GUIDELINES FOR DETERMINING CAPTURE EFFICIENCY
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1.0 INTRODUCTION

1.1 Purpose

The primary purpose of this document is to provide technical guidance to U. S. Environmental Protection Agency (EPA) Regional Offices regarding capture efficiency (CE) testing. The document may also prove useful to State and local agency personnel and owners and operators of stationary sources required to determine CE.

1.2 Background

In April 1990, EPA issued new guidance on CE testing.[1] This guidance replaced the traditional liquid/gas mass balance determinations, which had often resulted in very poor precision and CE values well in excess of 100 percent. The new protocols involved permanent total enclosures (PTE's), temporary total enclosures (TTE's), and building enclosures (BE's). This guidance was later codified as part of the Chicago Federal implementation plan (FIP) and included in the document "Model Volatile Organic Compound Rules for Reasonably Available Control Technology."[2,3]

In the beginning, the new protocols were met with resistance from the regulated community, primarily on grounds of safety and expense. Over time, the safety issue has largely been dispelled as it has become clear that, with proper design and operation, PTE's and TTE's pose minimal risk. However, it has also become clear that in some cases, the new CE protocols are more costly than the traditional liquid/gas procedures.

To address the cost issue, EPA temporarily suspended certain federal applicability aspects of its guidance while it embarked on a 12-month study of alternatives with potential for reducing CE testing costs. This document is a result of that study and of simultaneous studies voluntarily undertaken by industry groups. In this document, EPA presents technical guidance on recommended procedures and on alternative procedures that may reduce costs. Revisions to current State implementation plans (SIP's) are required to use the alternative CE test methods described herein. By calling these procedures "alternatives", the agency does not intend to imply that they are more difficult to approve than the "recommended" procedures where the stated criteria for approval are satisfied. Guidance for implementing these SIP revisions is provided in the cover memorandum.

1.3 Document Organization

In Section 2.0, EPA's recommended protocols and test methods are summarized. Section 3.0 presents two sets of criteria by which alternative procedures can be approved, as well as the recommended reporting requirements for using alternative

procedures. Section 4.0 presents a technical description for aggregate sampling using the building as a TTE and for testing multiple lines which share a common control device.

2.0 RECOMMENDED CAPTURE EFFICIENCY (CE) PROTOCOLS AND TEST METHODS

The CE determination protocols and test methods recommended by EPA are largely unchanged from those issued in the April 1990 guidance memo and codified in the Chicago FIP.[1,2] The EPA continues to recommend the use of a PTE, TTE, or BE for determining CE. When a TTE or BE is used, either a gas/gas protocol or a liquid/gas protocol may be selected. The EPA test methods for carrying out the recommended protocols have been revised and will be proposed in the Federal Register for addition to 40 CFR 51, Appendix M, as Method 204 through Method 204F. Methods 204 through 204E were originally referred to as Procedures T, L, G.1, G.2, F.1 and F.2 respectively. Some changes have been made to the test methods, so the latest version of the methods, which is included as an appendix, should be consulted when planning CE testing. The draft revisions to date are summarized below.

First, Appendix B, section 1.4, Sampling requirements, originally contained a requirement that the sampling time for each TTE and BE test run should be at least 8 hours, unless otherwise approved. This provision has been revised to specify that each TTE or BE run shall cover at least one complete production cycle and must be at least 3 hours long. The sampling time for each run need not exceed 8 hours, even if the production cycle has not been completed. The maximum allowable time for a test run is 24 hours. Alternative sampling times would be subject to EPA approval.

Second, a new section on audit sample procedures has been added to Procedure L, VOC Input.

Third, the directions for analysis audits have been expanded (newly added for Procedure L) to include information on audit sample availability and reporting directions for audit results.

Next, a new method, Method 204F (called the distillation approach), has been added for measuring liquid VOC input, as an alternative to Procedure L.

Finally, Procedures T, Criteria for and Verification of a Permanent or Temporary Total Enclosure, and F.2, Fugitive VOC Emissions from Building Enclosures, have been revised to clarify the acceptability criteria of a BE and to clarify which openings in a building constitute an exhaust point or a natural draft opening (NDO).

