



A Honeywell Company

## **Low Trace Sulfur in LPG and Gaseous Hydrocarbons by Oxidative Combustion with Ultraviolet Fluorescence Detection**

---

### **UOP Method 988-11**

#### **Scope**

This method is for determining sulfur in liquefied petroleum gas (LPG) and gaseous hydrocarbons at concentrations ranging from 10 to 1400 ng/g (0.01 to 1.40 mass-ppm). A trap & release procedure is used to increase the sensitivity of the analysis.

Higher concentrations can be determined by ASTM Method D6667, "Standard Test Method for Determination of Total Volatile Sulfur in Gaseous Hydrocarbons and Liquefied Petroleum Gases by Ultraviolet Fluorescence," or ASTM Method D7551, "Total Volatile Sulfur in Gaseous Hydrocarbons and Liquefied Petroleum Gases and Natural Gas by Ultraviolet Fluorescence," by using the instrument without the trap & release module.

LPG samples are expanded into the gas phase before analysis. If any heavy sulfur compounds are present in the LPG that do not volatilize quantitatively with the LPG, they may be underreported.

Halogens interfere at concentrations greater than approximately 0.3%. The method can also be applied to the analysis of hydrogen and other gas samples.

#### **References**

ASTM Method D6667, "Total Volatile Sulfur in Gaseous Hydrocarbons and Liquefied Petroleum Gases by Ultraviolet Fluorescence" [www.astm.org](http://www.astm.org)

ASTM Method D7551, "Total Volatile Sulfur in Gaseous Hydrocarbons and Liquefied Petroleum Gases and Natural Gas by Ultraviolet Fluorescence," [www.astm.org](http://www.astm.org)

UOP Method 373, "Composition of C<sub>2</sub> through C<sub>5</sub> Hydrocarbon Mixtures by GC," [www.astm.org](http://www.astm.org)

UOP Method 516, "Sampling and Handling of Gasolines, Distillate Fuels and C<sub>3</sub>-C<sub>4</sub> Fractions," [www.astm.org](http://www.astm.org)

UOP Method 539, "Refinery Gas Analysis by Gas Chromatography," [www.astm.org](http://www.astm.org)

UOP Method 999, "Precision Statements in UOP Methods," [www.astm.org](http://www.astm.org)

#### **Outline of Method**

A commercial instrument is set up and calibrated with different volumes of LPG standards. The

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>IT IS THE USER'S RESPONSIBILITY TO ESTABLISH APPROPRIATE PRECAUTIONARY PRACTICES AND TO DETERMINE THE APPLICABILITY OF REGULATORY LIMITATIONS PRIOR TO USE. EFFECTIVE HEALTH AND SAFETY PRACTICES ARE TO BE FOLLOWED WHEN UTILIZING THIS PROCEDURE. FAILURE TO UTILIZE THIS PROCEDURE IN THE MANNER PRESCRIBED HEREIN CAN BE HAZARDOUS. MATERIAL SAFETY DATA SHEETS (MSDS) OR EXPERIMENTAL MATERIAL SAFETY DATA SHEETS (EMSDS) FOR ALL OF THE MATERIALS USED IN THIS PROCEDURE SHOULD BE REVIEWED FOR SELECTION OF THE APPROPRIATE PERSONAL PROTECTION EQUIPMENT (PPE).</b></p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

© COPYRIGHT 2011 UOP LLC. All rights reserved.

Nonconfidential UOP Methods are available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, USA. The UOP Methods may be obtained through the ASTM website, [www.astm.org](http://www.astm.org), or by contacting Customer Service at [service@astm.org](mailto:service@astm.org), 610.832.9555 FAX, or 610.832.9585 PHONE.

gas or LPG materials are dispensed into fluoropolymer gas sampling bags and, if LPG, are allowed to evaporate. The atmospheric pressure gas sample is injected into an argon carrier flow using a syringe-based gas injector. The gas mixture is combined with oxygen at high temperature. The organic material is converted to carbon dioxide and water. The sulfur in the sample is converted to sulfur dioxide and preconcentrated using a trap & release unit prior to measurement. The signal is proportional to the total volatile sulfur in the sample.

## Apparatus

References to catalog numbers and suppliers are included as a convenience to the method user. Other suppliers may be used.

