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Air

APTI Course SI:476B Continuous Emission Monitoring Systems: Operation and Maintenance of Gas Monitors

Self Instructional Handbook

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Availability

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Cover Design

The cover design depicts the basic components of the Dynatron TM 401 Oxygen Monitoring System designed and marketed by Lear Siegler Measurement Controls Corporation, Englewood, Colorado. This system is described in Lesson 6.

TABLE OF CONTENTS

Page

COURSE INTRODUCTION v

UNIT 1 INTRODUCTION TO THE ANALYTICAL METHODS

Lesson 1: Types of Emission Monitoring Systems 1-1

Lesson 2: General Principles of Detection in Monitoring Systems 2-1

Lesson 3: Specific Analytical Methods used by Analyzers 3-1

UNIT 2 OPERATION OF COMMERCIALLY AVAILABLE GAS MONITORS

Lesson 4: Operation of Two Spectroscopic Absorption Analyzers 4-1

Lesson 5: Operation of a Chemiluminescence Analyzer. 5-1

Lesson 6: Operation of an Electrocatalytic Analyzer. 6-1

Lesson 7: Operation of General Purpose analyzers 7-1

UNIT 3 SYSTEM DESIGN

Lesson 8: Extractive Systems Design 8-1

Lesson 9: In-situ Systems Design 9-1

Lesson 10: Applications of Systems 10-1

UNIT 4 REGULATIONS

Lesson 11: Regulatory Requirements for Gas Emission Monitoring Systems. . . 11-1

Lesson 12: Performance Specification Test Procedures 12-1

Lesson 13: The Requirements of Appendix F - Quality Assurance Requirements for Continuous Gas Emission Monitors. 13-1

UNIT 5 CONTINUING OPERATIONS

Lesson 14: Quality Assurance /Quality Control and Audit Programs for Continuous Gas Emission Monitors 14-1

Lesson 15: Maintenance Procedures - Problems and Troubleshooting for Continuous Gas Emission Monitoring Systems 15-1

CC:414
Quiz 1

- This quiz is designed to measure whether you have mastered the objectives of Lessons A through D of your guidebook.
- It is intended that this quiz be an ***open-book*** exam. Since you will be using Volume III as a reference document in your work, you may also use it here, along with your guidebook.
- You will have thirty minutes to complete this quiz.
- On the answer sheet, circle the letter that corresponds to the best answer to each test question. There is only one "best" answer for each question.

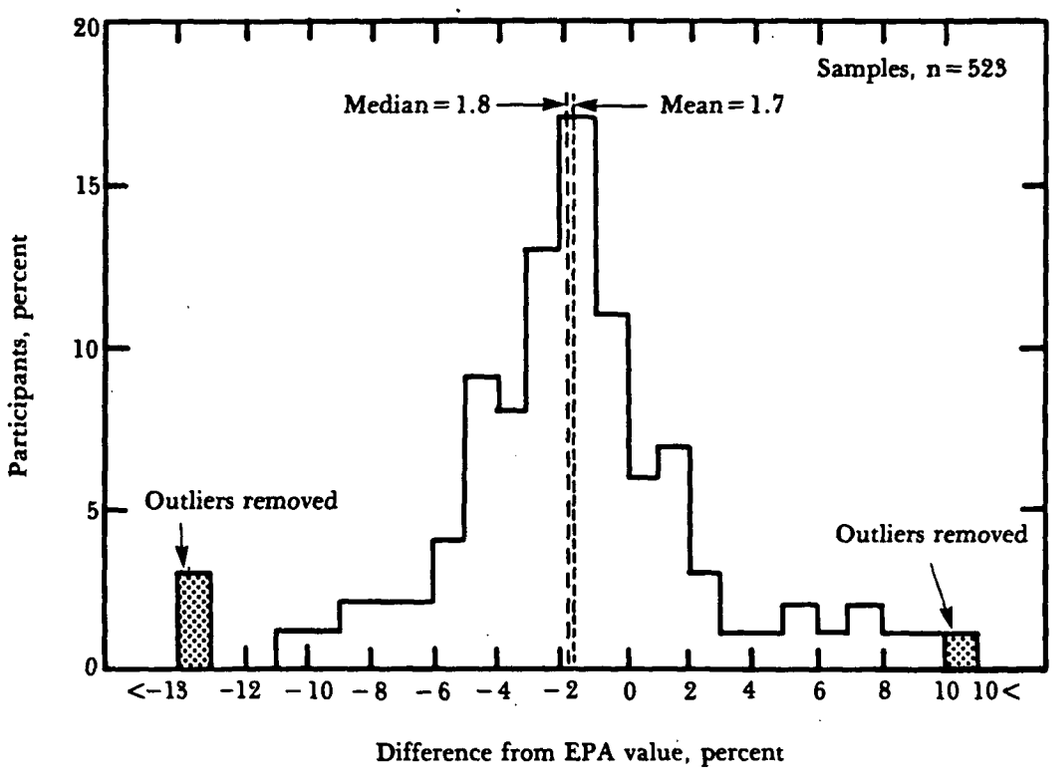
1. Quality assurance programs are a vital part of the Environmental Protection Agency's air monitoring programs because
   a. two EPA administrators have endorsed QA programs.
   b. agency actions and decisions need to be based on reliable data.
   c. QA programs allow extramural projects to increase in cost.
   d. accurate data is never obtained without QA programs.

2. EPA quality assurance requirements could be applicable to which of the following?
   a. a source test team performing an efficiency test on a new ESP for Acme Power
   b. a source test team performing a Method 6 test for a compliance determination at Coalpower Utilities
   c. a source test team performing a combustion evaluation on a new incinerator for Quad Cities Municipal Public Works
   d. a source test team developing an opacity-mass correlation for Timberline Paper Company

3. *Quality control*
   a. means the same thing as *quality assurance*.
   b. is the system of activities performed to provide assurance that the control system is performing adequately.
   c. is a system of checklists and data forms used to assure data quality.
   d. is the system of activities performed to provide a quality product.

6/82

4. The figure below shows the results of an audit program using an EPA calibrated orifice for checking Method 5 trains.



If the EPA value is considered the true value, this figure shows that the participants in the program

a. exhibit a negative bias of about 2%.
b. exhibit a positive bias of about 10%.
c. exhibit a negative bias of about 10%.
d. exhibit a positive bias of about 2%.

5. A beginning source tester
   a. needs only "on-the-job" training since the reference methods are so simple they can be learned in a week.
   b. would benefit most from short-course training combined with on-the-job training.
   c. would need to obtain a two-year AA degree in source sampling before being allowed on a stack.
   d. would be an expert sampler after completing a two-day short course.

6. A quality assurance report to management should
   a. be as detailed as possible so that all activities can be exactly reproduced.
   b. always present raw data and tables instead of graphs.
   c. be understandable at a glance.
   d. include the forms given in Volume III for each reference method.

7. In the Volume III documentation scheme, the second digit of a three-digit section number, 3.__.__, is associated with
   a. the number of pages in the section.
   b. procurement, calibration, calculations, etc.
   c. Reference Method 2, 3, 4, 5, 6, 7, or 8.
   d. pre-sampling operations.

8. Section 3.6.4 of Volume III would address
   a. on-site measurements.
   b. calculations.
   c. presampling operations.
   d. maintenance.

9. In Volume III, where in each method discussion can clean data forms be found?
   a. Method Highlights section only
   b. Section 12.0 only
   c. both the Method Highlights section and Section 12.0
   d. Sections 1 through 12

10. Which sections of Volume III could be abstracted to develop a calculations reference manual?
    a. 3.1.1, 3.1.2, 3.1.3, 3.1.4,...,3.1.12
    b. 3.1.7, 3.2.7, 3.3.7,...,3.7.7
    c. 6.1, 6.2, 6.3,...,6.7
    d. 3.1.6, 3.2.6, 3.3.6,...,3.7.6

11. The purpose of emission testing is
    a. to extract from the stack or duct, a sample that is representative of emissions from that source during a time period in which the process is under a specified operating condition.
    b. to extract from the stack or duct a sample that is representative of emissions from that source under all possible operating conditions.
    c. to extract from the stack or duct a sample that can be analyzed in the laboratory for materials hazardous to human health and welfare.
    d. to get rich quick.

12. A source test presurvey should be performed
    a. only when requested.
    b. in all but the most routine cases.
    c. almost never, since it adds to the sampling costs.
    d. always by telephone.

13. Gas flow conditions are not acceptable at a sampling site if the average of the traverse point angles of rotation is greater than
    a. 5°.
    b. 1°.
    c. 0°.
    d. 10°.

14. The figure below illustrates an example of a Volume III
    a. data form.
    b. checklist.
    c. calculation sheet.
    d. sample label.

Container No. _____

Plant _____ City _____

Site _____ Pollutant _____

Date _____ Run No. _____

Front half Front filter no. _____

Back half Back filter no. _____

Rinse _____

Volume: Initial _____ Final _____

Cleanup by _____ Field Chief _____

Remarks _____

Filter

15. Form MD-4.1 is titled
    a. Pretest Preparations.
    b. On-site Measurements Checklist.
    c. Pitot Tube Calibration Data.
    d. Method 2 Gas Velocity and Data Form.

16. Method 1 presents guidelines for the selection of a sampling site and minimum number of sampling points for a particulate traverse for a stack diameter greater than 24 inches. The criterion for using 12 sampling points in the duct states that the sampling site is at least
    a. 8 duct diameters downstream and 2 duct diameters upstream of a flow disturbance.
    b. 2 duct diameters downstream and 8 duct diameters upstream of a flow disturbance.
    c. 4 duct diameters downstream and 8 duct diameters upstream of a flow disturbance.
    d. 6 duct diameters downstream and 2 duct diameters upstream of a flow disturbance.

17. A procurement log
    a. is a quality assurance tool used to track purchased sampling equipment.
    b. is used to record calibration data of newly purchased sampling equipment.
    c. should be used only when purchasing your first sampling train.
    d. is a record of equipment to be included in compliance test reports.

18. The principal action(s) suggested in the activity matrices for "Procurement of Apparatus", if acceptance limits are not met, is(are)
    a. adjust or repair.
    b. return to supplier or repair.
    c. take corrective action.
    d. recalibrate.

19. To leak check a differential pressure gauge,
    a. a wet test meter is required.
    b. the vendor's certification that the system is leak-free is the only thing that must be checked.
    c. both positive and negative sides are checked.
    d. a mercury barometer is connected in parallel.

20. A well-designed Orsat analyzer
    a. provides for the easy reading of liquid levels.
    b. is as compact as possible.
    c. has a large connecting manifold volume.
    d. has a minimum of glassware.

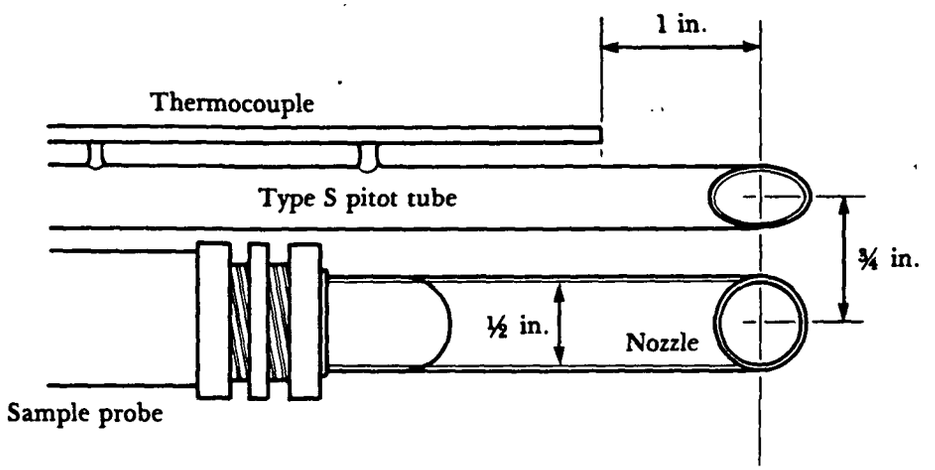
21. A probe liner should
    a. be Teflon® to reduce gas absorption.
    b. be stainless steel to reduce breakage.
    c. meet the requirements of the sampling job.
    d. not soften or melt at 820 °C (1508 °F).

22. Graduated cylinders used in source sampling should have subdivisions
    a. ≥ 4 ml.
    b. ≥ 2 ml.
    c. ≤ 4 ml.
    d. ≤ 2 ml.

23. Isopropanol used for SO_2 determinations should
    a. be checked for peroxide impurities using the barium-thorin titration method.
    b. be checked for sulfate impurities using a spectrometer.
    c. be checked for peroxide impurities using a spectrometer.
    d. be checked for sulfate impurities using the PDS method.

24. Method 5 sampling nozzles
    a. should be measured regularly to the nearest 0.025 mm (0.001 in.).
    b. must not exceed ¾ in. in diameter.
    c. should be tapered to $\leq 40°$.
    d. should be replaced at specific intervals.

25. Given the probe configuration shown below,



a. a value of $C_p = 0.84$ can be assigned to the pitot tube.
b. the probe configuration is unacceptable for testing.
c. the C_p for the configuration should be determined in a wind tunnel.
d. a value of $C_p = 0.84$ can be assigned to the pitot tube if the thermocouple is removed.

26. The proper relationship for obtaining the calibration coefficient of a Type S pitot tube by wind tunnel measurements is

a. $C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$

b. $C_{p(s)} - \overline{C}_p = 0.01$

c. $v_s = C_p K_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$

d. $s(A) = \left(\frac{\sum_{i}^{3} [C_{p(s)} - \overline{C}_p(A)]^2}{2} \right)^{1/2}$

27. When calibrating a stack temperature sensor for Method 2, the absolute value of the sensor reading should be within ____ of the reference thermometer reading.
a. ±1 °C (2 °F)
b. ±10%
c. ±5 °C (10 °F)
d. ±1.5%

28. Data obtained from the Orsat analysis of replicate air samples should
a. agree to within ±0.1% of 20.8% O_2.
b. be recorded on an $\overline{X}$ and R chart.
c. be correlated with the O_2 readings of a continuous paramagnetic O_2 analyzer.
d. be used in an F factor calculation before comparison.

29. When performing a positive leak check on a Method 4 dry gas metering system, a leak is indicated by
    a. a gurgling noise in the vacuum pump.
    b. a loss of pressure on the oil manometer connected to the orifice meter.
    c. an increase in pressure on the oil manometer connected to the orifice meter.
    d. movement on the dial of the wet test meter.

30. What is the arrangement of equipment in the initial calibration of a dry gas meter?
    a. orifice meter, dry gas meter, wet test meter, pump
    b. orifice meter, pump, dry gas meter, wet test meter
    c. orifice meter, wet test meter, pump, dry gas meter
    d. orifice meter, dry gas meter, pump, wet test meter

Name _____

Date _____

CC:414

Quiz 1

Answer Sheet

1.	a	b	c	d	16.	a	b	c	d
2.	a	b	c	d	17.	a	b	c	d
3.	a	b	c	d	18.	a	b	c	d
4.	a	b	c	d	19.	a	b	c	d
5.	a	b	c	d	20.	a	b	c	d
6.	a	b	c	d	21.	a	b	c	d
7.	a	b	c	d	22.	a	b	c	d
8.	a	b	c	d	23.	a	b	c	d
9.	a	b	c	d	24.	a	b	c	d
10.	a	b	c	d	25.	a	b	c	d
11.	a	b	c	d	26.	a	b	c	d
12.	a	b	c	d	27.	a	b	c	d
13.	a	b	c	d	28.	a	b	c	d
14.	a	b	c	d	29.	a	b	c	d
15.	a	b	c	d	30.	a	b	c	d

I certify that this test was administered in accordance with the specified test instructions.

_____

Quiz Supervisor

6/82

CC:414

Quiz 2

- This quiz is designed to measure whether you have mastered the objectives of Lessons E through G of your guidebook.
- It is intended that this quiz be an *open-book* exam. Since you will be using Volume III as a reference document in your work, you may also use it here, along with your guidebook.
- You will have thirty minutes to complete this quiz.
- On the answer sheet circle the letter that corresponds to the best answer to each test question. There is only one "best" answer for each question.

1. What is the most common acceptance criteria given in the Method 5 activity matrix for packing equipment for shipment.
   a. all equipment labeled
   b. no visual sign of breakage
   c. rigid container lined with polyethylene foam
   d. follow specified packing instructions

2. When shipping a meter box,
   a. the oiler jar should be removed and packed separately to prevent breakage.
   b. the oiler jar should be drained to prevent fouling of the components during shipment.
   c. the dry gas meter should be removed and packed in a separate shipping container.
   d. a shipping container is never needed for commercial models.

3. A description of checks that should be made on a Type S pitot tube and inclined manometer assembly before a field test, can be found in Volume III in
   a. Section 3.1.1, Paragraph 1.1.
   b. Section 3.1.2, Paragraph 2.1.1.
   c. Section 3.1.3, Paragraph 3.1.1.
   d. Section 3.1.4, Paragraph 4.2.1.

4. The integrated gas sampling train used in conjunction with an Orsat determination of $\%O_2$ and $\%CO_2$ should
   a. be cleaned and leak checked before each field test.
   b. be cleaned and leak checked once every three months.
   c. be leak checked only, before each field test.
   d. be leak checked only, once every three months.

6/82

5. When should the absorbing solutions of an Orsat gas analyzer be changed?
   a. before each field test
   b. if more than 10 passes are needed to obtain a constant reading
   c. only at the request of the administrator
   d. if more than 5 passes are needed to obtain a constant reading

6. A probe liner
   a. should be sealed inside the metal sheath, since most stacks are under negative pressure.
   b. does not have to be leak free, since it is in the stack.
   c. does not have to be cleaned between runs, since any residues will subtract out.
   d. should be constructed of stainless steel to prevent corrosion by sulfuric acid.

7. A Method 7 collection flask should not be cleaned with which of the following?
   a. strong detergent and hot water
   b. decahydronaphthalene ($C_{10}H_{18}$)
   c. dichromate cleaning solution
   d. nitric acid

8. A Method 7 flask should be leak checked at 75 mm (3 in.) Hg vacuum before the test. What level of fluctuation would be acceptable?
   a. ≥ 75 mm (3 in.) Hg for at least 1 min
   b. ≤ 10 mm (0.4 in.) Hg for at least 1 min
   c. ≤ 75 mm (3 in.) Hg for at least 1 min
   d. ≥ 10 mm (0.4 in.) Hg for at least 1 min

9. Before a test, a Method 5 filter must be
   a. desiccated for at least 24 hours at 20 °C (68 °F) and weighed to constant weight.
   b. desiccated for at least 6 hours at 20 °C (68 °F) and weighed to constant weight.
   c. oven dried for at least 24 hours at 105 °C (220 °F) and weighed to constant weight.
   d. oven dried for at least 6 hours at 105 °C (220 °F) and weighed to constant weight.

10. How many Method 5 filter blanks should be weighed for one field test?
    a. 0
    b. 1
    c. 3
    d. 9

11. A Type S pitot tube was used to determine the velocity of an exhaust gas stream containing a high concentration of particulate matter. What precaution should have been taken during the test?
    a. The thermocouple should have been removed from the tube.
    b. Both legs of the pitot tube should have been blown out frequently during the test.
    c. A Magnehelic® gauge should have been used instead of an oil manometer.
    d. A standard tube should have been used instead of a Type S tube.

12. Three methods can be used to obtain a sample for Orsat analysis (single-point grab sample, single-point integrated sample, multipoint integrated sample). What determines the procedure that should be followed?
    a. the stack temperature
    b. the capability of the stack test team
    c. the presence or absence of stratification
    d. the applicable standard

13. The impinger water volume of a Method 4 test should be measured to the nearest
    a. 1 ml.
    b. 1 g.
    c. 0.1 ml.
    d. 0.02 ft^3.

14. A Method 4 analysis indicated that the moisture content of an exhaust gas stream at 82 °C (180 °F) was 85% H_2O. Is there a problem here?
    a. Yes. The ice probably melted and the impinger temperatures were too high.
    b. Yes. The sampling rate was probably not held constant within ± 10%.
    c. Yes. Entrained water droplets were probably collected and calculated as being in the form of water vapor.
    d. No problem.

15. All leak checks for the sample train should be conducted
    a. from the nozzle inlet with all train components at operating temperature.
    b. from the filter inlet at room temperature.
    c. from the probe inlet at ambient temperature.
    d. from the nozzle inlet at ambient temperature.

16. How would you correct the "C" factor of your nomograph if your pitot tube had a coefficient of $C_p = 0.79$?
    a. use $C_{nomog}^{corr} = \frac{0.85}{0.79} C_{nomog}$
    b. use $C_{nomog}^{corr} = \frac{0.79}{0.85} C_{nomog}$
    c. use $C_{nomog}^{corr} = \frac{(0.79)^2}{(0.85)^2} C_{nomog}$
    d. The nomograph can't be corrected for a different C_p.

17. During a Method 5 test, the isokinetic sampling rate determined for a sampling point
    a. should be adjusted if the stack gas velocity increases 5%.
    b. must remain constant at that point.
    c. must be adjusted if the absolute stack temperature changes 15%.
    d. must be adjusted if the silica gel exit temperature increases to 25 °C (77 °F).

18. The absorbing medium used in the collection of NO_x is
    a. ascarite/silica gel.
    b. acidified hydrogen peroxide.
    c. 80% isopropanol.
    d. phenoldisulfonic acid.

19. The absolute internal pressure in the sampling flask used in the Federal Reference Method 7 procedure for oxides of nitrogen is equal to
    a. atmospheric pressure (mm Hg) plus the positive pressure (mm Hg) exerted by the sampling flask.
    b. atmospheric pressure (mm Hg) at the moment sampling begins.
    c. stack pressure (mm Hg) plus barometric pressure.
    d. barometric pressure minus internal pressure of the flask.

20. If a pitot tube is damaged during a run, what should be done?
    a. The tube should be repaired immediately.
    b. The tube should be recalibrated and all of the data taken during the day should be corrected.
    c. The tube should be recalibrated and the new coefficient used to correct all data collected while the tube was damaged.
    d. A value of 0.79 instead of 0.84 should be used to correct all data collected while the tube was damaged.

21. According to Reference Method 4, the posttest leak check is acceptable if
    a. the leak rate does not exceed the maximum vacuum rate occurring during sampling.
    b. the percent volume of gas leaked during sampling does not exceed 5%.
    c. the pretest leak check demonstrated a leak rate of 2% of the maximum sampling rate obtained during testing.
    d. a leak rate of 4% or less of the average sampling rate is obtained.

22. In the clean-up procedures of an EPA particulate train, acetone is used to wash all internal surfaces of the
    a. nozzle, probe, and front half of filter holder.
    b. Answer "a," except the probe is rinsed only if the liner is glass.
    c. probe and filter holder only.
    d. Acetone is not used because it is highly volatile.

23. After a routine Reference Method 6 for SO_2, a posttest leak check is mandatory. If the posttest leak check indicates a leak rate of 0.1 liter per minute, the test should be
    a. accepted, since it is 10% of the sampling rate of 1 liter per minute.
    b. accepted, with the final volume adjusted to account for the leak rate.
    c. accepted, since the leak rate is less than the ±0.5% of sampling rate allowed under the procedure.
    d. rejected.

24. A yellow complex is formed when
    a. ammonium hydroxide is added to an NO_x sample.
    b. thorin is added to an SO_2 sample.
    c. starch is added to an iodine solution.
    d. phenolphthalein is added to a KHP solution.

25. As part of the postsampling quality assurance activities, the stack temperature sensor
    a. should agree within 1.0°C with each of three temperature readings obtained with a reference thermometer.
    b. should agree within 1.5% with the ambient temperature reading of a reference thermometer.
    c. should automatically be recalibrated.
    d. should agree within 1.5% with the stack temperature reading determined by an ASTM reference thermometer.

26. Where in Volume III can you find a description of posttest calibration checks for a dry gas meter?
    a. Section 3.3.2 only
    b. Section 3.4.3 only
    c. Sections 3.3.2, 3.4.2, and 3.5.2
    d. Sections 3.3.3, 3.4.3, and 3.5.3

27. A calculated Method 5 acetone blank residue
    a. cannot be subtracted from the sample weight if it is <0.01 mg/g of the total acetone rinse weight.
    b. should never be subtracted from the sample weight.
    c. should be multiplied by the number of rinse bottles and added to the sample weight.
    d. cannot be subtracted from the sample weight if it is >0.001% of the acetone rinse weight.

28. The 0.0100 N barium perchlorate solution used in Method 6
    a. must be exactly 0.0100 N in order for the method to work.
    b. must be standardized with sulfuric acid.
    c. must be standardized with an ammonium sulfate audit sample.
    d. must be standardized with three different sulfuric acid solutions to develop a calibration curve.

29. Method 6 control samples should be
    a. analyzed only by the most proficient chemist in the laboratory.
    b. analyzed before and after the actual collected source samples are analyzed.
    c. analyzed immediately after the $Ba(ClO_4)_2$ solution is made up.
    d. analyzed to an accuracy of within 0.5% of the true value.

30. Method 7 control samples are solutions of
    a. nitric acid and water.
    b. PDS and water.
    c. pure NO_2 bubbled through distilled water.
    d. potassium nitrate and water.

CC:414

Examination 1

- This test is designed to measure whether you have mastered the objectives of the course.
- This is an *open-book* exam. Since you will be using Volume III as a reference document in your work, you may also use it here, along with your guidebook.
- You will have 75 minutes to complete the test.
- On the answer sheet, circle the letter that corresponds to the best answer to each question. There is only one "best" answer for each question. Each correct answer is worth two points.

1. Quality assurance techniques and practices provide the best means of
   a. increasing the costs of extramural projects.
   b. developing source sampling reference methods.
   c. ensuring reliable source test data.
   d. bringing stationary sources in compliance with EPA standards.

2. Which of the following is an(are) objective(s) of quality assurance activities to produce data that meet user requirements?
   a. completeness
   b. accuracy
   c. precision
   d. all of the above

3. Performance audits are a _____ appraisal of quality.
   a. qualitative
   b. quantitative
   c. system audit-type
   d. all of the above

4. In which section of Volume III can a discussion of EPA Reference Method 1 be found?
   a. Section 3.1
   b. Section 3.0.2
   c. Section 3.0.1
   d. Section 3.2.1

5. What is the heading for paragraph 3.1.2 of Section 3.2.3 of Volume III?
   a. Integrated Sampling Train
   b. Presampling Operations
   c. Calibration of Apparatus
   d. Apparatus and Calibration Checks

6/82

6. Where in Volume III can a listing of source sampling tools and equipment be found?
   a. Section 3.0.1, pages 3 of 19 through 5 of 19
   b. Section 3.5.1, pages 13 of 15 through 15 of 15
   c. Section 3.4.3, pages 3 of 20 through 15 of 20
   d. Section 3.0.12, pages 3 of 15 through 5 of 15

7. Section 3.4.5 of Volume III would address postsampling operations for Method
   a. 2.
   b. 3.
   c. 4.
   d. 5.

8. A sampling location 8 duct diameters downstream from a flow disturbance and 2 duct diameters upstream from a flow disturbance
   a. guarantees that the sample will be representative of emissions.
   b. has been scientifically determined as the location where gas stratification will not occur.
   c. allows the source tester to sample at the minimum number of EPA-specified points.
   d. will not exhibit cyclonic flow.

9. Chain-of-custody procedures
   a. are a critical part of source test procedures.
   b. are not necessary in most sampling programs.
   c. are important only in Method 5 compliance tests.
   d. are used in CEM performance specification tests.

10. A Type S pitot tube calibration coefficient, C_p,
    a. can always be assumed to have a value of 0.84.
    b. can be assumed to have a value of 0.84 if it meets EPA design criteria.
    c. can be assigned a value of 0.84 only if it is calibrated in a wind tunnel.
    d. will not change if the pitot tube is attached to a Method 5 sampling probe.

11. Type S pitot tube misalignment angles can be determined by using a(n)
    a. degree-indicating level.
    b. standard pitot tube.
    c. oil-filled manometer.
    d. Fecheimer probe.

12. The gas-confining solution in the leveling bottle of an Orsat analyzer should contain
    a. anti-freeze and alkaline pyrogallic acid.
    b. distilled water only.
    c. potassium or sodium hydroxide, and water.
    d. sodium sulfate, sulfuric acid, methyl orange, and water.

13. The use of continuous O_2 and CO_2 analyzers
    a. is an approved alternative to Reference Method 3.
    b. is valid only for the determination of molecular weight.
    c. is acceptable as an alternative procedure upon approval by the EPA Administrator.
    d. is acceptable only for F factor calculations.

14. A heated sampling probe
    a. should be leak free.
    b. should be capable of attaining a maximum temperature of 100°C (212°F).
    c. should have an outside diameter of 5 mm (0.196 in.).
    d. should always be constructed out of quartz glass.

15. A glass impinger should be checked for
    a. breaks.
    b. cracks.
    c. poorly shaped connections.
    d. all of the above

16. A newly purchased aneroid barometer should be checked against a(n)
    a. U-tube oil manometer.
    b. mercury-in-glass barometer.
    c. orifice meter.
    d. Magnehelic® gauge.

17. When should an Orsat analyzer be calibrated?
    a. upon receipt
    b. before every third field test
    c. if it has not been checked during the previous three months
    d. all of the above

18. What grade of acetone should be used in the Method 5 probe washing procedure?
    a. commercial grade
    b. ACS reagent grade
    c. primary standard grade
    d. chemically pure grade

19. Hydrogen peroxide used in source testing
    a. should be prepared fresh daily.
    b. can be stored for up to two months in a brown bottle.
    c. should be boiled to remove ozone before testing.
    d. should be checked for sulfate before testing.

20. A Magnehelic® gauge can be calibrated using
    a. an orifice meter.
    b. a mercury barometer.
    c. an inclined manometer.
    d. a pitot tube.

21. When calibrating a Type S pitot tube in a wind tunnel,
    a. only one reading is obtained using the standard pitot tube.
    b. a standard pitot tube reading is obtained only before each Type S "A" side measurement.
    c. a standard pitot tube reading is obtained only before each Type S "B" side measurement.
    d. a standard pitot tube reading is obtained before each Type S "A" and "B" side measurement.

22. A metering system is unacceptable if an individual Y value deviates from $(Y)_{avg}$ by more than
    a. 1%.
    b. 5%.
    c. 4%.
    d. 3%.

23. A rate meter, such as a rotameter, can be calibrated against
    a. an oil manometer.
    b. a pitot tube.
    c. a wet test meter.
    d. a mercury barometer.

24. An Orsat analyzer should be leak checked
    a. before packing and shipping.
    b. before each sample measurement.
    c. on-site, before the test.
    d. on-site, after the test.

25. The glass fiber filter used in Method 5 particulate sampling must
    a. exhibit at least 96.5% collection efficiency.
    b. be desiccated 24 hours and weighed to a constant weight.
    c. be desiccated 24 hours and weighed to the nearest 1.0 mg.
    d. be desiccated 6 hours and weighed.

26. If a $\%O_2$ value determined from an Orsat measurement is to be used in an F factor calculation, how close should three analyses be before the average is judged acceptable?
    a. They should differ by $\leq 0.3\%$ if the O_2 is $\leq 15.0\%$.
    b. They should differ by $\geq 0.3\%$ if the O_2 is $> 15.0\%$.
    c. They should differ by $\leq 0.2\%$ if the O_2 is $\leq 15.0\%$.
    d. They should differ by $\geq 0.3\%$ if the O_2 is $< 15.0\%$.

27. An estimate of the stack gas moisture content is necessary for a Method 5 test because
    a. the moisture content is used in the F factor calculations.
    b. the moisture content is a parameter needed to calculate the isokinetic sampling rate.
    c. the probe temperature needs to be adjusted accordingly.
    d. the number of sampling points are determined using this parameter.

28. In Method 5, a pretest leak check is
    a. recommended.
    b. required.
    c. ill-advised.
    d. a waste of time.

29. What assumptions does the nomograph make about the stack gas molecular weight?
    a. The molecular weight can be corrected for $\%CO_2$ and $\%O_2$.
    b. The dry stack gas molecular weight is measured to be 29.
    c. The molecular weight (wet) is assumed to be 29.
    d. The stack gas molecular weight is directly related to v_s, the stack gas velocity.

30. The leak-check procedure for Reference Method 7 requires evacuation of the collection flask to 5 in. Hg, then observation of the leak rate over a period of time. If there is a leak,
    a. the rate cannot be any greater than 0.4 in. Hg per minute.
    b. the flask cannot be used and must be replaced.
    c. the rate will be accounted for in the final volume of sample acquired.
    d. the leak rate will be adjusted to ± 10% of sampling rate.

31. Federal Reference Method 7 requires a pretest leak check. During a recent test, a pretest leak rate of 1 in. Hg per minute was observed. The sampling team should
    a. continue sampling by adjusting the sampling rate so that it is proportional to the leak rate.
    b. continue with the test.
    c. accept the leak rate by adjusting final volume sampled.
    d. stop the test and correct the leak problem.

32. The actual color-forming step in Reference Method 7 occurs
    a. during addition of PDS with the sodium salt.
    b. after the 16-hour waiting period and upon addition of 50 ml of TCM.
    c. during the addition of concentrated NH_4OH which attacks the PDS ring.
    d. Color development does not take place because the procedure is an iodometric titration.

33. As part of the postsampling quality assurance operations, what should be checked on the dry gas meter after the test?
    a. the calibration factor (Y) at three orifice meter settings
    b. the calibration factor (Y) at one intermediate orifice meter setting and the thermometer at room temperature
    c. the thermometer at ice point, boiling point, and room temperature
    d. leak tightness, only

34. A balance used to weigh Method 5 filters
   a. should be zeroed and checked with at least five Class-S weights in order to develop a calibration curve.
   b. should be zeroed and checked with a 0.500-g Class-S weight.
   c. does not need to be checked with standard weights.
   d. must be an electronic balance.

35. Control samples for Method 6 are solutions of
   a. NaOH and water.
   b. $Ba(ClO_4)$ and Isopropanol.
   c. H_2SO_4 and water.
   d. $(NH_4)_2 SO_4$ and water.

36. If fibers from a filter adhere to the gasket part of the filter assembly, a proper procedure to follow would be to
   a. wash the gasket in an acetone/water rinse.
   b. retain the fibers on the gasket for the next run.
   c. scrape off the fibers into the filter recovery dish.
   d. wipe the fibers off with a Kimwipe®.

37. In Method 5, the percent isokinetic should be 100%, and if it is
   a. it ensures sampling accuracy.
   b. it means only that, based on the volumetric and velocity data, the proper sampling rates were used.
   c. it means that the source is in compliance with regulations.
   d. it means that only the pollutant mass rate will be accurate.

38. The addition of NaOH to the recovered sample in the reference method for oxides of nitrogen serves to
   a. fix the nitrate to a sodium salt for additional analysis.
   b. evaporate excess NH_3, which interferes with the analysis, from the solution.
   c. adjust the pH of the solution so interfering metals precipitate out as sodium salts.
   d. NaOH does not have to be added.

39. The molecular weight of a stack gas can be determined, on a wet basis, by which of the following equations?
   a. $M_s = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$
   b. $M_s = 18(\%H_2O) + M_d$
   c. $M_s = M_d(1 - B_{ws}) + 18B_{ws}$
   d. $M_s = \left[\dfrac{\%O_2 - 0.5\%CO}{0.264\%N_2(\%O_2 - 0.5\%CO)}\right]$

40. Calculations performed for a reference method should be checked by
   a. the plant engineer who contracted the test team.
   b. the agency test observer.
   c. a test team member other than the one who performed them originally.
   d. all of the above

41. Intermediate calculations should be carried out to at least
   a. one significant figure.
   b. one decimal figure beyond that of the acquired data.
   c. seven significant figures.
   d. three decimal figures beyond that of the acquired data.

42. The units associated with each symbol in reference method calculations are important because
   a. many of the equations have constants expressed in specific units.
   b. all work performed for governmental agencies must follow the metric system.
   c. the equations can be solved using only English units.
   d. source sampling data is generated by computer systems.

43. A Method 7 calculation for μg NO_2 per sample, $m = 2\ K_c AF$, was performed using the following data:

$$K_c = 519$$
$$A = 0.612$$
$$F = 1.00.$$

   The value of m should be reported as
   a. 635.256 μg of NO_2.
   b. 635.26 μg of NO_2.
   c. 635.3 μg of NO_2.
   d. 635 μg of NO_2.

44. In the reference methods, pressure drop across a pitot tube or orifice meter is expressed in units of
   a. in. H_2O or mm H_2O.
   b. ft H_2O or m H_2O.
   c. mm Hg or in. Hg.
   d. ft/s or m/s.

45. A programmed calculator or computer
   a. cannot be used for compliance testing calculations.
   b. can be advantageous in reducing calculation errors.
   c. can be used for compliance tests only when calculations are checked with a slide rule.
   d. cannot be used for reference method calculations because programs are not available.

46. In the normal use of sampling equipment,
   a. maintenance should never be required.
   b. routine maintenance should be conducted at most once a year.
   c. routine maintenance should be conducted at least quarterly.
   d. maintenance should be conducted only when something breaks.

47. A fiber vane pump requires a periodic check of
    a. the oil and oiler jar.
    b. the rotor speed.
    c. the magnetic flux.
    d. the power factor.

48. Quick disconnects should be replaced
    a. after every 1000 ft^3 of operation.
    b. once every quarter.
    c. when the sampling system doesn't leak check.
    d. when damaged.

49. Volume III recommends that a source test observer perform a system audit
    a. once for every four tests conducted by an experienced test team.
    b. once for every four tests conducted by an inexperienced test team.
    c. for every test conducted by an experienced test team.
    d. only when the source is out of compliance.