Table 2-1 lists the protocols, their associated EPA recommended CE test methods, and the formulas for calculating CE. Table 2-2 lists the EPA recommended CE test methods with the full title of each. The PTE, TTE, and BE are discussed further in Sections 2.1 through 2.3, respectively.

TABLE 2-1.

Protocols	EPA recommended CE test methods[a]				CE formula
	Enclosure verification	Liquid input (L)	Captured emissions (G)	Fugitive emissions (F) or (F_B)	
PTE	M204	NA	NA	NA	Assume 100%
TTE -- gas/gas	M204	NA	M204B or M204C	M204D	G/(G+F)
TTE -- liquid/gas	M204	M204A or M204F	NA	M204D	(L-F)/L
BE -- gas/gas	M204	NA	M204B or M204C	M204E	G/(G+F_B)

TABLE 2-2.

Method 204	Criteria for and Verification of a Permanent or Temporary Total Enclosure
Method 204A	Volatile Organic Compounds Content in Liquid Input Stream
Method 204B	Volatile Organic Compounds Emissions in Captured Stream
Method 204C	Volatile Organic Compounds Emissions in Captured Stream (Dilution Technique)
Method 204D	Volatile Organic Compounds Emissions in Fugitive Stream from Temporary Total Enclosure
Method 204E	Volatile Organic Compounds Emissions in Fugitive Stream from Building Enclosure
Method 204F	Volatile Organic Compounds Content in Liquid Input Stream (Distillation Approach)

2.1 Permanent Total Enclosure

Method 204 lists the PTE requirements and the procedures for verifying that an enclosure qualifies as a PTE. A PTE is an enclosure that completely surrounds a source such that all volatile organic compound (VOC) emissions are contained and directed to a control device. If an enclosure meets the criteria listed below then the enclosure is a PTE and the CE for the source may be assumed to be 100 percent and need not be measured. The PTE criteria are as follows:

1. Any NDO shall be at least 4 equivalent opening diameters from each VOC-emitting point. An "equivalent diameter" is the diameter of a circle that has the same area as the opening. The equation for an equivalent diameter (ED) is:

$$ED = \left(\frac{4 \times \text{area}}{\pi} \right)^{0.5} \quad \text{Eq. 1}$$

For a circular NDO, the equation simply reduces to the diameter of the opening.

2. The total area of all NDO's shall not exceed 5 percent of the surface area of the enclosure's walls, floor, and ceiling.

3. The average face velocity (FV) of air through all NDO's shall be at least 200 ft/min. The direction of air flow through all NDO's shall be into the enclosure.

4. All access doors and windows whose areas are not included as NDO's and are not included in the calculation of FV shall be closed during routine operation of the process.[4]

5. All the exhaust gases from the enclosure are directed to the control device.

If the PTE criteria are not met, then CE must be measured.

2.2 Temporary Total Enclosure

Method 204 lists the TTE requirements and the test procedures for verifying that an enclosure qualifies as a TTE. A TTE is an enclosure temporarily installed specifically for the CE test.[4] For an enclosure to qualify as a TTE, the criteria listed below must be met. These five criteria ensure that all VOC's are captured for measurement while minimizing disruption of the capture normally achieved by the existing capture device(s) in the absence of a TTE.[4] The TTE criteria are as follows:

1. Any NDO shall be at least 4 equivalent opening diameters from each VOC-emitting point. An "equivalent diameter" is the

diameter of a circle that has the same area as the opening. The equation for an equivalent diameter (ED) is:

$$ED = \left(\frac{4 \text{ area}}{\pi} \right)^{0.5} \quad \text{Eq. 1}$$

For a circular NDO, this equation simply reduces to the diameter of the opening.

2. The total area of all NDO's shall not exceed 5 percent of the surface area of the enclosure's walls, floor, and ceiling.

3. The average face velocity (FV) of air through all NDO's shall be at least 200 ft/min. The direction of air flow through all NDO's shall be into the enclosure.

