

State of California
AIR RESOURCES BOARD

METHOD 3

Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight

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1 Principle and Applicability

1.1 Principle

A gas sample is extracted from a stack, by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. The gas sample is analyzed for percent carbon dioxide (CO₂), percent oxygen (O₂), and, if necessary, percent carbon monoxide (CO). For dry molecular weight determination, either an Orsat or a Fyrite analyzer or other analyzers specified in Method 100 may be used for the analysis; for excess air or emission rate correction factor determination, an Orsat analyzer or analyzers specified in Method 100 must be used.

1.2 Applicability

1.2.1

This method is applicable for determining CO₂ and O₂ concentrations, excess air, and dry molecular weight of a sample from a gas stream of a fossil-fuel combustion process. The method may also be applicable to other processes where it has been determined that compounds other than CO₂, O₂, CO, and nitrogen (N₂) are not present in concentration sufficient to affect the results.

1.2.2

Other methods, as well as modifications to the procedure described herein, are also applicable for some or all of the above determinations. Any modification of this method beyond those expressly permitted shall be considered a major modification subject to the approval of the Executive Officer. The term Executive Officer as used in this document shall mean the Executive Officer of the Air Resources Board (ARB), or his or her authorized representative. Examples of specific methods and modifications include: (1) a multi-point sampling method using an Orsat analyzer to analyze individual grab samples obtained at each point; (2) a method using CO₂ or O₂ and stoichiometric calculations to determine dry molecular weight and excess air; (3) assigning a value of 30.0 for dry molecular weight, in lieu of actual measurements, for processes burning natural gas, coal, or oil. These methods and modifications may be used, but are subject to the approval of the Executive Officer.

1.2.3

Note. Mention of trade names or specific products does not constitute endorsement by the Air Resources Board.

2 Apparatus

As an alternative to the sampling apparatus and systems described herein, other sampling systems (e.g., liquid displacement) may be used provided such systems are capable of obtaining a representative sample and maintaining a constant sampling rate, and are otherwise capable of yielding acceptable results. Use of such systems is subject to the approval of the Executive Officer.

2.1 Grab Sampling (Figure 3-1)

2.1.1 Probe

Stainless steel or borosilicate glass tubing equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Any other material inert to O₂, CO₂, CO, and N₂ and resistant to temperature at sampling conditions may be used for the probe; examples of such material are aluminum, copper, quartz glass and Teflon.

2.1.1 Pump

A one-way squeeze bulb, or equivalent, to transport the gas sample to the analyzer.

2.2 Integrated Sampling (Figure 3.2)

2.2.1 Probe

Same as in Section 2.1.1.

2.2.2 Condenser

An air-cooled or water-cooled condenser, or other condenser no greater than 250 ml that will not remove O₂, CO₂, CO, and N₂, to remove excess moisture which would interfere with the operation of the pump and flow meter.

2.2.3 Valve

A needle valve, to adjust sample gas flow rate.

2.2.4 Pump

A leak-free, diaphragm-type pump, or equivalent, to transport sample gas to the flexible bag. Install a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.2.5 Rate Meter

A rotameter, or equivalent rate meter, capable of measuring flow rate to within 2 percent of the selected flow rate. A flow rate range of 500 to 1000 cc/min is suggested.

2.2.6 Flexible Bag

Any leak-free plastic (e.g., Tedlar, Mylar, Teflon) or plastic-coated aluminum (e.g., aluminized Mylar) bag, or equivalent, having a capacity consistent with the selected flow rate and time length of the test run. A capacity in the range of 55 to 90 liters is suggested.

To leak-check the bag, connect it to a water manometer and pressurize the bag to 5 to 10 cm H₂O (2 to 4 in H₂O). Allow to stand for for 10 minutes. Any displacement of the water manometer indicates a leak. An alternative method is to pressurize the bag to 5 to 10 cm (2 to 4 in.) H₂O and allow to stand overnight. A deflated bag indicates a leak.