50. An audit is
    a. used to correct source test data.
    b. a part of the Federal reference method procedures.
    c. conducted by the test team leader.
    d. an independent assessment of data quality.

Name _____

Date _____

CC:414

Examination 1

Answer Sheet

1.	a	b	c	d
2.	a	b	c	d
3.	a	b	c	d
4.	a	b	c	d
5.	a	b	c	d
6.	a	b	c	d
7.	a	b	c	d
8.	a	b	c	d
9.	a	b	c	d
10.	a	b	c	d
11.	a	b	c	d
12.	a	b	c	d
13.	a	b	c	d
14.	a	b	c	d
15.	a	b	c	d
16.	a	b	c	d
17.	a	b	c	d
18.	a	b	c	d
19.	a	b	c	d
20.	a	b	c	d
21.	a	b	c	d
22.	a	b	c	d
23.	a	b	c	d
24.	a	b	c	d
25.	a	b	c	d

(Please Print)

Address:

_____

_____

_____

26.	a	b	c	d
27.	a	b	c	d
28.	a	b	c	d
29.	a	b	c	d
30.	a	b	c	d
31.	a	b	c	d
32.	a	b	c	d
33.	a	b	c	d
34.	a	b	c	d
35.	a	b	c	d
36.	a	b	c	d
37.	a	b	c	d
38.	a	b	c	d
39.	a	b	c	d
40.	a	b	c	d
41.	a	b	c	d
42.	a	b	c	d
43.	a	b	c	d
44.	a	b	c	d
45.	a	b	c	d
46.	a	b	c	d
47.	a	b	c	d
48.	a	b	c	d
49.	a	b	c	d
50.	a	b	c	d

I certify that this test was administered in accordance with the specified test instructions.

_____

Test Supervisor

6/82

REGISTRAR
AIR POLLUTION TRAINING INSTITUTE
US EPA MD-17
RESEARCH TRIANGLE PARK NC 27711

* ERRATA *

Requirements for Successful Completion of Course CC:414

In order to receive 3.5 Continuing Education Units (CEU's) and a certificate of course completion you must:

* complete and submit a final exam to the APTI

* achieve a final course grade of at least 70%.

The quizzes associated with the course are for review purposes. The answers are enclosed for the student to use to correct his or her own quizzes. This way the student can assses his/her understanding of the material before taking the final exam. Do not send in the answer sheets to the quizzes to be graded. **The final exam counts for 100% of the course grade.**

If you have questions please contact:

Registrar
Air Pollution Training Institute
US EPA MD-17
Research Triangle Park, NC 27711

CC:414

Quiz 1

Grading Key

1.	a	**b**	c	d
2.	a	**b**	c	d
3.	a	b	c	**d**
4.	**a**	b	c	d
5.	a	**b**	c	d
6.	a	b	**c**	d
7.	a	b	**c**	d
8.	**a**	b	c	d
9.	a	b	**c**	d
10.	a	b	c	**d**
11.	**a**	b	c	d
12.	a	**b**	c	d
13.	a	b	c	**d**
14.	a	b	c	**d**
15.	a	**b**	c	d
16.	**a**	b	c	d
17.	**a**	b	c	d
18.	a	**b**	c	d
19.	a	b	**c**	d
20.	**a**	b	c	d
21.	a	b	**c**	d
22.	a	b	c	**d**
23.	a	b	**c**	d
24.	**a**	b	c	d
25.	a	b	**c**	d
26.	**a**	b	c	d
27.	a	b	c	**d**
28.	a	**b**	c	d
29.	a	**b**	c	d
30.	a	b	c	**d**

10/3/90

ERRATA SHEET

CC 414: Quality Assurance for Source Emission Measurement Methods

There are now Reference Methods 3A and 3B. For Methods 3A and 3B respectively, see 40 CFR 60, App. A, Meth. 3A and Federal Register notice Vol 55, p. 05211, Feb. 14, 1990.

For cyclonic flow, an average 20 degree angle of rotation is now acceptable. See 40 CFR 60, App. A, Meth. 1.

p. 196, Reading Assignment 16 Review Exercises. The correct answer to question 1.a., "How many significant figures are in 0.007?" is 1 not 3. This is supported by Rule 1 on p. 194 which states, "Disregard all initial zeros."

CC:414

Quiz 2

Grading Key

1.	a	b	**c**	d
2.	a	**b**	c	d
3.	a	b	**c**	d
4.	**a**	b	c	d
5.	a	**b**	c	d
6.	**a**	b	c	d
7.	a	b	c	**d**
8.	a	**b**	c	d
9.	**a**	b	c	d
10.	a	b	**c**	d
11.	a	**b**	c	d
12.	a	b	c	**d**
13.	**a**	b	c	d
14.	a	b	**c**	d
15.	**a**	b	c	d
16.	a	b	**c**	d
17.	a	b	**c**	d
18.	a	**b**	c	d
19.	a	b	c	**d**
20.	a	b	**c**	d
21.	a	b	c	**d**
22.	**a**	b	c	d
23.	a	b	c	**d**
24.	**a**	b	c	d
25.	a	**b**	c	d
26.	a	b	**c**	d
27.	a	b	c	**d**
28.	a	**b**	c	d
29.	a	**b**	c	d
30.	a	b	c	**d**

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2. No exam will be graded unless accompanied by the loaned materials. We encourage you to complete the course within 30 days.

3. If you choose not to take the final exam, please indicate that on this form, and return it along with the loaned materials. This will ensure your cancellation from the course.

Direct all correspondence to:

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U S E P A
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Date: _____

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I choose not to take the exam for Course #_____.

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*** ERRATA ***

Requirements for Successful Completion of Course SI:476B

In order to receive 3.0 Continuing Education Units (CEU's) and a certificate of course completion you must:

* complete and submit a final exam to the APTI

* achieve a final course grade of at least 70%.

The quizzes associated with the course are for review purposes. The answers are enclosed for the student to use to correct his or her own quizzes. This way the student can assses his/her understanding of the material before taking the final exam. Do not send in the answer sheets to the quizzes to be graded. **The final exam counts for 100% of the course grade.**

If you have questions please contact:

Registrar
Air Pollution Training Institute
US EPA MD-17
Research Triangle Park, NC 27711

Name: _____
Date: _____

Course SI: 476B
Quiz Number 1
Units 1-3
Answer Sheet

1.	a	**b**	c	d
2.	a	b	**c**	d
3.	**a**	b	c	d
4.	a	**b**	c	d
5.	a	b	**c**	d
6.	a	b	**c**	d
7.	a	b	c	**d**
8.	a	b	**c**	d
9.	a	**b**	c	d
10.	a	b	c	**d**
11.	**a**	b	c	d
12.	**a**	b	c	d
13.	a	b	c	**d**
14.	a	b	**c**	d
15.	**a**	b	c	d
16.	a	b	**c**	d
17.	a	b	**c**	d
18.	a	**b**	c	d
19.	a	**b**	c	d
20.	a	b	c	**d**
21.	a	**b**	c	d
22.	a	b	**c**	d
23.	a	b	c	**d**
24.	**a**	b	c	d
25.	a	**b**	c	d

I certify that this quiz was administered in accordance with the specified test instructions.

_____
Quiz Supervisor

Name: _____

Date: _____

Course SI: 476B
Quiz Number 2
Units 4-5
Answer Sheet

1.	a	b		
2.	a	b	c	d
3.	a	b	c	d
4.	a	b		
5.	a	b		
6.	a	b	c	d
7.	a	b	c	d
8.	a	b		
9.	a	b	c	d
10.	a	b	c	d
11.	a	b		
12.	a	b		
13.	a	b	c	d
14.	a	b		
15.	a	b		
16.	a	b	c	d
17.	a	b	c	d
18.	a	b	c	d
19.	a	b	c	d
20.	a	b	c	d
21.	a	b		
22.	a	b		
23.	a	b	c	d
24.	a	b		
25.	a	b	c	d

I certify that this quiz was administered in accordance with the specified test instruction

_____

Quiz Supervisor

Continuous Emission Monitoring Systems
Operation and Maintenance of Gas Monitors

Quiz Number 1
Units 1-3

Directions: This is a closed book test, so you may not use your manual and notes. On your answer sheet, circle the letter that corresponds to the best answer or write the answer in the space provided. You will have ___ minutes to complete the test. When you have completed it, turn in only the Answer Sheet.

1. CEMSs are used on a _____ basis.

   a. semi-annual
   b. continuous
   c. nominal
   d. yearly

2. A typical monitoring system contains all of the following except

   a. a readout instrument.
   b. an analyzer.
   c. a concentration enhancer.
   d. a data recorder.

3. _____ and _____ are the two monitoring methods that are primarily dependent of the characteristics of light.

   a. Spectroscopic absorption ... luminescence
   b. Electroanalysis ... chemical reaction
   c. Paramagnetic ... diatomic
   d. Absorption ... dilution

4. The sample gas must be conditioned in _____ systems.

   a. in-the-stack
   b. extractive
   c. all
   d. in-situ

5. The spectropic absorption techniques used in many systems are based on

   a. a gas' ability to absorb water.
   b. paramagnetic phenomenon.
   c. the absorption of a unique wavelength of light by the target gas.
   d. the attraction between gases.

6. Light energy released from excited atoms is the principle behind

   a. magnetopneumatic techniques.
   b. electroanalytical techniques.
   c. luminescence techniques.
   d. paramagnetic techniques.

7. In polarographic analyzers, the gas diffuses through a _____ in order to generate a _____.

   a. beam splitter ... high bias reading
   b. reference cell ...light wave
   c. large valve ... low bias reading
   d. thin-film membrane ... reaction and current flow

8. As a gas absorbs some light energy, the intensity of the light beam will _____ from its original value.

   a. increase
   b. not change
   c. decrease
   d. fluctuate

9. Nearly all spectrophotometers found in CEMSs use a broad band of wavelengths that are centered on the _____ of the target gas molecules.

   a. luminescence
   b. absorption peak
   c. molecular weight
   d. zero point

10. A _____ flame is used in flame photometric analyzers in order to excite the gas molecules.

    a. luminescent
    b. coal-fired
    c. natural gas-fired
    d. hydrogen

11. The Bodenseewerk Model 677 forces high pressure air through the secondary filter assembly in order to

    a. alleviate blockage.
    b. keep the system from decompressing.
    c. compress the sample into a smaller volume.
    d. force more HCl sample through the analyzer.

12. The Teledyne Analytical Instruments Model 691 is an example of a

    a. differential absorption analyzer.
    b. gas filter correlation analyzer.
    c. particulate analyzer.
    d. density analyzer.

13. A heat traced sampling system, as in the Teledyne Analytical Instruments Model 691, prevents _____ during analysis.

    a. corrosion
    b. leaks
    c. cracking
    d. water condensation

14. The electrons of excited molecules _____.

    a. stop moving
    b. interfere with the monitoring equipment
    c. are temporarily moved to higher energy levels
    d. are temporarily moved to lower energy levels

15. The LSI Dynatron 401 uses the principle of _____ as the basis for the measurement of O_2 concentration.

a. electrocatalysis
b. electrolysis
c. absorbance
d. opacity

16. The _____ equation relates voltage to oxygen concentration.

a. Newton
b. Reynolds
c. Nernst
d. Faraday

17. Magnetopneumatic analyzers are generally _____ by temperature fluctuations.

a. damaged
b. high biased
c. unaffected
d. low biased

18. NDIR cross-flow modulation analysis requires the sample gas and the reference gas to be introduced _____ into the measurement cell.

a. simultaneously
b. alternately
c. randomly
d. pseudo-randomly

19. The moveable membrane in the NDIR cross-flow modulation's detector senses _____.

a. ion concentration
b. pressure differential
c. temperature changes
d. porosity

20. Sample gas from a potentially challenging stack environment is conditioned by the application of a (n) _____ design.

a. in-the-stack
b. streamline
c. in-situ
d. extractive

21. In-situ systems do all of the following tasks except

a. minimize interference from particulate matter.
b. remove moisture from the stack.
c. analyze a representative portion of stack gas.
d. operate in high temperature combustion sources.

22. A constant flow of purge air prevents _____ and _____.

a. sample loss ... corrosion
b. vibration ... water condensation
c. water condensation ... particulate buildup
d. pressure loss ... cracking

23. Anti-vibration equipment is used to help maintain

a. sample purity.
b. sample integrity.
c. constant pressure.
d. optical alignment of the transmitter and receiver.

24. The purpose of surface and depth filters is to

a. collect particulate matter greater than 1 micron.
b. protect probe from particulate buildup.
c. clean the purge air.
d. remove water.

25. Heat tolerance, chemical stability, and corrosion resistance should be considered when selecting

a. which gas to monitor.
b. sample transport tubing.
c. a signal processor.
d. the analyzer to be used.

Name: _____

Date: _____

Course SI: 476B
Quiz Number 1
Units 1-3
Answer Sheet

1.	a	b	c	d
2.	a	b	c	d
3.	a	b	c	d
4.	a	b	c	d
5.	a	b	c	d
6.	a	b	c	d
7.	a	b	c	d
8.	a	b	c	d
9.	a	b	c	d
10.	a	b	c	d
11.	a	b	c	d
12.	a	b	c	d
13.	a	b	c	d
14.	a	b	c	d
15.	a	b	c	d
16.	a	b	c	d
17.	a	b	c	d
18.	a	b	c	d
19.	a	b	c	d
20.	a	b	c	d
21.	a	b	c	d
22.	a	b	c	d
23.	a	b	c	d
24.	a	b	c	d
25.	a	b	c	d

I certify that this quiz was administered in accordance with the specified test instructions.

_____
Quiz Supervisor

Continuous Emission Monitoring Systems
Operation and Maintenance of Gas Monitors

Quiz Number 2
Units 4-5

Directions: This is a closed book test, so you may not use your manual and notes. On your answer sheet, circle the letter that corresponds to the best answer or write the answer in the space provided. You will have ___ minutes to complete the test. When you have completed it, turn in only the Answer Sheet.

1. The Federal Register Index and the LSA Index are the two federally published indices which can be revised to keep track of changes in the code of federal regulations.

   a. True
   b. False

2. Types of regulatory procedures which are used by state and local agencies for assuring compliance with air quality standards include:

   a. operating permits.
   b. the promulgation of regulations.
   c. the issuing of variances.
   d. all of the above.

3. Performance specification tests are used to evaluate a CEM's performance:

   a. over an extended period of time.
   b. every thirty days.
   c. every sixty days.
   d. upon, or soon after the initial installation of the system.

4. "Span value" refers to the upper limit of a gas concentration measurement range specified for affected source categories in the applicable subpart of the regulations.

   a. True
   b. False

5. Stratification is a term which refers to the amount of variation in pollutant emission concentrations at the Reference Method measurement locations.

   a. True
   b. False

6. The Relative Accuracy Audit (RAA) test requires that only _____ sets of measurements be taken.

   a. 9
   b. 12
   c. 3
   d. 6

7. Appendix F states that if excessive inaccuracies in data occur for ___consecutive quarters, then the source owner shall modify or replace the CEMs.

   a. two
   b. four
   c. three
   d. none of the above

8. Quality control refers to activities which will provide a quality product and quality assurance refers to activities which provide assurance that the quality control program is satisfactory.

   a. True
   b. False

9. The temperature compensation circuit on an in-situ monitoring system can be bypassed whenever:

   a. the instrument is being calibrated.
   b. the instrument is calibrated manually using calibration gases.
   c. whenever the temperature of the CEMs falls below 20°C.
   d. this circuit should never be by passed.

10. Which of the following has not been shown by recent surveys as a problem area encountered in CEM maintenance programs?

   a. data handling systems.
   b. emergency service.
   c. locating the CEMs.
   d. spare parts.

11. The recommended period for performing routine maintenance checks on both extractive and in-situ monitoring systems is every 45 days.

a. True
b. False

12. The submittal of a Data Accuracy Report (DAR) is an option which a source subject to TNG requirements of Appendix F may or may not choose to abide by.

a. True
b. False

13. Regulations for New Source Performance Standards (NSPS) are contained in 40 CFR Part ____.

a. 51
b. 60
c. 61
d. 65

14. The calibration drift (CD) test involves the comparison of the monitor's response to a known concentration of gas.

a. True
b. False

15. The issuance of operating permits are a type of regulatory procedure which state and local air pollution control agencies use for assuring compliance with air quality standards.

a. True
b. False

16. In performing a daily calibration drift (CD) test of the CEM, the instrument is considered to be out-of-control if the CD value is _____ times the applicable performance specification contained in Appendix B of 40 CFR Part 60.

a. 6
b. 2
c. 4
d. 10

17. A Cylinder Gas Audit (CGA) tests both pollutant and diluent (if applicable) monitors for accuracy three times at ___ points specified in Appendix F, Procedure 1.

a. 5
b. 4
c. 2
d. 3

18. Which of the following criteria should be considered in the development of a quality assurance program?

a. How the CEMs works.
b. The criteria for determining CEMs deficiencies.
c. The possible things which can go wrong with the CEM.
d. All of the above.

19. Two stages of quality control involved in a CEMs program are operation checks and routine and corrective maintenance. The third stages of a CEMs quality control program is

a. schedule system regulatory inspections.
b. management system audits.
c. level system regulatory inspections.
d. performance audits.

20. A performance audit:

a. provides an evaluation of the role of management in a QA program.
b. provides a quantitative assessment of the monitoring system in order to verify the adequacy of the quality assurance procedures used to determine adequate CEM performance.
c. evaluates the documentation which is used to show that the data is of a known quality.
d. all of the above.

21. Three types of maintenance programs are preventive maintenance, routine maintenance and corrective maintenance.

a. True
b. False

22. Gas cells used to calibrate in-situ monitoring systems are always certified by independent laboratories.

a. True
b. False

23. The relative accuracy of a gas CEM is defined as:

a. A comparison of the monitor's response to a known concentration of gas.
b. The percent difference in the continuous monitor's measurement of the pollutant versus the value of the measurement as a result of using an EPA Reference Method.
c. The accuracy of the instrument's strip recorder.
d. None of the above.

24. Both the Relative Accuracy Audit Test (RATA) and the Relative Accuracy Audit (RAA) need not be calculated in terms of the applicable standard (e.g/ 1 b./million BTU).

a. True
b. False

25. Continuous emission monitoring requirements for fossil fuel fired steam generators and electric utility generating units are contained in 40 CFR Part 60 subparts __ and ____, respectively.

a. G, H
b. BB, J
c. D, Da
d. Db, G

Name: _____

Date: _____

Course SI: 476B
Quiz Number 2
Units 4-5
Answer Sheet

1.	a	b		
2.	a	b	c	d
3.	a	b	c	d
4.	a	b		
5.	a	b		
6.	a	b	c	d
7.	a	b	c	d
8.	a	b		
9.	a	b	c	d
10.	a	b	c	d
11.	a	b		
12.	a	b		
13.	a	b	c	d
14.	a	b		
15.	a	b		
16.	a	b	c	d
17.	a	b	c	d
18.	a	b	c	d
19.	a	b	c	d
20.	a	b	c	d
21.	a	b		
22.	a	b		
23.	a	b	c	d
24.	a	b		
25.	a	b	c	d

I certify that this quiz was administered in accordance with the specified test instructions.

_____
Quiz Supervisor

Continuous Emission Monitoring Systems
Operation and Maintenance of Gas Monitors

Final Exam 1

Directions: This is a closed book test, so you may not use your manual and notes. On your answer sheet, circle the letter that corresponds to the best answer or write the answer in the space provided. You will have ___ minutes to complete the test. When you have completed it, turn in only the Answer Sheet.

1-1. The two monitoring techniques that are based on the characteristics of light waves are _____ and _____.

a. luminescence ... spectroscopic absorption
b. absorption ... adsorption
c. paramagnetism ... polarography
d. electrolysis ... luminescence

1-2. _____ systems condition the sample gas prior to its analysis.

a. Extractive
b. In-situ
c. Opacity
d. Ambient air

1-3. Sample vessels used for spectroscopic analysis should be _____.

a. metal
b. ceramic
c. transparent
d. magnetic

1-4. Differential absorption spectroscopy analyzers may use a diffraction grating to distinguish between _____ and _____.

a. measuring gas ... reference gas
b. measuring wavelength ... reference wavelength
c. SO_x ... NO_x
d. moisture ... particulate matter

1-5. Which of the following gases cannot be measured by a flame photometric analyzer?

a. SO_2
b. HCl
c. H_2S_5
d. H_2S

1-6. Electroanalyzers can relate subject gas concentration to _____ and _____.

a. voltage ... capacitance
b. current ... capacitance
c. Planck's constant ... Faraday's constant
d. current ... voltage

1-7. Paramagnetic molecules, like oxygen, are _____ by magnetic fields.

a. repelled
b. attracted
c. condensed
d. diluted

1-8. High pressure purge air is forced through the secondary filter assembly of the Bodenseewerk Model 677 in order to

a. compress the sample volume.
b. purge the filter, alleviating blockage.
c. decompress the system.
d. remove HCl from the gas stream.

1-9. A _____ protects the ceramic diffuser from erosion caused by particulate matter.

a. dispersive spectrophotometer
b. compact design
c. platinum electrode
d. particulate deflector

1-10. The Horiba MPA-311 analyzer uses the magneto-pneumatic method to measure _____.

a. O_2
b. diamagnetism
c. velocity profile
d. temperature fluctuations

1-11. Analyzers that use a _____ sampling volume may provide longer intervals between maintenance.

a. spectroscopic
b. small
c. proportional
d. porous

1-12. The NDIR cross-flow modulation process requires the sample gas and the reference gas to be introduced alternately into the measurement cell.

a. True
b. False

1-13. Extractive CEMSs require _____ equipment for a single sample point compared to in-situ CEMSs.

a. more
b. less
c. the same amount of

1-14. A _____ allows gases to permeate and prevents particulate matter from entering the in-situ analyzer.

a. diaphragm pump
b. high pressure blowback system
c. splitter
d. ceramic thimble

1-15. In-situ monitors which measure across a distance greater than 10% of the equivalent stack diameter are classified as point monitors.

a. True
b. False

1-16. In-situ analyzers use anti-vibration equipment to help maintain

a. sample integrity.
b. constant temperature.
c. optical alignment of the transmitter and receiver.
d. a clean sample that is free of all particulate matter greater than one micron.

1-17. CEMSs data has generally been collected on _____.

a. a yearly basis
b. a weekly basis
c. computers and semi-log paper
d. computers and operator log sheets

1-18. The initial cost of an in-situ CEMS is _____ the initial cost of an extractive CEMS when monitoring at a single location.

a. less than
b. about the same as
c. greater than

1-19. A sample transport system contains _____.

a. a retroreflector
b. depth filters
c. a torsion pendulum
d. tubing

1-20. System calibration should be performed under the same conditions encountered during normal operation.

a. True
b. False

1-21. In extractive designs, the separation of the probe and analyzer

a. increases analytical error.
b. decreases particulate buildup.
c. causes a time lag between extraction and analysis.
d. decreases sampling volume.

1-22. Moisture content of stack gas should be determined in order to

a. assess the effect of stratification.
b. estimate the amount of water recycled per hour.
c. purge the filters.
d. calculate the water removal needs of the system.

1-23. Moisture reduction is not accomplished by _____.

a. heating
b. permeation
c. dilution
d. refrigeration

1-24. In-situ CEMSs can be designed in a manner to accommodate time-sharing of a single analyzer.

a. True
b. False

1-25. Reliable CEMSs data can be used to enhance process control systems.

a. True
b. False

1-26. The use of heat traced sample lines prevents _____ and _____ during transport.

a. water condensation ... sample loss
b. corrosion ... cracking
c. dilution ... corrosion
d. quenching ...luminescence

1-27. In the Horiba ENHA-C900 Series, the reduction catalyst assists in the reaction of ammonia with sulfur dioxide.

a. True
b. False

1-28. A constant sample flow rate can be more easily maintained with the use of a _____.

a. primary filter
b. secondary filter
c. pressure trap
d. diffraction grating

1-29. The pressure differential in the fuel type cell sensor in the Dynatron analyzer results in a _____.

a. high amplitude
b. voltage
c. low temperature
d. zero setting

1-30. The release of excitation energy in the form of light is the basis for the _____ _____ method of analysis.

a. catalytic
b. inductive
c. reduction
d. luminescence

1-31. The process of relaxing an excited gas molecule without the release of light energy is called _____ and is caused by fluctuations in diluent gas concentration.

a. quenching
b. cleansing
c. modulation
d. filtering

1-32. The intensity of a light beam will _____ as a subject gas absorbs some of that light energy.

a. remain the same
b. become ultraviolet
c. increase
d. decrease

1-33. The purpose of a gas filter cell is to

a. filter gas before going to the analysis unit.
b. remove all the sample gas from the stack.
c. absorb all light energy from the absorption peak associated with a subject gas.
d. purify air.

1-34. An order is usually issued as a result of public hearings and is an authorized method for assuring compliance with applicable air quality standards.

a. True
b. False

1-35. Continuous emissions monitoring requirements for nitric acid plants are contained in which subpart to 40 CFR Part 60?

a. R
b. G
c. Da
d. BB

1-36. The National Emissions Standards for Hazardous Air Pollutants (NESHAPS) are contained in 40 CFR Part 50.

a. True
b. False

1-37. Excess Emission Monitoring Data are used whenever the use of continuous emission monitoring data:

a. is the state's approved compliance method.
b. is not the state's approved compliance method.
c. must be reported to the EPA headquarters in Washington, D.C.
d. none of the above.

1-38. In situations where a source's emissions are less than 50% of the applicable standard, the source may use an alternative mathematical expression in determining the relative accuracy of the source monitor. This alternative method involves dividing the absolute difference between the monitor value and reference method value plus the 2.5 percent confidence internal by the applicable standard.

a. True
b. False

1-39. Performance Specification Tests 3-5 (Appendix B) use none of the same procedures outlined in Performance Specification Test 2.

a. True
b. False

1-40. The EPA Reference Methods are contained in Appendix ____ to 40 CFR Part 60.

a. B
b. A
c. F
d. P

1-41. A Cylinder Gas Audit (CGA) test may be performed in any of ____ calendar quarters.

a. Four
b. Three
c. Two
d. May not be performed at any time during the fiscal year.

1-42. The audit gas used in performing a CGA test is used to check the CEM at four points within the specified ranges.

a. True
b. False

1-43. Procedures for maintaining a spare parts inventory is a QC requirement as stated in Appendix F to 40 CFR Part 60.

a. True
b. False

1-44. The level I function in a quality assurance program involves:

a. duties of the CEM operator.
b. the implementation and support of the QA program.
c. writing the monthly and quarterly reports.
d. none of the above.

1-45. Routine and corrective maintenance is one of the three stages of a CEMS quality control program.

a. True
b. False

1-46. The "level" approach involved in a regulatory inspection audit program involves:

a. source records review and stack testing to determine compliance.
b. issuing source permits.
c. observing the initial CEMS performance specification test.
d. all of the above.

1-47. Problems encountered with extractive monitoring systems generally occur:

a. in the system electronics.
b. in the gas transport system and gas conditioning components.
c. because the calibration gases are usually not NIST certified.
d. none of the above.

1-48. Daily operation checks for an extractive monitoring system should include:

a. system indicator lights.
b. strip charts / other data recording devices.
c. conditioning system.
d. a daily calibration check.
e. all of the above.

1-49. Recent surveys have identified emergency service as the only problem to be encountered in CEM maintenance programs.

a. True
b. False

1-50. A performance specification test will determine if a continuous emission monitoring system is:

a. accurate.
b. durable.
c. reliable.
d. all of the above.

Name: _____

Date: _____

Course SI: 476B
Final Exam 1
Answer Sheet

1.	a	b	c	d	26.	a	b	c	d	
2.	a	b	c	d	27.	a	b			
3.	a	b	c	d	28.	a	b	c	d	
4.	a	b	c	d	29.	a	b	c	d	
5.	a	b	c	d	30.	a	b	c	d	
6.	a	b	c	d	31.	a	b	c	d	
7.	a	b	c	d	32.	a	b	c	d	
8.	a	b	c	d	33.	a	b	c	d	
9.	a	b	c	d	34.	a	b			
10.	a	b	c	d	35.	a	b	c	d	
11.	a	b	c	d	36.	a	b			
12.	a	b			37.	a	b	c	d	
13.	a	b	c		38.	a	b			
14.	a	b	c	d	39.	a	b			
15.	a	b			40.	a	b	c	d	
16.	a	b	c	d	41.	a	b	c	d	
17.	a	b	c	d	42.	a	b			
18.	a	b	c		43.	a	b			
19.	a	b	c	d	44.	a	b	c	d	
20.	a	b			45.	a	b	c	d	
21.	a	b	c	d	46.	a	b	c	d	
22.	a	b	c	d	47.	a	b	c	d	
23.	a	b	c	d	48.	a	b	c	d	e
24.	a	b			49.	a	b			
25.	a	b			50.	a	b	c	d	

I certify that this quiz was administered in accordance with the specified test instructions.

_____
Test Supervisor

Course Introduction

Description

This course is a self-instructional study program designed to help you develop a working knowledge of the operation and maintenance of continuous gas emission monitoring systems. It presents the detailed operating characteristics of commercially available continuous emission monitors and the common maintenance techniques use to provide for continuing operation. A comprehensive discussion of regulatory specifications in terms of instrument design, installation, and performance testing is also included. Major topics include the following:

- Analytical methods
- Operation of commercially available monitors
- System design
- Regulations
- Continuing operations (quality assurance / quality control and audits)

Course Goal and Objectives

Goal

To present basic operational principles of continuous gas emission monitors and to develop a comprehensive understanding of maintenance requirements and procedures.

Objectives

Upon completing this course, you should be able to:

1. describe the types of emission monitoring systems and identify the scientific principles associated with the various analytical techniques;

2. explain the operation and describe the special features of specific analyzers in the these categories: spectroscopic, luminescence, electroanalytical, and paramagnetic;

3. identify the analytical techniques of and gases monitored by general purpose analyzers;

4. describe the primary subsystems and list the criteria to be evaluated in the selection of extractive systems and in-situ systems;

5. identify source categories required to install continuous emission monitoring systems and explain how to find the applicable requirements;

6. explain performance specification test procedures, quality assurance/quality control requirements, audit programs, and maintenance procedures for CEMs.

Identification of Constraints / Prerequisite Skills

Before studying this self-instructional course, you should have some knowledge of continuous emission monitoring systems. This knowledge should be at the level of material presented in APTI Course 474. Continuous Emission Monitoring, or in equivalent introductory workshops presented by the EPA Stationary Source Compliance Division.

If you are not able to attend such course offerings, but wish to study this self-instructional course on continuous gas emission monitoring, the handbook, Continuous Air Pollution Source Monitoring Systems, EPA 625/6-79-005 should first be reviewed. This document is available at no cost as Handbook No. 6005 from:

Center for Environmental Research Information
U.S. EPA Cincinnati, Ohio 45628

Description of Intended Trainees

This course is designed for persons in regulatory agencies and in industry, who, as part of their job function, will evaluate continuous gas emission monitoring systems and system data or who will be responsible for the actual systems. The intended trainees are either engineers, physical scientists, or supervisory engineers involved in environmental compliance programs. Trainees should have bachelor's degrees in some technical field of study. Technicians who are responsible for emissions monitoring systems, and who have either an associate degree or several years experience in instrumental monitoring, should experience little difficulty with the course.

Requirements for Successful Completion of this Course

In order to receive 2.0 Continuing Education Units (CEUs) and a certificate of course completion you must:

- take two supervised quizzes and a supervised final examination.
- achieve a final course grade of at least 70 (out of 100) determined as follows:
  - Quiz 1 is 25% of the final grade.

- Quiz 2 is 25% of the final grade.
- The final examination is 50% of the final grade.

Materials

Reading

This text - supplementary reading materials are not required.

Using the Handbook

This handbook contains fifteen lessons separated into five units. Each lesson contains the following:

- lesson learning goal and objectives,
- text of the lesson,
- review exercises,
- answers to review exercises, and
- references

Complete the review exercises immediately after reading the assigned materials. You may find it helpful to look over the review questions before reading. By having an idea of what to look for in the reading materials, your attention will be better focused and your study will be more efficiently directed.

To complete an exercise, place a piece of paper across the page, covering the questions below the one you are answering. After answering the question, slide the paper down to uncover the next question. The answer for the first question will be given on the right side of the page, as shown here. All answers to review questions will appear below and to the right of their respective questions. The answer will be numbered to match the question.

REVIEW EXERCISES	
1. Question	
2. Question	1. Answer
3. Question	2. Answer

Complete each review exercise in the lessons. If you are unsure abut a question or answer, review the material preceding the question. Then proceed to the next section.

NOTE: If more than one person will be using these materials, we recommend that you use a separate sheet of paper to record your answers to the review exercises.

Instructions for Completing the Quizzes and the Final Examination

- You should have received , along with this guidebook, a separate sealed envelope containing two quizzes and a final examination.

- You must arrange to have someone serve as your test supervisor.

- You must give the sealed envelope containing the quizzes and the final examination to your test supervisor.

- At designated times during the course, under the supervision of your test supervisor, complete the quizzes and the final exam.

- After you have completed a quiz or the exam, your test supervisor must sign a statement on the quiz/exam answer sheet certifying that the quiz or exam was administered in accordance with the specified test instructions.

- After signing the quiz/exam answer sheet, your test supervisor must mail the quiz or exam and its answer sheet to the following address:

  Air Pollution Training Institute
  MD 17 Research Triangle Park, NC 27711

- After completing a quiz, continue with the course. Do not wait for quiz results.

- Quiz/exam and course grade results will be mailed to you.

If you have questions, contact:

Air Pollution Training Institute
MD 17
Research Triangle Park, NC 27711

Telephone numbers
Commercial: (919) 541-2401
FTS: 629-2401

UNIT 1

INTRODUCTION

TO THE

ANALYTICAL METHODS

LESSON 1

Types of Emissions Monitoring Systems

Lesson Goal and Objectives

Goal

To introduce some general information and terminology associated with continuous emissions monitoring systems (CEMSs).

Objectives

At the end of this lesson, you should be able to —

1. list primary reasons for having a continuous emissions monitoring program;
2. describe, in general terms, the means by which gases can be analyzed; and
3. describe the primary differences among the various designs of CEMSs.

Introduction

Though there are many reasons why a facility might install a continuous emissions monitoring system, perhaps the most pervasive reasons are to optimize process and control systems and to satisfy regulatory requirements. CEMSs are required to be installed at certain facilities which are subject to the New Source Performance Standards (NSPSs) and other Clean Air Act regulations promulgated by the United States Environmental Protection Agency (USEPA). Other federal and state regulatory agencies might also have requirements for the installation of CEMSs. These systems are used on a continuous basis for several purposes.

For the plant, properly installed and operating CEMSs can provide information about the operation of key processes and describe the effectiveness of the air pollution control techniques. Having the ability to examine various aspects of the facility's operation can provide the user the opportunity to make critical adjustments for

process optimization and cost reduction. Additionally, CEM records can prove to be important documentation of compliance status in this time of heightened public concern about air pollution.

For regulatory agencies, the data provided by a CEMS are used to supplement on-site visits, to identify "problem" sources, and to determine if source emission limits and proper operation and maintenance requirements are being met. With a better picture of actual emissions, the agency's ability to develop strategies for future programs directed at emissions reduction can be enhanced.

The main goal of both the plant and the regulatory agency is to obtain accurate and repeatable information about stack emissions. The EPA standards require continuous emissions monitoring data to be obtained from a representative location. Meeting this requirement entails studying the applicable regulations with respect to the gases to be monitored.

Analytical Methods

A system, which is defined as the total equipment necessary for the accurate determination and recording of flue gas concentration, typically consists of a probe, an analyzer, and some form of data readout/recorder. It is used to generate emissions data which are representative of the total actual emissions from the facility. CEMSs have been developed to monitor gases including, but not limited to, sulfur dioxide (SO_2), nitrogen oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrogen chloride (HCl), and ammonia (NH_3).

In general, monitoring techniques are based on both physical and chemical properties of gases. The method selected for gas analysis is primarily dependent on characteristics of the subject gas, but it can also be affected by other parameters such as regulatory requirements and stack conditions. Brief discussions of the commonly used analytical techniques are given in the following sections.

Spectroscopic Absorption Techniques

Some of the most common analytical methods used in CEMSs are spectroscopic absorption techniques. These methods are able to monitor specific gases because various types of gaseous molecules are known to behave differently in the presence of electromagnetic radiation ("light").

Luminescence Techniques

Luminescence techniques can selectively monitor gases by examining the emission of light from an atom or molecule that has been "excited" in some manner. Because the spectral emissions occur at different wavelengths, depending on the gas that is excited, these monitors can be used for very specific analysis.

Electroanalytical Techniques

Another technique used for continuous emissions monitoring is electroanalysis. Analyzers that use this method can quantify a target gas by measuring the current (or voltage) that is produced in the electrochemical cell. Different types of electrodes and electrolytes are required depending on which gas is selected for monitoring.

Paramagnetic Techniques

Paramagnetic methods, used primarily for oxygen monitoring, are based on the fact that molecules behave differently when placed in magnetic fields. The behavior is classified as either diamagnetic or paramagnetic. Paramagnetic molecules, like O_2, are attracted to and interact with a magnetic field. Measurement of these interactions can be related to O_2 concentration.

Systems Design

CEMSs can be divided into two general classifications based on the means by which sample gas is delivered to the analyzer. These two categories are extractive systems and in-situ systems.

Extractive CEMSs

Extractive systems withdraw flue gas from the stack, condition it, and transport the gas to the analysis *Section* which is usually at some convenient site within the plant. The separation of the probe and the analyzer imposes a time lapse between extraction of the sample gas and its analysis. Consequently, the output reading (concentration value) will lag behind the process conditions.