4. All access doors and windows whose areas are not included as NDO's and are not included in the calculation of FV shall be closed during routine operation of the process.[4]

5. Any exhaust point from the TTE shall be at least 4 equivalent duct or hood diameters from each NDO.

Two protocols may be used to measure the CE using a TTE, a gas/gas protocol or a liquid/gas protocol. The associated test methods and CE formula for each protocol are listed in Table 2-1.

2.3 Building Enclosure

Building enclosure protocols involve using the building that houses the process as the enclosure. First, one must verify that the BE meets the requirements for a TTE that are presented in Method 204. Then, using the procedures specified in Method 204E, one must identify all the emission points from the building enclosure (e.g., roof exhausts, windows, etc.) and determine which emission points must be tested. Test procedures are given for determining the flow rate and VOC concentration in the exhaust from each of the various emission test points.

As with a TTE, two BE protocols may be used to measure the CE, a gas/gas protocol or a liquid/gas protocol. The associated test methods and CE formula for each protocol are listed in Table 2-1.

3.0 REQUIREMENTS FOR ALTERNATIVE CE PROTOCOLS

To provide flexibility, EPA has developed two sets of approval criteria which, when either of them is met, allow the use of the data obtained with the alternative protocols and test methods for determining CE. Alternative CE protocols and test

methods must meet either the requirements of the data quality objective (DQO) approach or the lower confidence limit (LCL) approach and the additional criteria presented below. The DQO, LCL, and additional criteria are described in Sections 3.1, 3.2, and 3.3, respectively. The recommended reporting requirements for using alternative CE protocols and test methods are discussed in Section 3.4.

NOTE: Although the Method 204 test series was developed for TTE and BE testing, the same procedures can also be used in an alternative CE test method. For example, a traditional liquid/gas mass balance test could employ Method 204F to measure liquid VOC input and Method 204 B to measure captured VOC emissions.

3.1 Data Quality Objective Approach

The purpose of the DQO is to allow sources to use alternative CE test procedures while ensuring reasonable precision consistent with pertinent requirements of the Clean Air Act. The DQO requires that the width of the 2-sided 95 percent confidence interval of the mean measured value be less than or equal to 10 percent of the mean measured value (see Figure 1). This ensures that 95 percent of the time, when the DQO is met, the actual CE value will be ±5 percent of the mean measured value (assuming that the test protocol is unbiased).

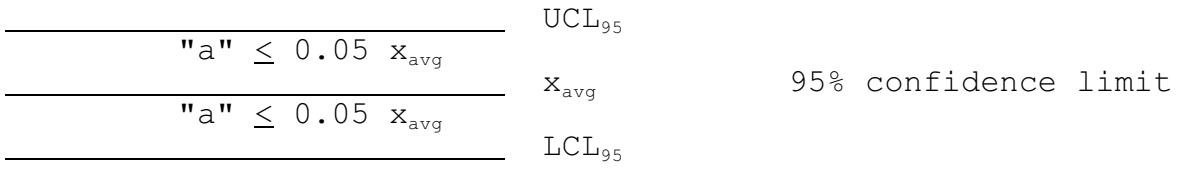

Figure 1. Deviation around 95 percent (2-sided) confidence interval.

Where:

a = distance from the average measured CE value to the endpoints of the 95-percent (2-sided) confidence interval that meets the DQO for the measured value.

LCL_{95} = Lower 95 percent confidence limit

UCL_{95} = Upper 95 percent confidence limit

x_{avg} = Average CE value.

The DQO calculation is as follows:

$$P = \frac{a}{x_{avg}} 100 \qquad \text{Eq. 2}$$

where:

$$a = \frac{t_{0.975}\, s}{\sqrt{n}} \qquad \text{Eq. 3}$$

a = distance from the average measured CE value to the endpoints of the 95-percent (2-sided) confidence interval for the measured value.

n = number of valid test runs.

P = DQO indicator statistic, distance from the average measured CE value to the endpoints of the 95-percent (2-sided) confidence interval, expressed as a percent of the average measured CE value.

s = sample standard deviation.

$t_{0.975}$ = t-value at the 95-percent confidence level (see Table 3-1).

x_{avg} = average measured CE value (calculated from all valid test runs).

x_i = the CE value calculated from the ith test run.