*Regulator*, argon, single-stage, with stainless steel diaphragm, delivery pressure range 30-700 kPa (4-100 psi), Matheson Tri-Gas, Cat. No. 3231. This regulator is installed downstream of the two-stage regulator to provide better flow control.

*Regulator*, argon, two-stage, with stainless steel diaphragm, delivery pressure range 30-700 kPa (4-100 psi), Matheson Tri-Gas, Cat. No. 3122-580

*Regulator*, oxygen, single-stage, with stainless steel diaphragm, delivery pressure range 30-700 kPa (4-100 psi), Matheson Tri-Gas, Cat. No. 3231. This regulator is installed downstream of the two-stage regulator to provide better flow control.

*Regulator*, oxygen, two-stage, with stainless steel diaphragm, delivery pressure range 30-700 kPa (4-100 psi), Matheson Tri-Gas, Cat. No. 3122-540

*Sulfur analyzer*, with attached furnace, autosampler, controls and computer, Model TS-100V, with SD-100 Sulfur Detector, TRU-100 Trap & Release Unit and GI-220 Gas Injector, Mitsubishi Chemical Analytech, available from COSA Instrument. This method was developed and validated using the Mitsubishi analyzer. The procedure for analysis may be different for other instruments and other instruments need to be validated before using for this method. Not all combustion/UV fluorescence instruments are capable of running this analysis. The Mitsubishi analyzer must be equipped with the following accessories:

*Gas Injector*, Mitsubishi GI-220, COSA Instruments

*Membrane drier*, Perma Pure MD-110-24F-4 or Tube Dryer, Mitsubishi, Cat. No. TN6RPC, COSA Instruments (see *Note 1*)

*Trap & Release Unit*, Mitsubishi TRU-100, COSA Instruments

## Reagents and Materials

References to catalog numbers and suppliers are included as a convenience to the method user. Other suppliers may be used.

The following items are required to perform the analysis. Additional reagents and materials may be required depending on the specific instrument.

*Air*, compressed, dry, oil-free, for membrane drier (if instrument does not purge the drier with argon), local supply

*Alumina balls*, Mitsubishi, Cat. No. TS3CAT, COSA Instruments

*Argon*, compressed gas, 99.99% minimum purity. UHP, Matheson Tri-Gas or local supply

*Gas sampling bags*, 1.6-L or 3.8-L, Cat. No. 10-923-10 or -11, Fisher Scientific, See *Note 2*

*LPG standard*, 1.0 mass-ppm methyl mercaptan (methanethiol) in n-butane, Matheson Tri-Gas

*Oxygen*, compressed gas, 99.98% minimum purity, UHP, Matheson Tri-Gas or local supply

*Quartz wool*, Mitsubishi Cat. No. TNQWL, COSA Instruments

## Procedure

The analyst is expected to be familiar with general laboratory practices, the technique of sulfur analysis, and the equipment being used.

### Preparation of Standards

The calibration standard of methylmercaptan in butane is purchased as a certified standard from gas suppliers. A 1.0 mass-ppm methylmercaptan in n-butane standard is 0.667 mass-ppm S. When expanded to atmospheric pressure in the gas sampling bag, it contains 1.728 ng/mL (as S) at 0°C or 1.583 ng/mL (as S) at 25°C. Calculate the gaseous sulfur concentration in the vaporized standard from the concentration of the methylmercaptan in n-butane LPG standard using Equation 1.

$$A = 1.728 C \left( \frac{273.15}{T} \right) \quad (1)$$

where:

**A** = gaseous sulfur concentration of the vaporized standard, ng/mL

**C** = concentration of methylmercaptan in LPG blend, µg methylmercaptan/g of LPG (mass-ppm)

**T** = absolute temperature, K

$$1.728 = \left( \frac{32.064}{48.107} \right) \left( \frac{58.124}{22.414} \right) \quad (1a)$$

where:

**32.064** = atomic mass of S, g/mol

**48.107** = molecular mass of methylmercaptan, g/mol

**58.124** = molecular mass of butane, g/mol

**22.414** = volume of ideal gas at STP, L/mol

Calculate the mass of sulfur injected from the injection volume and the gaseous sulfur concentration using Equation 2.

$$B = A V \quad (2)$$

where:

**A** = gaseous sulfur concentration in bag, at specific temperature, ng/mL

**B** = mass of injected sulfur, ng

**V** = gaseous volume of expanded calibration blend injected, mL

### Sampling

The sample should be collected according to UOP Method 516, "Sampling and Handling of Gasolines, Distillate Fuels and C3-C4 Fractions." The use of a passivated cylinder (e.g. Silcosteel™, Sulfinert™, etc) is required (see *Note 3*). The transfer of the LPG or gas sample to the gas sampling bag should be performed in a fume hood. A new bag should be used for each sample to prevent contamination.