The first generation of extractive CEMSs were essentially ambient air analyzers which were modified to incorporate a simple dilution system suitable for reducing the pollutant concentration to a level which could be measured by the analyzer. Such systems were used mostly at combustion sources. Because of the relative lack of sophistication of these early systems, there were significant operational problems associated with them. By using the specially designed transport and conditioning subsystems, subsequent monitors have been able to avoid the difficulties posed by particulate matter, moisture, and corrosive gases.

In-situ CEMSs

In-situ systems have at least some part of their analysis subsystem mounted in the stack in direct contact with the flue gas. Because they perform analyses at the stack, in-situ systems neither condition the sample gas nor transport it to a remote analytical unit. The lack of conditioning and transport subsystems indicates that in-situ CEMSs designs require substantially less equipment than do extractive CEMSs designs. However, the analytical subsystems of these CEMSs are generally exposed to a more harsh environment than those of extractive systems.

There are generally two approaches taken in in-situ system design. One approach is to monitor across a certain path of stack gas; the other is to monitor at a single point within the stack. EPA distinguishes between path and point monitors by the percentage of the stack diameter (or equivalent diameter for non-circular ducts) represented by the measurement path. An instrument that measures gas concentrations along a path which is greater than 10 percent of the diameter is said to be a path analyzer. If the measurement path is less than or equal to 10 percent of the diameter, the instrument is considered a point analyzer.

Summary

Lesson 1 introduced some terminology and general information associated with the different types of continuous emissions monitoring systems (CEMSs). More specifically, this lesson gave reasons for having a monitoring program, briefly described gas analysis techniques, and described some differences in systems' designs. The material in Lesson 1 provides the basis for more detailed discussions in forthcoming lessons.

In addition to meeting federal and state regulations, other reasons for having a monitoring program include:

1. gaining information about the effects of certain process parameters,
2. describing the effectiveness of installed control devices, and
3. recording information pertaining to non-compliance situations.

Monitoring techniques are based on both chemical and physical properties of gases and include the following methods:

1. spectroscopy,
2. luminescence,
3. electroanalysis, and
4. paramagnetism.

CEMSs can be divided into two general classifications based on the means by which sample gas is delivered to the analyzer. Those two categories are extractive systems and in-situ systems. Extractive systems withdraw flue gas from the stack, condition it, and transport the gas to the analysis *Section* which is usually at some convenient site within the plant. In-situ systems have at least some part of their analysis subsystem mounted in the stack in direct contact with the flue gas. Because they perform analyses at the stack, in-situ systems neither condition the sample gas nor transport it to a remote analytical unit.

REVIEW EXERCISES	
1. True or false. CEMSs are often used by plant personnel to optimize the processes and control systems in addition to meeting regulatory requirements.	
2. CEMSs are used on a _____ basis. a. yearly b. nominal c. continuous	1. True
3. True or false. In order to determine the requirements for representative sampling, one should consult federal and state regulations.	2. c
4. The entire monitoring system contains all of the following except a. a data recorder. b. a concentration enhancer. c. an analyzer. d. a readout instrument.	3. True
5. True or false. Monitoring techniques are dependent upon the molecular weight of the gases to be measured.	4.. b
6. The two monitoring techniques that are primarily dependent on the characteristics of light are ____ and _____ methods. a. paramagnetic, metaphysical b. absorption, dilution c. electroanalysis, electrocution d. spectroscopic absorption, luminescence	5. False
7. _____ systems condition the sample gas before analysis. a. In-situ b. Opacity c. Ambient air d. Extractive	6. d

8. True or false. Oxygen is a diamagnetic gas and is attracted to a magnetic field.	7. d
9. True or false. Extractive analyzers are usually designed as path and point monitors.	8. False
10. True or false. A primary objective of continuous emissions monitoring programs is to obtain accurate and repeatable emissions data.	9. False
	10. True

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1. Jahnke, J.A. and Aldina, G. J. 1979. *Continuous Air Pollution Source Monitoring Systems*. EPA 625/6-79-005.

2. Kilkelly Environmental Associates. 1988. *Continuous Emission Monitoring Guidelines: Update*. Electric Power Research Institute, Inc. Palo Alto, CA. Report CS-5998.

3. U. S. Environmental Protection Agency. 1986. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III*. Stationary Source Specific Methods. EPA-600/4-77-027b.

LESSON 2

General Principles of Detection in Monitoring Systems

Lesson Goal and Objectives

Goal

To describe the fundamental means by which gases are detected and analyzed within commercially available continuous emissions monitoring systems (CEMSs).

Objectives

At the end of this lesson, you should be able to —

1. identify the primary analytical techniques for the detection of gases by commercially available CEMSs,
2. identify the scientific principles which enable specific gases to be monitored and analyzed, and
3. recognize the most common detection methods used within both extractive and in-situ CEMSs.

Introduction

In Lesson 1, a variety of CEMSs were discussed. Some information on their background and capabilities was presented in an effort to acquaint you with those systems and the extent of their utility. Using that information as a foundation, we are now ready to examine the principles of detection in monitoring systems.

Comprehending the principles and techniques used to monitor certain gases will not only enable you to gain a better understanding of equipment operation, but it will also provide the technical background necessary to improve troubleshooting strategies for currently operating systems. The knowledge gained in this lesson will also help you select the appropriate CEMS to be used in future monitoring applications.

This lesson will identify some analytical techniques, describe their underlying scientific principles, and discuss their use in specific types of CEMSs.

Monitoring Techniques

The monitoring techniques upon which this lesson focuses are based on both physical and chemical properties of gases. Detection of individual gases is possible because of the unique characteristics they exhibit when subjected to specific, analytical methods. These characteristics determine the principles of design and operation of reliable CEMSs. The four analytical techniques to be discussed herein are spectroscopic absorption, luminescence, electroanalysis, and paramagnetism.

Spectroscopic Absorption Techniques

Some of the most common analytical methods used in CEMSs are spectroscopic absorption techniques. Using these methods, CEMSs are able to identify and to measure the amounts of selected gases via the attenuation (weakening) of a beam of electromagnetic radiation whose wavelength is known. *Figure* 2-1, below, provides a pictorial representation of the electromagnetic spectrum and the general categories of electromagnetic radiation ("light").

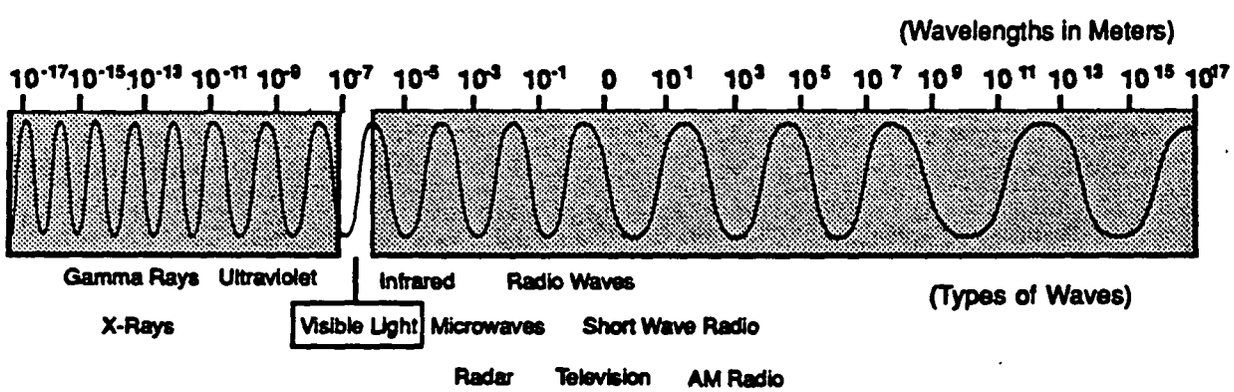

FIGURE 2-1 ELECTROMAGNETIC SPECTRUM

Identification of a gas is possible because different types of gaseous molecules are known to absorb specific, unique wavelengths of electromagnetic radiation. The points (wavelengths) in the spectrum where gases absorb the maximum amount of radiation are termed "peaks." Determining the amount of gas is accomplished by converting the percent of the beam's absorbance to the concentration of the identified gas. Though there are several types of absorption spectroscopy which can identify and measure gases, each method employs similar equipment for the purposes of gas monitoring. The five basic components for such instrumentation include:

1. a stable source of radiant energy ("light"),

2. a wavelength selector (filter) for the isolation of the desired region of spectral emissions,

3. a sample vessel,

4. a radiation detector/transducer used to convert the radiant energy to a usable signal, and

5. a signal processor and readout.

Figure 2-2 depicts a common set-up for the most fundamental instrumentation used in spectroscopic analyzers. More detailed information about the various methods and analyzers is presented in the upcoming paragraphs.

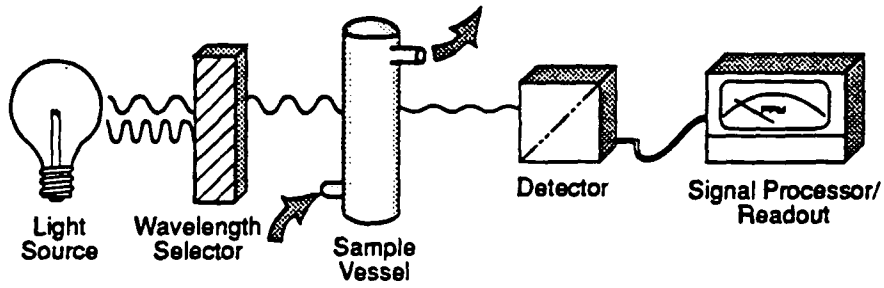

FIGURE 2-2 BASIC SPECTROSCOPIC INSTRUMENTATION

Non-dispersive infrared (NDIR) spectroscopy uses infrared "light" in a limited range of the electromagnetic spectrum. The light is filtered in order to isolate the wavelengths which will be absorbed by the gaseous molecules selected for monitoring. (The light is not scanned or "dispersed" as with scanning laboratory spectrometers). The filtered light passes through a cell that contains flue gas extracted from the stack. Another portion of the light passes through a cell which contains a reference gas that does not absorb any of the filtered light (reference = 0.0% absorbance). A detector senses the amount of light absorption in the sample cell relative to the signal from the reference cell. The detector responses are then electronically converted to concentration readings for the specified gas.

Non-dispersive IR analyzers (like the one shown in *Figure* 2-3) are commonly used for extractive CEMSs. Such instruments have been developed to measure SO_2, NO, NO_2, HCl, CO, and CO_2. The commercially available monitors differ primarily in the design of the detector and the level of rejection of interfering gases (i.e., the degree to which interference from extraneous gases is suppressed or eliminated).

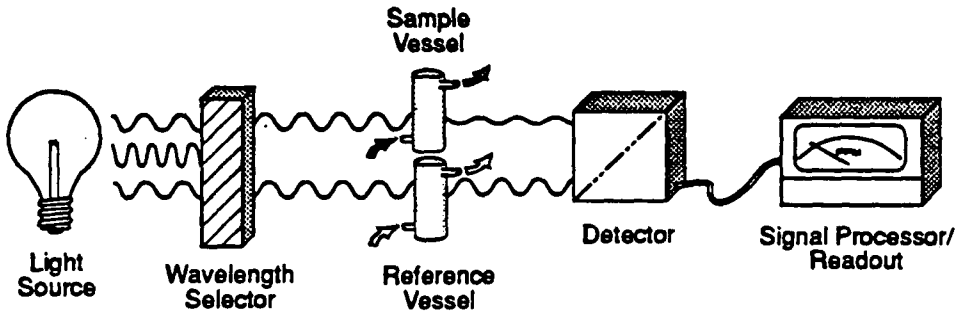

FIGURE 2-3 NDIR ANALYZER

A variant of this technique, called gas filter correlation (GFC) spectroscopy, requires light, usually in the IR region, to pass through the sample cell and into a receiving unit. In this unit, the beam (which is usually split) is sent to two, parallel cells called the gas filter cell and the neutral density filter cell. The gas filter cell contains a high concentration of the gas being analyzed, and therefore removes nearly all of the energy of the predetermined wavelength (reference = 100% absorbance). What remains of that beam (i.e., the wavelengths not absorbed in the gas filter cell) passes to the detector. The beam from the neutral density filter cell also goes to the detector. The difference in energy of these two beams can then be related to the concentration of the gas of interest. *Figure* 2-4 illustrates a GFC Analyzer.

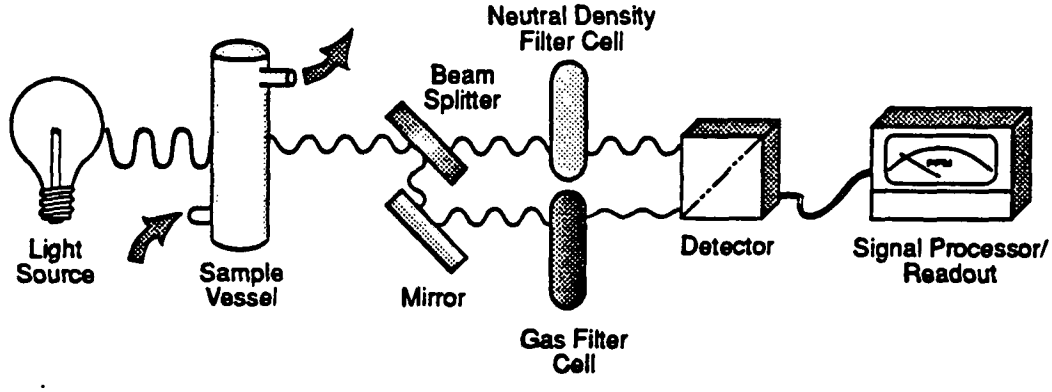

FIGURE 2-4 GFC ANALYZER

The advantage of this method is that low levels of particulate matter will not adversely affect the concentration reading. Particulate matter can further reduce the intensity of a light beam which is transmitted through a sample cell. But because the beam goes to two separate cells and the signals from these cells are ratioed, the effect of particulate matter will then cancel and the concentration reading of the subject gas will be more accurate.

Gas filter correlation spectroscopy is used in single-pass, in-situ analyzers as well as ambient air analyzers in order to measure SO_2, NO, CO, and CO_2. This method has also been used by extractive CEMSs for monitoring HCl.

Differential absorption spectroscopy is also based on the principle that certain gas molecules absorb unique wavelengths of light. Unlike non-dispersive IR spectroscopy which uses a sample cell and a reference cell, differential absorption analyzers employ a "measuring" wavelength and a "reference" wavelength. The measuring wavelength corresponds to a region of the spectrum where the gaseous molecules of interest absorb light energy, whereas the reference wavelength corresponds to a region of the spectrum in which the gaseous molecules of interest absorb little or no light energy. The concentration of the identified gas is determined by finding the difference in energy for the measuring wavelength and the reference wavelength. The detected difference is then processed and sent to the readout instrument as a concentration value. *Figure* 2-5 ilustrates a differential absorption analyzer.

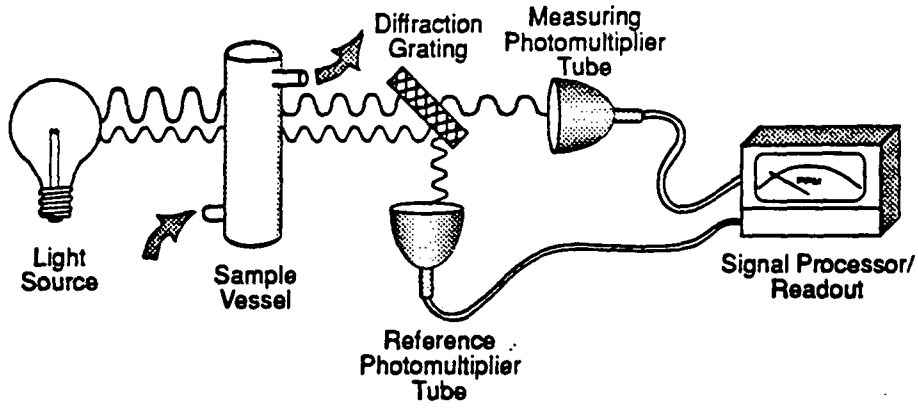

FIGURE 2-5 DIFFERENTIAL ABSORPTION ANALYZER

Some differential absorption systems are single-pass, in-situ, path monitors that use a diffraction grating to distinguish between measuring and reference wavelengths in the ultra-violet (UV) region of the spectrum. These monitors measure SO_2 and NO, although by changing the optical system it is possible to measure other gases. Certain filters can also be used to distinguish between measuring and reference wavelengths. This alteration allows the monitoring of CO by IR light.

The differential absorption method can also be used in extractive CEMSs. While most of these systems operate in the UV region, it is also possible to use IR radiation. When using a UV apparatus, subject gases may be measured hot without removing water vapor; however, it is generally advisable to dry the sample before taking measurements.

Many extractive CEMSs use differential absorption spectroscopy to monitor SO_2. This technique has also been modified in order to measure NO from flue gas. By injecting oxygen into the sample chamber and sealing it, NO is measured via the production of NO_2 from NO while monitoring an NO_2 absorption wavelength.

Second derivative spectroscopy uses a different means of concentration determination than the previously described absorption techniques. In this case, a scanner moves back and forth across the absorption peak of the subject gas. The scanning is related to the second derivative of the absorption peak, with respect to wavelength. The signal from scanning is then used to determine the concentration of the selected gas. A second derivative spectroscopy analyzer is shown in *Figure* 2-6. Second derivative spectroscopy is used in a widely marketed in-situ, point monitor for SO_2 and NO.

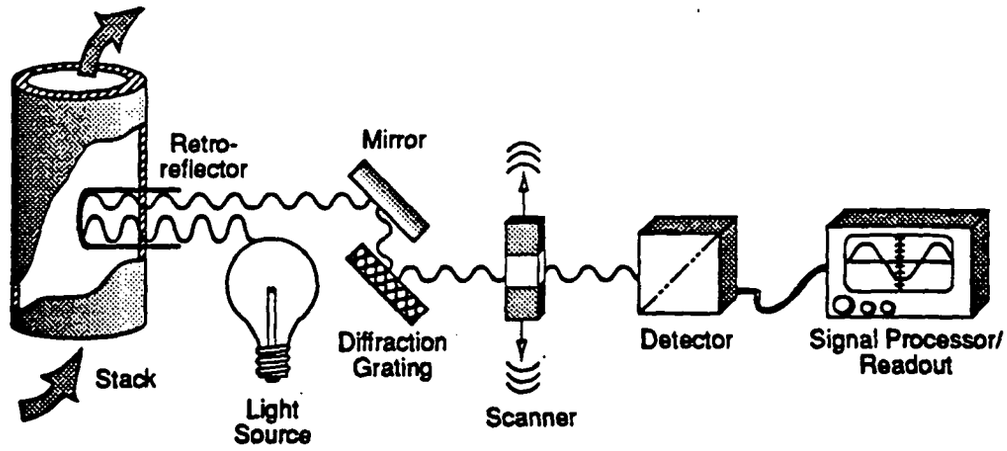

FIGURE 2-6 SECOND DERIVATIVE SPECTROSCOPIC ANALYZER

Luminescence Techniques

Luminescence is the emission of light from an atom or molecule that has been excited in some manner. Excitation refers to the temporary placement of electrons into energy levels (orbitals) which are higher than the ground (i.e., relaxed) state energy levels for that atom or molecule. As the electrons return to their normal levels, excitation energy in the form of light is emitted. Three luminescence techniques are used in the field of source monitoring. They are UV fluorescence, chemiluminescence, and flame photometry. Since each method differs primarily with respect to their means of excitation rather than their means of measurement, similar instrumentation can be employed for each technique. The basic requirements are the same as for spectroscopic techniques, though their configuration is somewhat different for luminescence techniques. They are:

1. a stable source of radiant energy,
2. a sample vessel,
3. a wavelength selector for the isolation of the desired region of spectral emissions,
4. a radiation detector/transducer used to convert the radiant energy to a usable signal, and
5. a signal processor and readout.

Shown in *Figure* 2-7 is a schematic representation of a typical set-up for the basic equipment requirements. Please note that the equipment is basically the same as that which is used in absorption spectroscopy; however, its configuration differs slightly.

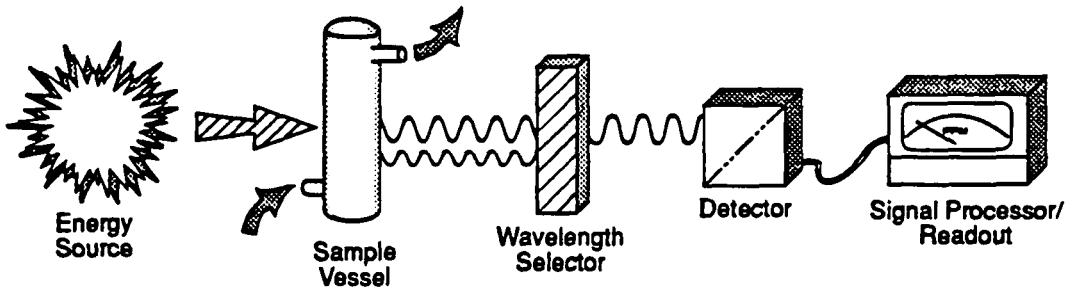

FIGURE 2-7 BASIC INSTRUMENTATION FOR LUMINESCENCE TECHNIQUES

The UV fluorescence method of analysis is primarily used to measure SO_2 present in exhaust gas streams. SO_2 molecules are excited to SO_2* by using UV light of wavelength 210 nanometers (nm). Excitation is the result of an atom's absorption of this beam of electromagnetic radiation. The excited molecular state persists for only a few nanoseconds during which time some of the energy is lost through vibrational transitions of the electrons. As the molecule returns to its relaxed state, light of a longer wavelength, 350 nm, is released. The released light can be detected by the instrumentation within the monitor. Its intensity is then related to gas concentration.

Fluorescence monitors are affected by changes in the flue gas composition (%O_2, %CO, and %N_2). These fluctuations in diluent gas concentration result in the relaxation of SO_2* molecules through a process called quenching. Quenching occurs when excited molecules return to their normal state by losing their extra energy through interactions with other gases instead of releasing their energy in the form of light; consequently, some of the excitation energy would not be detected. In order to reduce the problems caused by quenching, the background gas composition should be held relatively constant.

Fluorescence analyzers which employ a dilution system provide the constant background required for successful measurements. Dilution systems consequently dictate the use of extractive CEMSs for this type of monitoring for SO_2. *Figure* 2-8 depicts a UV fluorescence analyzer.

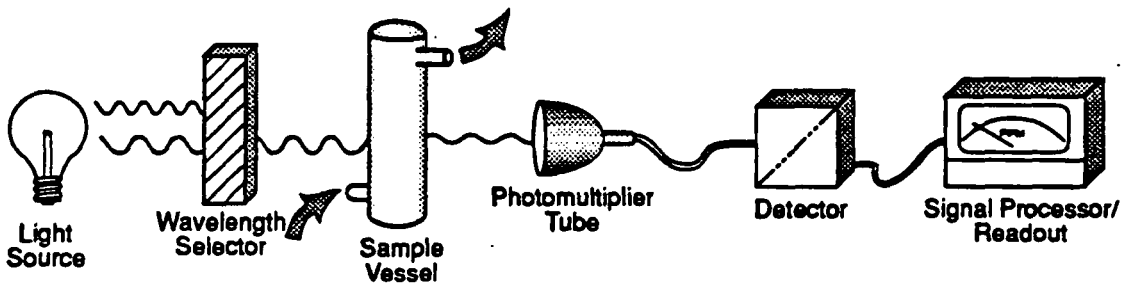

FIGURE 2-8 UV FLUORESCENCE ANALYZER

Chemiluminescence is used in flue gas analysis to measure NO and NO_2 concentrations. In this application of chemiluminescence, excited molecules, NO_2*, are produced by reacting ozone with the NO present in the exhaust stream. The excited product, NO_2*, returns to its ground state with the release of light energy. The emitted light enters a photomultiplier tube and is later related to the concentrations of NO and NO_2.

Quenching effects can also occur in this method, but dilution of the sample by the introduction of the reactant ozone gas stream minimizes the effect. This technique also requires the use of extractive CEMSs. Chemiluminescence methods for monitoring NO and NO_2 already exist and are being developed for NH_3.

Flame photometry can be used to measure compounds that contain sulfur. In this method, the compounds are "burned" in a hydrogen flame which results in the formation of excited diatomic sulfur molecules, S_2^*. The conversion of the high energy S_2^* molecules to the lower energy ground state, S_2, occurs with the emission of light. The intensity of this light is measured and related to the concentration of sulfur species in the sample.

The flame photometric method does not discriminate between sulfur-containing compounds, so scrubbers or gas chromatographic columns may be required if more than one species is present in the sample. As with the two, prior luminescence methods, flame photometry involves the use of extractive CEMSs. A flame photometry analyzer is shown in *Figure* 2-9.

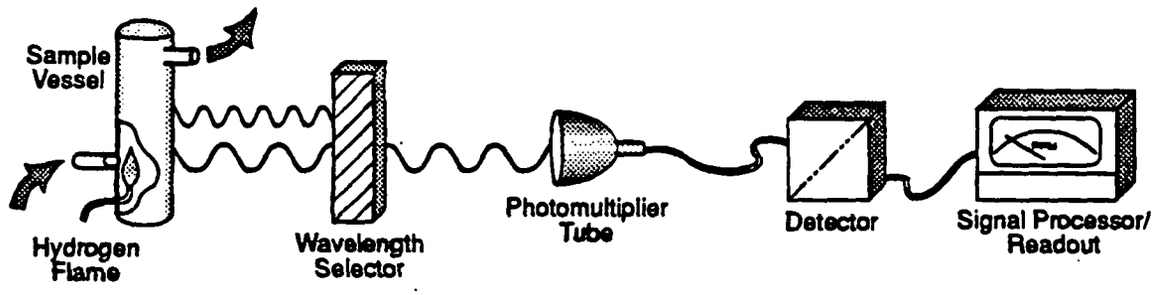

FIGURE 2-9 FLAME PHOTOMETRIC ANALYZER

Electroanalytical Techniques

Two principal electroanalytical techniques have been developed for the measurement of gases in exhaust streams. They are polarography and electrocatalysis. These methods can quantify flue gases by measuring the currents or voltages that are produced in the electrochemical cells.

Polarography utilizes analyzers which are basically diffusion-controlled electrochemical cells. The current across the cell is proportional to the rate of diffusion of the pollutant into the cell and also proportional to the pollutant concentration. Being constructed much like batteries, the cells have a sensing electrode, an electrolyte, and a counter electrode. The main difference from a wet cell battery is that polarographic analyzers also possess a thin-film membrane through which the pollutant must diffuse in order to initiate the electrochemical reaction and current flow.

Polarographic analyzers (*Figure* 2-10) have been developed to measure gases such as O_2, SO_2, NO, NO_2, CO, and CO_2. Different types of electrodes and electrolytes are required depending on which gas is selected for monitoring. As with batteries, the electrolyte will eventually be consumed and the cell must either be replaced or recharged. Because these types of analyzers require clean, dry gas samples, they can only be used in conjunction with extractive CEMSs.

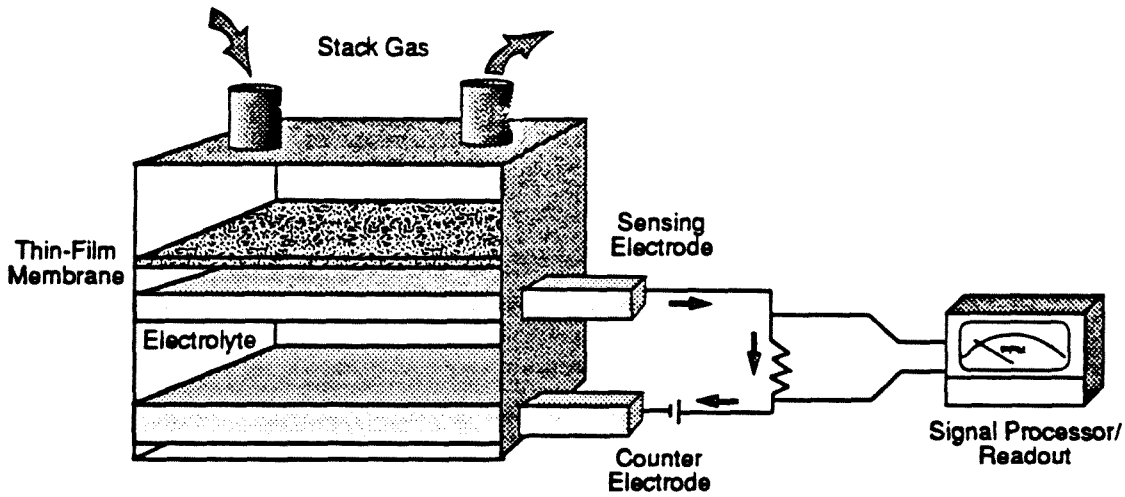

FIGURE 2-10 POLAROGRAPHIC ANALYZER

Electrocatalysis employs analyzers like the one shown in *Figure* 2-11 that use a solid electrolyte instead of a liquid electrolyte often associated with electrochemical cells. A thin film, applied to the solid's surface, catalyzes a reaction which allows gaseous molecules to migrate through the solid and generate a current.

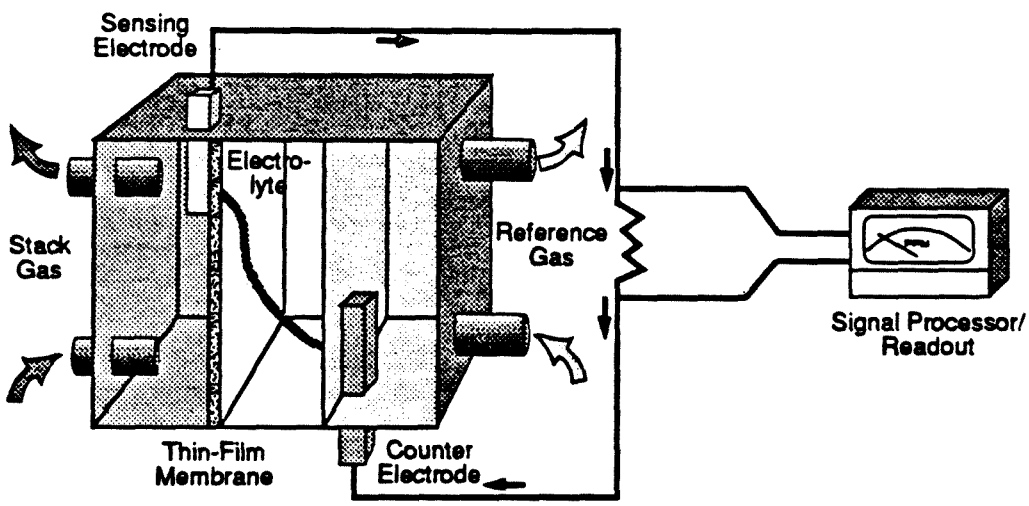

FIGURE 2-11 ELECTROCATALYTIC ANALYZER

In oxygen electrocatalytic analyzers, a zirconium oxide (ZrO_2) disc which has been coated with a thin film of platinum is heated to 850°C. A reference gas of about 21 percent oxygen is maintained on one side of the solid; the sample gas is on the other side. Oxygen ions are generated at the platinum surface and then migrate through vacancies in the solid electrolyte. Electrons are released in the process as the system attempts to reach an equilibrium concentration of oxygen. The electron flow, or current, is then related to the concentration of oxygen in the sample.

An electrocatalytic analyzer has also been developed for the measurement of SO_2. This apparatus uses a potassium sulfate crystal and requires the simultaneous measurement of oxygen concentration in the sample. This type of in-situ analyzer is used exclusively as a point monitor and has a ceramic thimble to keep the solid electrolyte free of particulate matter. Both O_2 and SO_2 are able to be monitored by this technique.

Paramagnetic Techniques

Oxygen is known to exhibit paramagnetic behavior. That is to say that oxygen is attracted by and interacts with a magnetic field. This behavior is discussed in relation to the following three extractive flue gas analyzers.

The thermomagnetic technique is used to monitor oxygen by the following procedures. Such analyzers use a magnet to channel the flow of oxygen through a designated tube. A higher concentration of O_2 in the gas will result in a higher velocity of gas through the tube. As illustrated in *Figure* 2-12, the flow of O_2 gas past a resistor will cause the resistor to cool. Beacuse a constant voltage is maintained across the resistor, a decrease in resistance due to cooling will be compensated by an increase in current (because V = I x R). The current can then be related to oxygen concentration.

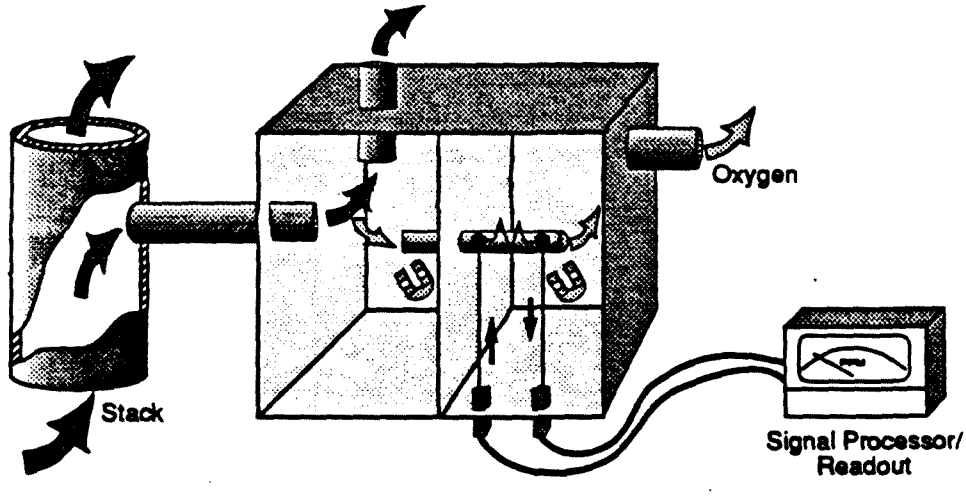

FIGURE 2-12 THERMOMAGNETIC ANALYZER

The magnetodynamic technique is used in CEMSs to relate oxygen concentration in sample gas to disturbances in a magnetic field about a torsion pendulum. As shown in *Figure* 2-13, O_2 gas flows through a magnetic field and disrupts the alignment of the magnetic charges which consequently causes the torsion pendulum to turn. The degree of this movement can then be related to the amount of O_2 within the sample.

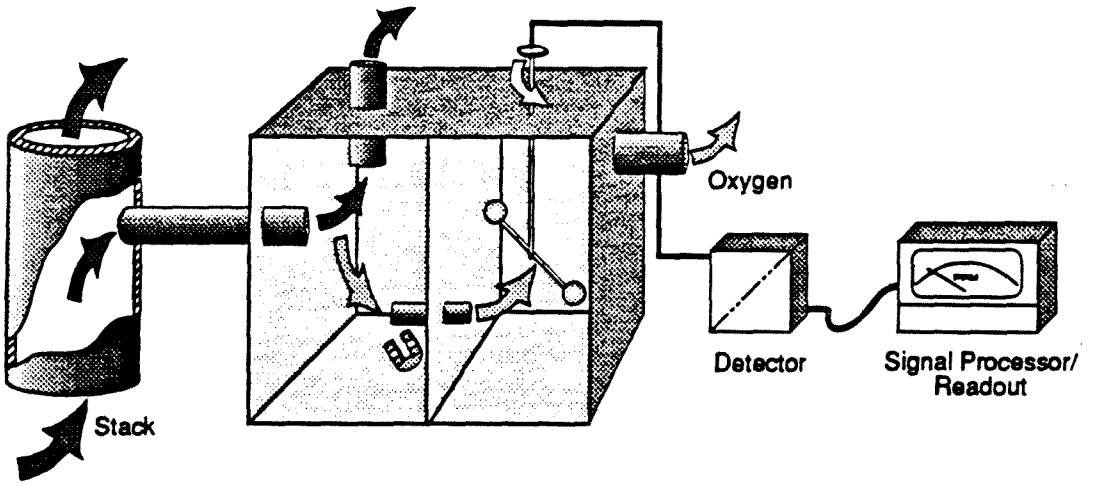

FIGURE 2-13 MAGNETODYNAMIC ANALYZER

Paramagnetic pressure is the pressure imbalance which results from the interaction of O_2 molecules with a magnetic field. The resulting movement is measured by a device (magnetopneumatic analyzer) which is very sensitive to this change and is then related to the concentration of O_2 in the sample.

Summary

Lesson 2 presented the four primary methods used in commercially available CEMSs for the analysis of flue gas. These methods are:

1. Spectroscopic Absorption,
2. Luminescence,
3. Electroanalysis, and
4. Paramagnetism.

The requirements of and limitations to certain analytical methods were presented so that the user can better understand the real-world utility of gas analyzers.

Additionally, the physical and chemical principles by which these instruments operate were discussed in relation to specific gases. Lesson 3 will give more information about these general principles as well as their application in analytical devices.

Tables 2-1 through 2-4 summarize the types of monitors and gases monitored by the analytical techniques cited in Lesson 2. Full comprehension of this information will aid the reader in the selection of the appropriate CEMS for his needs and also aid him with maintenance and troubleshooting programs.