The sample standard deviation and average CE value are calculated as follows:

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - x_{avg})^2}{n-1} \right)^{0.5} \qquad \text{Eq. 4}$$

$$x_{avg} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{Eq. 5}$$

Individual CE values greater than 105 percent are invalid and cannot be used to calculate the average CE and DQO. The source must have 3 valid test runs to use the DQO approach. The DQO is achieved when P 5 percent. In order to meet this objective, facilities may have to conduct more than three test runs. Examples of calculating P, given a finite number of test runs, are shown below.

Number of test runs, n	$t_{0.975}$	$t_{0.90}$	Number of test runs, n	$t_{0.975}$	$t_{0.90}$
2	12.706	3.078	12	2.201	1.363
3	4.303	1.886	13	2.179	1.356
4	3.182	1.638	14	2.160	1.350
5	2.776	1.533	15	2.145	1.345
6	2.571	1.476	16	2.131	1.341
7	2.447	1.440	17	2.120	1.337
8	2.365	1.415	18	2.110	1.333
9	2.306	1.397	19	2.101	1.330
10	2.262	1.383	20	2.093	1.328
11	2.228	1.372	21	2.086	1.325

TABLE 3-1. t-values.

Facility A conducted a CE test using a traditional liquid/gas mass balance and submitted the following results:

Run	CE
1	96.1
2	105.0
3	101.2

therefore:

$n = 3$

$t_{0.975} = 4.30$

$x_{avg} = 100.8$

$s = 4.51$

$$a = \frac{(4.30)\ (4.51)}{\sqrt{n}} = 11.20 \qquad \text{Eq. 6}$$

Since the facility did not meet the DQO, they ran three more test runs. $P = \frac{11.2}{110.8}100 = 11.11$ Eq. 7

Run	CE
4	93.2
5	96.2
6	87.6

The calculations for Runs 1-6 are as follows:

$n = 6$

$t_{0.975} = 2.57$

$x_{avg} = 96.6$

$s = 6.11$

$$a = \frac{(2.57)\ (6.11)}{\sqrt{6}} = 6.41 \quad \text{Eq. 8}$$

The facility still did not meet the DQO. They ran three more test runs with the following results: $P = \frac{6.41}{96.6}100 = 6.64$ Eq.9

Run	CE
7	92.9
8	98.3
9	91.0

The calculations for Runs 1-9 are as follows:

$n = 9$

$t_{0.975} = 2.31$

$x_{avg} = 95.7$

$s = 5.33$

$$a = \frac{(2.31)\ (5.33)}{\sqrt{9}} = 4.10 \quad \text{Eq. 10}$$

$$P = \frac{4.10}{95.7}100 = 4.28 \quad \text{Eq. 11}$$

Based on these results, the average CE from the nine test runs can be used to determine compliance.

3.2 Lower Confidence Limit Approach

The purpose of the LCL approach is to provide sources, who may be performing much better than their applicable regulatory requirement, a screening option by which they can demonstrate compliance. The approach uses less precise methods and avoids additional test runs which might otherwise be needed to meet the DQO while still being assured of correctly demonstrating compliance. It is designed to reduce "false positive" or so called "Type II errors" which may erroneously indicate compliance where more variable test methods are employed. Because it encourages CE performance greater than that required in exchange for reduced compliance demonstration burden, the sources that successfully use the LCL approach could produce emission reductions beyond allowable emissions. Thus, it could provide additional benefits to the environment as well.