1. Flush the sample cylinder outlet with sample for a few seconds before connecting to the gas sampling bag.
2. Open the valve on the gas sampling bag.

- Open the cylinder valve briefly, allowing sample to flow into the bag. Do not overfill the bag.
  - For LPG samples, transfer a small volume of LPG (2 - 4 mL) and allow to vaporize (this is for a 1.6-L bag; approximately twice that amount for a 3.2-L bag).
  - For gas samples, fill until the bag expands, but is not completely full.
- Close the valve on the gas sampling bag and remove from the cylinder.
- Analyze the sample within 3 hours of transferring to the gas sampling bag.

### Preparation of Apparatus

- Set up the instrument according to the manufacturer's instructions for the trap and release unit. Connect the membrane drier in series between the combustion tube and the detector. Allow the instrument to warm up and the baseline to stabilize before injecting samples. Suggested Operating Conditions for the Mitsubishi TS-100V analyzer are listed in Table 1. The same trap time must be used for the calibration and the samples – use the longest trap time if calibrating for multiple ranges. A 25-mL syringe is installed in the GI-220 gas injector.

**Table 1**  
**Operating Conditions for Mitsubishi TS-100V/SD-100/TRU-100**

|                                |            |
|--------------------------------|------------|
| Upper temperature <sup>a</sup> | 900°C      |
| Lower temperature <sup>b</sup> | 1000°C     |
| Argon main                     | 170 mL/min |
| Oxygen main                    | 150 mL/min |
| Argon auxiliary                | 50 mL/min  |
| Oxygen auxiliary               | 400 mL/min |
| GI-220 carrier argon           | 80 mL/min  |
| Gain                           | Ultra      |
| Normal end                     | Off        |
| Minimum area                   | 40000      |
| Base line                      | 75%        |
| GI-220 Syringe                 | 25 mL      |
| Absorption rate                | 50 mL/min  |
| Injection rate                 | 20 mL/min  |

<sup>a</sup>Combustion tube, upper portion

<sup>b</sup>Combustion tube, lower portion

**Table 2**  
**Recommended Sample Size and Instrument Timing**

| <b>Concentration<br/>Range (ng/g)</b> | <b>Sample<br/>Volume (mL)</b> | <b>Trap Time (s)</b> | <b>Timer Start (s)</b> | <b>Timer End (s)</b> |
|---------------------------------------|-------------------------------|----------------------|------------------------|----------------------|
| 10 - 200                              | 80                            | 532                  | 535                    | 835                  |
| 200 - 500                             | 40                            | 296                  | 310                    | 610                  |
| 500 - 1400                            | 10                            | 250                  | 270                    | 570                  |

### Calibration

Calibrate weekly when in use. Check the calibration daily when in use, by analyzing one of the calibration standards or a reference material.

- Transfer the calibration standard to a gas sampling bag, and then connect to the GI-220 gas injector module.
  - The same gas sampling bag can be re-used for the standard. Empty the bag before refilling.

2. Set up the sample table for multiple sample volumes and replicate injections of the sulfur standard. Three or four injections are recommended for volumes below 10 mL and two injections for volumes above 10 mL.
  - Use the trap time and timer start/end from Table 2. If calibrating for multiple ranges, use the trap and integration times for the longest method that will be used for all standards and samples.
  - For a low level calibration, use 1-, 2-, 3-, 5-, and 10-mL volumes. For a mid or high level calibration, use 5-, 10-, 20-, and 30-mL volumes.
  - Do not exceed 30 mL of the standard, or the trap may be saturated. See *Note 4*.
  - If run as a "calibration" method, the "START" button will need to be pressed for each new sample volume. If run as a "sample" method, the instrument will run all measurements on the same material automatically, and the S content and response areas can be entered in manually. See *Note 5*.
  - Relative standard deviation (RSD), as calculated by the instrument for the standards, should be within 15% for the 1- or 2-mL injections and within 10% for 3-mL or larger injections.
3. Analyze the standard according to the instrument manufacturer's instructions.
4. Create a regression line using the instrument software using the appropriate volumes of the standards. Set the regression line to " $y=bx+c$ " for this calibration.