2.2.7 Pressure Gauge

A water-filled U-tube manometer, or equivalent, of about 30 cm (12 in), for the flexible bag leak-check.

2.2.8 Vacuum Gauge

A mercury manometer, or equivalent, of at least 760 mm (30 in.) Hg is used for the sampling train leak-check.

2.3 Analysis

For Orsat and Fyrite analyzer maintenance and operation procedures, follow the instructions recommended by the manufacturer, unless otherwise specified herein.

2.3.1 Dry Molecular Weight Determination

An Orsat analyzer or Fyrite-type combustion gas analyzer may be used.

2.3.2 Emission Rate Correction Factor or Excess Air Determination

An Orsat analyzer must be used. For low CO₂ (less than 4.0 percent) or high O₂ (greater than 15.0 percent) concentrations, the measuring burette of the Orsat must have at least 0.1 percent subdivisions.

3 Dry Molecular Weight Determination

Any of the three sampling and analytical procedures described below may be used for determining the dry molecular weight.

3.1 Single-Point, Grab Sampling and Analytical Procedure

3.1.1

The sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Executive Officer.

3.1.2

Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight. If an Orsat analyzer is used, it is recommended that the analyzer be leak-checked by following the procedure in Section 5; however, the leak check is optional.

3.1.3

Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line long enough to allow at least 5 exchanges. Draw a sample into the analyzer and immediately analyze it for percent CO₂ and percent O₂. Determine the percentage of the gas that is N₂ and CO by subtracting the sum of the percent CO₂ and percent O₂ from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.1.4

Repeat the sampling, analysis, and calculation procedures, until the dry molecular weights of any three grab samples differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (lb/lb-mole).

3.2 Single-Point, Integrated Sampling and Analytical Procedure

3.2.1

The sampling point in the duct shall be located as specified in Section 3.1.1.

3.2.2

Leak-check (optional) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (optional) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in Hg), plugged the outlet at the quick disconnect, and then turning off the pump. The vacuum should remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight.

3.2.3

Sample at a constant rate. The sampling run should be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft³) of sample gas is recommended; however, smaller volumes may be collected, if desired.

3.2.4

Obtain one integrated flue gas sample during each pollutant emission rate determination. Within 8 hours after the sample is taken, analyze it for percent CO₂ and percent O₂ using either an Orsat analyzer or a Fyrite-type combustion gas analyzer. If an Orsat analyzer is used, it is recommended that the Orsat leak-check described in Section 5 be performed before this determination; however the check is optional. Determine the percentage of the gas that is N₂ and CO by subtracting the sum of percent CO₂ and percent O₂ from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.2.5

Repeat the analysis and calculation procedures until the individual dry molecular weights for any three analyses differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole).

Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (0.1 lb/lb-mole).

3.3 Multi-Point, Integrated Sampling and Analytical Procedure

3.3.1

Unless otherwise specified by the Executive Officer, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in), and a minimum of twelve traverse points shall be used for all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to approval of the Executive Officer.

3.3.2

Follow the procedures outlined in Sections 3.2.2 through 3.2.5, except for the following: traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4 Emission Rate Correction Factor or Excess Air Determination

NOTE: A Fyrite-type combustion gas analyzer is not acceptable for excess air or emission rate correction factor determination, unless approved by the Executive Officer. If both percent CO₂ and percent O₂ are measured, the analytical results of any of the three procedures given below may also be used for calculating the dry molecular weight.

Each of the three procedures below shall be used only when specified in an applicable subpart of the standards. The use of these procedures for other purposes must have specific prior approval of the Executive Officer.

4.1 Single Point, Grab Sampling and Analytical Procedure

4.1.1

The Sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Executive Officer.

4.1.2

Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. Leak check the Orsat analyzer according to the procedure described in Section 5. This leak check is mandatory.