TABLE 2-1
SUMMARY OF SPECTROSCOPIC ABSORPTION TECHNIQUES

Spectroscopic Method	System Type	Gas Monitored
Nondispersive Infrared	Extractive	SO_2, NO, NO_2, HCl, CO, CO_2
Gas Filter Correlation	Extractive	HCl
	In-situ	SO_2, NO, CO, CO_2
Differential Absorption	Extractive and In-situ	SO_2, NO_2
Second Derivative	In-situ	SO_2, NO_2

TABLE 2-2
SUMMARY OF LUMINESCENCE TECHNIQUES

Luminescence Method	System Type	Gas Monitored
Ultraviolet Fluorescence	Extractive	SO_2
Chemiluminescence	Extractive	NO, NO_2, NH_3
Flame Photometry	Extractive	Gases containing Sulfur

TABLE 2-3
SUMMARY OF
ELECTROANALYTICAL TECHNIQUES

Electroanalytical Method	System Type	Gas Monitored
Polarography	Extractive	O_2, SO_2, NO, CO_2
Electrocatalysis	Extractive and In-situ	O_2, SO_2

TABLE 2-4
SUMMARY OF
PARAMAGNETIC TECHNIQUES

Paramagnetic Method	System Type	Gas Monitored
Thermomagnetic	Extractive	O_2
Magnetodynamics	Extractive	O_2
Magnetopneumatics	Extractive	O_2

REVIEW EXERCISES	
1. Detection of specific gases is posible because a. they are different colors of the electromagnetic spectrum. b. of their unique characteristics. c. each has a different smell.	
2. Spectroscopic absorption techniques are based on a. the molecular weight of the gas. b. a gas' ability to absorb water. c. the absorption of a unique wavelength of light by the gas.	1. b
3. Spectroscopic methods relate the gas concentration to a. the amount of light absorbance. b. the wavelength of the gases. c. radioactivity.	2. c
4. Sample vessels for spectroscopic analysis & gases should be a. transparent. b. transcendental. c. transducers.	3. a
5. True or false. Gas filter correlation spectroscopy uses a cell which absorbs all of the gas to be analyzed.	4. a
6. In differential absorption spectroscopy, a diffraction grating is used to distinguish between a. species of gases emitted from the stack. b. measuring and reference wavelengths. c. extractive and in-situ systems	5. False
7. Excitation energy released as light is the principle behind a. luminescence techniques. b. electroanalytical techniques. c. paramagnetic techniques	6. b

8. Quenching is a. the altering of a magnetic field. b. not a problem in luminescence analysis. c. the relaxation of excited gas molecules by diluent gas fluctuations.	7. a
9. In polarographic analyzers, the gas diffuses through a _____ in order to generate a _____	8. c
10. Paramagnetic techniques are primarily used to detect _____. a. S_2 b. NO c. O_2	9. a
	10. c

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LESSON 3

Specific Analytical Methods Used by Analyzers

Lesson Goal and Objectives

Goal

To provide a better understanding of detection principles when applied to certain gases and their measurement.

Objectives

At the end of this lesson, you should be able to —

1. describe the process of spectroscopic absorption and analysis,
2. explain the primary differences among spectroscopic techniques,
3. explain how luminescence techniques work,
4. describe electrocatalysis and its means of determining gas concentration, and
5. discuss the fundamental similarities and differences of paramagnetic techniques.

Introduction

In Lesson 2, four primary analytical techniques used in continuous emissions monitoring systems (CEMSs) were introduced. This lesson will provide more specific information about the four detection methods (spectroscopic absorption, luminescence, electroanalysis, and paramagnetism) used to measure gaseous emissions. The theories, derivations, and applications of each principle will be discussed in order to provide you with a sound understanding of the analytical basis of each type of instrument.

Spectroscopic Absorption

Theory and Derivation

CEMSs which use spectroscopic analyzers (spectrophotometers) rely on the interaction of light energy with gaseous molecules in order to determine the gas concentration. Since light energy and wavelength are related, analyzers can employ light from different parts of the spectrum for monitoring. The proper spectral region is selected by using the equations below.

Given that:

E = energy
h = Planck's constant
c = speed of light (constant)
υ = frequency
λ = wavelength

we can then determine the relationship of light to wavelength.

Since

(Eq. 3-1) $$E = (h)(\upsilon)$$

and

(Eq. 3-2) $$c = (\lambda)(\upsilon),$$

then

(Eq. 3-3) $$E = (h)(c)/\lambda$$

This derivation shows that light energy is inversely proportional to its wavelength.

Light is absorbed by a substance only when the energy of the light corresponds to the amount of energy needed to cause a change within the chemical species. Consequently, light of certain wavelengths is absorbed while light of other wavelengths is not. This behavior enables analyzers to be designed for operation in different areas of the spectrum (IR, visible, or UV), thus incorporating a degree of selectivity for gases into each device.

When a certain gas absorbs some amount of the energy from a light beam, the intensity of that beam will decrease. As more light energy is absorbed, the intensity of the light will accordingly decrease from its original value. This decrease in intensity can then be converted to the concentration of the gas through the following relationships.

Given that:

I_o = intensity of original light beam
I = intensity of attenuated light beam
A = absorbance
a = absorptivity constant
b = path length through absorbing medium
c = concentration of absorbing species

we can then determine the gas concentration.

Since

(Eq. 3-4) $$A = \log (I_o / I)$$

and

(Eq. 3-5) $$A = (a)(b)(c) \quad \text{[Beer's Law]},$$

then

(Eq. 3-6) $$(a)(b)(c) = \log (I_o / I), \text{ and}$$

therefore

(Eq. 3-7) $$c = [\log (I_o / I)] / (a)(b)$$

Since all the quantities on the right of the equation are known or can be measured, the gas concentration can be calculated.

Applications

The theories and relationships just presented provide the basis for all spectrophotometric techniques in general use. Of course, the implementation of these schemes will vary from one analytical device to another. Though spectrophotometers may be either dispersive or non-dispersive, nearly all which are used in CEMSs are non-dispersive, as indicated in Lesson 2. These analyzers do not separate light into its component wavelengths; instead, they utilize a broad band of wavelengths which is centered on the absorption peak of the subject gas. Some absorption bands of common gases are given in *Table* 3-1.

Non-dispersive IR spectrophotometers use a filtered band of light from the infrared region of the spectrum. The filtered light passes through a sample cell that contains flue gas extracted from the stack. Another portion of the light passes through a cell which contains a reference gas that does not absorb any of the filtered light. The beams from each cell enter the detector where the difference in intensity is measured.

TABLE 3-1
INFRARED BAND CENTERS OF SOME COMMON GASES

Gas	Location of Band Centers (μm)	Wave Number (cm^{-1})
NO	5.0-5.5	1800-2000
NO_2	5.5-20	500-1800
SO_2	8-14	700-1250
H_2O	3.1 5.0-5.5 7.1-10	1000-1400 1800-2000 3200
CO	2.3 4.6	2200 4300
CO_2	2.7 5.2 8-12	850-1250 1900 3700
NH_3	10.5	950

Typically, microphone detectors are used in these analyzers. They are gas-filled cells with two compartments that are separated by a flexible metal diaphragm. The cells contain the same gas that is being measured. As the IR light passes through the sample cell and the reference cell, the molecules in the detector are heated. Because of the absorption of some of the IR energy in the sample cell, the intensity of the beams is different. Consequently, the gas in the detector cells will be heated to different temperatures which will cause the diaphragm to flex due to the higher pressure in the warmer cell. This produces a signal which is in turn converted to gas concentration. This process is illustrated in *Figure* 3-1.

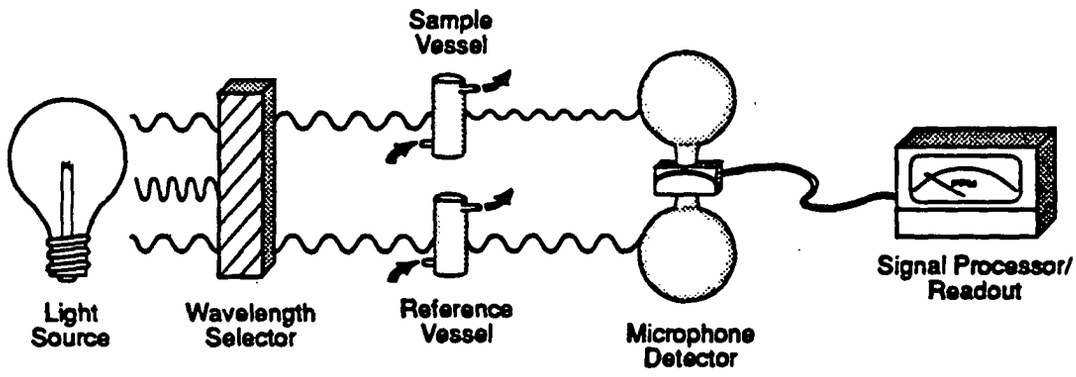

FIGURE 3-1 NDIR ANALYZER WITH MICROPHONE DETECTOR

Gas filter correlation (GFC) analyzers measure the degree of similarity between the absorption of light by a gas of known concentration and the absorption of light by a sample gas. In GFC systems, light emitted from the lamp passes through the sample gas and then into a receiving unit. In this unit, the beam (which is usually split) is sent to two, parallel cells called the gas filter cell and the neutral density filter cell. The gas filter cell contains a high concentration of the gas being analyzed, and therefore removes nearly all of the energy of the predetermined

wavelength. What remains of the beam (i.e., the wavelengths not absorbed in the gas filter cell) passes to the detector. The light which passes through the neutral density filter cell also goes to the detector where its energy is measured and compared to that of the other beam. The difference in energy of these two beams can then be related to the concentration of the gas of interest. This process is illustrated in *Figure* 3-2.

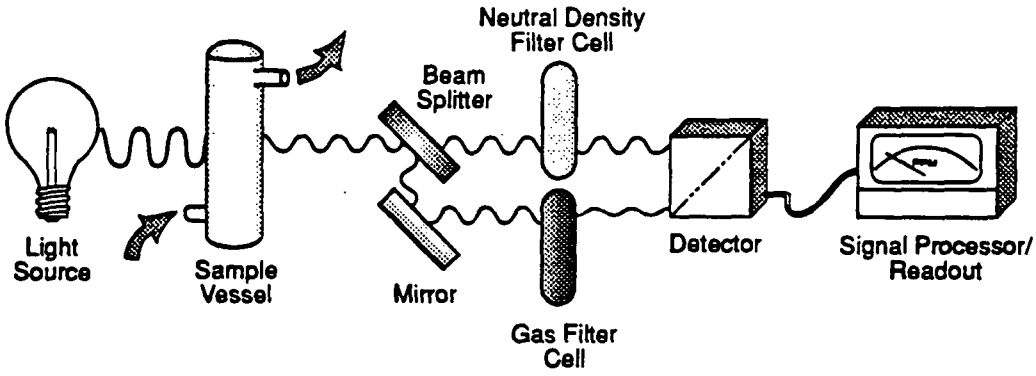

FIGURE 3-2 GFC ANALYZER

Other gases do not usually cause interference since they absorb the reference and measurement beams equally. Therefore, the system responds only to the gas of interest and provides higher sensitivity when compared to some other instruments.

Differential absorption spectrophotometers employ a measuring wavelength and a reference wavelength. The measuring wavelength corresponds to a region of the spectrum where the gaseous molecules of interest absorb light energy, whereas the reference wavelength corresponds to a region of the spectrum in which the gaseous molecules of interest absorb little or no light energy. A beam of UV radiation passes through the sample cell and goes to a diffraction grating. One beam is directed to the sample photomultiplier tube while the other is sent to the reference photomultiplier tube. The concentration of the identified gas is determined by finding the difference in energy for the measuring wavelength and the reference wavelength. The detected difference is then processed and sent to the readout instrument as a concentration. A representation of this process is given in *Figure* 3-3.

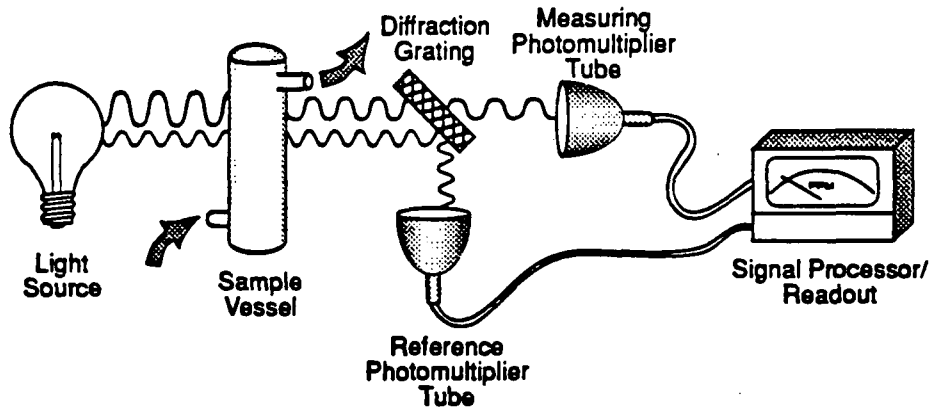

FIGURE 3-3 DIFFERENTIAL ABSORPTION ANALYZER

Second derivative spectroscopic analyzers rely on two devices not found in ordinary spectrophotometers. The first, a diffraction grating, is used to narrow the region of light wavelengths which is initially emitted from the light source. More specifically, the diffraction grating separates the wavelengths associated with the target gas. The second device, a scanner (or moving slit), moves back and forth across the central wavelength that corresponds to the maximum absorption peak of the subject gas. The result of this process is a gradual decrease to a minimum transmittance value followed by a gradual increase to its maximum value and is seen as a sinusoidal wave. The resulting signal varies at twice the frequency of the scanner. The signal's amplitude is directly related to the concentration of the target gas. A diagram of this scanning process is provided in *Figure* 3-4.

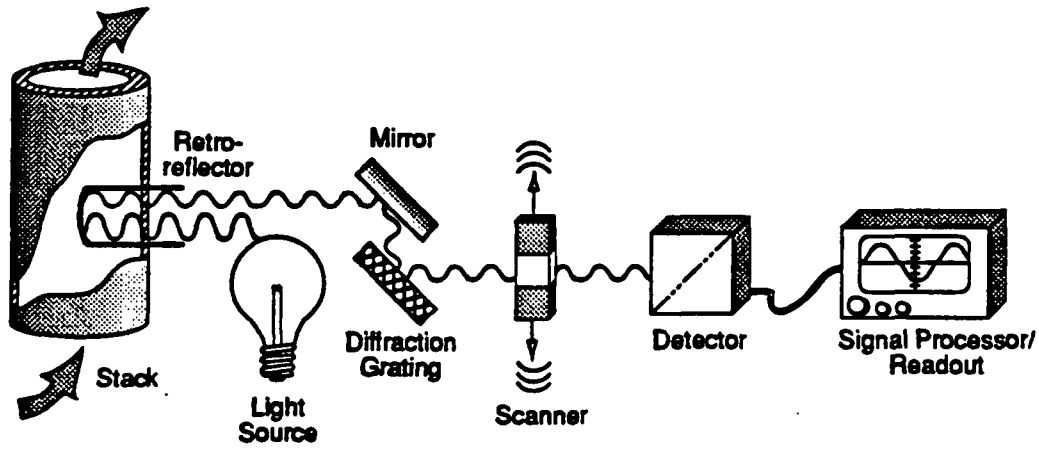

FIGURE 3-4 SECOND DERIVATIVE SPECTROSCOPIC ANALYZER

Luminescence

Theory and Derivation

CEMSs which use luminescence analyzers rely on light emissions from excited molecules. In this process, energy converts the absorbing atom, molecule, or ion (M) to a more excited form (M*). Excitation refers to the temporary placement of electrons into higher energy levels (orbitals) and can be represented by the following equation:

(Eq. 3-8) $$M + (h)(\upsilon) \longrightarrow M^*$$

Please recall that the product of h (Planck's constant) and nu (frequency) is defined as the energy of a particular wavelength of light.

As the electrons return to their normal levels, excitation energy in the form of light is emitted. The release of this energy is basically the reverse of the prior process and is represented by this equation:

(Eq. 3-9) $$M^* \longrightarrow M + (h)(\upsilon)$$

The difference in the second equation is that the light emitted will have a different frequency and wavelength than that of the absorbed beam. Measuring the energy of the emitted beam can be used to calculate the gas concentration. The methods described below differ primarily with respect to their means of excitation rather than their means of measurement.

Applications

<u>UV fluorescence analyzers</u> are primarily used to measure SO_2 present in exhaust gas streams. SO_2 molecules are excited to SO_2* by using UV light of wavelength 210 nanometers (nm). Excitation is the result of an atom's absorption of this beam of electromagnetic radiation and is written as:

(Eq. 3-10) $$SO_2 + (h)(\upsilon) \longrightarrow SO_2^*$$

The excited molecular state persists for only a few nanoseconds during which time some of the energy is lost through vibrational transitions of the electrons. As the molecule returns to its relaxed state, light of a longer wavelength, 350 nm, is released.

(Eq. 3-11) $$SO_2^* \longrightarrow SO_2 + (h)(\upsilon')$$

The released light can be detected by the instrumentation within the monitor. Its intensity is then related to gas concentration.

<u>Chemiluminescence analyzers</u> are primarily used to measure NO and NO_2 concentrations. In this application of chemiluminescence, excited molecules, NO_2*, are produced by reacting ozone with the NO present in the exhaust stream.

(Eq. 3-12) $$NO + O_3 \longrightarrow NO_2^* + O_2$$

The excited product, NO_2^*, returns to its ground state with the release of light energy whose wavelength is in the range of 600 to 900 nm. The emitted light is measured with a photomultiplier tube and is related to the concentrations of NO.

(Eq. 3-13) $$NO_2^* \longrightarrow NO_2 + (h)(\upsilon)$$

In the case of measuring NO_2, the NO_2 is heated in the presence of a catalyst and converted to NO. The equation is as follows:

(Eq. 3-14) $$NO_2 \xrightarrow[\text{cat.}]{\text{heat}} NO + 1/2\, O_2$$

Upon conversion of the NO_2 to NO, the analysis proceeds as described for NO measurement and the concentration is reported as total NO_x (i.e., both NO and NO_2).

Flame photometry analyzers excite a subject gas sample by introduction into a hydrogen flame. This method is primarily used to analyze gas streams which contain sulfur and sulfur compounds. The sulfur compounds are "burned" in a hydrogen flame which results in the formation of excited sulfur atoms. The conversion of the high energy molecules to the lower energy ground state occurs with the emission of light. The following equation illustrates this process.

(Eq. 3-15) $$S_2^* \longrightarrow S_2 + (h)(\upsilon)$$

The intensity of this light is amplified by a photomultiplier tube and is related to the concentration of sulfur species in the sample. The flame photometric method does not discriminate between sulfur-containing compounds, so reported concentrations will be for total sulfur content.

Electroanalysis

Theory and Derivation

CEMSs that employ electroanalytical equipment for measuring flue gas components use basic electrochemistry to determine the amounts of the target gases. Typical electrochemical cells contain electrodes which have been selected for the specific gas in mind. As the chemical reaction within the cell proceeds, substances will either gain electrons or lose electrons. The electrons migrate through the medium and create an electrical current between the electrodes. As a consequence of the reaction, the chemical potential across the electrodes will be different; this difference is termed electromotive force (EMF) or voltage. These measurable quantities (current and voltage) can be related to the concentration of the subject gas.

Applications

Polarographic analyzers (also called voltametric analyzers or electrochemical transducers) contain an electrochemical cell where the subject gas is involved in a chemical reaction. In the first part of the process, the subject gas diffuses through a selective, semi-permeable membrane. In the second part, the gas will participate in a reaction within the cell during which time a flow of electrons will be generated and detected by the sensing electrode. For SO_2, the oxidation reaction will proceed as follows:

(Eq. 3-16) $SO_2 + 2H_2O \longrightarrow SO_4^{2-} + 4H^+ + 2e^-$

This reaction generates two moles of electrons for every one mole of SO_2 that reacts.

If the rate of this process is controlled by the rate of diffusion, then the current is proportional to the concentration of the subject gas. The following equation, known as Fick's Law, shows this relationship:

(Eq. 3-17) $i = (n)(F)(A)(D)(c) / \delta = (k)(c)$

when

- i = current
- n = # of electrons exchanged per mole of gas
- F = Faraday's constant
- A = exposed electrode surface area
- D = diffusion coefficient (constant)
- c = concentration of gas
- δ = thickness of diffusion layer
- k = proportionality constant

Since i, A, and δ are measurable and n, F, and D are known, the equation can be solved for the gas concentration.

Electrocatalytic analyzers use the principle that solutions of two concentrations will proceed to equilibrium upon coming in contact with each other. The two sections of an electrocatalytic cell have different concentrations of the subject gas which also means that the chemical potential of those sections is different. This difference in potential across the electrode can be measured as EMF or voltage. The Nernst equation gives the relationship of voltage to concentration as:

(Eq. 3-18) $EMF = [(R)(T) / (4)(F)] \; [\ln (c_1 / c_2)]$

when

- EMF = electromotive force (voltage)
- R = gas constant
- T = absolute temperature
- F = Faraday's constant
- c_1 = concentration of gas in section 1 (stack)
- c_2 = concentration of gas in section 2 (known)

As the system attempts to reach an equilibrium concentration of gas in both sections, a measurable flow of electrons is generated. The current can then be related to the concentration of the target gas in the sample.

Paramagnetism

Theory and Derivations

CEMSs which use paramagnetic analyzers employ the principle that molecules behave differently when placed in magnetic fields. The behavior is classified as either diamagnetic or paramagnetic. Most molecules are diamagnetic and are repelled when placed in a magnetic field. A few molecules possess paramagnetic properties and are attracted by the magnetic field. Though most molecules have paired electrons (i.e., the same number of electrons spinning clockwise as there are spinning counterclockwise), some molecules have one or more electrons spinning in the same direction. This characteristic gives rise to paramagnetic behavior as is the case with oxygen. Specifically, oxygen has two unpaired electrons that cause O_2 molecules to be attracted to and interact with a magnetic field. Paramagnetic analyzers are primarily used to measure the concentration of O_2 molecules based on their interaction with the magnetic field.

The only other molecules typically found in flue gas which exhibit a significant amount of paramagnetic behavior are NO and NO_2. If the concentration of NO_x is sufficiently high, some interference in the measurement of O_2 may occur.

Applications

Thermomagnetic monitors measure oxygen by the following procedures. A magnet is used to channel the flow of oxygen through a designated tube. A higher concentration of O_2 in the gas will result in a higher velocity of gas through the tube. As illustrated in *Figure* 3-5, the flow of O_2 gas past a resistor will cause the resistor to cool. Because a constant voltage is maintained across the resistor, a decrease in resistance due to cooling will be compensated by an increase in current. This relationship is described below. The current can then be related to oxygen concentration.

(*Eq. 3-19*) $$V = (i)(R)$$

when

V = voltage
i = current
R = resistance

Magnetodynamic analyzers use a torsion pendulum to measure disturbances in a magnetic field. In these analyzers, a dumbbell-shaped, platinum ribbon is suspended in a magnetic field. Since platinum is diamagnetic, it is slightly repelled. When a sample that contains O_2 is introduced, it causes the magnetic field to become reoriented. This process, shown in *Figure* 3-6, causes the dumbbell to turn and realign itself within the new field. As the dumbbell repositions, light hitting a small reflector on the pendulum will indicate the degree of the turn. The degree of the turn is used to calculate the concentration of O_2 in the sample.

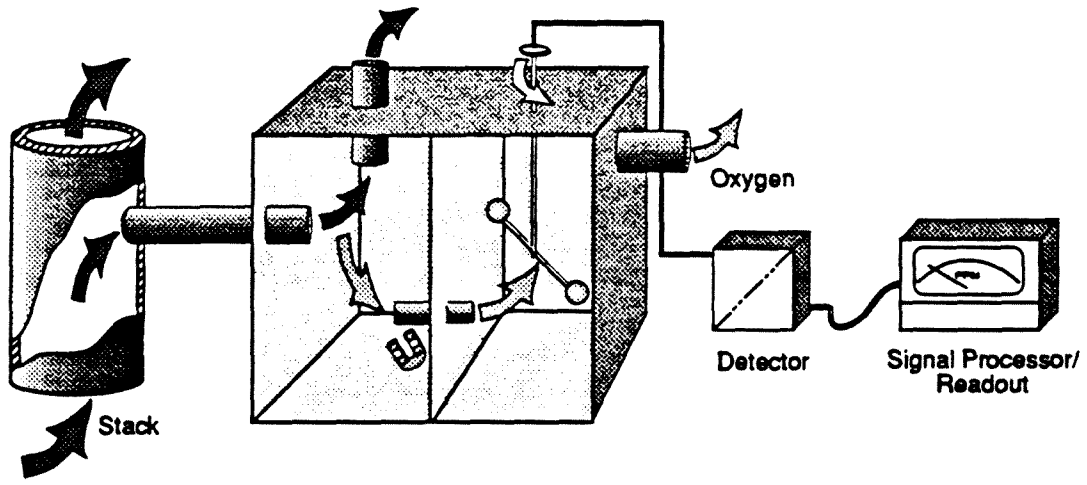

FIGURE 3-6 MAGNETODYNAMIC ANALYZER

Paramagnetic pressure (magnetopneumatic) analyzers measure the pressure imbalance which results from the migration of O_2 molecules in an uneven magnetic field. As the O_2 enters the magnetic field, it will be drawn to the stronger side of the field and cause a pressure rise. This increase in pressure can be represented by the following equation:

(Eq. 3-20) $$\delta P = 1/2\,(H)^2\,(X)\,(C)$$

where

H = strength of magnetic field
X = magnetic susceptibility of O_2, and
C = concentration of O_2

The resulting movement is measured by a device which is very sensitive to this change and is then related to the concentration of O_2 in the sample.

Summary

Lesson 3 provided specific information about the four detection methods (spectroscopic absorption, luminescence, electrocatalysis, and paramagnetism) used to measure gaseous emissions. The theories, derivations, and applications of each principle were presented in order to provide you with a sound understanding of the analytical basis of each type of instrument.

Spectroscopic analyzers (spectrophotometers) rely on the interaction of light energy with gaseous molecules in order to determine the gas concentration. Since light energy and wavelength are related, analyzers can employ light from different parts of the spectrum for monitoring. The selection of the proper spectral region is dependent upon the amount of energy absorbed by the gas.

Luminescence analyzers rely on light emissions from excited molecules for monitoring purposes. In this process, light energy converts the absorbing atom, molecule, or ion (M) to a more excited form (M*). Excitation refers to the temporary placement of electrons into higher energy levels (orbitals) than the ground state of that particular atom. As the electrons return to their normal levels, excitation energy, in the form of light, is emitted.

Electroanalytical equipment is also used for measuring the amount of a target gas. Typical electrochemical cells contain electrodes which have been selected for the specific gas in mind. As the chemical reaction within the cell proceeds, substances will either gain electrons or lose electrons. The electrons migrate through the medium and create an electrical current between the electrodes. As a consequence of the reaction, the chemical potential across the electrodes will be different; this difference is termed voltage. These measurable quantities (current and voltage) can be related to the concentration of the subject gas.

Paramagnetic analyzers are based on the fact that molecules behave differently when placed in magnetic fields. The behavior is classified as either diamagnetic or paramagnetic. Most molecules are diamagnetic and are repelled when placed in a magnetic field. A few molecules possess paramagnetic properties and will be attracted by the magnetic field. Though most molecules have paired electrons (i.e. the same number of electrons spinning clockwise as there are spinning counterclockwise), some molecules have one or more electrons spinning in the same direction. This characteristic gives rise to paramagnetic behavior as is the case with oxygen. Specifically, oxygen has two unpaired electrons that cause O_2 molecules to be attracted to and interact with a magnetic field. Measurement of these interactions can be related to O_2 concentration.

REVIEW EXERCISES	
1. In spectroscopic absorption, the amount oflight energy absorbed by a subject gas corresponds to a. the amount of light given off by that same gas. b. the value of Planck's constant. c. the amount of energy required to cause a change in the gas. d. its luminescence.	
2. As a gas absorbs some light energy, the intensity of the light beam will _____ from its original value. a. increase b. decrease c. not change	1. c
3. Nearly all spectrophotometers used in CEMSs are ____ and use a broad band of wavelengths that are centered on the ___ of the target gas molecules. a. dispersive ... reference b. dispersive ... absorption peak c. non-dispersive ... luminescence d. non-dispersive ... absorption peak	2. b
4. The purpose of a gas filter cell is a. to remove all the sample gas from the stack. b. to separate the target gas from interfering gases. c. to absorb from a light beam the spectral absorption wavelengths of the gas. d. to filter gas before going to the reference cell.	3. d
5. The scanning done in a second derivative spectroscopic analyzer results in a. a fluctuation in the transmittance value received at the detector. b. an emission of light from excited molecules. c. a longer wavelength of light. d. a diffraction detector.	4. c

6. Flame photometric analyzers employ a _____ flame for the excitation of gas molecules. a. hydrogen b. luminescent c. natural gas	5. a
7. Flame photometry can be used to measure a. H_2S b. H_2S_5. c. both of the above. d. none of the above.	6. a
8. Electroanalysis is able to relate gas concentration to a. current and capacitance. b. voltage and current. c. resistance and capacitance. d. Faraday's constant and Planck's constant.	7. c
9. Some molecules, especially O_2, termed _____ since they are attracted by magnetic fields. a. diamagnetic b. magnetic c. paramagnetic d. interactive	8. b
10. The torsion pendulum in magnetodynamic analyzers ____ as the concentration of O_2 in the sample changes. a. cools b. turns c. glows d. heats	9. c
	10. b

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UNIT 2

OPERATION

OF

COMMERICALLY AVAILABLE

GAS MONITORS

LESSON 4

Operation of Two Spectroscopic Absorption Analyzers

Lesson Goal and Objectives

Goal

To explain the operation of both a Bodenseewerk HCl monitor and a Teledyne SO_2 monitor.

Objectives

At the end of this lesson, you should be able to —

1. identify which region of the electromagnetic spectrum is employed by each of the analyzers,
2. describe the development and utility of reference signals for each of the analyzers, and
3. describe the "special features" of each instrument which are intended to improve the accuracy and repeatability of the measurements.

Introduction

In Lessons 2 and 3, four primary analytical techniques used in continuous emissions monitoring systems (CEMSs) were presented. These techniques are: spectroscopic absorption, luminescence, electroanalysis, and paramagnetism. A general overview of detection procedures and calculation methods within the various types of analyzers has already been given. This lesson will more specifically describe the operation of two commercially available CEMSs which are based on spectroscopic analysis.

Spectroscopic Absorption Analyzers

CEMSs which use spectrophotometers rely on the interaction of light energy with gaseous molecules in order to determine the gas concentration. Since light energy and wavelength are related, analyzers can employ light from

different parts of the spectrum for monitoring. When a certain gas absorbs some amount of the energy from a light beam, the intensity of that beam will decrease. This decrease in intensity can then be related to the concentration of the gas.

As discussed in previous lessons, there are a number of variations in the application of spectroscopy to the analysis of flue gases. Monitors which use two of those techniques, gas filter correlation and differential absorption, will be described in this lesson.

Gas Filter Correlation (GFC) Analyzer

Bodenseewerk Geosystem GmbH of West Germany has developed the Model 677 IR HCl Emissions Monitoring System for the measurement of hydrogen chloride gas (HCl). (KVB, Inc. is the distributor in the U.S. for this monitoring system.) This system employs the GFC technique to obtain accurate and repeatable measurements of HCl gas emissions from sources such as waste incinerators. A view of this monitoring system is shown in *Figure* 4-1.

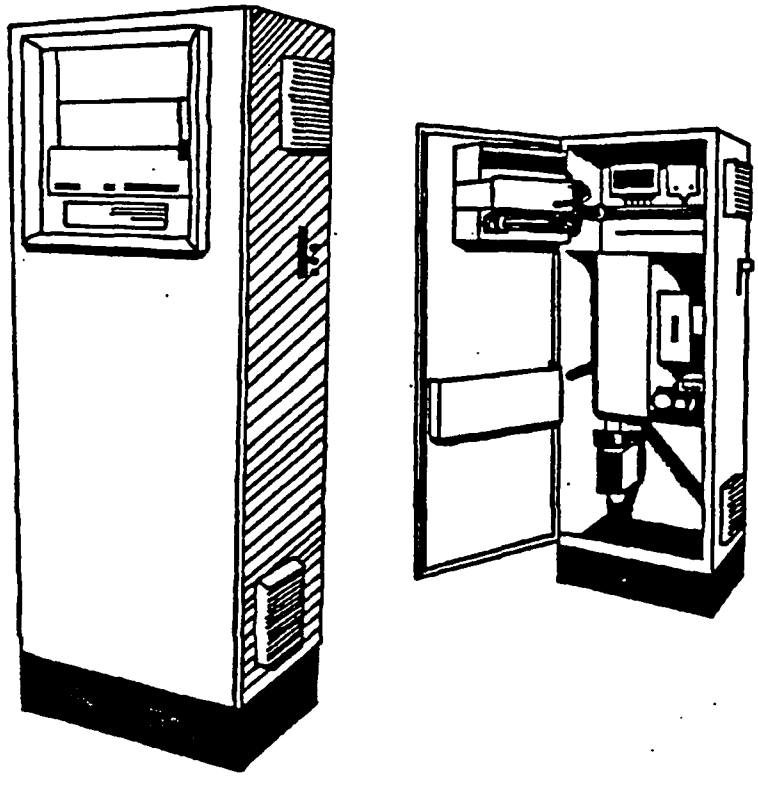

FIGURE 4-1 BODENSEEWERK MODEL 677 HCL MONITOR

The handling and conditioning of sample gases is of great importance in all CEMSs, especially those which monitor HCl. The potential for measurement errors due to reaction of the HCl with other components could threaten the reliability of the data from HCl analyzers. The Bodenseewerk Model 677 uses an extractive sampling system which is designed to eliminate errors caused by HCl reaction. *Figure* 4-2 is a diagram of the sampling system of the Model 677.

Flue gas is extracted from the stack through a coarse, sintered stainless steel filter which has a typical porosity of 50 microns. The filter assembly is held in the stack by a 1/2" pipe that is connected to a 150 pound mounting flange.

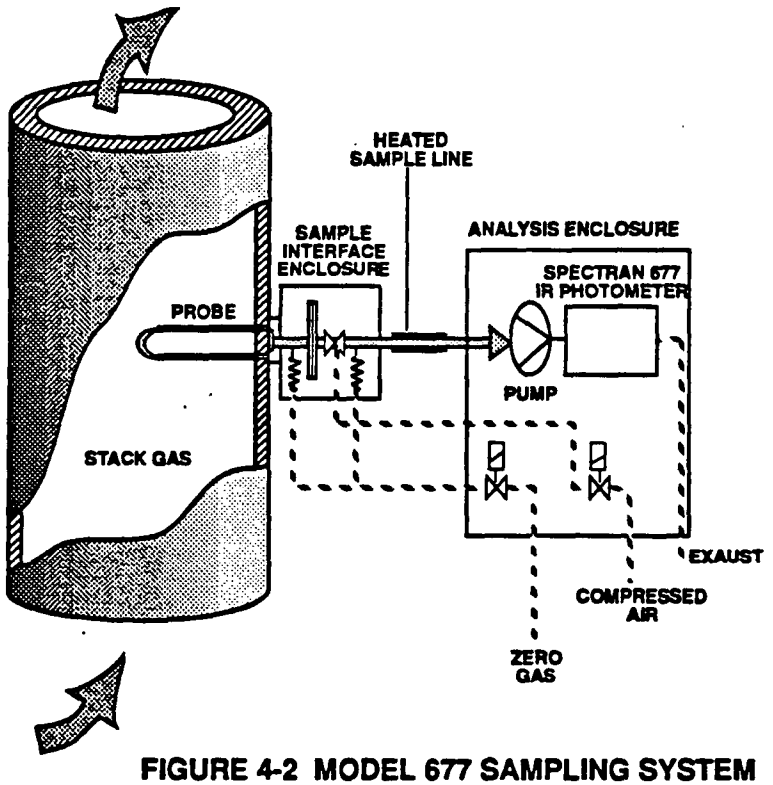

FIGURE 4-2 MODEL 677 SAMPLING SYSTEM

A heated sample interface enclosure is attached to the other side of the mounting flange. Within the enclosure is a secondary fine filter with a porosity of 5 microns which is to keep smaller particulate matter from migrating into the system. Air, at approximately 80-100 psig, is piped through this enclosure and is used to backpurge the filters in order to alleviate blockage. If particulate matter were allowed to accumulate on the filters, the entering HCl could react with these deposits and cause the measurement errors already mentioned.

Because it has been shown that HCl absorbs on sampling component surfaces of temperatures less than 185°C (which not only results in measurement errors but also in metal degradation), the sample interface enclosure on the Bodenseewerk's Model 677 is constantly maintained at 185°C. Since this temperature is above the sample's dewpoint, HCl losses which could occur by its reaction with the surface areas of the sample system are consequently eliminated.

Next, the sample gas exits the interface enclosure and is transported to the analysis section via a heated Teflon™ sample line which terminates at the inlet of a heated sample pump. This diaphragm pump, specially designed on the Bodenseewerk's Model 677 for use at 185°C, maintains a sample flow rate of approximately 10 liters per minute. A heated flowmeter, which measures the flow of gas from the outlet of the sample pump, is

equipped with an optical sensor that triggers an alarm if the sample flow rate falls below a predetermined limit. It also automatically places the system in stand-by mode by shutting off the sample gas flow and purging the system with ultra-pure, "zero" air.

Sample gas exits the flowmeter and enters the heated sample cell which uses infrared (IR) light to determine the concentration of HCl in the sample gas. The sample cell, like the rest of the sampling system, is heated to 185°C. Its interior is coated to resist corrosion and to alleviate the possibility of HCl reaction with the walls. After analysis, and upon exiting the cell, the sample gas exhaust is allowed to cool to ambient temperature; the water vapor, which is no longer above its dewpoint, will then condense and be removed by the condensate trap.