The LCL approach compares the 80 percent (2-sided) LCL for the mean measured CE value to the applicable CE regulatory requirement. The LCL approach requires that either the LCL be greater than or equal to the applicable CE regulatory requirement or that the DQO is met. A more detailed description of the LCL approach follows:

A source conducts an initial series of at least three runs. The source may choose to conduct additional test runs during the initial test if it desires. All individual runs resulting in CE values above 105 percent are invalid and cannot be used in calculating the average CE and the LCL. If the data using only the valid test runs meets the DQO, then the average CE value is used to determine compliance. If the data does not meet the DQO and the average CE, using all valid test runs, is above 100 percent then the test sequence is considered invalid. At this point the facility has the option of (a) conducting more test runs in hopes of meeting the DQO or of bringing the average CE for all test runs below 100 percent or (b) discarding all previous test data and retesting. [The purpose of this requirement is to protect against test methods which may be inherently biased high. This is important because it is theoretically impossible to have a CE greater than 100 percent and the LCL approach only looks at the lower end variability of the test results. This is different from the DQO which allows average CE values up to 105 percent because the DQO sets both upper and lower limits on test variability.] At any point during testing when the results meet the DQO and the average CE is less than 105 percent, the average CE can be used for demonstrating compliance with the applicable regulatory requirement. Similarly, if the average CE is below 100 percent then the LCL

can be used for demonstrating compliance with the applicable regulatory requirement without regard to the DQO.

The LCL is calculated at a 80 percent (two-sided) confidence level as follows:

$$LC_1 = x_{avg} - \frac{t_{0.90}s}{\sqrt{n}} \qquad \text{Eq. 12}$$

where:

LC_1 = LCL at a 80 percent (two-sided) confidence level.
n = number of valid test runs.
s = sample standard deviation.
$t_{0.90}$ = t-value at the 80-percent (two-sided) confidence level (see Table 3-1).
x_{avg} = average measured CE value (calculated from all valid test runs).

The resulting LC_1 is compared to the applicable CE regulatory requirement. If LC_1 exceeds (i.e. is higher than) the applicable regulatory requirement, then a facility is in initial compliance. However, if the LC_1 is below the CE requirement, then the facility must conduct additional test runs. After this point the test results will be evaluated not only looking at the LCL but also the DQO of $\pm$5 percent of the mean at a 95 percent confidence level. If the test results with the additional test runs meet the DQO before the LCL exceeds the applicable CE regulatory requirement, then the average CE value will be compared to the applicable CE regulatory requirement for determination of compliance.

If there is no specific CE requirement in the applicable regulation, then the applicable CE regulatory requirement is determined based on the applicable regulation and an acceptable destruction efficiency test. If the applicable regulation requires daily compliance and the latest CE compliance demonstration was made using the LCL approach, then the calculated LC_1 will be the highest CE value which a facility is allowed to claim until another CE demonstration test is conducted. This last requirement is necessary to assure both sufficiently reliable test results in all circumstances and the potential environmental benefits referenced above.

An example of calculating the LCL is shown below. Facility B's applicable regulatory requirement is 85 percent CE. Facility B conducted a CE test using a traditional liquid/gas mass balance and submitted the following results:

Run	CE

1	94.2
2	97.6
3	90.5

therefore:

$n = 3$
$t_{0.90} = 1.886$
$x_{avg} = 94.1$
$s = 3.55$

$$LC_1 = 94.1 - \frac{(1.886)(3.55)}{\sqrt{3}} = 90.23 \quad \text{Eq. 13}$$

Since the LC_1 of 90.23 percent is above the applicable regulatory requirement of 85 percent then the facility is in compliance. The facility must continue to accept the LC_1 of 90.23 percent as its CE value until a new series of valid tests is conducted.

3.3 Additional Criteria

The Office of Air Quality Planning and Standards (OAQPS) has developed an additional set of criteria that must be incorporated into alternative CE protocols and associated test methods in order for them to be approved. The following criteria apply:

1. A CE test shall consist of at least three sampling runs. Each test run shall be at least 20 minutes long. The sampling time for each run shall not exceed 24 hours.

2. All test runs must be separate and independent. For example, liquid VOC input and output must be determined independently for each run. The final liquid VOC sample from one run cannot be the initial sample for another run. In addition, liquid input for an entire day cannot be apportioned among test runs based on production.

3. Composite liquid samples will not be permitted to obtain an "average composition" for a test run. For example, separate initial and final coating samples must be taken and analyzed for each run; initial and final samples cannot be combined prior to analysis to derive an "average composition" for the test run.

4. All individual test runs that result in a CE of greater than 105 percent are invalid and must be discarded. A test must consist of at least 3 valid test runs.