4.1.3

Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line long enough to allow at least 5 exchanges. Draw a sample into the analyzer. For emission rate correction factor determination, immediately analyze the sample, as outlined in Sections 4.1.4 and 4.1.5, for percent CO₂ or percent O₂. If excess air is desired, proceed as follows: (1) immediately analyze the sample, as in Sections 4.1.4 and 4.1.5, for percent CO₂, O₂ and CO; (2) determine the percentage of the gas that is N₂ by subtracting the percent CO₂, percent O₂ and percent CO from 100 percent; and (3) calculate percent excess air as outlined in Section 6.2.

4.1.4

To ensure complete absorption of the CO₂, O₂, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) shall be made between the readings. If constant readings cannot be obtained after three consecutive readings replace the absorbing solution.

4.1.5

After the analysis is completed, leak check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat

analyzer must pass this leak test before and after the analysis. Note: Since this single-point, grab sampling and analytical procedure is normally conducted in connection with a single-point, grab-sampling and analytical procedure for a pollutant, only one analysis is ordinarily conducted. Therefore, great care must be taken to obtain a valid sample and analysis. Although in most cases only CO₂ or O₂ is required, it is recommended that both CO₂ and O₂ be measured and that Section 4.4 be used to validate the analytical data.

4.2 Single-Point, Integrated Sampling and Analytical Procedure

4.2.1

The sampling point in the duct shall be located as specified in Section 4.1.1.

4.2.2

Leak check (mandatory) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak check (mandatory) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum shall remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag, and make sure that all connections are tight.

4.2.3

Sample at a constant rate or as specified by the Executive Officer. The sampling run must be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft³) of sample gas is recommended; however, smaller volumes may be collected if desired.

4.2.4

Obtain one integrated flue gas sample during each pollutant emission rate determination. For emission rate correction factor determination, analyze the sample within 4 hours after it is taken for percent CO₂ or percent O₂ (as outlined in Sections 4.2.5 through 4.2.7). The Orsat analyzer must be leak-checked (see Section 5) before the analysis. If excess air is desired, proceed as follows: (1) within 4 hours after the sample is taken, analyze it (as in Sections 4.2.5 through 4.2.7) for percent CO₂, O₂, and CO; (2) determine the percentage of the gas that is N₂ by subtracting the sum of the percent CO₂, percent O₂ and percent CO from 100 percent; (3) calculate percent excess air, as outlined in Section 6.2.

4.2.5

To ensure complete absorption of the CO₂, O₂, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same.

Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after 3 consecutive readings, replace the absorbing solution.)

4.2.6

Repeat the analysis until the following criteria are met:

4.2.6.1

For percent CO₂, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when CO₂ is greater than 4.0 percent or (b) 0.2 percent by volume when CO₂ is less than or equal to 4.0 percent. Average the three acceptable values of percent CO₂ and report the results to the nearest 0.1 percent.

4.2.6.2

For percent O₂, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when O₂ is less than 15.0 percent or (b) 0.2 percent by volume when O₂ is greater than or equal to 15.0 percent. Average the three acceptable values of percent O₂ and report the results to the nearest 0.1 percent.

4.2.6.3

For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7

After the analysis is completed, leak-check the Orsat Analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note: Although in most cases only CO₂ or O₂ is required, it is recommended that both CO₂ and O₂ be measured, and that carbon balance calculations considering the composition of the fuel be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure

4.3.1

Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points is subject to the approval of the Executive Officer.

4.3.2

Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points, and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4.4 Quality Control Procedures

4.4.1 Data Validation when Both CO₂ and O₂ are measured

Although in most instances, only CO₂ or O₂ measurement is required, it is recommended that both CO₂ and O₂ be measured to provide a check on the quality of the data. The following quality control procedure is suggested. Note: Since the method for validating the CO₂ and O₂ analyses is based on combustion of organic and fossil fuels and dilution of the gas stream with air, this method does not apply to sources that (1) remove CO₂ or O₂ through processes other than combustion (2) add O₂ (e.g. oxygen enrichment) and N₂ in proportions different from that of air, (3) add CO₂ (e.g. cement or lime kilns), or (4) have no fuel factor, F_o values obtainable (e.g., extremely variable waste mixtures). This method validates the measured proportions of CO₂ and O₂ for the fuel type, but the method does not detect sample dilution resulting from leaks during or after sample collection. This method is applicable for samples collected downstream of most lime or limestone flue-gas desulfurization units as the CO₂ added or removed from the gas stream is not significant in relation to the total CO₂ concentration. The CO₂ concentrations from other types of scrubbers using only water or basic slurry can be significantly affected and would render the F_o check minimally useful.