The gas filter correlation technique, as implemented by the Bodenseewerk Model 677 HCl monitor, is schematically represented in *Figure* 4-3.

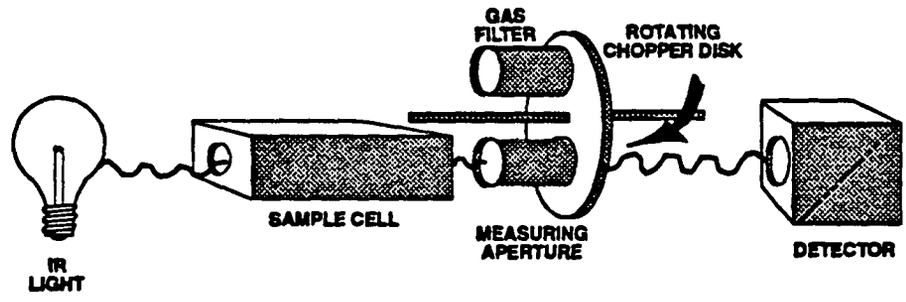

FIGURE 4-3 GFC INSTRUMENTATION FOR BODENSEEWERK MODEL 677 MONITOR

An energy source emits a broad band of infrared light that passes through the sample cell which contains a continuous flow of sample gas. The intensity of the IR light is reduced in the sample cell at the wavelengths absorbed by the HCl molecules. The greater the concentration of HCl in the sample cell, the greater the absorption.

The IR light that exits the sample cell is mechanically chopped by a rotating disk containing two apertures. One of these apertures is actually the gas filter cell which is filled with a high concentration of HCl. When the gas filter cell comes in line with the light beam, the energy corresponding to the wavelengths absorbed by the HCl molecules is removed from the beam; the energy of the remaining light going to the detector is independent of the HCl concentration and is used as a reference signal.

The second aperture in the rotating disk is the measuring cell. This cell contains an inert gas, typically nitrogen, which does not further reduce the energy of the IR beam. The beam passing through the measuring cell will only have been attenuated while in the sample cell. The IR absorbance of HCl is measured by calculating the log of the ratio of the signals from the filter cell and the measuring cell. Please recall the appropriate discussion in Lesson 3 for further details about this process.

Though the Bodenseewerk Model 677 employs the gas filter correlation (GFC) technique, there are a number of marketed CEMSs which use other spectroscopic methods for monitoring purposes. Among these other

techniques is differential absorption spectroscopy. A commercially available SO_2 monitor that uses this method is discussed in the following section.

Differential Absorption Analyzer

Teledyne Analytical Instruments has developed the Model 691 for the continuous monitoring of SO_2 from stacks, especially combustion sources. It uses ultraviolet (UV) light for the differential absorption method of analysis. *Figure* 4-4 presents an internal view of the Model 691 monitoring system.

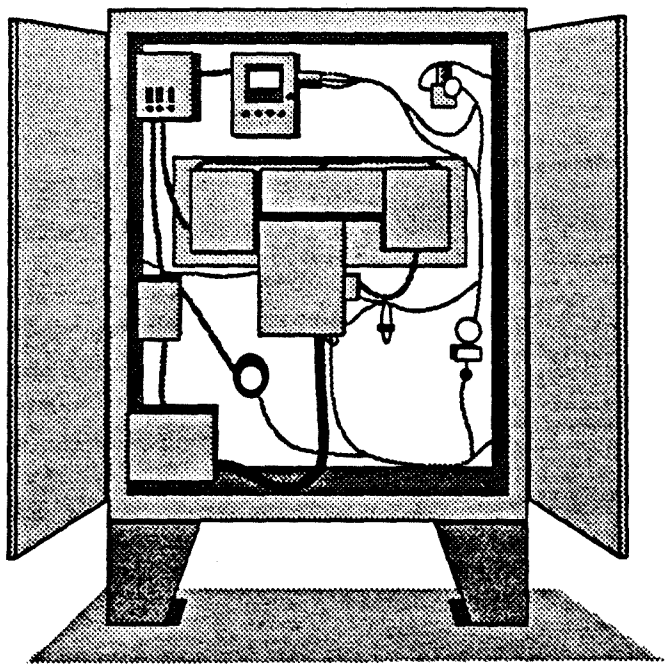

FIGURE 4-4 INTERNAL VIEW OF TELEDYNE MODEL 691 SO_2 MONITOR

The Model 691 is a fully integrated system which provides extractive sample handling and conditioning. The sample is drawn from the stack through a specially designed filter probe which removes entrained particulate matter. From the probe, the sample gas passes to the sample handling and conditioning system that effectively controls the temperature and pressure of the sample gas to prevent water condensation and SO_2 loss before and during analysis. This system also includes a manual selector valve for the introduction of a span gas used for calibration.

On Teledyne's Model 691, the electronic zero mode (i.e., the time during which the analyzer's zero concentration output is reset in order to provide "drift-free" readings) is automatically repeated once each hour to provide long-term stability of the system. A three-way solenoid valve controls the flow of sample gas and zero

air while in the zero mode. During the zero mode, zero air (ultra-pure grade air) is fed to the "common" port of the valve. When the system introduces zero air, the output from the analyzer is automatically adjusted to zero. Also during the zero mode, the zero gas flows back through the probe, providing a backflush to clear away blockage due to particulates collecting on the filter. When the zero mode is completed, the valve closes and zero air is replaced by the sample gas in the cell.

Using the differential absorption method of analysis, the Teledyne Model 691 employs two filters to select the specific wavelengths to be monitored. The measuring wavelength, 289 nanometers, corresponds to the absorption peak of SO_2 molecules while the reference wavelength corresponds to a region of the spectrum where little or no light energy is absorbed by SO_2 or other interfering gas molecules.

Since the output of the analyzer is a ratio of the absorbances at the measuring and reference wavelengths, extraneous interferences (which reduce the signals from both wavelengths equally) are effectively cancelled and, thus, do not affect the accuracy of the SO_2 analysis.

Summary

Different systems have been developed which use spectroscopic analysis. The CEMSs examined in this lesson are summarized in the following paragraphs.

The Bodenseewerk Model 677 IR HCl Emissions Monitoring System uses infrared light for the measurement of hydrogen chloride gas (HCl). This system uses an extractive design and the gas filter correlation (GFC) technique which allow for the development of a reference signal that is independent of HCl concentration to obtain accurate measurements of HCl gas emissions from sources such as waste incinerators. This system has also incorporated some features which are important for HCl monitoring. In order to minimize HCl losses, the entire sampling system is maintained at a temperature which is above the dew point of HCl. A special backpurge technique is incorporated to eliminate particulate build-up on the filters which could adversely affect the HCl measurements.

The Teledyne Analytical Instruments Model 691 SO_2 Analyzer System uses ultraviolet light for the continuous monitoring of SO_2 from stacks, especially combustion sources. The reference wavelength used in this device provides a reference signal that is independent of SO_2 concentration. The Model 691 extractive system possesses several features which make accurate analyses possible. The temperature and pressure of the sampling system are effectively controlled in order to prevent water condensation and SO_2 loss during analysis. Also, an electronic zero mode is automatically repeated once each hour to provide long-term stability of the system.

REVIEW EXERCISES	
1. What type of sampling train does the Bodenseewerk Model 677 utilize? a. Extractive. b. In-situ	
2. High pressure air is forced through the Bodenseewerk Model 677 secondary filter assembly in order to a. force more HCl sample thru the analyzer. b. compress the sample, so there will be less to measure. c. purge the filters, alleviating blockage. d. keep the system from decompressing.	1. a
3. The diaphragm pump maintains a sample flow rate of about ____. a. 10 gal/day b. 1 gal/day c. 10 liters/min d. 100 liters/min	2. c
4. The Model 677 sample cell uses _____ to deter mine HCl concentration. a. IR light b. UV light c. an orifice meter d. a dry gas meter	3. c
5. The absorption of IR light increases at _____ concentrations of HCl. a. lower b. higher	4. a
6. Teledyne Analytical Instruments Model 691 uses ____ to monitor _____. a. IR light, NO_2 b. UV light, NO_2 c. IR light, SO_2 d. UV light, SO_2	5. b

7. The Teledyne Analytic Instruments Model 691 is a a. gas filter correlation analyzer. b. differential absorption analyzer.	6. d
8. The Model 691 employs _____ filters to select the specific wavelengths to be monitored. a. 1 b. 2 c. 3 d. 4	7. b
9. Heat tracing in the TAI Model 691's sampling system prevents _____ and _____ during analysis. a. SO_2 loss, energy waste b. cracking, HCl loss c. corrosion, HCl loss d. water condensation, SO_2 loss	8. b
10. Model 677 and Model 691 both use _____ to determine the concentration of _____. a. spectrophotometers, gaseous molecules b. spectrophotmeters, SO_2 c. light energy, HCl d. light energy, NO_2	9. d
	10. a

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1. Kilkelly Environmental Associates. 1988. *Continuous Emission Monitoring Guidelines: Update. Electric Power Research Institute, Inc.* Palo Alto, CA. Report CS-5998.

2. KVB, Inc. 1988. *Hydrogen Chloride (HCl) Emissions Monitor (Advertising Brochure).* HCl PP 1/9/88. KVB, Inc., 9342 Jeronimo, Suite 101, Irvine, CA 92718 or P.O. Box 19518, Irvine, CA 92713.

3. Skoog, D. A. and West, D. M. 1982. *Fundamentals of Analytical Chemistry.* Saunders College Publishing, Philadelphia, PA.

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LESSON 5

Operation of a Chemiluminescence Analyzer

Lesson Goal and Objectives

Goal

To explain the operation of a Horiba Ammonia (NH_3) monitoring system.

Objectives

At the end of this lesson, you should be able to —

1. describe the sample probe used for NH_3 monitoring,
2. explain the significance of NO to this particular technique,
3. explain the use of a pressure trap, and
4. identify the special features of this series of instruments.

Introduction

Lessons 2 and 3 provided a general overview of the detection procedures and calculation methods used for gas analysis in continuous emissions monitoring systems (CEMSs). Lesson 4 gave more specific information about the operation of marketed CEMSs which use spectroscopic absorption as their basis of gas analysis. Similarly, this lesson will give more detailed information about the operation of a commercially available monitoring system that is based on the principle of luminescence.

Luminescence Analyzers

CEMSs which use luminescence analyzers rely on light emissions from excited molecules for monitoring purposes. In this process, light energy converts the absorbing atom, molecule, or ion (M) to an excited form (M*). Excitation refers to the temporary placement of electrons into energy higher levels (orbitals). As the electrons return to their normal levels, excitation energy in the form of light is emitted. The amount of this energy can then be related to the gas concentration.

Chemiluminescence Analyzers

Horiba Instruments, Incorporated has developed two stack gas analyzer systems for monitoring ammonia (NH_3). The ENHA-C900 Series is comprised of the ENHA-C900 and the ENHA-C901 models. The ENHA-C900 is designed for the continuous monitoring of residual NH_3 in exhaust gas, while the ENHA-C901 also offers the independent measurement of nitrogen oxides (NO_x). These systems use the principle of chemiluminescence detection for gas analysis. *Figure* 5-1 gives an internal view of this series of monitors.

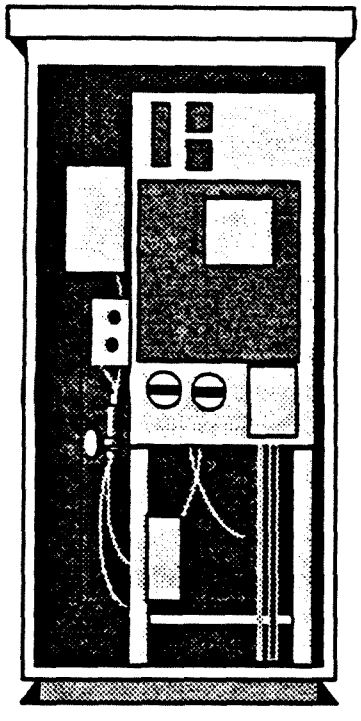

FIGURE 5-1 INTERNAL VIEW OF ENHA-C6900 SERIES NH_3 MONITOR FROM HORIBA

The Horiba ENHA-C900 Series monitors use an extractive sampling system to draw flue gas from the stack. The double-tube sample probe, with integral reduction catalyst, is designed for direct insertion into the stack. A diagram of the probe and heated catalyzer section is shown in *Figure* 5-2. An optional blowback system can be added to the probe assembly to prevent blockage caused by dust and particulate matter.

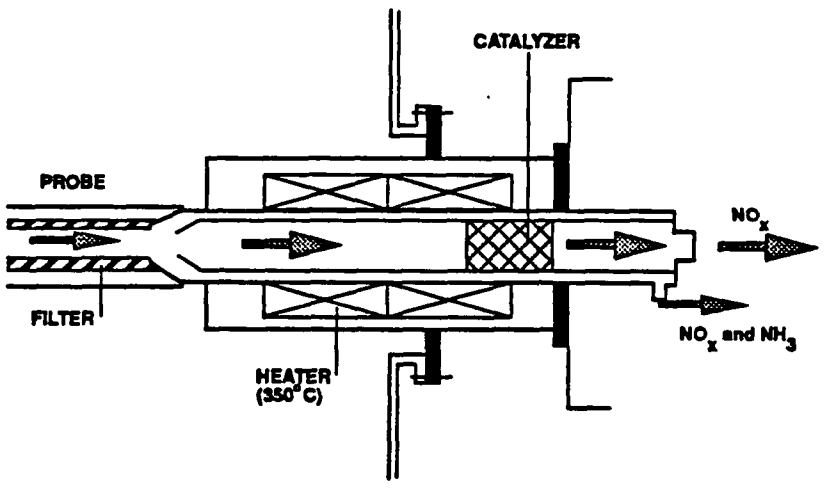

FIGURE 5-2 ENHA-C900 SERIES SAMPLE PROBE

From the probe assembly, the gas travels to the analyzer through sample lines which are maintained at approximately 100 - 120°C in order to prevent moisture condensation. A pressure trap is included to provide stable control of the sample flow from the stack and through the system. The sample gas will pass through a mist catcher that efficiently removes only SO_3, thus minimizing constituent changes in the sample preconditioning unit.

The NH_3 is reduced by the reduction catalyst as the sample gas passes through the inner tube of the probe, and an amount of NO proportional to the volume of NH_3 is consumed as described by the following equation:

(Eq. 5-1) $$NO + NH_3 + 1/4\ O_2 \longrightarrow N_2 + 3/2\ H_2O$$

Meanwhile, the sample gas passing through the outer tube of the probe undergoes no change. These two samples travel through heat-traced lines to an NO_2-to-NO converter. They are then introduced alternately at 1 Hertz (Hz) into the chemiluminescence analyzer by the flow chopper. The analyzer determines the concentration of NO in each sample.

Horiba Instruments notes that the NO content of the sample which passes through the inner tube is reduced due to the aforementioned reduction reaction by an amount proportional to the NH_3 in the sample. The sample in the other line has the original content of NO in the flue gas. Accordingly, the difference between the two values represents the NH_3 content in the gas from the stack. The integral microprocessor calculates the difference.

The techniques just described for the analysis of NH_3 in exhaust gas streams are the same for the ENHA-C900 and the ENHA-C901. However, the ENHA-C901 incorporates twin chemiluminescence analyzers. One

determines the NH_3 content and the other simultaneously and independently determines the NO_x of the flue gas stream by a similar procedure involving the flow chopping of the original sample and a zero gas.

Some of the special features of both models include the automatic calibration system and flow chopping technique which are intended to provide "drift-free" readings. Furthermore, the ammonia monitoring procedures are unaffected by co-existing SO_x, NO_x, or other substances.

Many of the functions are easily selected via the control panel. Power, gas species, range, calibration, and other switches are provided. There is also a digital display and alarm lamps on the face of the panel. *Figure* 5-3 is an illustration of the control panel.

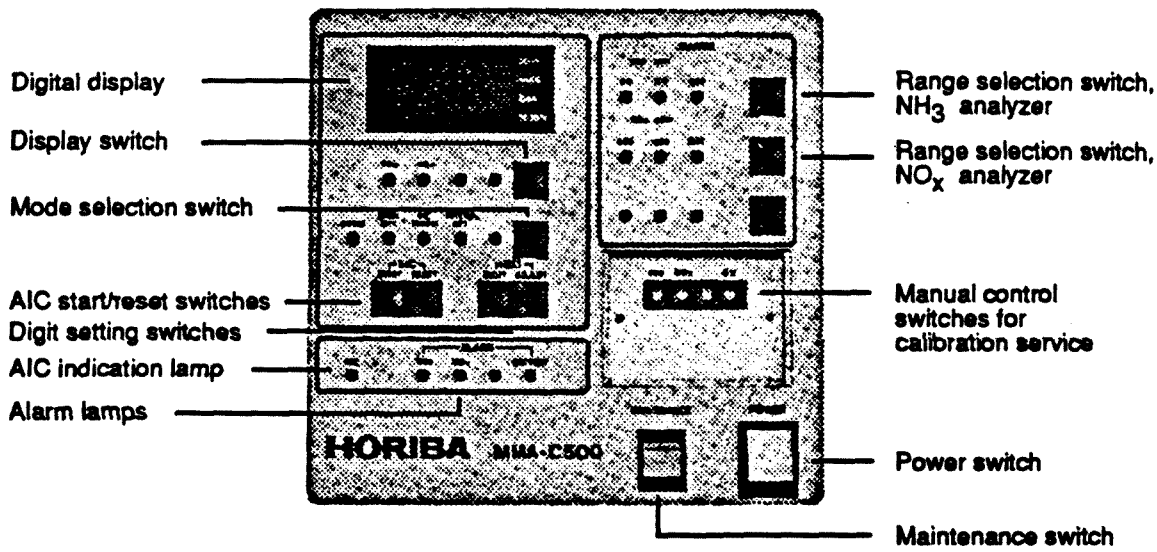

FIGURE 5-3 EHNA-C900 SERIES CONTROL PANEL

Summary

Horiba Instruments, Inc. has developed two stack gas analysis systems for monitoring ammonia (NH_3) via chemiluminescence detection. The ENHA-C900 is designed for the continuous monitoring of residual NH_3 in exhaust gas, while the ENHA-C901 also offers the independent measurement of nitrogen oxides (NO_x). Both systems use an extractive design and a double-tube sample probe, with integral reduction catalyst, for gas analysis.

The NH_3 is reduced by the reduction catalyst as the sample gas passes through the inner tube of the probe, and an amount of NO proportional to the volume of NH_3 is consumed. The sample gas passing through the outer tube of the probe undergoes no change. Since the NO content of the inner tube has been reduced and the NO content of

the outer tube is that of the stack gas, the difference between the two values represents the NH_3 content in the gas from the stack.

The special features include heat-traced sample lines which are used to deliver the sample gas from the probe while preventing moisture condensation. A pressure trap enables a constant sample flow rate to be maintained more easily. Also, an optional blowback system can be added to the probe assembly to prevent blockage caused by dust and particulate matter.

REVIEW EXERCISES	
1. The electrons of excited molecules _____. a. interfere with the monitoring equipment. b. stop moving c. are temporarily moved to lower energy levels d. are temporarily moved to higher energy levels	
2. The ENHA C900 Series' sample lines are heated in order to a. prevent leaks. b. prevent dew formation. c. condense NH_3 vapor. d. condense NO_x vapor	1. d
3. The mist catch efficiently removes a. SO_3. b. NO_2. c. NH_3. d. O_3.	2. b
4. True or false. The sample probe cannot be inserted into the stack due to its double tube construction.	3. a
5. True or false. The optional blowback system prevents blockage caused by NO_x and SO_3.	4. False
6. True or false. The reduction catalyst reduces the NH_3 with NO and O_2.	5. False
7. The ENHA-C901 measures the concentration of a. NO_x only. b. NH_3 only. c. NH_3 and NO_x. d. NH_3 and SO_3.	6. True

8. Luminescence analyzers relate the light energy emitted from excited molecules to the _____. a. gas temperature b. gas concentration c. gas pressure d. gas opacity	7. c
9. True or false. The ammonia monitoring procedures are affected by SO_x and NO_x.	8. b
10. True or false. A constant sample flow rate is maintained more easily due to the pressure trap.	9. False
	10. True

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2. Kilkelly Environmental Associates. 1988. *Continuous Emission Monitoring Guidelines: Update.* Electric Power Research Institute, Inc. Palo Alto, CA. Report CS-5998.

3. Skoog, D. A. and West, D. M. 1982. *Fundamentals of Analytical Chemistry.* Saunders College Publishing, Philadelphia, PA.

4. U.S. Environmental Protection Agency. 1986. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III. Stationary Source Specific Methods.* EPA-600/4-77-027b.

LESSON 6

Operation of an Electrocatalytic Analyzer

Lesson Goal and Objectives

Goal

To explain the operation of an Lear Siegler Measurement Controls Corporation (LSI) oxygen (O_2) monitoring system.

Objectives

At the end of this lesson, you should be able to —

1. describe the LSI sample probe used for O_2 monitoring,
2. explain how the fuel cell sensor measures the concentration of O_2 in the flue gas, and
3. identify the special features of the LSI O_2 monitoring instrument.

Introduction

Lessons 2 and 3 provided a general overview of the detection procedures and calculation methods used for gas analysis in continuous emissions monitoring systems (CEMSs). Lessons 4 and 5 described the operation of analytical systems which use spectroscopic and luminescence techniques. Similarly, this lesson will explain the operation of a commercially available CEMS which is based on the principle of electrocatalysis.

Electroanalyzers

CEMSs that use electroanalytical equipment for measuring flue gas components use basic electrochemistry to determine the concentrations of the target gases. Typical electrochemical cells contain electrodes which have

been selected for the specific gas in mind. As the chemical reaction within the cell proceeds, substances will either gain electrons or lose electrons. The ions migrate through the medium and create an electrical current between the electrodes. As a consequence of the reaction, the chemical potential across the electrodes will be different; this difference is termed electromotive force (EMF) or voltage. These measurable quantities can be related to the concentration of the subject gas.

Electrocatalytic Analyzers

Lear Siegler Measurement Controls Corporation (LSI) has designed and marketed the Dynatron™ 401 Oxygen Monitoring System for the measurement of O_2 in stack gas from sources such as oil-, coal-, and gas-fired boilers, packaged boilers, incinerators, furnaces, dryers, process heaters, kilns, and other industrial combustion efficiency monitoring applications. This system uses the principle of electrocatalysis as the basis for the measurement of O_2 in flue gas. *Figure* 6-1 depicts the basic components of the Dynatron™ 401 Oxygen Monitoring System.

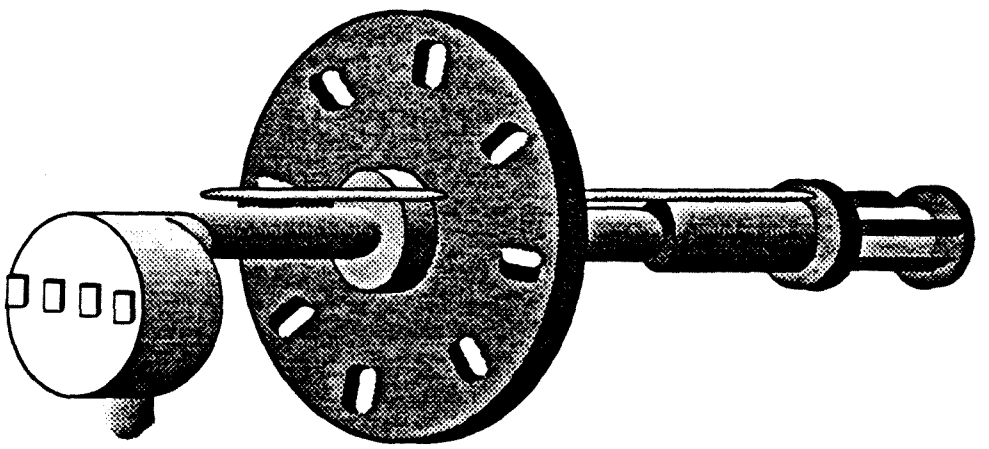

FIGURE 6-1 DYNATRON™401 OXYGEN MONITORING SYSTEM BY LSI

LSI indicates that the in-situ design of the 401 System provides rapid response, analytical accuracy, and low maintenance. This model takes measurements at temperatures which are at or above the dewpoint of the flue gases, so sample conditioning systems and their associated maintenance are not required.

The 2000A sample probe, used in the Dynatron™ 401 System, is available in a variety of lengths and can withstand process temperatures of 760°C or, with the use of a high temperature bypass, up to 1093°C. Parts of the probe can be replaced quickly and easily, thereby making field service possible. *Figure* 6-2 provides a more detailed view of the probe tip.

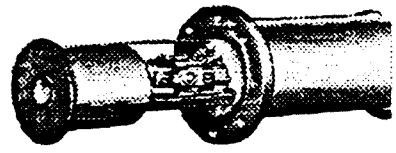

FIGURE 6-2 2000A PROBE WITH ZIRCONIUM OXIDE SENSOR

On LSI's Dynatron™ 401 System, the zirconium oxide cell is located at the probe tip and is encased in a ceramic diffuser. A particulate matter deflector protects the diffuser from erosion and creates a tangential flow across the sides of the diffuser. Two airfoils, positioned at 120° angles to the deflector, divert heavy particulate matter; they also aid in channeling the gas sample to the sheltered downstream side of the diffuser. This gas flow creates a "self-cleaning" effect which helps minimize particulate matter build-up on the sides of the diffuser. LSI can also provide a cell protector when the probe is to be used in especially dirty environments. These special features enable this in-situ system to operate successfully in harsh conditions.

The fuel cell sensor on the Dynatron™ 401 System has porous, platinum electrodes. When the cell is heated above 593°C, it is permeable to oxygen ions and becomes an oxygen ion-conducting solid electrolyte. Reference gas (instrument air) on one side of the cell and sample gas on the other side of the cell create a pressure differential which causes oxygen ions to travel from one side of the cell to the other. The resulting electronic imbalance provides a voltage potential between the electrodes. The voltage is a function of the cell temperature and the partial pressures (concentrations) of oxygen on each side of the cell.

The output voltage from the cell is related to the concentration of oxygen in the sample gas by the following equation called the Nernst equation:

(Eq. 6-1) $$EMF = [(R)(T)/(4)(F)]\,[\ln(c_1/c_2)]$$

where

EMF = electromotive force (voltage)
R = gas constant
T = absolute temperature
F = Faraday's constant
c_1 = concentration of gas in section 1 (stack)
c_2 = concentration of gas in section 2 (known)

The basic control unit, as illustrated in *Figure* 6-3, provides an analog output that can be interfaced with a remote strip chart recorder or process control system. The standard enclosure is a rugged wall mount and can be used in harsh environments. The control unit and enclosure can be modified to include high and low oxygen alarm relays which can inform the operator when oxygen readings go outside of the preset limits. A push-button test

for temperature and an analog meter can also be added. The analog meter provides an indication of percent oxygen on a log-scale. The meter is available with or without adjustable high and low setpoints.

FIGURE 6-3 CONTROL UNIT

The 401 System can be equipped with a manual stack-mounted reference and calibration gas package. The manual package facilitates interconnection to a source of reference and calibration gases. Manual zero and span checks can be initiated at the stack.

Summary

LSI has designed and marketed the Dynatron™ 401 Oxygen Monitoring System for use in a variety of sources. This system uses the principle of electrocatalysis and an in-situ design for monitoring O_2 concentration.

The fuel cell-type sensor in the tip of the probe has porous, platinum electrodes. When the cell is heated above 593°C, it is permeable to oxygen ions and becomes an oxygen ion-conducting solid electrolyte.

Reference gas (instrument air) on one side of the cell and sample gas on the other side of the cell create a pressure differential which causes oxygen ions to travel from one side of the cell to the other. The resulting electronic imbalance provides a voltage potential between the electrodes. The voltage is a function of the cell temperature and the partial pressures (concentrations) of oxygen on each side of the cell. The output voltage from the cell is converted to the concentration of oxygen in the sample gas by using a mathematical relationship called the Nernst equation.

The primary features of the 401 System are:

1. the zirconium oxide sensor encased in a ceramic diffuser,

2. a particulate deflector which protects the diffuser from erosion, and

3. two airfoils which aid in channeling the gas sample to the sheltered downstream side of the diffuser.

REVIEW QUESTIONS	
1. The LSI Dynatron 401 uses the principle of ____ as the basis for the measurement of O_2 concentration. a. opacity b. absorbance c. electrocatalysis d. electrolysis	
2. The 401 system uses an _____ design. a. extractive b. in-situ	1. c
3. True or false. Sample conditioning systems are required with the 401 System.	2. b
4. True or false. The zirconium oxide cell is only utilized in low temperature environments.	3. False
5. True or false. The zirconium oxide cell is encased in a ceramic diffuser	4. False
6. The voltage in the fuel cell sensor is a functionof cell ____ and the _____ of oxygen on each side of the cell. a. pressure ... absorbance b. temperature ... partial pressures c. temperature ... absorbance d. shape ... partial pressures	5. True
7. The fuel cell sensor is permeable to ____ above _____. a. oxygen ions, 120°C b. oxygen ions, 593°C c. oxygen, 120°C d. oxygen, 593°C	6. b

8. The pressure differential in the fuel cell sensor results in a _____. a. high resistance b. low temperature c. zero setting d. voltage potential	7. b
9. The voltage is related to oxygen concentration by the_____ equation. a. Reynolds b. Nernst c. Menton d. Faraday	8. d
10. The _____ protects the diffuser from erosion. a. compact design b. ceramic case c. particulate deflector d. platinum electrode	9. b
	10. c

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1. Kilkelly Environmental Associates. 1988. *Continuous Emission Monitoring Guidelines: Update.* Electric Power Research Institute, Inc. Palo Alto, CA. Report CS-5998.

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3. Skoog, D. A. and West, D. M. 1982. Fundamentals of Analytical Chemistry. Saunders College Publishing, Philadelphia, PA.

4. U. S. Environmental Protection Agency. 1986. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III. Stationary Source Specific Methods.* EPA-600/4-77-027b.

LESSON 7

Operation of General Purpose Analyzers

Lesson Goal and Objectives

Goal

To explain the operation of Horiba General Purpose Gas Analyzers.

Objectives

At the end of this lesson, you should be able to —

1. identify the analytical techniques of and the gases monitored by these systems,
2. explain the two primary modes of analysis, and
3. describe the special features of these instruments.

Introduction

The prior lessons have presented material on the operation of several types of commercially available CEMSs. Likewise, this lesson will discuss the operation of the CMA/CFA/MPA Series of general purpose gas analyzers manufactured by Horiba. Each instrument in this line of equipment uses a different number and combination of non-dispersive, infra-red spectroscopy (NDIR) analyzers and magnetopneumatic analyzers to monitor exhaust gases.

Modes of Analysis

As Lesson 4 explained, CEMSs which use spectrophotometers rely on the interaction of light energy with gaseous molecules in order to determine the gas concentration. Since light energy and wavelength are related, analyzers can employ light from different parts of the spectrum for monitoring. When a gas absorbs some energy from a light beam, the intensity of the light will decrease. This decrease in intensity can then be converted to the concentration of the gas. Because the monitors described in this lesson use a combination of analytical techniques including spectroscopy, this topic will be briefly reviewed.

CEMSs which use paramagnetic analyzers operate on the principle that molecules behave differently when placed in magnetic fields. The behavior is classified as either diamagnetic or paramagnetic. Most molecules are diamagnetic and are repelled when placed in a magnetic field. However, a few molecules possess paramagnetic properties and will be attracted by and interact with the magnetic field; such is the case with oxygen.

General Purpose Gas Analyzers

Horiba Instruments, Inc. has developed a line of general purpose gas analyzers, the CMA/CFA/MPA Series, for the measurement of NO_x, SO_2, CO, CO_2, and O_2 in exhaust gas streams. Each model requires the extraction of sample gas from the stack and delivery to the analysis unit. CFA-311/321 analyzers use NDIR cross-flow modulation to measure up to two of the above components, with the exception of O_2. The MPA-311 uses the magnetopneumatic method of measuring oxygen content and is applicable only to O_2. The CMA-321/331 combine one or two NDIR analyzers and a magnetopneumatic analyzer in a single unit for measurement of oxygen and up to two other components.

The CMA/CFA/MPA Series of analyzers provides the opportunity to monitor several components of flue gas with one extractive system. As the number of gases being monitored increases, the complexity of the analyzer also increases. The CMA-331, which monitors two gases in addition to O_2, is depicted in *Figure* 7-1.

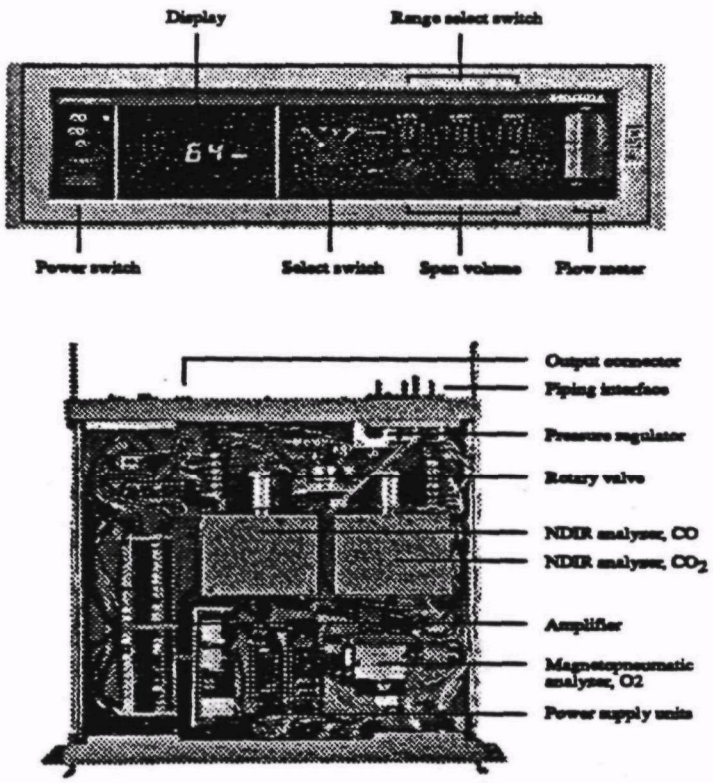

FIGURE 7-1 CMA-331 MONITORING SYSTEM

Spectrophotometry

NDIR cross-flow modulation analysis requires the sample gas and the reference gas to be introduced alternately into the measurement cell by a rotary valve. When the cell contains the reference gas, the IR beam reaches the detector without any energy loss. When the cell contains the sample gas, however, the energy received by the detector is less due to some IR absorption by the target gas.

Contained within the detector is a movable membrane which senses pressure differential. Because of the energy loss due to IR absorption, the pressure which corresponds to sample gas analysis will be less than the pressure which corresponds to the reference gas. The displacement of the membrane is converted to an electrical signal and is amplified for output. This process is depicted in *Figure* 7-2. Horiba's cross-flow modulation method is used for monitoring such gases as NO_x, SO_2, CO, and CO_2.

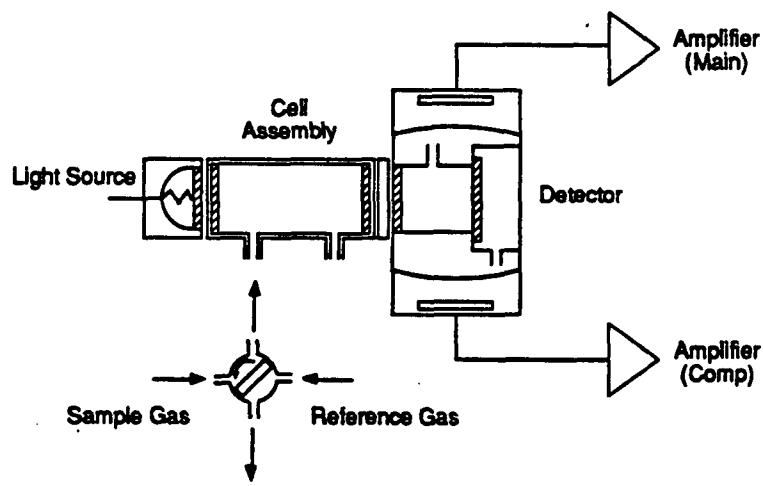

FIGURE 7-2 NDIR CROSS-FLOW MODULATION PROCESS

Magnetopneumatics

Magnetopneumatic oxygen analysis requires O_2 to be introduced to an uneven magnetic field, where the O_2 is drawn to the stronger side of the field and causes a pressure rise. A pressure rise is also produced outside the field using a non-magnetic gas (e.g., nitrogen); the differential pressure (between the two gases) is measured using a condenser microphone. The pressure difference is related to oxygen concentration according to the following equation:

(Eq. 7-1) $$\Delta P = 1/2\,(H)^2\,(X)\,(C)$$

where

ΔP = difference in pressure
H = strength of magnetic field
X = magnetic susceptibility of O_2 (known), and
C = concentration of O_2

A stable signal is produced and transmitted from the detector by exciting the magnet intermittently and processing an alternating current (signal). There will be no signal if there is no O_2 in the sample gas, and therefore, no zero drift. Precise oxygen measurement is possible because the magnetic susceptibility of the gas is accurately known. *Figure* 7-3 shows a basic set-up for a magnetopneumatic analyzer.

