout the system. When leaks are found, tighten or replace fittings before proceeding.

10.2 Adjust the carrier gas flow rate so that an average linear velocity at the starting temperature of the run is between 21 and 24 cm/s, as determined in **Eq 1**. Flow rate adjustment is made by raising or lowering the carrier gas pressure (head pressure) to the injector. The following starting point pressures can be useful to adjust the carrier gas flow:

|                                     |          |          |          |
|-------------------------------------|----------|----------|----------|
| Column length                       | 50 m     | 100 m    | 150 m    |
| Starting point pressure, kPa (psig) | 262 (38) | 275 (40) | 552 (80) |

### 10.2.1 Average Linear Gas Velocity:

$$u_{ave} = L/t_m \quad (1)$$

where:

$L$  = the length of the column in cm, and

$t_m$  = the retention time in seconds of methane.

10.3 Adjust the operating conditions of the gas chromatograph to conform to the list in **Table 1**. Turn on the detector, ignite the flame, and allow the system to equilibrate.

10.4 When the method is first set up, ensure that the FID is not saturated. Plot the peak area versus MTBE concentration for prepared standards in the concentration range of interest. If the plot is not linear, increase the split ratio, or use a less sensitive detector range, or both.

<sup>10</sup> The sole source of supply of the apparatus, reference samples that contain only contaminants boiling above ambient, known to the committee at this time is Supelco, Inc., Bellefonte, PA.

## 11. Column Evaluation and Optimization

11.1 In order to establish that the column/temperature program will perform the required separation, the resolution between *cis*-2-pentene and *tert*-butanol and between *trans*-2-pentene and *tert*-butanol must be determined. The retention of *tert*-butanol relative to *cis*- and *trans*-2-pentene is very temperature dependent. The order of elution of *cis*-2-pentene and *tert*-butanol reverses at subambient temperature. A column which does not resolve these components after adjusting operating conditions is unsuitable.

11.2 Analyze a standard mixture that contains approximately 1 % each of *tert*-butanol, *cis*-2-pentene, and *trans*-2-pentene in MTBE by the procedure in Section 13. Calculate resolution ( $R$ ) between *tert*-butanol and *cis*-2-pentene and between *trans*-2-pentene and *tert*-butanol using Eq 2. Both resolutions must be at least 1.3.

$$R = \frac{2(t_B - t_A)}{1.699(W_A + W_B)} \quad (2)$$

where:

- $R$  = resolution,
- $t_A$  = retention time Component A,
- $t_B$  = retention time Component B,
- $W_A$  = peak width at half height of Component A, and
- $W_B$  = peak width at half height of Component B and  $t_B > t_A$

## 12. Calibration and Standardization

12.1 Component peaks from a sample analysis are identified by matching their retention time with the retention time of reference compounds analyzed under identical conditions. Typical retention times of most common contaminants in MTBE products are listed in Table 2. Analyze mixtures containing these compounds to verify their retention times. Mixtures used for determining retention times can be blended from pure compounds or purchased.<sup>8,6</sup> Retention times of other suspected contaminants can be established by analyzing mixtures containing these materials under identical conditions. A typical chromatogram of a MTBE product sample, analyzed on the 150 meter column, is shown in Fig. 1. The peaks are indexed to Table 2.

12.2 Typical mass relative response factors are found in Table 2. These response factors must be verified by analyzing a prepared standard<sup>8,6</sup> with concentrations similar to those encountered in a MTBE product sample and comparing the measured results with the prepared composition. If the measured composition does not agree with the prepared composition, the response factors should be experimentally determined according to Practice D4626 by measuring the response factors of certified blends that have been purchased or blends prepared according to Practice D4307.

## 13. Procedure

13.1 Set the instrument operating variables to the values specified in Table 1 or to a temperature determined to be suitable by the evaluation in Section 11.

13.2 When the gas chromatograph has been inoperative for more than 24 h, raise the column temperature to the maximum temperature used in the method and hold for 20 min to remove contaminants from the column. Lower the temperature to the initial method temperature.

13.3 Set the recorder or integration device, or both, for accurate presentation of the data. Set instrumental sensitivity such that any component of at least 0.02 % mass will be detected, integrated, and reported.

13.4 Inject 0.1  $\mu$ L to 0.5  $\mu$ L of sample into the injection port and start the analysis. Sample size must follow guidelines discussed in 7.2. Obtain a chromatogram and peak integration report.

## 14. Calculation

14.1 Identify each peak by matching retention times with known reference standards or sample components as discussed in 12.1. If a computing integrator is used, examine the report to ensure that peaks are properly identified and integrated. *It is very important that all oxygenate peaks be separated from hydrocarbon peaks and correctly identified since oxygenates have very different response factors than hydrocarbons and normalization is used for quantification.*