4.4.1.1

Calculate a fuel factor, F_o using the following equation:

$$F_o = (20.9 - \%O_2) / (\%CO_2) \quad \text{Eq. 3-3}$$

Where:

%O₂ = Percent O₂ by volume (dry basis).

%CO₂ = Percent CO₂ by volume (dry basis).

20.9 = Percent O₂ by volume in ambient air.

If CO is present in quantities measurable by this method, adjust the O₂ and CO₂ values before performing the calculation for F_o as follows:

$$\%CO_2 \text{ (adj)} = \%CO_2 + \%CO$$

$$\%O_2 \text{ (adj)} = \%O_2 - 0.5 \%CO$$

Where:

%CO = Percent CO by volume (dry basis).

4.4.1.2

Compare the calculated F_o factor with the expected F_o values. The following table may be used in establishing acceptable ranges for the expected F_o if the

fuel being burned is known. When fuels are burned in combination, calculate the combined fuel F_d and F_c factors (as defined in EPA Method 19, 40 CFR 60 Appendix A) according to the procedure in EPA Method 19 Section 3. Then calculate the F factor as follows:

$$F_o = 0.209 F_d / F_c \quad \text{Equation 3-4}$$

	Fuel Type	F_o range
Coal:	Anthracite and Lignite	1.016 - 1.130
	Bituminous	1.083 - 1.230
Oil	Distillate	1.260 - 1.413
	Residual	1.210 - 1.370
Gas	Natural	1.600 - 1.838
	Propane	1.434 - 1.586
	Butane	1.405 - 1.553
	Wood	1.000 - 1.120
	Wood Bark	1.003 - 1.130

Calculated F_o values beyond the acceptable ranges shown in this table should be investigated before accepting the test results. For example, the strength of the solutions in the gas analyzer and the analyzing technique should be checked by sampling and analyzing a known concentration, such as air, the fuel factor should be reviewed and verified. An acceptability range of +/- 12 percent is appropriate for the F_o factor of mixed fuels with variable fuel ratios. The level of the emission rate relative to the compliance level should be considered in determining if a retest is appropriate, i.e., if the measured emissions are much lower or much greater than the compliance limit repetition of this test would not significantly change the compliance status of the source and would be unnecessarily time consuming and costly.

5. LEAK-CHECK PROCEDURE FOR ORSAT ANALYZER

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be thoroughly leak checked on site before the flue gas sample is introduced into it. The procedure for leak checking an Orsat analyzer is as follows:

5.1

Bring the liquid level in each pipette up to the reference mark on the capillary tubing, and then close the pipette stopcock.

5.2

Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.3

Record the meniscus position.

5.4

Observe the meniscus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.5

For the Orsat analyzer to pass the leak check, two conditions must be met:

5.5.1

The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.5.2

The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.6

If the analyzer fails the leak-check procedure, check all rubber connections and stopcocks to determine whether they might be the cause of the leak. Disassemble, clean and regrease leaking stopcocks. Replace leaking rubber connections. After the analyzer is reassembled, repeat the leak-check procedure.

6. Calculations

6.1 Nomenclature

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).

%EA = Percent Excess Air.

%CO₂ = Percent CO₂ by volume, (dry basis).

%O₂ = Percent O₂ by volume, (dry basis).

%CO = Percent CO by volume, (dry basis).

%N₂ = Percent N₂ by volume, (dry basis).

0.264 = Ratio of O₂ to N₂ in air, v/v

0.280 = Molecular weight of N₂ or CO, divided by 100.