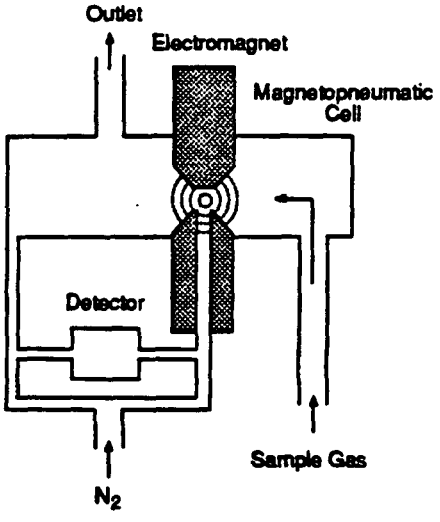

FIGURE 7-3 MAGNETOPNEUMATIC ANALYZER

Horiba CMA/CFA/MPA Series models are designed so that all routine adjustments, operations, and maintenance work can be conducted from the front of the instrument which reduces time and labor requirements. Use of a small sampling volume also reduces maintenance frequency.

Summary

Horiba Instruments, Inc. has developed a line of general purpose gas analyzers, the CMA/CFA/MPA Series, for the measurement of NO_x, SO_2, CO, CO_2, and O_2 in exhaust gas streams. Each model requires the extraction of sample gas from the stack and delivery to the analysis unit. These models differ according to the number and types of gases that can be simultaneously monitored.

NDIR spectroscopy cross-flow modulation analysis requires the sample gas and the reference gas to be introduced alternately into the measurement cell by a rotary valve. When the cell contains the reference gas, the IR beam reaches the detector without any energy loss. When the cell contains the sample gas, however, the energy received by the detector is less due to some IR absorption by the target gas. The electrical signal from the detector is amplified and sent to the readout as concentration.

Magnetopneumatic oxygen analysis requires O_2 to be introduced to an uneven magnetic field. As the O_2 enters the magnetic field, it will be drawn to the stronger side of the field and cause a pressure rise. A non-magnetic gas produces a pressure rise outside the field, and the pressure differential from the two gases is measured using a condenser microphone. It can then be related to O_2 concentration which is presented on the readout.

UNIT 3

SYSTEM DESIGN

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3. Skoog, D. A. and West, D.M. 1982. Fundamentals of Analytical Chemistry. Saunders College Publishing, Philadelphia, PA.

4. U. S. Environmental Protection Agency. 1986. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III. Stationary Source Specific Methods*. EPA-600/4-77-027b.

9. In the NDIR cross-flow modulation process, the detector contains a moveable membrane which senses _____. a. porosity b. temperature changes c. ion concentration d. pressure diffential	8. False
10. In the Horiba magnetopneumatic oxygen analyzer, a _____ is used to measure a pressure differential which is related to oxygen concentration. a. flowmeter b. magnet c. condenser microphone d. zirconium oxide cell	9. d
	10. c

REVIEW EXERCISES	
1. CEMSs which use spectrophotometers rely on the interaction of _____ with gaseous molecules to determine gas concentration. a. magnetic fields b. light energy c. particulates d. filters	
2. CEMSs which use ____ operate on the principle that molecules behave differently when placed in magnetic fields. a. UV light b. infrared light c. spectrophotometers d. paramagnetic analyzers	1. b
3. The Horiba general purpose gas analyzers use an_____ design. a. extractive b. in-situ	2. d
4. The MPA-311 uses the magnetopneumatic method to measure _____. a. CO_2 b. O_2 c. CO d. SO_2	3. a
5. True or false. The magnetopneumatic analyzers are unaffected by temperature fluctuations.	4. b
6. True or false. The use of a large sampling volume in the Horiba Series reduces maintenance frequency.	5. True
7. True or false. The CFA-311/321 units are capable of measuring more than one type of gas at a time.	6. False
8. True or false. NDIR cross flow modulation analysis requires the sample gas and the reference gas to be introduced simultaneously into the measurement cell.	7. True

This line of monitors from Horiba offers several important features. The Horiba magnetopneumatic analyzers provide linear output and respond only to oxygen. They are said to be free from zero drift and unaffected by temperature fluctuations. The Horiba cross-flow modulation method, used in their NDIR analyzers for monitoring NO_x, SO_2, CO, and CO_2, provides stable, long-term operation. Because some of the monitors in this series combine both types of analyzers in a single CEMS, it is possible for the user to monitor several gases of interest.

LESSON 8

Extractive Systems Design

Lesson Goal and Objectives

Goal

To describe extractive continuous emissions monitoring systems (CEMSs) design in terms of monitoring objectives as well as systems' components and their functions.

Objectives

At the end of this lesson, you should be able to —

1. define the objectives of an extractive CEMS as related to system requirements and user needs,
2. list the criteria to be evaluated prior to selection of the monitoring system, and
3. describe the primary subsystems of an extractive CEMS.

Introduction

As noted in Lesson 1, CEMSs can be divided into two general classifications based on the means by which sample gas is delivered to the analyzer. Those two categories are extractive systems and in-situ systems. Extractive systems withdraw flue gas from the stack, condition it, and transport the gas to the analysis section which is usually located within the plant. In-situ CEMSs have at least some part of their analysis subsystem mounted in the stack. Because they perform analyses at the stack, in-situ systems neither condition the sample gas nor transport it to a remote analytical unit.

Extractive sampling permits the analyzer to be located at some convenient site within the plant. The separation of the probe and the analyzer does, however, impose a time lapse between extraction of the sample gas and its analysis. For this reason, the output reading will always be somewhat behind the process.

Understanding all aspects of a system's design, including its objectives, components, and functions, will assist in guiding the user through the selection and installation period. This knowledge will also be invaluable during routine calibrations and maintenance.

Objectives

Obtaining accurate and on-going information about stack emissions and other parameters is a primary goal of continuous emissions monitoring projects and is dependent upon many variables. Therefore, it is imperative to begin such a project correctly. Proper planning and investigation are essential for a successful program. Knowing the requirements of the system and the needs of the potential users should be the first step in designing a CEMS.

System Requirements

The requirements of a continuous emissions monitoring system can be considered two-fold. The two main questions regarding the requirements are:

1. What are the intended functions of the system, or equivalently, what is the CEMS expected to do? (e.g., process control, compliance demonstation, general research) and

2. What criteria must be met in order for the CEMS to execute these functions properly?

In response to the first question, extractive systems, in general, should be able to:

1. remove a representative gas sample from the source on a continuous basis,

2. maintain sample integrity during its transportation,

3. condition the sample so that it will be compatible with the selected analytical method,

4. accurately measure the concentration of the subject gas, and

5. allow for the accurate calibration and QA/QC of the system.

In response to the second question, of meeting the system's requirements, it is suggested that the user:

1. study the applicable regulations with respect to the gases and other parameters to be monitored;

2. review the specifications and operating characteristics of several analyzers capable of monitoring the selected gases;

3. determine the gas stream parameters and the most feasible and representative sampling sites;

4. select the best site;

5. select the analyzer that is most compatible with the site and the gas parameters; and

6. ensure access to electricity, high pressure air, steam, water or other items required for proper operation of the system's components.

In an effort to meet the requirements of the system, representative sampling sites should be located as described in the appropriate regulations. Among the parameters needed to chose the appropriate location are stack gas temperature and velocity profile, as well as the distance from the proposed location to the nearest upstream and downstream flow disturbances (including process and control equipment). It will also be necessary to determine the amount of moisture in the stack gas in order to calculate the water removal and drainage needs of the system.

Representative sampling also requires that existence of stratification within a stack be assessed. A more detailed discussion of stratification is given Lesson 12.

Another physical factor to keep in mind is the system's operating environment. The location of the equipment should not limit or restrict its utility due to temperature extremes, support facilities, vibration, or other prohibitive ambient conditions such as corrosion or particulate buildup. A protective housing is a recommended way of protecting the entire system.

User Needs

Satisfying the requirements of the hardware accomplishes only one of the main design objectives. Meeting the needs of the user is also of great importance. There are several physical factors which should be evaluated. One of these factors includes accessibility to the monitor and the interface for day-to-day usage, routine maintenance, and QA/QC. Being able to reach controls and inspect equipment with ease is a must since these activities will be ongoing. The potential loss of time due to inappropriate equipment orientation should be avoided.

Other user needs which should be addressed during the design phase of a continuous emissions monitoring project include the overall system design and its response time. The overall system design refers to the way in which the individual components connect and interact. If an existing system is being expanded or if equipment is being purchased from several vendors, it will be necessary to consider the separate functions of each piece, whether it will be possible to join them in such a manner which ensures the delivery of a representative sample to the analyzer, and whether results suitable for the application will be obtained reliably.

Consideration of the system's response time is also suggested. This parameter is especially important when dealing with extractive CEMSs. If the operator were able to observe a discrete portion of sample gas as it moved through the entire system, it would become quite evident that there is, in fact, a time delay between sample extraction and analysis. This lag is attributed to the time required for the sample gas to travel through the tubing as it is being conditioned, diluted, and transported to the analysis unit. As the length of sample line increases, so does the response time. This issue is most important when CEMSs are being used as part of a process control scheme. Also, some regulations specify a maximum allowable response time.

From the few preceding paragraphs, the importance of carefully considering the system's and the user's needs should be apparent. Once these objectives are understood, developing a successful extractive system design may proceed to the next step.

Components and Functions

After clearly defining and understanding the objectives of the CEM project, the next step of the design phase may begin. There are generally two approaches taken in extractive system design. One approach is to condition the gas near the analyzer; the other is to condition the gas as near to the stack as possible.

In the first approach, a probe is inserted into the stack where it takes in flue gas which passes through a coarse particulate filter and into a heated sample line. This sample line, which is sometimes rather long (possibly over 100 feet), would enter some kind of control room or environmental enclosure where the gas would then be conditioned. The conditioning system cools the gas and reduces the amount of water vapor. Reduction of the amount of water vapor is usually accomplished by some type of refrigeration, dilution, or permeation device. A fine filter is placed just before the entrance of the analyzer to prevent any small particulates from entering. Pumps or aspirators are used to transport the sample from the probe to the analyzer.

In the second approach, sample gas is extracted through the probe and conditioned at the stack. Filters, chillers, and/or dilution systems are located at the sampling site. Of these three devices, only the chillers are designed to remove moisture from the sample gas. In the case of dilution systems, the concentration of all constituents in the sample, including moisture, is greatly reduced by combining the sample stream with a stream of non-interfering, dry gas. Each of these methods enables a low moisture sample to be delivered to the analyzer and avoids long sections of heat-traced or insulated sample lines.

Regardless of which approach is used to condition the flue gas removed from the stack, all extractive CEMSs have five common subsystems. Those subsystems are:

1. the effluent/monitor interface subsystem,
2. the sample transport subsystem,
3. the sample conditioning subsystem,
4. the analysis subsystem, and
5. the data acquisition subsystem.

The first subsystem (the effluent/monitor interface subsystem) consists primarily of the sample probe. The second subsystem (the sample transport subsystem) is comprised of tubing and a pump. Moisture reduction devices and more filters are found in the third subsystem (the sample conditioning subsystem). Calibration equipment, analyzers, detectors, and convertors are part of the fourth or analysis subsystem. The data recording and processing equipment is in the fifth subsystem.

As indicated above, some extractive designs combine the sample transport and conditioning subsystems into one overall sample handling subsystem. A schematic of a typical extractive CEMS is given in *Figure* 8-1.

The following list of equipment identifies the most common components found in extractive monitoring systems. They are usually constructed from items such as valves, filters, tubing, tube fittings, and solenoids with which plant maintenance personnel are familiar. Though individual manufacturers may deviate somewhat in their systems' designs, most systems usually include:

1. coarse (in-stack) filter,
2. sampling probe,
3. gas transport tubing,
4. sampling pump,
5. moisture removal system,
6. fine filter,
7. analyzer,
8. calibration system, and
9. data processor/recorder.

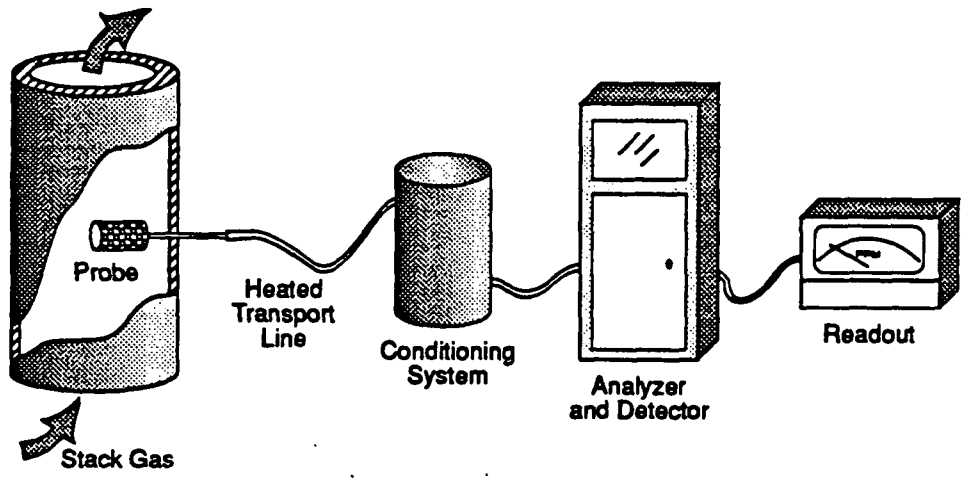

FIGURE 8-1 TYPICAL EXTRACTIVE CEMS CONFIGURATION

Design considerations for these components should be made in light of their expected, predetermined functions. Some suggested parameters for evaluation of the components within each subsystem are given in the following sections.

Effluent/Monitor Interface Subsystem

The basic purpose of the interface is to provide continuous access to a representative portion of stack gas which will be extracted and analyzed. It is therefore necessary to position the probe in a proper location and to make sure that it is not adversely affected by the conditions of its operating environment. That is to say that the probe should be:

1. located to obtain a representative gas sample;

2. protected from a build-up of particulate matter;

3. unaffected by temperature, moisture, and vibration;

4. capable of accepting calibration gases; and

5. constructed of some corrosion resistant material such as Hastelloy[R], 316 stainless steel, glass, quartz, or ceramic material in order to minimize deterioration and maximize its operating life.

Sample Transport Subsystem

The sample transport subsystem begins at the junction of the probe and the sample line and travels from the stack to the analysis section of the monitoring system. The first primary component of this subsystem, the tubing, has several aspects which should be considered. Some of the more important factors to evaluate when selecting the type of tubing for a particular system include corrosion resistance, heat tolerance, and chemical resistance/ stability. These parameters deserve special attention due to the harsh environments typically encountered in combustion and other sources and the nature of the gases being sampled.

The other main component of the sample transport subsystem is the pump. Though there are numerous pumps marketed, it is generally recommended that diaphragm or bellows pumps be used in transport subsystems for the reasons which follow. Those types of pumps:

1. provide adequate suction and discharge for stack gas analysis applications,

2. do not require a shaft seal (which means that they would not be prone to seal failure and subsequent air in-leakage),

3. do not require internal lubrication (which could lead to sample contamination), and

4. are relatively inexpensive.

5. may also need to be heated and corrosion resistant.

In some continuous emissions monitoring applications, the sample gas will leave the transport subsystem and enter the conditioning system. Various aspects of that section will be discussed in the upcoming paragraphs.

Sample Conditioning Subsystem

The purpose of this subsystem is to provide a clean, dry gas sample to the analytical section. Sample conditioning equipment often includes primary and secondary particulate filters as well as some type of water removal apparatus.

The primary filter is usually located at the probe inlet. Since this filter is the first one to be contacted by stack gas, it performs the initial screening of particulates and removes large particulates (greater than 50 microns in diameter) from the extracted sample gas stream. The secondary particulate filter, located downstream of the primary filter, remove nearly all of the remaining particulates that are greater than one micron.

Secondary filters (or fine filters) can generally be divided into two broad categories which are surface filters and depth filters. Surface filters, as depicted in *Figure* 8-2, have a porous matrix which allows anything smaller than 1 micron to pass while collecting the larger particulates on the "front" side of the filter.

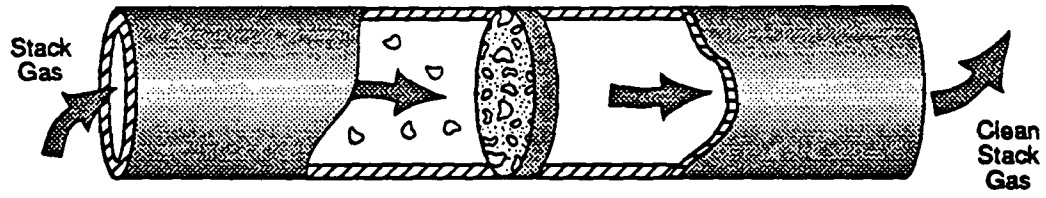

FIGURE 8-2 SURFACE FILTER

As shown in *Figure* 8-3, depth filters are usually made of some type of loosely packed material, such as fibers or glass wool, and have the ability to entrain the undesirable particulates while permitting the passage of gaseous molecules.

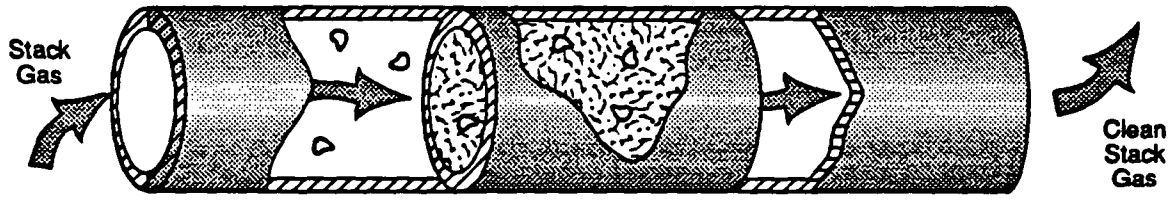

FIGURE 8-3 DEPTH FILTER

Moisture removal is usually accomplished by condensation, permeation, or dilution. Condensation of the moisture is accomplished by rapidly cooling the sample and trapping the condensed water in a collection vessel which is periodically emptied. To avoid absorption of the target gases by the condensate through prolonged contact, design precautions can be taken. The first and most common design involves the standard compressor-type refrigeration unit. More recent approaches are the thermoelectric plate cooler, which is a solid-state unit with no moving parts, and the vortex chiller which uses the chilling effect due to rapid expansion of a compressed gas.

Permeation dryers can be used with or in place of refrigerated condensers. The operation of permeation dryers is based on the selective permeability of water through a membrane. As illustrated in *Figure* 8-4, permeation occurs continuously as moist stack gas flows along one side of the membrane and dry purge air flows counter-currently along the other side of the membrane. Since the water vapor will tend to migrate from a point of high concentration to low concentration, the stack gas will become dryer as the purge air acquires some of that moisture through the membrane.

The third conditioning method employed by some units is the addition of dilution air (usually cleaned and dried ambient air) to the sample stream as a means of reducing the moisture concentration of the stream to a level which is acceptable for the particular analyzer that is being used. This step may take place in the stack, at the sample interface, or at a remote location. Dilution requires very accurate metering and monitoring of the air so that the diluted sample concentration measured by the analyzer can be corrected to the actual stack concentration.

In any case, the gases of interest, the detection principle, and parameters of the individual analyzers will dictate the complexity of the conditioning subsystem used to supply the clean, dry sample.

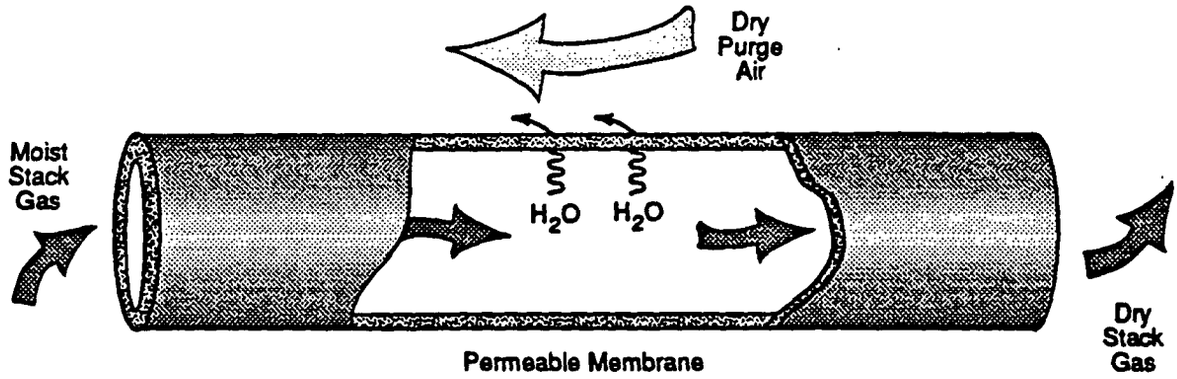

FIGURE 8-4 PERMEATION DRYING PROCESS

Analysis Subsystem

The overall purpose of the analysis subsystem is to determine and to provide the accurate concentration value of the target gas to the user. This goal is accomplished by the integration of the functions of several components belonging to this subsystem.

The first aspect of the analysis subsystem to be examined is the calibration procedure. Calibration gases are used to validate the performance of each component of the analysis subsystem and to correct the pollutant concentration values as required. The calibration gases should be injected as close to the probe as possible, and the calibration check should be performed at the normal operating conditions (i.e., temperature, pressure, flow rate, etc.) encountered during the analysis of sample gases.

The other components of the analysis subsystem include analyzers, detectors/convertors, readouts, and recorders. A variety of analyzers have been developed to monitor certain pollutants. The principles employed by these analyzers include spectroscopic absorption, luminescence, electroanalysis, and paramagnetism. As these analyzers measure selected parameters, a signal will be received by the detector, converted to an electrical current, and sent to a readout instrument as a concentration value. Often, there will be some type of data recorder included in this subsystem for the purpose of maintaining written documentation about stack conditions, concentration readings, and other parameters of interest. Discussions of these analytical techniques and devices have been presented separately in prior lessons, so please refer to those sections for more details.

Summary

Lesson 8 defined the objectives of an extractive CEMS as related to system requirements and user needs. Furthermore, it identified the four primary extractive CEMSs' subsystems as well as their components and functions.

When establishing a continuous emissions monitoring program, it is essential for the user to define clearly the system requirements by asking the following questions:

1. What are the intended functions of the system, and

2. What criteria must be met in order for the CEMS to execute these functions properly?

The CEMS should also meet the various needs of the user in terms of:

1. accessibility to the monitor and the interface for day-to-day usage, routine maintenance, and QA/QC;

2. the overall system design which should allow for some future modifications or adjustments as necessary; and

3. a reasonable response time.

After clearly defining and understanding the objectives of the CEM project, the next step of the design phase may begin. There are generally two approaches taken in extractive system design. One approach is to condition the gas near the analyzer; the other is to condition the gas as near to the stack as possible. Regardless of which approach is used to condition the flue gas removed from the stack, all extractive CEMSs have five common subsystems. Those subsystems are:

1. the effluent/monitor interface subsystem,

2. the sample transport subsystem,

3. the sample conditioning subsystem,

4. the analysis subsystem, and

5. the data acquisition subsystem.

The first subsystem consists primarily of the sample probe. The second subsystem is comprised of tubing and a pump. Moisture reduction devices and more filters are found in the third subsystem. Calibration equipment, analyzers, detectors, and convertors as well as readouts and recorders are part of the fourth subsystem. Data recording and processing occur in the fifth subsystem.

Understanding these subjects will assist in guiding the user through the selection and installation period. This knowledge will also be invaluable during routine calibrations and maintenance.

REVIEW EXERCISES

1. Which of the following functions is not performed by an extractive CEMS? a. In-stack analysis. b. Sample transportation. c. Sample conditioning. d. Particulate filtering.	
2. The separation of the probe and the analyzer a. decreases analysis time. b. increases sampling volume. c. causes a time lapse between extraction and analysis. d. decreases particulate buildup.	1. a
3. Extractive systems should not a. condition the sample prior to analysis. b. operate continuously. c. permit particulate matter to enter the analyzer. d. deliver a representative portion of gas to the analyzer.	2. c
4. It is necessary to determine the moisture content of the stack gas in order to a. calculate the water removal needs of the system. b. assess the effect of stratification. c. calibrate the system. d. estimate the amount of water recycled per hour.	3. c
5. Moisture reduction is accomplished by all the following except a. permeation. b. dilution. c. refrigeration. d. heating.	4. a
6. The sample transport subsystem contains a. an in-stack analyzer. b. particulate filters. c. moisture detectors. d. a diaphragm pump.	5. d
7. Hastelloy® or quartz might be used in the construction of a sample probe in order to a. filter particulates. b. reduce moisture condensation. c. calibrate the system. d. resist corrosion.	6. d

8. Surface and depth filters are used a. to remove water. b. to collect particulates between 1 and 50 microns. c. protect the probe from particulate buildup. d. clean the purge air.	7. d
9. True or false. System calibration should be performed under the same conditions encountered during sample gas analysis.	8. b
10. Heat tolerance, chemical stability, and corrosion resistance should be considered when selecting a. which gas to monitor. b. the analyzer to be used. c. sample transport tubing. d. a signal processor.	9. True
	10. c

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LESSON 9

In-situ Systems Design

Lesson Goal and Objectives

Goal

To describe in-situ continuous emissions monitoring systems (CEMSs) design in terms of monitoring objectives as well as systems' components and their functions.

Objectives

At the end of this lesson, you should be able to —

1. define the objectives of an in-situ CEMS as related to system requirements and user needs,
2. list the criteria to be evaluated prior to selection of the monitoring system,
3. describe the two design approaches of in-situ systems, and
4. describe the two analytical techniques used by in-situ CEMS in terms of their components and functions.

Introduction

As noted in Lesson 1, continuous emissions monitoring systems (CEMSs) can be divided into two general classifications based on the means by which sample gas is delivered to the analyzer. Those two categories are extractive systems and in-situ systems. Extractive systems withdraw flue gas from the stack, condition it, and transport the gas to the analysis unit which is located within the plant. In-situ monitoring systems, as the name implies, are designed to carry out most of their operations in the stack.

In-situ CEMSs have at least some part of their analysis subsystem mounted in the stack in direct contact with the flue gas. Because they perform analyses at the stack, in-situ systems neither condition the sample gas nor transport it to a remote analytical unit. The lack of conditioning and transport subsystems indicates that in-situ CEMSs designs require substantially less equipment than do extractive CEMSs designs.

Understanding all aspects of a system's design, including its objectives, components, and functions, will assist in guiding the user through the selection and installation period. This knowledge will also be invaluable during routine calibrations and maintenance.

Objectives

As stated in Lesson 8, obtaining accurate and repeatable information about stack emissions is a primary goal of continuous emissions monitoring projects and is dependent upon many variables. Therefore, it is imperative to begin such a project correctly. Proper planning and investigation are essential for a successful program. Knowing the requirements of the system and the needs of the potential users should be the first step in designing a CEMS.

System Requirements

The requirements of a continuous emissions monitoring system can be considered two-fold. The two main questions regarding the requirements are:

1. What are the intended functions of the system, and
2. What criteria must be met in order for the CEMS to execute these functions properly?

In response to the first question, in-situ systems, in general, should be able to:

1. operate at the required source conditions (e.g., temperature, pressure, etc.);
2. analyze a representative portion of flue gas on a continuous basis;
3. accurately measure source-level concentrations of the subject gas;
4. minimize possible interferences from particulates, water vapor, or "non-subject" gases; and
5. allow for the accurate calibration of the system.

In response to the second question, of meeting the system's requirements, it is suggested that the user:

1. study the applicable regulations with respect to the gases to be monitored;
2. review the specifications and operating characteristics of several analyzers capable of monitoring the selected gases;
3. determine the gas stream parameters and the most feasible and representative sampling sites;
4. select the best site;
5. select the analyzer that is most compatible with the site and the gas parameters; and
6. ensure access to electricity, high pressure air, steam, water or other items required for proper operation of the system's components.

In an effort to meet the requirements of the system, reperesentative sampling sites should be located as described in the appropriate regulations. Among the parameters needed to chose the appropriate location are stack gas temperature and velocity profile, as well as the distance from the proposed location to the nearest upstream and downstream flow disturbances (including process and control equipment). Stratified zones, as discussed in Lesson 8, should be assessed.

Another physical factor to keep in mind is the system's operating environment. The potential interferences of the environment, including temperature extremes, support facilities, corrosion, or particulate buildup, should not restrict the utility of the analyzer. The use of a measurement cavity which is enclosed by a filtration device (e.g., a ceramic thimble) will allow gases to permeate while preventing interference from particulates. A high pressure blowback system can be used to remove accumulated particulates from the surface of the ceramic thimble or other filtration device.

User Needs

Satisfying the requirements of the monitoring system accomplishes only one of the main design objectives. Meeting the needs of the user, which includes having access to the monitor and the interface for day-to-day usage and routine maintenance, is also of great importance. Being able to reach controls and inspect equipment with ease is a must since these activities will be ongoing. The potential loss of time due to inappropriate equipment orientation or location should be avoided.

From the preceeding paragraph, the importance of carefully considering the system's and the user's needs should be apparent. Once these objectives are understood, developing a successful in-situ system design may proceed to the next step.

Components and Functions

After clearly defining and understanding the objectives of the CEM project, the next step of the design phase may begin. There are generally two approaches taken in in-situ system design. One approach is to monitor a certain path of stack gas; the other is to monitor at a single point within the stack. EPA distinguishes between path and point monitors by the percentage of the stack diameter (or equivalent diameter for non-circular ducts) represented by the measurement path. An instrument that measures gas concentrations along a path which is greater than 10 percent of the diameter is said to be a path analyzer. If the measurement path is less than or equal to 10 percent of the diameter, the instrument is considered a point analyzer.

Regardless of the type of in-situ design that is to be implemented, calibration procedures are required. Calibration gases are used to validate the performance of each component of the analysis subsystem and to correct the pollutant concentration values as required. The calibration gases should be injected as close to the probe as possible, and the calibration check should be performed at the normal operating conditions (i.e., temperature, pressure, flow rate, etc.) encountered during the analysis of sample gases. When it is not feasible to inject calibration gases, it is possible to use gas filled cells for calibration checks. These techniques are discussed further in Lesson 10.

In-situ, Path Monitors

In-situ, path monitors are usually made up of two units which are aligned opposite of each other in the stack. This system analyzes flue gas that passes through the specific "line of sight" between the units. This line of sight, or path, typically ranges from a few feet to the entire width of the stack. For accurate readings, it is critical to ensure proper alignment of these units. In-situ, path monitors use spectroscopic absorption techniques in which either infrared (IR) or ultraviolet (UV) light is directed through the flue gas. As discussed in Lessons 2 and 3, the percent absorption of light energy at a specific wavelength quantifies the amount of target gas present in the stack.

Path monitors may be designed to direct the light through the gas once or twice. "Once-through" systems are named single-pass monitors, whereas "twice-through" systems are identifed as double-pass monitors.

In single-pass monitors, a transmitter and a receiver comprise the stack units as shown in *Figure* 9-1. The transmitter contains an IR or UV light source which beams the light directly across the stack to the receiving unit. The receiver detects the amount of light energy present in the beam and converts that signal to a concentration reading. The transmitter and receiver are protected by windows, over which is blown a constant flow of purge air (generally filtered ambient air).

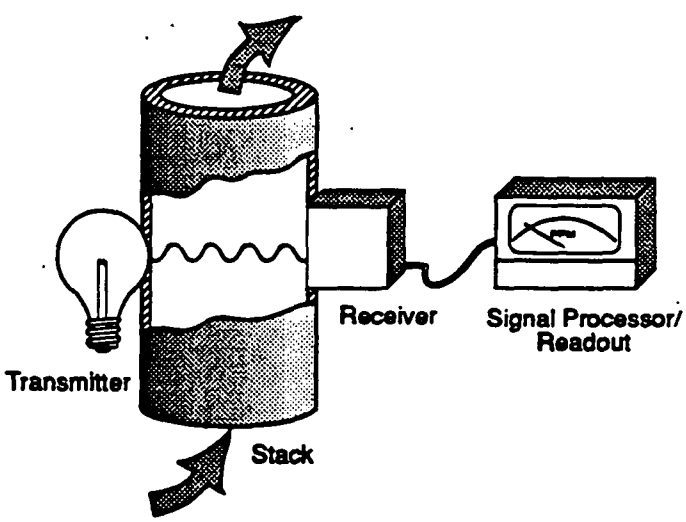

FIGURE 9-1 SINGLE-PASS, IN-SITU, PATH MONITOR

The purge air:

1. prevents the build-up of particulate matter on the windows,
2. aids in cooling the units mounted on the stack, and
3. assists in preventing the condensation of water or corrosive materials on the cooler instrument windows.

Double-pass monitors consist of a transceiver and a retroreflector. Light is sent out of the transceiver and through the flue gas. Upon reaching the retroreflector unit on the opposite end of the path, the light is returned through the flue gas and enters the transceiver for analysis. Since the light travels through the flue gas twice, the

beam is considerably weaker than the one in single-pass systems. Therefore, most commercial path monitors are designed as single-pass units. The double-pass systems are protected by windows and employ purge air for the same reasons as given for single-pass units. *Figure* 9-2 is an illustration of a double-pass monitor.

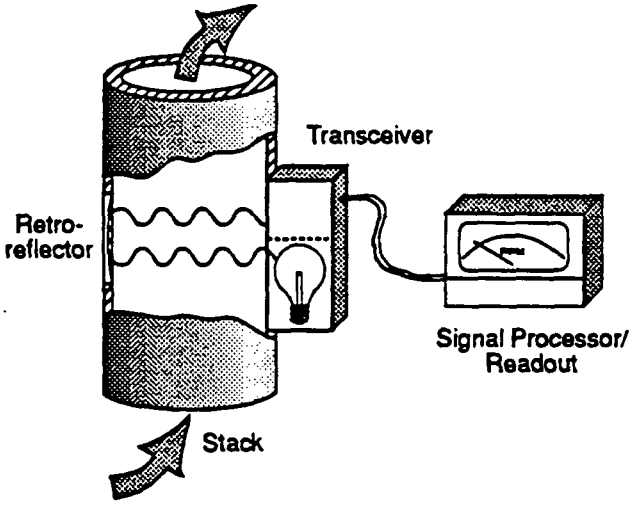

FIGURE 9-2 DOUBLE-PASS, IN-SITU, PATH MONITOR

Path monitors require a number of accessories to protect them from the hostile environments often encountered at their installation sites. Transmitters, retroreflectors, and receivers need hoods or covers to protect them from meteorological phenomena such as wind, rain, hail, and lightning. Anti-vibration equipment may be needed to prevent optical and electrical components from shaking loose. A dedicated, constant voltage transformer can be useful in eliminating voltage transients which could upset the sensitive electronics of many instruments.

In-situ, Point Monitors

Like path monitors, in-situ, point monitors can use absorption spectroscopy for flue gas analysis. Point monitors are constructed in much the same way as path monitors. Such point monitors are made up of two units which are aligned opposite of each other in the stack. The light is emitted from the first unit and sent through the flue gas. Upon reaching the receiving unit, the amount of light energy is measured and the gas concentration is related to absorbance. A ceramic thimble encases the probe and allows gaseous molecules to enter its shell while retaining particulates in order to minimize interference with analysis. Though the ceramic thimbles used in point monitors do not require blowers for cleansing purposes, they should be checked and replaced periodically to ensure proper operation.

Another type of point monitor based on absorption spectroscopy utilizes an open probe containing a retroreflector as seen in *Figure* 9-3. In this device, the transceiver is placed behind a window and the retroreflector

is supported on the other end of the monitoring path. Since there is no ceramic thimble or other filtration device included on the probe, blowers supply purge air which:

1. prevents the build-up of particulate matter on the windows,

2. aids in cooling the units mounted on the stack, and

3. assists in preventing the condensation of water or corrosive materials on the cooler instrument windows.

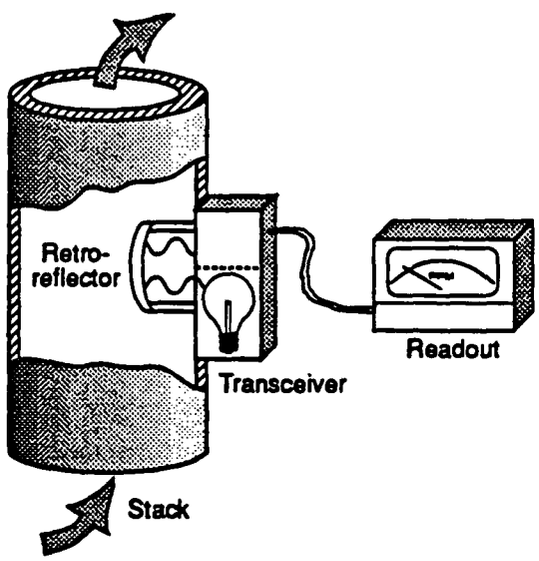

FIGURE 9-3 IN-SITU, POINT MONITOR

One widely marketed point monitor uses electroanalysis for the measurement of O_2 and SO_2. Such point monitors have an electrocatalytic cell which is mounted on the probe and is covered by a ceramic thimble. As in other applications, the ceramic thimble allows gaseous molecules to enter the shell, but it retains particulates so that a clean sample may be introduced to the electrocatalytic cell. A thin film, applied to the solid electrolyte's surface, catalyzes a reaction which allows gaseous molecules to migrate through the solid and generate a measurable current. More detailed discussions about this type of analyzer have already been presented in Lessons 2 and 3.

Point monitors require protective accessories similar to those used with path monitors. Transceivers and retroreflectors should be protected from the elements. Anti-vibration equipment may be needed to prevent optical and electrical components from shaking loose or becoming detached. A dedicated, constant voltage transformer can be useful in eliminating voltage transients which could upset the sensitive electronics of many instruments.

Summary

Lesson 9 defined the objectives of an in-situ CEMS as related to system requirements and user needs. It described the two design approaches of in-situ systems, and finally, it described the two analytical techniques used by in-situ CEMS in terms of their components and functions.