5. If the source can demonstrate to the regulatory agency that a run should not be considered due to an identified testing or analysis error such as spillage of part of the sample during

shipping or an upset or improper operating conditions that is not considered part of normal operation then the test result for that individual run may be discarded. This limited exception allows sources to discard as "outliers" certain individual runs without replacing them with a valid run so long as the facility has at least 3 valid test runs to use when calculating its DQO or LCL. This exception is limited solely to test runs involving the types of errors identified above.

6. All valid test runs that are conducted must be included in the average CE determination. The individual CE results and average CE results cannot be truncated (i.e. 105 percent cannot be reported as 100+ percent).

7. For the DQO approach the average CE for the test program cannot be greater than 105 percent.

8. Alternative test methods for measuring VOC concentration must include a three-point calibration of the gas analysis instrument in the expected concentration range.

3.4 Reporting Requirements for Alternative CE Protocols

If a facility chooses to use alternative CE protocols and test methods, the following information should be submitted with each test report to the appropriate regulatory agency:

1. A copy of all alternative test methods, including any changes to EPA reference methods, QA/QC procedures and calibration procedures.

2. A table with information on each liquid sample, including the sample identification, where and when the sample was taken, and the VOC content of the sample;

3. The coating usage for each test run (for protocols in which the liquid VOC input is to be determined);

4. The quantity of captured VOC measured for each test run;

5. The CE calculations and results for each test run;

6. The DQO or LCL calculations and results; and

7. The QA/QC results, including information on calibrations (e.g., how often the instruments were calibrated, the calibration results, and information on calibration gases, if applicable).

3.5 Recordkeeping Requirements for Alternative CE Protocols.

A record should be kept at the facility of all raw data recorded during the test in a suitable form for submittal to the appropriate regulatory authority upon request.

4.0 MULTIPLE LINE TESTING

4.1 Aggregate Sampling

A potential way to add further flexibility to determining CE is to utilize aggregate sampling using a building enclosure. This involves testing all regulated lines in the building enclosure simultaneously. It must be noted that this technique may not be feasible for all facilities. The applicable regulations must be written to allow aggregate sampling and a standard must be set for the building as a regulated entity. The building must be able to meet the criteria in Method 204 for a building enclosure and the building enclosure protocol described in Section 2.3 must be followed.

4.2 Multiple Lines With Common Control Device

A second potential way to add further flexibility for determining CE is to test multiple lines sharing a common control device simultaneously. It must be noted that this technique may not be feasible for all facilities. The applicable regulations must be written to allow multiple line testing. The facility must also meet additional guidelines as follows:

1. The multiple lines must share a common control device.

2. Multiple line testing may be performed using recommended EPA protocols and test methods or alternative CE protocols and test methods. The alternative protocols must meet the requirements of Section 3.0.

3. The lines that are tested in combination are considered to be in compliance only if the CE determined for the combination of lines meets the most stringent CE required for any individual line.

5.0 REFERENCES

1. Memorandum and attachments from Seitz, J.S., EPA/SSCD, to Regional Office air division directors. April 16, 1990. Guidelines for developing a State protocol for the measurement of capture efficiency.

2. Office of the Federal Register. Control strategy: Ozone control measures for Cook, DuPage, Kane, Lake, McHenry and Will Counties. 40 CFR 52.741. Washington, DC. U. S. Government Printing Office. 1992.

3. OAQPS. Model Volatile Organic Compound Rules for Reasonably Available Control Technology. U. S. Environmental Protection Agency. Research Triangle Park, NC. June 1992. pp. 340-349.

4. The Measurement Solution: Using a Temporary Total Enclosure for Capture Efficiency Testing. EPA-450/4-91-020. August 1991. Research Triangle Park, NC.

5. Mendenhall, W. Introduction to Probability and Statistics, Third Edition. Belmont, California. Duxbury Press. 1971. p. 419.

APPENDIX

The appendix is Method 204, Method 204A, Method 204B, Method 204C, Method 204D, Method 204E, and Method 204F. These methods, requirements, and procedures can be located under <W> CFR Promulgated Methods on the BBS.