### Sample Analysis

1. Determine the average molecular weight of the sample, see the *Appendix*.
2. Attach the gas sampling bag with the first sample to the GI-220 gas injector module.
3. Add the sample to the sample table. If unsure of concentration, start with a small volume such as 5 mL; otherwise, select the volume based on Table 2.
  - The amount of sulfur injected should not exceed 50 ng per measurement.
  - Analyze samples above 100 ng/g in duplicate. For samples below 100 ng/g, 3 or more measurements should be made.
  - Enter the sample average molecular weight to calculate the results as mass-ppm.
4. Analyze the sample replicates according to the instrument manufacturer's instructions.
5. Repeat Steps 1 through 4 for each additional sample.
  - If the detector becomes contaminated (trace off scale), disconnect the gas sampling bag and analyze air blanks until the response stabilizes. Then, confirm that the sensitivity has not changed by analyzing a calibration standard or a control standard.
  - Integration and calculations are done automatically. The average of the replicate injections is calculated by the instrument software.

### Calculations

All calculations are performed by the software, and results are displayed and printed in mass-ppm (mg/kg) or mass-ppb (ng/g). The molecular weight of the sample is input during sample data entry and is used by the instrument to convert results from mass/volume to mass/mass.

- Multiple injections of the same sample are averaged by the instrument software.

### Report

Report results as mg/kg (mass-ppm) to two decimal places.

## Notes and Precautions

1. The membrane drier is used to remove the water produced during combustion. If not removed, the water vapor would enter the detector and result in a reduction of the chemiluminescence intensity. The membrane drier consists of a thin walled Nafion™ tube within a larger plastic tube. The combustion product gas flows through the Nafion™ tube. Dry air or other dry gas flows counter-current through the outer plastic tube. The Nafion™ membrane allows water to pass through, and be carried away by the air stream on the other side.
2. Gas sampling bags are made of Tedlar™ or other fluoropolymers. The fitting on the gas sampling bags may not match the connector on the GI-220. In that case, an adapter, such as a short section of silicone tubing, should be used to make the connection. Samples should be analyzed within 3 hours of transfer into the gas sampling bag.
3. The use of passivated cylinders (e.g. Silcosteel, Sulfinert, etc) is required to prevent the loss of S compounds to the cylinder wall. The internal components of the cylinder valves should be similarly treated.
4. Do not exceed 50 ng of S for the TRU-100 trap and release unit. If a single measurement contains more than 50 ng S, it may be necessary to bake out the trap and release unit to remove excess sulfur. Follow the manufacturer's instructions if the bake out is needed.
5. When running the calibration as "samples," type in the calibration data manually to create a calibration. Run the sample report to print the individual measurements. Calculate the sulfur content for each injection volume using the equations in "Preparation of Standards." Under the "System" menu, select "Default Calibration Curve." Click "Edit" and enter all of the calibration data points. Save the calibration.

## Precision

Precision statements were determined using UOP Method 999, "Precision Statements in UOP Methods." As described in the *Procedure* and *Calculations*, two to four replicate injections were averaged for each analysis.

### Repeatability and Site Precision

A nested design was carried out for determining impurities in three LPG samples and one gas sample by two analysts on two separate days, performing two analyses each day for a total of 32 analyses. Using a stepwise analysis of variance procedure, the within-day estimated standard deviations (esd) were calculated at the concentration means listed in Table 3. Two analyses performed in one laboratory by the same analyst on the same day should not differ by more than the repeatability allowable differences shown in Table 3 with 95% confidence. Two analyses performed in one laboratory by different analysts on different days should not differ by more than the site precision allowable differences shown in Table 3 with 95% confidence.