0.320 = Molecular weight of O₂ divided by 100.

0.440 = Molecular weight of CO₂ divided by 100.

6.2 Percent Excess Air

Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O₂, CO and N₂ (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%EA = [(\%O_2) - 0.5(\%CO)] \times 100 / [0.264(\%N_2) - (\%O_2) + 0.5(\%CO)] \quad \text{Equation 3-1}$$

Note: The equation above assumes that ambient air is used as the source of O₂ and that the fuel does not contain appreciable amounts of N₂ (as do coke or blast furnace gases). For those cases when appreciable amounts of N₂ are present (coal, oil and natural gas do not contain appreciable amounts of N₂) or when oxygen enrichment is used, alternate methods, subject to approval of the Executive Officer, are required.

6.3 Dry Molecular Weight

Use Equation 3-2 to calculate the dry molecular weight of the stack gas.

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO) \quad \text{Equation 3-2}$$

Note: The above equation does not consider argon in air (about 0.9 percent, molecular weight of 39.9). A negative error of about 0.4 percent is introduced. The tester may choose to include argon in the analysis using procedures subject to approval of the Executive Officer.

7. Bibliography

1. EPA Method 3, Gas Analysis for Determination of Dry Molecular Weight, CFR40, Part 60, Appendix A

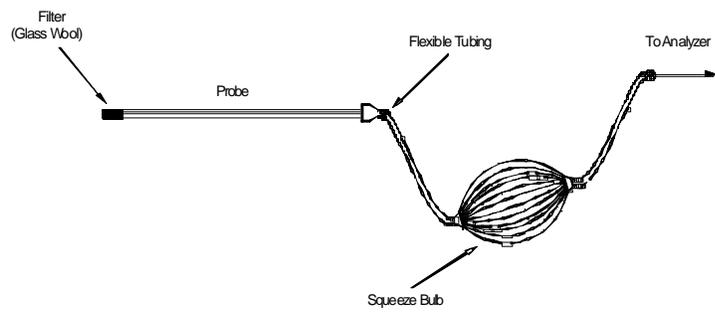


Figure 3-1 Grab Sampling Train

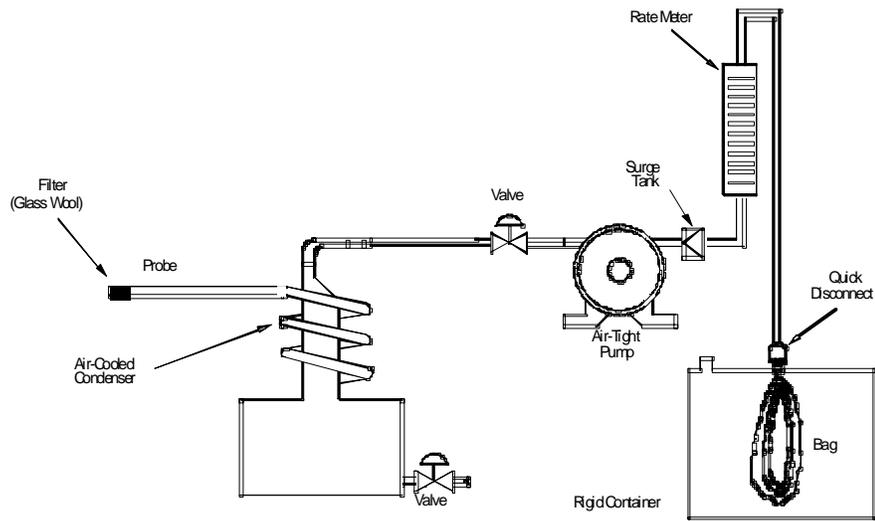


Figure 3-2 – Integrated Gas Sampling Train

Figure 3-3. Sampling Rate Data.

Time	Traverse Pt.	Q, liter/min	% dev. ^a
Average			

^a % dev. = $(Q - Q_{avg})/Q_{avg} * 100$ (Must be $\leq 10\%$)