When establishing a continuous emissions monitoring program, it is essential for the user to define clearly the system requirements by asking the following questions:

1. What are the intended functions of the system, and

2. What criteria must be met in order for the CEMS to execute these functions properly?

Additionally, the CEMS should meet the needs of the user in terms of accessibility to the monitor and the interface for day-to-day usage and routine maintenance. Their location and orientation should be established in a manner which does not restrict personnel from accomplishing these and other tasks.

After clearly defining and understanding the objectives of the CEM project, the next step of the design phase may begin. There are generally two approaches taken in in-situ system design. One approach is to monitor a certain path of stack gas; the other is to monitor at a single point within the stack.

In-situ, path monitors are usually made up of two units which are aligned opposite of each other in the stack. This system analyzes flue gas that passes through the specific "line of sight" between the units. This line of sight, or path, typically ranges from a few feet to the entire width of the stack. In-situ, path monitors use spectroscopic absorption techniques in which either infrared (IR) or ultraviolet (UV) light is directed through the flue gas. Path monitors may be designed to direct the light through the gas once or twice. "Once-through" systems are named single-pass monitors, whereas "twice-through" systems are identifed as double-pass monitors.

Like path monitors, in-situ, point monitors can also use absorption spectroscopy for flue gas analysis. These point monitors are constructed in much the same way as path monitors. They can be made up of two units which are aligned opposite of each other in the stack, yet are closer than the units used by path monitors. Another type of in-situ analyzer uses an electrocatalytic cell which is mounted on the probe and covered by a ceramic thimble.

Understanding all the design aspects just reviewed, including the objectives, components, and functions, will assist in guiding the user through the selection and installation period. This knowledge will also be invaluable during routine calibrations and maintenance.

REVIEW EXERCISES	
1. True or false. In-situ CEMSs should always be found at some conveniently located site within the laboratory.	
2. In-situ CEMSs require ____ equipment for a single sample point compared to extractive CEMSs. a. more b. less c. the same amount of	1. False
3. In-situ systems do all of the following tasks except a. minimize interference from particulates. b. operate in high temperature combustion sources. c. analyze a representative portion of stack gas. d. remove moisture from stack gas.	2. b
4. A _____ allows gases to permeate and prevents particulates from entering the in-situ analyzer. a. ceramic thimble b. retroreflector c. high pressure blowback system d. stratified zone	3. d
5. "Line of sight" refers to the path between the _____ and _____. a. probe ... stack wall b. transceiver ... retroreflector c. window ... mirror	4. a
6. A constant flow of purge air prevents ____ and _____. a. particulate buildup ... sample loss b. vibration ... water condensation c. sample loss ... corrosion d. water condensation ... particulate buildup	5. b
7. Anti-vibration equipment is used to help maintain a. optical alignment of the transmitter and receiver. b. sample integrity. c. a constant flow rate of stack gas. d. a constant pressure	6. d

8. The two most common methods of analysis used by in-situ CEMSs are a. luminescence and paramagnetism. b. spectroscopic absorption and luminescence. c. electroanalysis and spectroscopic absorption. d. magnetodynamics and mass spectroscopy	7. a
9. True or false. In-situ monitors which measure across a distance less than 10% of the stack diameter are classified as path monitors.	8. c
10. True or false. Calibration gases should be injected into the sample transport tubing	9. False
	10. False

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1. Elliot, T. C. 1986. *"Monitoring Pollution."* Power. 130:S.1-S.9.

2. Jahnke, J.A. and Aldina, G. J. 1979. *Continuous Air Pollution Source Monitoring Systems.* EPA 625/6-79-005.

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LESSON 10

Applications of Systems

Lesson Goal and Objectives

Goal

To discuss the applications of continuous emissions monitoring systems (CEMSs) in terms of their uses, limitations, and other considerations.

Objectives

At the end of this lesson, you should be able to —

1. name several reasons for the application of a continuous emissions monitoring program at a facility,
2. discuss the use of a data acquisition system (DAS),
3. list some considerations which should be made before the installation of either extractive or in-situ CEMSs,
4. identify the capabilities and limitations of both kinds of designs, and
5. identify some parameters which characterize a successful monitoring program.

Introduction

Lessons 8 and 9 presented the objectives and requirements for the design of both extractive and in-situ CEMSs; however, applications of these systems were not discussed in any detail. Lesson 10 will describe the application of CEMSs in terms of their uses, limitations, and other considerations. The evaluation and comprehension of those topics should lead to the implementation of a successful continuous emissions monitoring program.

Benefits of Monitoring

For the Plant

Though continuous emissions monitoring systems are mandatory for certain facilities subject to various federal regulations (e.g., New Source Performance Standards (NSPS)), their installation can prove to be beneficial to other facilities as well. In addition to meeting regulatory requirements, properly installed and operating CEMSs will provide large amounts of source emissions data. The data include far more than just the quantity of a pollutant which is being emitted to the atmosphere; the data also include parameters which can be used to:

1. assess source operating efficiency;

2. correlate emissions with process variables (e.g., fuel consumption, amount of excess air for combustion, raw material loss, etc.); and

3. evaluate the maintenance needs of control equipment.

Having the ability to examine various aspects of the process can provide the user the opportunity to make critical adjustments for process optimization and cost reduction. Consequently, it can be seen that facilities can benefit from the installation of a CEMS.

For the Regulatory Agency

The advantages of operating a CEMS are not limited to a plant however. Regulatory agencies are also benefited by the implementation of these programs. The data provided by a CEMS can be used to:

1. record potential non-compliance situations,

2. relate the effects of source emissions to ambient air quality,

3. assess regulatory needs, and

4. identify source operating and maintenance (O&M) inadequacies.

Having access to continuous emissions monitoring data provides the agency with a better picture of actual emissions and enhances their ability to develop strategies for future programs directed at emissions reduction.

Accessing the Data

The data acquisition subsystem (DAS) is an integral part of every monitoring system. The manner by which the pollution concentration data are output may vary widely from one system to another, depending upon applicable regulations and intended use of that information. Traditionally, data from CEMSs were kept on strip

chart recorders and/or operator log sheets. These methods required extensive manual data reduction to prepare the emission reports required by the agencies. With the availability of computers, these activities have consequently become more automated.

In general, a DAS receives an input from the detector that is proportional to the target gas concentration. It then executes some combination of the following functions:

1. performs zero or span drift corrections,

2. calculates the emission rate for the target gas in units of the applicable standard,

3. performs averaging based on the applicable emission standard,

4. activates alarms when emissions exceed a predetermined level or when a system failure occurs,

5. enables data editing,

6. provides long-term data storage, and

7. prepares emissions data for reports in a spreadsheet or other format.

As the number of functions and level of complexity increase, the ability of the DAS to perform adequately could tend to decrease. Therefore, selection of hardware and software for the DAS should be done carefully, and allowances for backup and future expansion or demands should be considered.

Use of a modern, computerized DAS can effectively reduce the amount of time a CEMS user would have to dedicate for manual data collection and report preparation. Additionally, the sophistication of these systems usually permits data acquisition and transfer for use in other investigations (e.g., dispersion modeling, risk assessment, etc.). A well-designed DAS effectively complements the other components of the overall monitoring system.

Considerations for System Implementation

In General

As discussed in Lessons 8 and 9, there are numerous factors which should be evaluated before the installation of a new CEMS. The selection of a representative sampling site is crucial and should be confirmed before the installation of the system. Consideration of temperature, particulate build-up, corrosion, vibration, electrical and other needs must be thoroughly examined. Control equipment layout and internal ductwork need to be reviewed closely for possible impacts on stratification. If the site should be deemed unacceptable after operation has begun, the process of moving support platforms, test ports, sample lines, signal cable, and other equipment would be enormously inconvenient to say the least.

Cost

Comparing the capabilities and limitations of both extractive and in-situ CEMSs is another consideration to be made in conjunction with system implementation. Due to the inherent differences of both types of systems, each will have its relative strengths and weaknesses. While certain strengths can be advantageous, there can also be significant economic differences between the two generic types. When only one system is required at a facility, the initial cost of an in-situ system may be less than a single point extractive system. However, extractive systems allow for expansion via multiplexing (time-sharing among several sampling locations) which can lead to cost reduction if monitoring requirements increase in the future.

Calibration Techniques

Cost is by no means the only basis of comparison for the two types of CEMSs. Calibration methods can also describe important differences among the various types of systems. Extractive systems can be calibrated directly with gases of a known concentration (cylinder gases), thereby providing a full check of the entire analytical subsystem. In-situ, point monitors can also be calibrated directly with cylinder gases without much difficulty. However, the difficulty in calibration generally occurs with in-situ, path monitors. Because the measuring path of this monitor occupies a significant portion of the stack, introduction of a calibration gas to the path is not feasible without modifications to the system. Such a modification might be the use of a movable pipe as an enclosure which could temporarily isolate the measuring path from stack gas and allow that chamber to be flooded with calibration gas.

With regard to any monitoring systems that use gas-filled cells for calibration, it should be noted that significant changes in concentration values over time have been observed. Changes in the pressure of the cells during transportation have also resulted in apparent changes in concentration. Use of this calibration technique should be done with care. These two problems could possibly be avoided by the use of flow-through cells.

Stack Conditions

Since in-situ CEMSs analyze the subject gas at stack conditions, compensating for high levels of moisture or particulate matter can possibly pose problems. Futhermore, when exhaust temperatures are above 260°C, changes can occur in the spectra of the flue gas, and interferences are likely to increase. Because extractive CEMSs condition the sample gas prior to analysis, flue gas conditions are less critical. However, extractive systems require additional routine maintenance of the conditioning subsystem in order to provide this advantage.

Sampling Location

Where sampling locations can be subject to stratification, in-situ, path monitors may possess an advantage when compared to in-situ, point monitors and extractive systems since the latter two sample from a single point within the stack. Even though in-situ, path monitors can also be affected by stratification, the error may not be as great because they linearly average the concentration of the subject gas across the measuring path. Additionally, locating a representative path may be easier than the location of a representative point.

If the desired sampling location is easily accessible, in-situ CEMSs can offer the ability of having all components at that one location. However, the installation of all equipment at the stack can impose the use of a protective housing which can slow the normal maintenance activities. Furthermore, the hostile environments at some sampling locations can create more difficulties for maintenance personnel.

The advantages and disadvantages of each of these general categories of CEMSs should be carefully considered since they are important for a successful program. A summary of this comparison is given in *Table* 10-1.

TABLE 10-1

Advantages and Disadvantages of Both Extractive and In-situ CEMS

EXTRACTIVE CEMS	IN-SITU PATH CEMS	IN-SITU POINT CEMS
Has more compinents and a more complicated mechanical design	Has fewer components	Has fewer components
Performs multiple point sampling via time-sharing	Analyzes only one gas per unit	Analyzes only one gas per ;unit
Expands easily for additonal sampling points	Does not allow for expansion	Does not allow for expansion
Has higher initial cost (for single point sampling)	Offers lower initial cost (for single point sampling)	Offers lower initial cost (for single point sampling)
Has time-lag during analysis	Provides rapid response during analysis	Provides rapid response during analysis
Analysis is performed in a protected environment	Operates in a potentially harsh environment	Operates in a potentially harsh environment
Is relatively accessible for service and maintenance	May be relatively inaccessible for service and maintenance	Maybe relatively inaccessible for service and maintenance

In general, there are a number of parameters that characterize a successful continuous emissions monitoring program. Such programs have these similarities:

1. management backing, which should provide adequate funds as well as enough personnel to support the project;

2. planning and site-specific engineering by the vendor and/or consultants, to avoid design pitfalls and ensure its overall reliability;

3. good plant/agency relations, to promote communication and an understanding of the needs of both parties; and

4. singular, designated responsibility for all aspects of the CEMS.

Summary

Lesson 10 described the application of CEMSs in terms of their uses, limitations, and other considerations. The evaluation and comprehension of these topics should lead to the implementation of a successful continuous emissions monitoring program.

In addition to meeting regulatory requirements, properly installed and operating CEMSs will provide large amounts of source emissions data to the facility. Having the ability to examine various aspects of the source can provide the user the opportunity to make critical adjustments for process optimization and cost reduction.

The advantages of operating a CEMS are not limited to a plant however. Regulatory agencies are also benefited by the implementation of these programs. Having access to continuous emissions monitoring data provides the agency with a better picture of actual emissions and enhances their ability to develop strategies for future programs directed at emissions reduction.

The data acquisition subsystem (DAS) is an integral part of every monitoring system. Use of a modern, computerized DAS can effectively reduce the amount of time a CEMS user would have to dedicate for manual data collection and report preparation. Additionally, the sophistication of these systems often permits data transfer for use in other investigations and applications. A well-designed DAS effectively complements the other components of the overall monitoring system.

Other factors related to systems' applications, such as cost, calibration techniques, stack conditions, and sampling locations need to be addressed.

Finally, successful continuous emissions monitoring programs often have the following similar characteristics:

1. management backing,
2. planning and site-specific engineering by the vendor and/or consultants,
3. good plant/agency relations, and
4. singular, designated responsibility for all aspects of the CEMS.

REVIEW EXERCISES

1. True or false. Monitoring systems are very limited in the services provided since they can only record non-compliance situations.	
2. CEMSs data has generally been collected on a. tape recorders and strip chart recorders. b. logarithmic paper. c. computers and strip chart recorders. d. graphs.	1. False
3. A data acquisition system (DAS) can do all of the following except a. record data. b. analyze the target gas. c. edit data. d. correct for span drift.	2. c
4. True or false. A useful application of CEMS data is to identify O&M inadequacies.	3. b
5. The initial cost of an extractive CEMS is ____ the initial cost of an in-situ CEMS when monitoring at a single location. a. about the same as b. less than c. greater than	4. True
6. Time-sharing can be accomplished in _____ designs. a. extractive b. in-situ c. both a and b. d. neither a nor b.	5. c
7. True or false. Gas filled, calibration cells are completely reliable for performing routine calibrations.	6. a

8. Flue gas conditions are more easily compensated for by the application of a _____ design. a. extractive b. in-situ	7. False
9. _____ monitors linearly average pollutant concentration within the stack. a. No b. In-situ, path c. In-situ, point d. Extractive	8. a
10. True or false. An increasingly common application of CEMS data is to assess source operating efficiency.	9. b
	10. True

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UNIT 4

REGULATIONS

LESSON 11

Regulatory Requirements for Gas Emission Monitoring Systems

Lesson Goal and Objectives

Goal

To provide an overview of the various regulatory requirements involving the use of continuous gas emission monitoring systems.

Objectives

At the end of this lesson you should be able to -

1. list at least five source categories required to install continuous gas emission monitoring systems (for both new and existing sources),

2. distinguish the difference between "direct Emission" compliance monitoring data and "indicator of compliance" (excess emissions) monitoring data ,

3. list the regulatory procedures used by state and local agencies to ensure compliance with air quality standards,

4. describe how to use the Federal Register index and the LSA index in keeping track of newly proposed regulations or changes in existing regulations and

5. describe the use of a performance specification in the continuous gas emission monitoring program.

Introduction

So far, we have discussed the technical aspects of how continuous gas emission monitoring systems are designed and how they work. It is also important for the CEM user to understand how these systems relate to local, state and federal regulations. These regulatory requirements stipulate who is required to install continuous emission monitors, the specific type of monitor which can be used for a specific source category, and the performance test criteria and quality assurance procedures necessary to ensure that the monitoring system is reliable and accurate. These next three lessons deal with these important issues.

The Reasons for Monitoring Gas Emissions Continuously

The Clean Air Act as amended in 1977 (42 U.S.C. 1857 et seq.) requires that several types of regulations be established by the U.S. Environmental Protection Agency (EPA) [e.g., New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAPS)]. In addition, the Act requires that the National Ambient Air Quality Standards (NAAQS) be established and that states adopt provisions for seeing that these ambient air quality standards are met. In order to comply with state and federal regulations promulgated pursuant to the Clean Air Act, many industries have installed air pollutant reduction devices such as wet scrubbers, baghouses, electrostatic precipitators and carbon absorbers. Such equipment is expensive to buy and install and must undergo a rigorous maintenance schedule in order to ensure proper continuous operation. State air pollution control agencies must also ensure that sources are in compliance with applicable air regulations. Both maintenance of control equipment and compliance with applicable regulations can be enhanced through the monitoring of air pollutant emissions.

Monitoring air pollutant emissions can be done either continuously or by the use of EPA manual methods which are performed on a periodic basis. Using the EPA manual methods creates problems in that they are done infrequently as part of inspection programs and usually while the source in question is being operated under optimum conditions. Normally, these results do not reveal the true day-to-day concentrations of gaseous pollutants released from a given source. Continuous monitoring on the other hand, provides a continuous record of gaseous emissions. Such records can be used by both the state and the source in the following ways:

1. as an indicator that the source is using good operating and maintenance practices on its process and its control equipment in order to minimize gaseous air emissions,

2. as a continuous record of the source's ability to comply with gas emission standards,

3. as sufficient data to issue a Notice of Violation (NOV) in case the source is not complying with agency regulations or standards, and

4. as data on upset conditions or trend data indicating degradation of control equipment performance.

For regulatory purposes, there are two types of emission monitoring data. They are direct emissions compliance monitoring data and indicators of compliance (excess emission) monitoring data. Direct emissions compliance monitoring data (e.g., when continuous emission monitors (CEMS) are the state-approved

compliance method) are used directly to determine an emissions limit violation requiring appropriate enforcement action which could include issuing penalties to a given source offender. The excess emission monitoring data are used whenever a continuous emission monitor is not the state or EPA region's approved emissions compliance method. In this case, the data should be used to monitor the compliance status of a source and to initiate follow-up action which includes on-site inspections, requesting further information, and issuing a Notice of Violation. The use of continuous emission monitor (CEM) data for determining compliance and enforcement is further discussed in the EPA document, "Guidance: Enforcement Applications of Continuous Emission Monitoring Data", available through the EPA Office of Air Quality Planning and Standards (OAQPS) and OECM (Office of Enforcement and Compliance Monitoring) dated April 22, 1986.

In each instance where CEMS have been promulgated or approved by the regulatory agency as an official method to determine source compliance with the applicable emission limitations, the regulatory agency can rely upon CEM data when making compliance determinations. Continuous Emission Monitoring Systems (CEMS) have been specifically prescribed as the method to establish emission violations for one or more pollutants in the following instances:

1. for electric utility steam generating units, regulated by 40 CFR 60 Subparts Da and Db (New Source Performance Standards (NSPS)),

2. for primary nonferrous smelters regulated by 40 CFR Part 60 Subparts P, Q, and R (NSPS)

3. for NSPS stationary gas turbines regulated by 40 CFR 60 Subpart GG,

4. for various sources which are regulated by permits, orders or consent decrees in which CEM has been specifically designated as the test method,

5. for various types of sources which are regulated by the State Implementation Plan and where the state has specified in that plan, the use of CEM as the compliance test method, and

6. federal regulations promulgated as part of State Implementation Plans for non-ferrous smelters.

The reader should note that each subpart to 40 CFR Part 60 contains CEMS requirements pertaining to availability (e.g., the percentage of time which a monitoring unit must record source emissions). For example, 40 CFR60.47b(c) (i.e., subpart Db which pertains to Industiral Commercial Insitutional Steam Generating Uits, emission monitoring requirements for sulfur dioxide), states:

> *"(c) The owner or operator of an affected facility shall obtain emission data for at least 75 percent of the operating hours in at least 22 out of 30 successive boiler operating days. If this minimum data requirement is not met with a single monitoring system, the owner or operator of the affected facility shall supplement the emission data with data collected with other monitoring systems as approved by the Administrator or the reference methods and procedures as described in paragraph (b) of this section."*

The use of continuous gas emission monitors for ensuring regulatory compliance can be summarized by the following policy stated in a 1988 EPA Office of Air Quality Planning and Standards (OAQPS) memorandum:

> *"QAQPS is committed to promoting, encouraging and utilizing CEMS data as a compliance assessment measure. Our Office is also committed to the use of CEMS in direct enforcement where CEMS is the compliance test method*

and for supporting enforcement where CEMS is not the compliance test method. OAQPS encourages the use of CEMS data by States in compliance monitoring and in supplementing or supporting enforcement actions. If it is technically feasible, CEMS requirements should be incorporated into NSR preconstruction reviews, operating permits and resolutions of enforcement actions including consent decrees and administrative orders."

"CEMS should be used to assure continuous compliance of sources in both attainment and non attainment areas. Resources should be allocated to monitor continuous compliance of sources in areas where the greatest environmental benefit is likely to occur. Therefore, priority should be given to NESHAPS sources subject to continuous monitoring requirements. (currently 40 CFR 61, subparts F, N, O and V) and to SIP (including major and minor NSR sources) and NSPS sources in non-attainment areas (for the pollutant for which the area is non-attainment). Next, CEMS should be used to monitor the continuous compliance of NSPS and PSD sources in attainment areas. Sources with excessive emission limit excursions identified by CEMS data should be targeted for follow-up action (on-site inspection or 114 letter). Where CEMS is the compliance test method, CEMS data should be used to identify significant violators. These sources will then be tracked in accordance with the 'Timely and Appropriate Enforcement Response Guidance,' issued by [the Office of Air and Radiation] OAR on April 11, 1986."

Additionally, except where prohibited by state law, both state and local agencies may impose more stringent standards on sources in their jurisdiction. The regulatory procedures used to bring about these additional standards can be in the form of operating permits, variances, orders, agreements or promulgated regulations. All of these options can require continuous emission monitoring.

In meeting the NAAQS, states issue operating permits to both new and existing sources. Under the New Source Review (NSR) program, State Implementation Plans must establish provisions for the review of new or modified sources to ensure that the NAAQS will not be exceeded. Another program, called Prevention of Significant Deterioration (PSD), is designed to ensure that the construction or modification of a facility will not cause a significant degradation of air quality. The issuance of an operating permit may require the source to install a continuous emission monitor so that any significant emissions increase potentially resulting in a NAAQS violation would be detected.

Variances are sometimes issued on a temporary basis to allow a source to pollute above the standard provided that it meets the standard by a specified period of time. The granting of a variance may involve the implementation of certain continuous emission monitoring requirements.

Orders are usually issued as a result of public hearings and are an authorized=method of assuring compliance as stipulated in Section 113 of the Clean Air Act. It takes a certain type of legal authority to issue an order, there can be administrative orders, delayed compliance orders and court orders. An order may require that a source submit a plan for installing, calibrating, maintaining and operating a CEM.

Sometimes the regulatory agency may end up negotiating an agreement with a source in order that it meet the regulatory requirements within a certain period of time. There are several types of agreements, namely, consent decrees, stipulation agreements, and court settlements. Again, the use of a CEM may be a part of an agreement with the agency.

Finally, the promulgation of regulations is mandated through the federal requirements for New Source Performance Standards (NSPS) and the State Implementation Plans (SIPs). SIPs are submitted by the states to the EPA, explaining how the State plans to attain and maintain the NAAQS. Regulations promulgated as a result of a SIP often require continuous emission monitoring.

Sources Required to Install Continuous Gas Emission Monitors

As mentioned above, the Clean Air Act mandates that EPA develop NSPS and NESHAPS. In addition, states must adopt legally enforceable emission standards to ensure that NAAQS are met. Each of these, NSPS, NESHAPS, and state rules developed to meet NAAQS, contain testing and monitoring requirements. The NSPS are found in the Code of Federal Regulations Title 40, Part 60 (40 CFR 60).

The NESHAPS rules are found in 40 CFR 61. Minimum emission monitoring requirements for State Implementation Plans are found in 40 CFR 51, Appendix P. In the event that a state fails to adopt rules adequate for attaining the NAAQS, the EPA is required to promulgate substitute regulations. Federal regulations promulgated as part of a SIP are found in 40 CFR 52. *Table* 11-1 is a listing of the pertinent subparts and sections of the aforementioned code of federal regulation parts which specify the continuous monitoring requirements for each source category as well as the gases required to be monitored.

Table 11-1. **Continuous Monitoring Requirements for Each Source Category Emitting Pollutant Gases**

Source Category	40 CFR 60 Subpart	(40 CFR 51)* Appendix P Section	40 CFR 61 Subpart	Gases Required to be Monitored
Fossil Fuel Fired Steam Generators	D	2.1		SO_2, NO_x,(%O_2 or CO_2)
Electric Utility Generating Units	Da			SO_2, NO_x, O_2, CO_2
Industrial Commercial-Institutional Steam Generating Units	Db			SO_2, NO_x
Nitric Acid Plants	G	2.2		NO_x
Sulfuric Acid Plants	H	2.3		SO_2, (O_2 & CO_2 in part H)
Petroleum Refineries	J			CO, SO_2
Primary Copper Smelters	P			SO_2
Primary Zinc Smelters	Q			SO
Primary Lead Smelters	R			SO_2
Kraft Pulp Mills	BB			TRS (Total Reduced Sulfer), %O_2
Stationary Gas Turbines	GG			SO_2, NO_x
Ethylene Dichloride Purification Systems/ Plants, Vinyl Chloride Plants, Polyvinyl Chloride Plants			F	Vinyl Chloride
Arsenic Trioxide and Metallic Arsenic Production Facilities			P	Ambient Air Monitoring of Inorganic Arsenic

* *These requirements also apply to 40 CFR 52, unless the continuous gas emission monitoring requirements are not approved in the State Implementation Plan.*

Federal and state monitoring requirements are subject to changes, and it is important to stay abreast of these changes in order to make sure that new requirements are met. New regulations, revisions to existing regulations, and notices of revisions to SIPs are all published in the Federal Register (FR). The FR is published daily and codified annually in the Code of Federal Regulations. The FR is a useful tool in keeping track of daily updates in the CFR. There are two indices which can be used in tracking the changes in the regulations. They are the Federal Register Index which is published monthly and is accumulated on a twelve month basis, and the LSA (List of CFR Sections Affected) Index which is published on a monthly basis. The steps employed in using these references are contained in the discussions which follow.

Federal Register Index

The first step in learning to use the Feeral Register Index is to obtain a copy of it. Most libraries subscribe to this publication, a copy of which is shown in *Figure* 11-1.

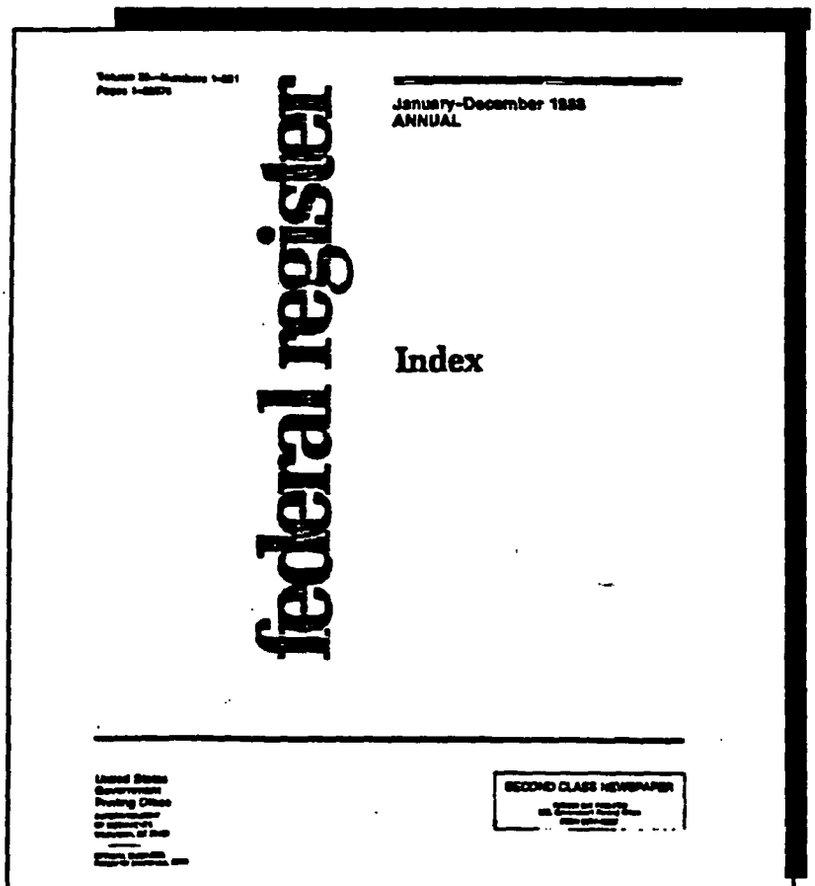


FIGURE 11-1 FEDERAL REGISTER INDEX TITLE PAGE

After obtaining a copy, find the listing of the agency or topic which is affected by the regulation of interest [in this case, the EPA, (see *Figure* 11-2)]. These topic or agency headings will be subdivided into Rules, Proposed Rules and Notices. Under the subheading, Rules, look for the specific area of interest (say air pollution; standards of performance for new stationary sources). Under this area look for the specific topic under the specific area of interest. *Figure* 11-3 shows how to find anything regarding continuous emission rate monitoring systems; specification and test procedures.

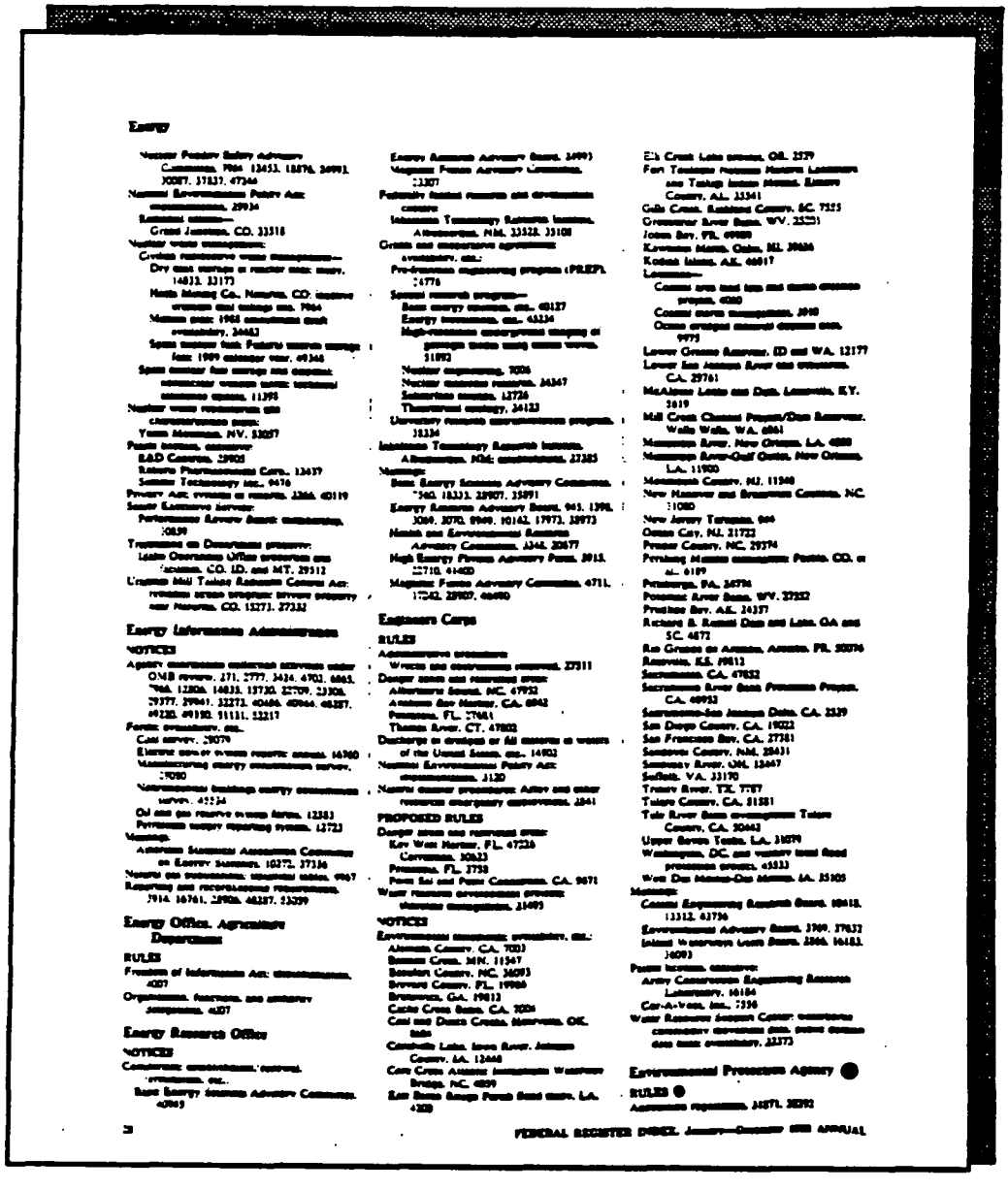


FIGURE 11-2 FEDERAL REGISTER INDEX - FEDERAL AGENCY OR TOPIC AND SUBTOPIS LISTINGS

You will notice that after each topic of interest, there is a page number. Remember that number as you turn to the back of the index and find the section "Federal Register Pages and Dates" (*Figure* 11-4). The first column gives the range of pages and the second column gives the date of the Federal Register notice that deals with the specific topic/area that you are interested in. The third column gives the Federal Register volume number. Using

the first column, find the page range which your issue falls into. The corresponding second and third columns tell you the date and volume of the Federal Register Notice where the required information can be found. Once the FR volume number has been found, find the page number [located in the upper left corner of each page, (see *Figure* 11-5)] corresponding to the number referenced in the FR index. The FR notice which you were looking for will be found on that page.