**Table 3**  
**Repeatability and Site Precision for Procedure, mg/kg**

| <u>Sample</u> | <u>Mean</u> | <u>Repeatability</u>  |                             | <u>Site Precision</u> |                             |
|---------------|-------------|-----------------------|-----------------------------|-----------------------|-----------------------------|
|               |             | <u>Within-Day esd</u> | <u>Allowable Difference</u> | <u>Within-Lab esd</u> | <u>Allowable Difference</u> |
| LPG 1         | 0.68        | 0.013                 | 0.05                        | 0.015                 | 0.06                        |
| LPG 2         | 0.26        | 0.002                 | 0.01                        | 0.002                 | 0.01                        |
| LPG 3         | 0.01        | 0.001                 | 0.01                        | 0.001                 | 0.01                        |
| Gas           | 0.06        | 0.001                 | 0.01                        | 0.001                 | 0.01                        |

The data in Table 3 represent short-term estimates of the repeatability of the method. When the test is run routinely, use of a control standard and a control chart is recommended to generate an estimate of long-term repeatability.

### **Reproducibility**

There is insufficient data to calculate the reproducibility of the test at this time.

### **Time for Analysis**

The elapsed time for the calibration is approximately 4 hours. When performed as in “calibration” mode, then the labor requirement for calibration is identical to the elapsed time, 4 hours. In “sample” mode, the labor requirement is approximately 1 hour. Each sample analysis requires 0.5 hour for duplicate measurement.

### **Suggested Suppliers**

COSA Instrument Corp., 55 Oak St., Norwood, NJ 07648, USA (201-767-6600), distributor for Mitsubishi Chemical Analytech, 370 Enzo, Chigasaki, Kanagawa Pref., 253-0084, Japan (+81-467-86-3864) [www.cosainstrument.com](http://www.cosainstrument.com)

Fisher Scientific, 711 Forbes Ave., Pittsburgh, PA 15219, USA (412-562-8300) [www.fishersci.com](http://www.fishersci.com)

Matheson Tri-Gas, 166 Keystone Dr., Montgomeryville, PA 18936, USA (215-641-2700) [www.mathesontrigas.com](http://www.mathesontrigas.com)

Perma Pure Inc., 8 Executive Dr., Toms River, NJ 08754, USA (732-244-0010) [www.permapure.com](http://www.permapure.com)

## Appendix

### Calculation of the Average Molecular Weight of a Gas

#### Scope

This appendix may be used to calculate the average molecular weight of a gaseous material from its known composition.

#### References

ASTM Method D2163, Hydrocarbons in Liquefied Petroleum (LP) Gases and Propane/Propene Mixtures by Gas Chromatography,” [www.astm.org](http://www.astm.org)

UOP Method 373, “Composition of C<sub>2</sub> through C<sub>5</sub> Hydrocarbon Mixtures by GC,” [www.astm.org](http://www.astm.org)

UOP Method 539, “Refinery Gas Analysis by Gas Chromatography,” [www.astm.org](http://www.astm.org)

#### Calculations

If the composition of the material is not known, analyze it using the following test methods. Other similar methods may be used.

For gas samples: UOP Method 539, “Refinery Gas Analysis by Gas Chromatography”

For LPG samples: UOP Method 373, “Composition of C<sub>2</sub> through C<sub>5</sub> Hydrocarbon Mixtures by GC,” or ASTM Method D2163, Hydrocarbons in Liquefied Petroleum (LP) Gases and Propane/Propene Mixtures by Gas Chromatography”

Calculate the average molecular weight of the gas sample (after expansion if the sample was an LPG), from its known composition, using Equation A1.

$$M = \sum_{i=1}^n \frac{P_i W_i}{100} \quad (\text{A1})$$

where:

**M** = average molecular weight of the gas

**P<sub>i</sub>** = concentration of each component in the sample, vol-%

**W<sub>i</sub>** = molecular weight of that component, Table A1

**100** = correction for %

**Table A1**  
**Molecular Weights of Gas Sample Components**

| <u>Component</u>         | <u>Molecular Weight</u> |
|--------------------------|-------------------------|
| Hydrogen                 | 2.02                    |
| Nitrogen                 | 28.01                   |
| Methane                  | 16.04                   |
| Ethane                   | 30.07                   |
| Ethylene                 | 28.05                   |
| Propane                  | 44.10                   |
| Propylene                | 42.08                   |
| C <sub>4</sub> Paraffins | 58.12                   |
| C <sub>4</sub> Olefins   | 56.11                   |