**TABLE 2 Typical Retention Times on Three Columns, Relative Mass Response Factors<sup>A</sup> and Densities<sup>B,C</sup> for Common MTBE Product Components**

| No. Component                         | Retention Time m, min |       |       | Typical Response Factor | Density at approximately 20 °C g/mL |
|---------------------------------------|-----------------------|-------|-------|-------------------------|-------------------------------------|
|                                       | 50                    | 100   | 150   |                         |                                     |
| 1 Methanol <sup>D</sup>               | 3.72                  | 7.84  | 12.89 | 3.20                    | 0.7914                              |
| 2 Isobutylene <sup>E</sup>            | 3.85                  | 8.00  | 13.39 | 1.18                    | 0.5942                              |
| 3 Butane                              | 3.92                  | 8.08  | 13.59 | 1.17                    | 0.5788                              |
| 4 Trans-2-butene                      | 3.99                  | 8.16  | 13.77 | 1.13                    | 0.6042                              |
| 5 Cis-2-butene                        | 4.10                  | 8.29  | 14.11 | 1.10                    | 0.6213                              |
| 6 3-methyl-1-butene                   | 4.41                  | 8.67  | 14.95 | 1.05                    | 0.6272                              |
| 7 Acetone                             | 4.61                  | 8.91  | 15.29 | 1.85                    | 0.7899                              |
| 8 Isopentane                          | 4.66                  | 8.93  | 15.51 | 1.04                    | 0.6201                              |
| 9 2-propanol                          | 4.77                  | 9.06  | 15.69 | 1.88                    | 0.7855                              |
| 10 1-pentene                          | 4.82                  | 9.15  | 15.95 | 1.05                    | 0.6405                              |
| 11 2-methyl-1-butene                  | 4.95                  | 9.31  | 16.15 | 1.00                    | 0.6504                              |
| 12 Pentane                            | 5.00                  | 9.37  | 16.37 | 1.05                    | 0.6262                              |
| 13 Trans-2-pentene                    | 5.12                  | 9.49  | 16.61 | 1.05                    | 0.6482                              |
| 14 Tert-butanol                       | 5.20                  | 9.57  | 16.70 | 1.30                    | 0.7887                              |
| 15 Cis-2-pentene                      | 5.26                  | 9.67  | 16.94 | 1.05                    | 0.6556                              |
| 16 2-methyl-2-butene                  | 5.37                  | 9.78  | 17.13 | 1.00                    | 0.6623                              |
| 17 Cyclopentene                       | 6.17                  | 10.72 | 18.84 | 1.00                    | 0.7457                              |
| 18 Methyl tert-butyl ether            | 6.51                  | 11.11 | 19.15 | 1.53                    | 0.7405                              |
| 19 2,3-dimethyl-1-butene              | 6.55                  | 11.17 | 19.25 | 1.00                    | 0.6803                              |
| 20 4-methyl-cis-2-pentene             | 6.57                  | 11.21 | 19.36 | 1.00                    | 0.669                               |
| 21 2-methylpentane                    | 6.63                  | 11.28 | 19.39 | 1.00                    | 0.6532                              |
| 22 Methyl ethyl ketone                | 6.86                  | 11.48 | 19.65 | 1.51                    | 0.8054                              |
| 23 3-methylpentane                    | 7.09                  | 11.80 | 20.17 | 1.00                    | 0.6645                              |
| 24 Sec-butyl methyl ether             | 7.22                  | 11.93 | 20.23 | 1.53                    | 0.7415                              |
| 25 Ethyl tert-butyl ether             | 8.54                  | 13.36 | 21.85 | 1.50                    | 0.7519                              |
| 26 Tert-amyl methyl ether             | 11.93                 | 16.27 | 25.19 | 1.41                    | 0.7703                              |
| 27 3,5-dimethyl-1-hexene              | 14.85                 | 18.23 | 27.39 | 0.90                    | 0.708                               |
| 28 2,4,4-trimethyl-1-pentene          | 15.03                 | 18.40 | 27.65 | 0.90                    | 0.715                               |
| 29 2,4,4-trimethyl-2-pentene          | 16.17                 | 19.27 | 28.47 | 0.90                    | 0.7218                              |
| 30 3,4,4-trimethyl-trans-2-pentene    | 17.86                 | 20.86 | 30.19 | 0.90                    | 0.739                               |
| 31 2,3,4-trimethyl-2-pentene          | 19.02                 | 22.00 | 31.28 | 0.90                    | 0.7434                              |
| 32 4,4-dimethyl-2-neopentyl-1-pentene | 26.26                 | 30.67 | 41.33 | 0.90                    | 0.759                               |
| 33 2,2,4,6,6-pentamethyl-3-heptene    | 26.46                 | 30.92 | 41.64 | 0.90                    | 0.759                               |

<sup>A</sup> Response factors are relative to heptane = 1.00.

<sup>B</sup> See Driesbach.<sup>13</sup>

<sup>C</sup> See Weast.<sup>12</sup>

<sup>D</sup> Methanol coelutes with isobutane on the 50 m and 100 m columns but is separated on the 150 m column. Subambient temperature conditions will separate these compounds.

<sup>E</sup> Isobutylene and 1-butene co-elute on all three columns at the typical temperature conditions. These components are known to separate using subambient temperature.

<https://standards.iteh.ai/catalog/standards/sist/c250a529-9201-4f93-8ad7-9cbe879eb5cb/astm-d5441-21>

14.2 Obtain the integrated areas of each component peak. Multiply each area by its appropriate response factor as determined in 12.2 to obtain peak areas corrected for response differences. Use a response factor of 1.00 for unknown contaminants.

14.3 Obtain the concentration of water in the sample as determined by Test Method D1364, or equivalent.

14.4 Determine the mass % of each component using Eq 3:

$$\text{mass \% component} = \frac{\text{corrected peak area} \times (100 - \% \text{ water})}{\text{total corrected peak area}} \quad (3)$$

14.5 Report the mass % of each component to two decimal places.

14.6 If the volumetric concentration of each oxygenate is desired, calculate the volumetric concentration of each oxygenate using Eq 4 as follows:

$$V_i = \frac{W_i \times D_s}{D_i} \quad (4)$$

where:

$V_i$  = volume % of Component  $i$ ,