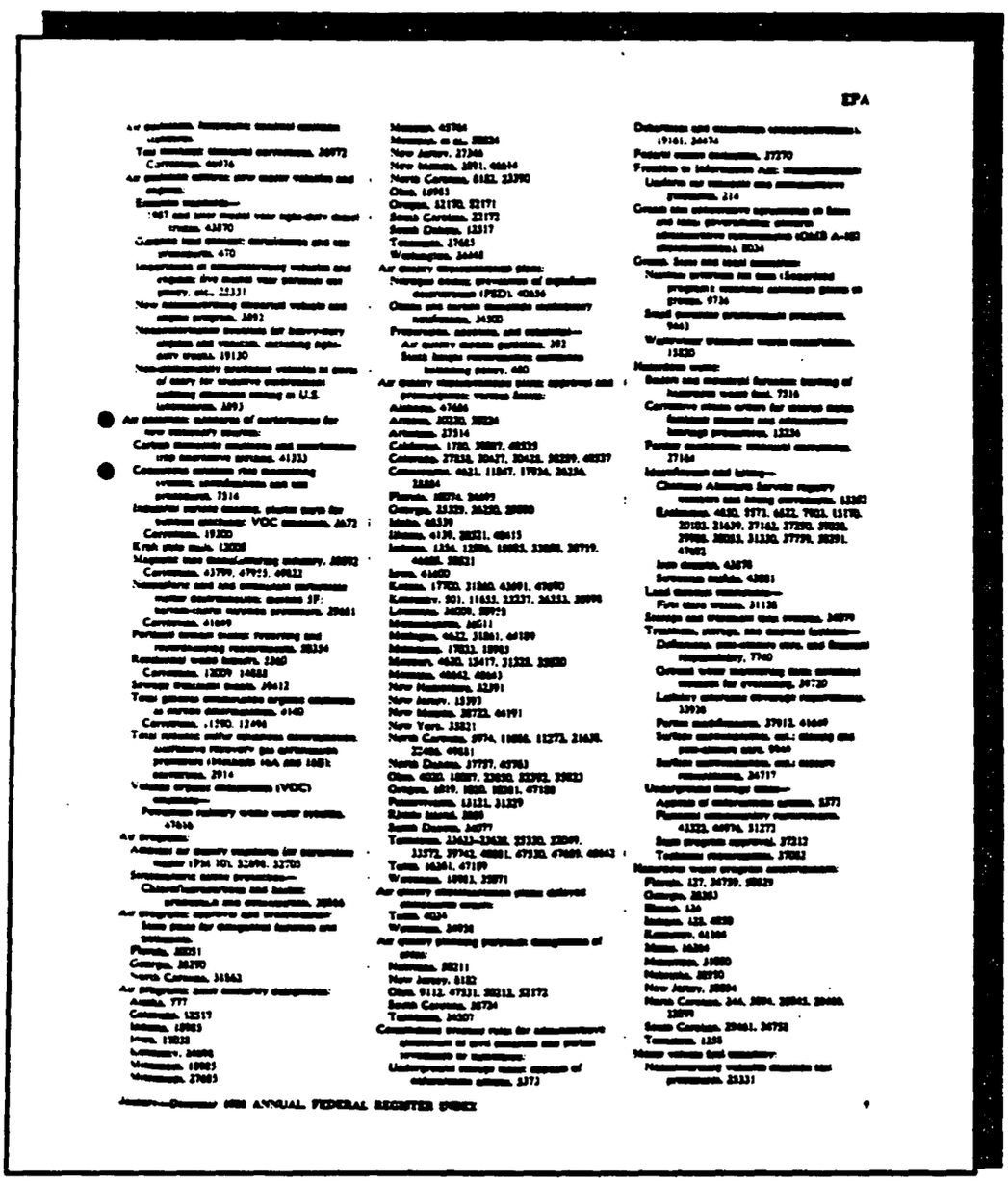
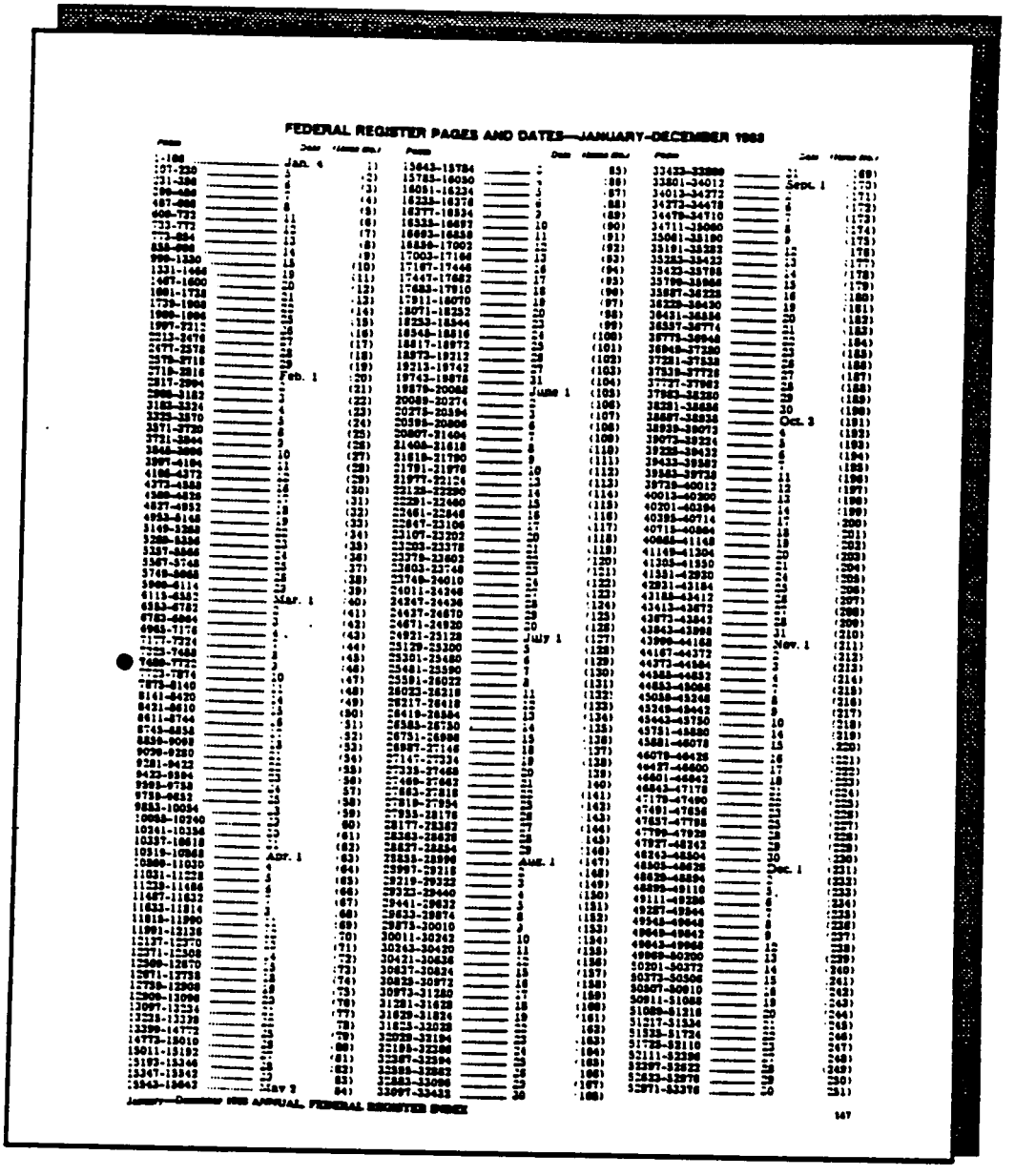


FIGURE 11-3 FEDERAL REGISTER INDEX LISTINGS OF SPECIFIC AREAS OF INTEREST

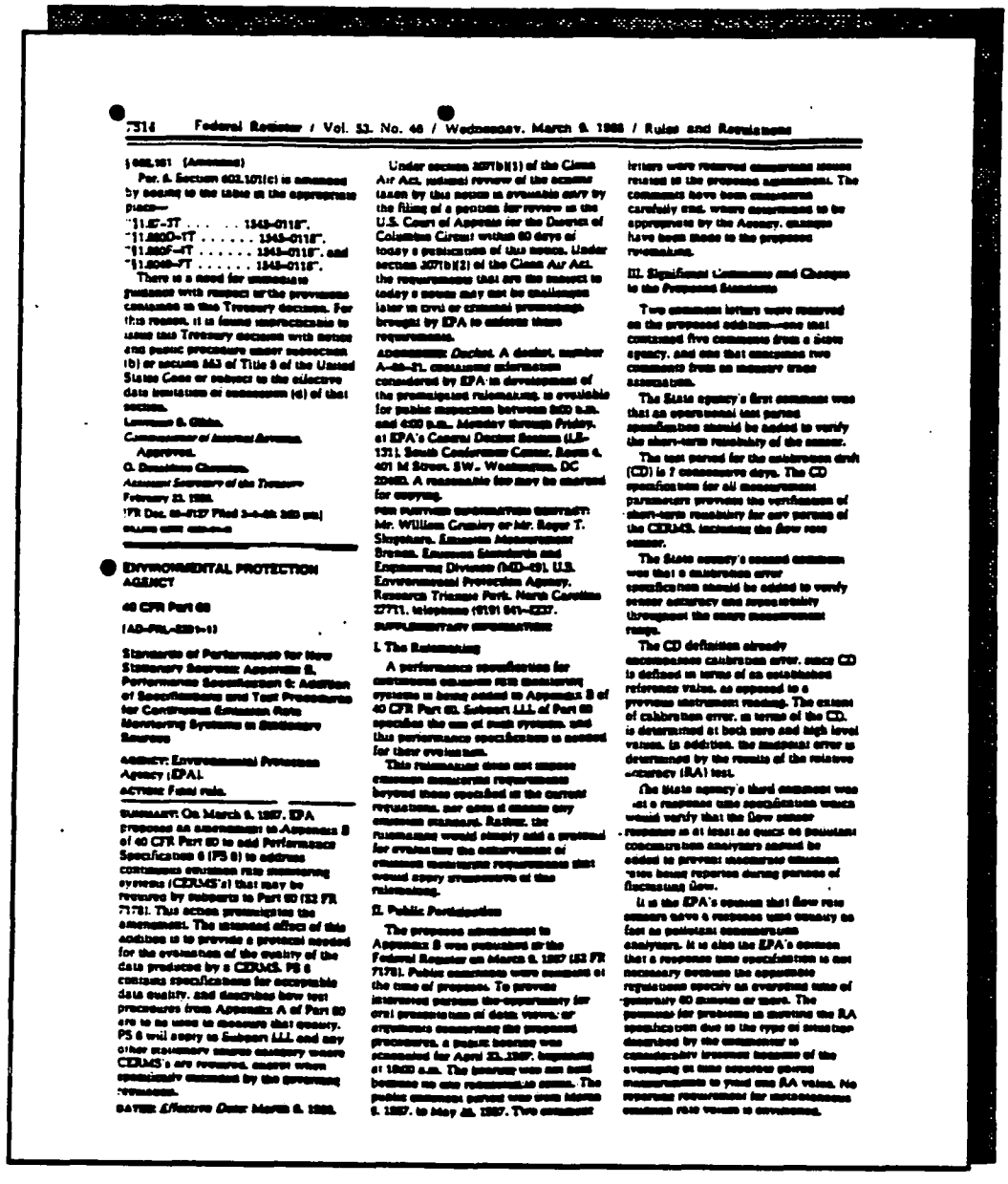


FEDERAL REGISTER PAGES AND DATES—JANUARY-DECEMBER 1988

FIGURE 11-4 FEDERAL REGISTER INDEX LISTING OF PAGES AND DATES OF FEDERAL REGISTER NOTICES

LSA Index

The second reference that can be used to stay abreast of changes in regulations is the LSA (see *Figure* 11-6). This index is arranged according to the CFR title and part. In this example, we will look for any amendments, revisions or proposals to Title 40 Part 60. First (refer to *Figure* 11-7), turn to the section in the index under Title 40 (the title number can be found at the top left corner of each page in bold print). Next, locate the section number of interest. Lets say that we want to research Section 60.8. Go down the column until you find 60.8 and look over



7314 Federal Register / Vol. 53, No. 46 / Wednesday, March 9, 1988 / Rules and Regulations

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 60

Standards of Performance for New Stationary Sources; Appendix B, Performance Specification 6; Addition of Specifications and Test Procedures for Continuous Emission Rate Monitoring Systems in Stationary Sources

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: On March 9, 1987, EPA proposed an amendment to Appendix B of 40 CFR Part 60 to add Performance Specification 6 (PS 6) to address continuous emission rate monitoring systems (CERMS's) that may be required by subparts to Part 60 (52 FR 7178). This action promulgates the amendment. The intended effect of this addition is to provide a protocol needed for the evaluation of the quality of the data produced by a CERMS. PS 6 contains specifications for acceptable data quality, and describes how test procedures from Appendix A of Part 60 are to be used to measure that quality. PS 6 will apply to Subpart LLL and any other stationary source category where CERMS's are required, except when specifically excluded by the governing regulation.

DATES: Effective Date: March 9, 1988.

Under section 307(b)(1) of the Clean Air Act, judicial review of the action taken by this notice is available only by the filing of a petition for review in the U.S. Court of Appeals for the District of Columbia Circuit within 60 days of today's publication of this notice. Under section 307(b)(2) of the Clean Air Act, the requirements that are the subject to today's notice may not be challenged later in civil or criminal proceedings brought by EPA to enforce these requirements.

ADDRESSES: Docket. A docket, number A-86-31, containing information considered by EPA in development of the promulgated rulemaking, is available for public inspection between 8:00 a.m. and 4:00 p.m., Monday through Friday, at EPA's Central Docket Section (LE-131), South Conference Center, Room 4, 401 M Street, SW., Washington, DC 20460. A reasonable fee may be charged for copying.

FOR FURTHER INFORMATION CONTACT: Mr. William Crawley or Mr. Roger T. Shigehara, Emission Measurement Branch, Emission Standards and Engineering Division (MD-19), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, telephone (919) 541-5237.

SUPPLEMENTARY INFORMATION:

I. The Rulemaking

A performance specification for continuous emission rate monitoring systems is being added to Appendix B of 40 CFR Part 60. Subpart LLL of Part 60 specifies the use of such systems, and this performance specification is needed for their evaluation.

This rulemaking does not impose emission monitoring requirements beyond those specified in the current regulations, nor does it impose any emission standard. Rather, the rulemaking would simply add a protocol for evaluating the enforcement of emission monitoring requirements that would apply irrespective of this rulemaking.

II. Public Participation

The proposed amendment to Appendix B was published in the Federal Register on March 9, 1987 (52 FR 7178). Public comments were accepted at the time of proposal. To provide interested persons the opportunity for oral presentation of data, views, or arguments concerning the proposed procedures, a public hearing was scheduled for April 23, 1987, beginning at 10:00 a.m. The hearing was not held because no one requested it. The public comment period was from March 9, 1987, to May 26, 1987. Two comment letters were received concerning issues related to the proposed amendment. The comments have been considered carefully and, where determined to be appropriate by the Agency, changes have been made to the proposed rulemaking.

III. Significant Comments and Changes to the Proposed Standards

Two comment letters were received on the proposed addition—one that contained five comments from a State agency, and one that contained two comments from an industry trade association.

The State agency's first comment was that an operational test period specification should be added to verify the short-term reliability of the sensor.

The test period for the calibration drift (CD) is 7 consecutive days. The CD specification for all measurement parameters provides the verification of short-term reliability for any parameter of the CERMS, including the flow rate sensor.

The State agency's second comment was that a calibration error specification should be added to verify sensor accuracy and repeatability throughout the entire measurement range.

The CD definition already encompasses calibration error, since CD is defined in terms of an established reference value, as opposed to a previous instrument reading. The extent of calibration error, in terms of the CD, is determined at both zero and high level values. In addition, the maximum error is determined by the results of the relative accuracy (RA) test.

The State agency's third comment was that a response time specification which would verify that the flow sensor response is at least as quick as pollutant concentration analyzers should be added to prevent inaccurate emission rates based reported periods of fluctuating flow.

It is the EPA's opinion that flow rate sensors have a response time comparable to fast as pollutant concentration analyzers. It is also the EPA's opinion that a response time specification is not necessary because the applicable regulations specify an averaging time of generally 60 minutes or more. The potential for problems in meeting the RA specification due to the type of detection described by the commenter is considerably lessened because of the averaging of data sources given measurements to yield one RA value. No separate requirement for instantaneous emission rate values is envisioned.

FIGURE 11-5 FEDERAL REGISTER NOTICE PAGE

to the right column and find the corresponding page number (page 6662, in this case). With that page number in mind, turn to the back of the index and locate the page(s) marked "*Table* of Federal Register Issue Pages and Dates" (see to *Figure* 11-8). In the left hand column, you will see the page ranges and in the right hand column the corresponding date of publication in the Federal Register. Simply match the number you obtained in the title section with the page ranges and then obtain the Federal Register Notice published on that date. You will note that the LSA index gives only the date and not the volume number of the FR notice. The page which was referenced in the LSA index is the Federal Register page which you will need to go to for the date referenced (in this case Tuesday, February 14, 1989). *Figure* 11-9 shows the page number in the Federal Register where the notice regarding the Part 60.8 amendment is contained.

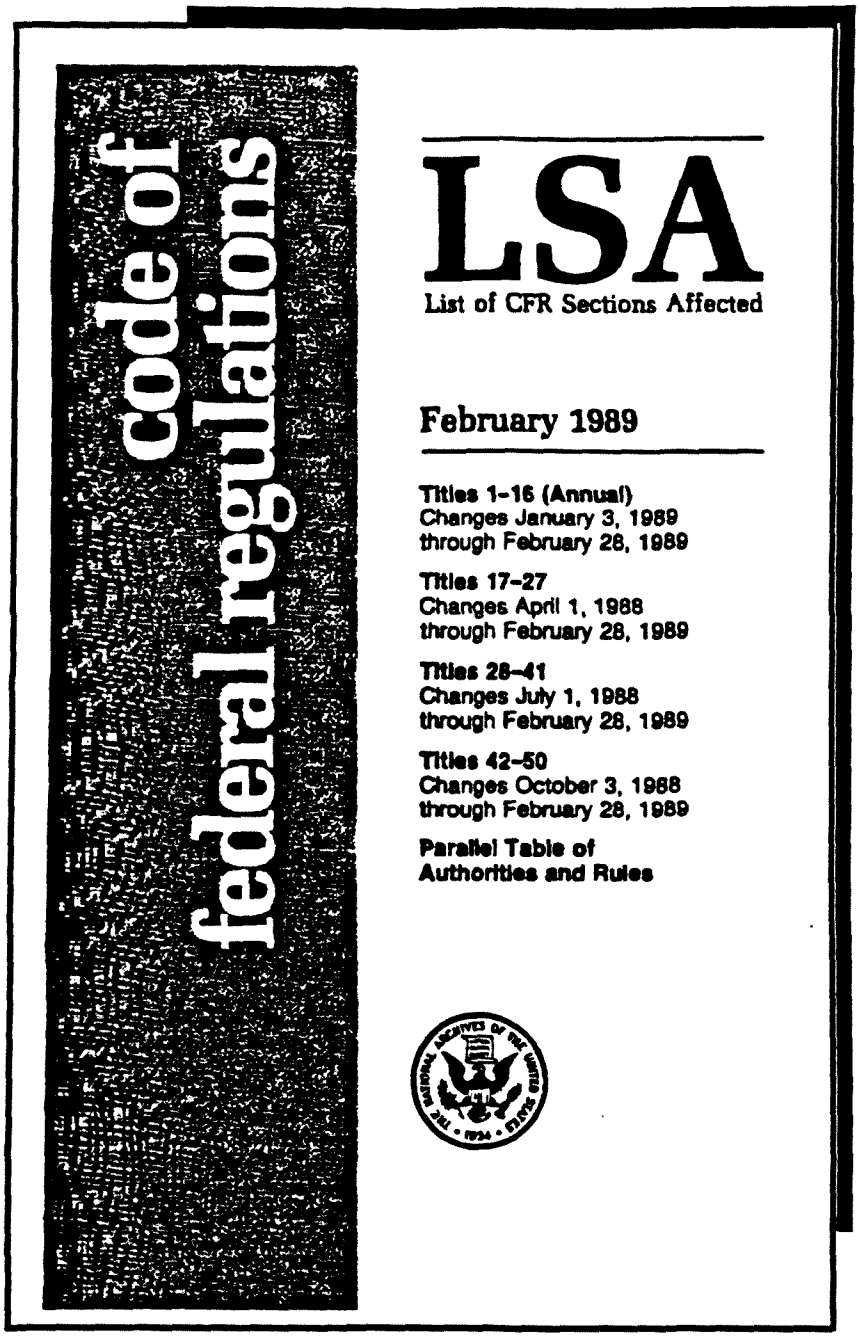
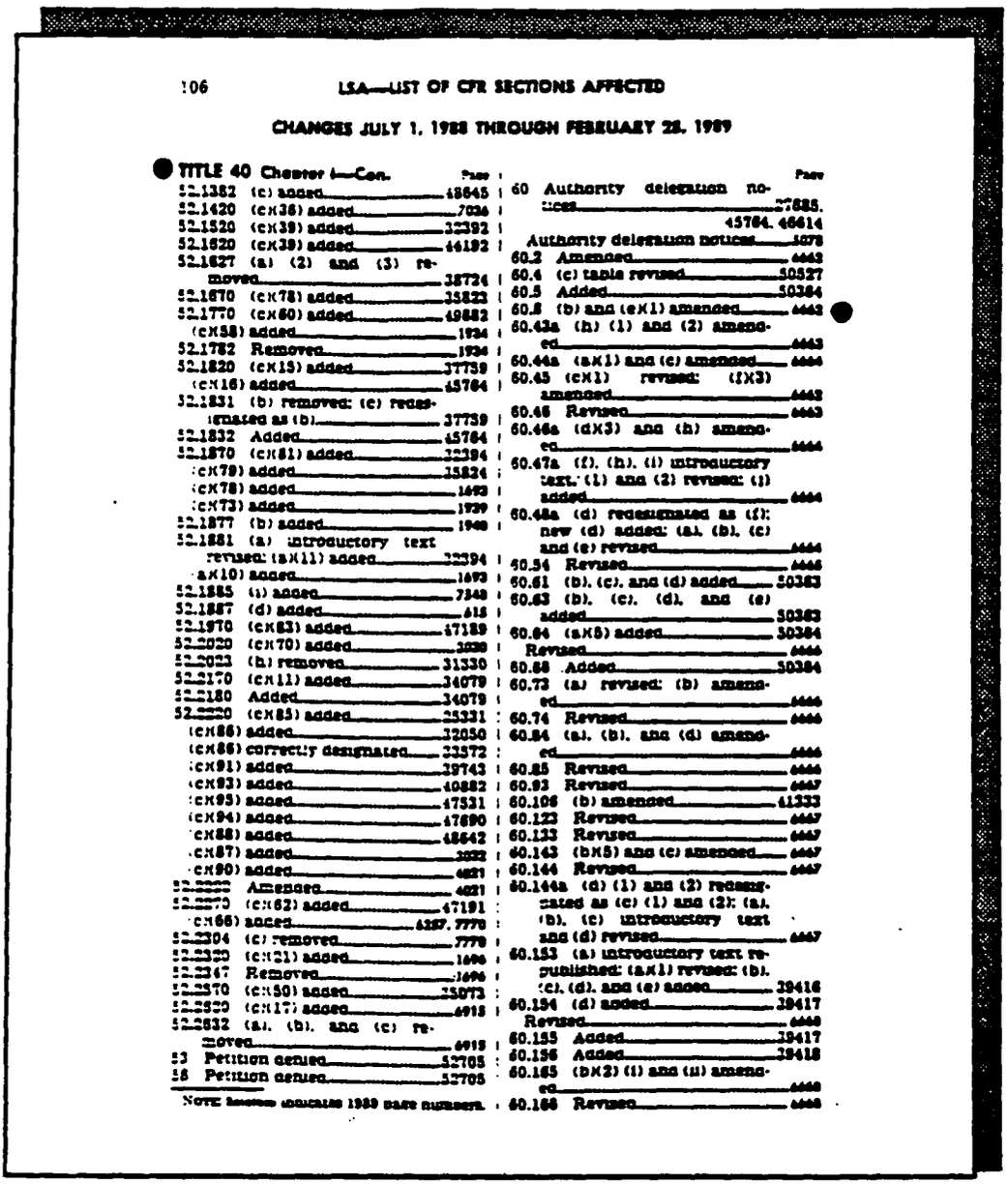


FIGURE 11-6 LSA - LIST OF C FR SECTIONS AFFECTED INDEX TITLE PAGE

Acceptable Monitor Criteria

When continuous gas emission monitoring systems are required in an NSPS, NESHAPS, or state rule, it is usually to ensure that control equipment performance is maintained in such a way that a source remains in compliance with the standard. In regard to NSPS, 40 CFR 60 states that all continuous emission monitoring systems which require gas pollutant monitoring are subject to the performance specifications under Appendix B

(Part 60) and, are subject to Appendix F (Part 60 Quality Assurances Procedures) if they are used to demonstrate compliance with emission limits on a continuous basis. We will discuss the requirements of Appendices B and F (Part 60) in lessons 12 and 13, respectively.



106 LSA—LIST OF CFR SECTIONS AFFECTED

CHANGES JULY 1, 1988 THROUGH FEBRUARY 28, 1989

TITLE 40 Chapter I—Con. Page

52.1382 (c) added 48645
52.1420 (cX38) added 7036
52.1520 (cX39) added 32392
52.1620 (cX39) added 44192
52.1627 (a) (2) and (3) removed 38724
52.1670 (cX78) added 35823
52.1770 (cX60) added 49882
(cX58) added 1934
52.1782 Removed 1934
52.1820 (cX15) added 37739
(cX16) added 45764
52.1831 (b) removed; (c) redesignated as (b) 37739
52.1832 Added 45764
52.1870 (cX81) added 32394
(cX79) added 35824
(cX78) added 1693
(cX73) added 1939
52.1877 (b) added 1940
52.1881 (a) introductory text revised; (aX11) added 32394
(aX10) added 1693
52.1885 (i) added 7348
52.1887 (d) added 618
52.1970 (cX83) added 47189
52.2020 (cX70) added 3030
52.2023 (h) removed 31330
52.2170 (cX11) added 34079
52.2180 Added 34079
52.2220 (cX85) added 25331
(cX86) added 32050
(cX88) correctly designated 33572
(cX91) added 39743
(cX93) added 40882
(cX95) added 47531
(cX94) added 47690
(cX88) added 48642
(cX87) added 3032
(cX90) added 4021
52.2222 Amended 4021
52.2270 (cX62) added 47191
(cX66) added 6287, 7770
52.2304 (c) removed 7770
52.2320 (cX21) added 1696
52.2347 Removed 1696
52.2370 (cX50) added 25073
52.2520 (cX17) added 6915
52.2532 (a), (b), and (c) removed 6915
53 Petition denied 32705
58 Petition denied 32705

NOTE: Boldface indicates 1989 date numbers.

60 Authority delegation notices 27685, 45764, 46614
Authority delegation notices 5078
60.2 Amended 4443
60.4 (c) table revised 50527
60.5 Added 50384
60.8 (b) and (eX1) amended 4443
60.43a (h) (1) and (2) amended 4443
60.44a (aX1) and (c) amended 4444
60.45 (cX1) revised; (fX3) amended 4443
60.46 Revised 4443
60.46a (dX3) and (h) amended 4444
60.47a (f), (h), (i) introductory text, (1) and (2) revised; (j) added 4444
60.48a (d) redesignated as (f); new (d) added; (a), (b), (c) and (e) revised 4444
60.54 Revised 4446
60.61 (b), (c), and (d) added 50383
60.63 (b), (c), (d), and (e) added 50383
60.64 (aX5) added 50384
Revised 4446
60.68 Added 50384
60.73 (a) revised; (b) amended 4446
60.74 Revised 4446
60.84 (a), (b), and (d) amended 4446
60.85 Revised 4446
60.93 Revised 4447
60.106 (b) amended 41333
60.123 Revised 4447
60.133 Revised 4447
60.143 (bX5) and (c) amended 4447
60.144 Revised 4447
60.144a (d) (1) and (2) redesignated as (c) (1) and (2); (a), (b), (c) introductory text and (d) revised 4447
60.153 (a) introductory text republished; (aX1) revised; (b), (c), (d), and (e) added 39416
60.154 (d) added 39417
Revised 4448
60.155 Added 39417
60.156 Added 39418
60.165 (bX2) (i) and (ii) amended 4448
60.166 Revised 4448

FIGURE 11-7 LSA LIST OF CFR SECTIONS AFFECTED INDEX PAGE CONTAINING THE CODE OF FEDERAL REGULATIONS TITLE PART NUMBER OF INTEREST

40 CFR 51, Appendix P requires that each State Implementation Plan establish requirements for the use of continuous emission monitors. This appendix includes requirements for source categories that must be monitored; incorporates performance specification tests required under Appendix B of Part 60; and lists recordkeeping and reporting requirements. The performance specifications mentioned under Appendix B of Part 60 are used to

evaluate continuous emission monitors for acceptance at the time of installation (or soon thereafter) and whenever the regulations specify that they be reevaluated. Essentially, the performance specification test is used to particular location may not be sufficient for use at another location due to differences in heat, vibration, etc. between these locations. Thus, each source and its continuous emission monitoring system must be evaluated to see that the monitoring system is suitable for that source and that it is operated properly.

172 TABLE OF FEDERAL REGISTER ISSUE PAGES AND DATES

35987-36228	Sept. 16
36229-36430	19
36431-36556	20
36557-36774	21
36775-36948	22
36949-37280	23
37281-37538	26
37539-37726	27
37727-37982	28
37983-38280	29
38281-38686	30
38687-38938	Oct. 3
38939-39072	4
39073-39224	5
39225-39432	6
39433-39582	7
39583-39738	11
39739-40012	12
40013-40200	13
40201-40394	14
40395-40714	17
40715-40864	18
40865-41148	19
41149-41304	20
41305-41550	21
41551-42930	24
42931-43184	25
43185-43412	26
43413-43672	27
43673-43842	28
43843-43998	31
43999-44166	Nov. 1
44167-44372	2
44373-44584	3
44585-44852	4
44853-45058	7
45059-45248	8
45249-45442	9
45443-45750	10
45751-45880	14
45881-46078	15
46079-46426	16
46427-46600	17
46601-46842	18
46843-47178	21
47179-47490	22
47491-47656	Nov. 23
47657-47798	25
47799-47926	28
47927-48242	29
48243-48504	30
48505-48628	Dec. 1
48629-48894	2
48895-49110	5
49111-49286	6
49287-49544	7
49545-49648	8
49649-49842	9
49843-49968	12
49969-50200	13
50201-50372	14
50373-50506	15
50507-50910	16
50911-51088	19
51089-51216	20
51217-51534	21
51535-51724	22
51725-52110	23
52111-52396	27
52397-52622	28
52623-52970	29
52971-53376	30
1989	
1-96	Jan. 3
97-270	4
271-386	5
387-594	6
595-786	9
787-960	10
961-1142	11
1143-1324	12
1325-1674	13
1675-1922	17
1923-2080	18
2081-2984	19
2985-3404	23
3405-3576	24
3577-3768	25
3769-3978	26
3979-4248	27
4249-4748	30
4749-5070	31
5071-5206	Feb. 1
5207-5404	2
5405-5582	3
5583-5920	6
5921-6114	7
6115-6262	8
6263-6380	9
6381-6502	10
6503-6640	13
6641-6860	14
6861-7028	15
7029-7170	16
7171-7390	17
7391-7520	21
7521-7750	22
7751-7924	23
7925-8180	24
8181-8266	27
8267-8518	28

FIGURE 11-8 LSA - LIST OF CFR SECTIONS AFFECTED INDEX TABLE OF FEDERAL REGISTER ISSUE PAGES AND DATES

40 CFR 61 lists the continuous emission monitoring requirements for sources regulated under the National Emission Standards for Hazardous Air Pollutants (NESHAPS). Specifically, these requirements are delineated in Subparts F and P.

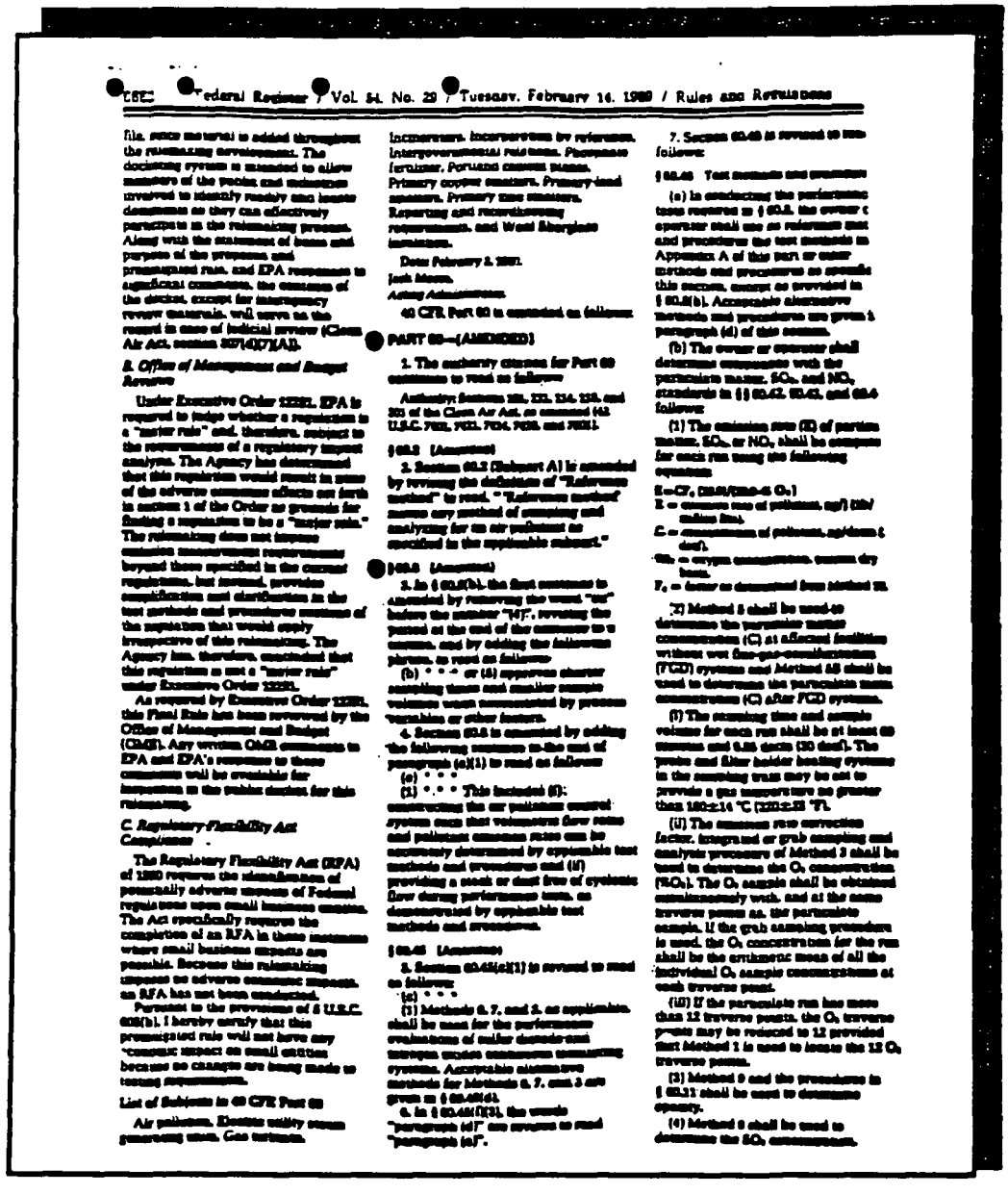


FIGURE 11-9 FEDERAL REGISTER NOTICE PAGE CONTAINING THE NOTICE REGARDING THE AMENDED CODE OF FEDERAL REGULATIONS TITLE PART

Summary

The U.S. Clean Air Act as amended in 1977, mandated EPA to promulgate New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAPS) and to establish National Ambient Air Quality Standards (NAAQS). States must see that sources are adequately controlled through a state-established permit review system in order to meet the NAAQS.

Continuous gas emissions monitoring requirements have been established in order to demonstrate whether a source is or is not in compliance with the applicable air quality standards. The continuous gas emission monitoring requirements for sources are contained in the applicable Code of Federal Regulation Parts. As we will learn in Lesson 12, performance specification tests (contained in 40 CFR 60, Appendix B) are required to be performed on CEMS in order to assure that such equipment is reliable, accurate and durable.

REVIEW EXERCISES	
1. True or false. Excess emission monitoring data are used whenever the use of continuous emission monitoring data is the state's approved compliance method.	
2. List three regulatory procedures which state or local agencies use in order to assure compliance with air quality standards.	1. False
3. Continuous Emission Monitoring Emissions Standards for Hazardous Air Pollutants (NESHAPS) are contained in 40 CFR Part ____.	2. Any three of the following variances, operating permits, orders, agreements, or promulgated regulations.
4. Title 40 Part ___ of the Code of Federal Regulations deals with continuous emission monitoring under State Implementation Plans.	3. 61
5. 40 CFR Part 51 (Appendix P) Section 2.1 pertains tocontinuous emission monitoring requirements for: a. Electric Utility Generating Units b. Kraft Pulp Mills c. Primary Zinc Smelters d. Fossil Fuel Steam Generators	4. 51
6. List the two federally published indices which can be used to keep track of changes in the Code of Federal Regulations.	5. d
7. Performance Specification Tests Index and the LSA Index. for continuous emission monitors are found in Appendix __.	6. Federal Register

8. A performance specification test will determine if a continuous emission monitoring system is: a. accurate b. durable c. reliable d. all of the above	7. 40 CFR 60, B
9. True or false. Continuous emission monitoring requirements for sulfuric acid plants are described in both 40 CFR 60 subpart H and in 40 CFR 51 Appendix P section 2.3.	8. d
10. True or false. Continuous emission monitoring requirements for nitric acid plants are found only in 40 CFR 51 Appendix P, section 2.2.	9. True
	10. False

REFERENCES

1. Protection Agency (EPA). 1975. *Requirements for Submittal of Implementatio Plans-Standards for New Stationary Sources-Emission Monitoring*. 40 FR 46240 (October 6, 1975).

2. Environmental Protection Agency (EPA). 1982. *Memorandum: Guidance Concerning EPA's Use of Continuous Emission Monitoring Data: K.M. Bennett to Regional Office Directors. EPA Air Programs Policy and Guidance Notebook-Office of Air Quality Planning and Standards*. Research Triangle Park, N.C. Policy Notebook Number: PN113-82-08-12-014. (Available for public inspection and copying at EPA Regional Offices).

3. Environmental Protection Agency (EPA). 1984. *APTI Course SI:476A Transmissometer Systems-Operation and Maintenance, An Advanced Course-Self Instructional Handbook*. EPA 450/2-84-004 (Revised March 24, 1986).

4. Environmental Protection Agency (EPA). 1988. *Memorandum: Transmittal of Reissued OAQPS CEMs Policy: Gerard A. Emison, Director, OAQPS to Regional Office Directors. EPA Air Programs Policy and Guidance Notebook-Office of Air Qaulity Planning and Standards*. Research Triangle Park, N.C. Policy Notebook Number: PN113-88-03-31-048. (Available for public inspection and copying at EPA Regional Offices).

LESSON 12

Performance Specification Test Procedures

Lesson Goal and Objectives

Goal

To explain the performance specification test procedures for continuous emission monitoring systems as required by *Appendix* B of Part 60 Title 40 of the Code of Federal Regulations (40 CFR 60) and to provide a basic outline of the requirements for the pollutant gases addressed in that appendix.

Objectives

At the end of this lesson, you should be able to -

1. describe the parameters which are measured in a performance specification test;
2. define span value, relative accuracy, calibration drift, EPA reference method, and stratification;
3. describe the specifications used for properly installing the continuous emission monitor (CEM) and how locations for taking performance specification test measurements are determined; and
4. define the variables used in calculating the relative accuracy and calibration drift.

Introduction

As we learned in Lesson 11, federal regulations pertaining to the installation and use of continuous gas emission monitoring equipment are found in 40 CFR Parts 51, 52 and 60. The CEM requirements mentioned in these Parts reference *Appendix* B to 40 CFR 60. This appendix delineates certain performance specification test procedure requirements which continuous emission monitors (CEMs) must pass before they can be used for regulatory purposes. These tests are performed on a one time basis at the time of or soon after (within 30 days) the initial installation of the monitoring system. Additionally, these tests may be required at other times by the EPA pursuant to *Section* 114 of the Clean Air Act. The performance specification tests are required in order to ensure that the monitoring equipment meets certain design and specification requirements with the intent being

that the equipment will be reliable once it has been installed for use. These performance specification tests were not designed to evaluate the installed CEM performance over an extended period of time nor do they identify specific calibration techniques and other auxiliary procedures to assess the CEM performance. The source owner, or operator, however, is responsible for proper calibration, maintenance, and operations of the CEM as stated in 40 CFR Part 60, *Appendix* B and 40 CFR Part 51, *Appendix* P.

The use of the phrases "performance specification test", and "performance tests" have been used interchangeably, but there are a couple of distinctions in the actual definitions of these terms. First of all, a "performance test" (as defined in 40 CFR Part 60) is an emission compliance test which is not related to testing a CEM system. This performance test is used to ensure that sources subject to continuous emission monitoring regulatory requirements (e.g., NSPS) are in compliance with the applicable emission standards. Secondly, a "performance specification test" is a set of procedures required by 40 CFR Part 60.13 to evaluate the accuracy and reliability of systems (CEMS).

CEM performance specification tests were initially promulgated in 1975 for opacity monitors (PS1), SO_2 and NO_x (PS_2), and CO_2 and O_2 (PS3). Since that time, these performance specification tests have undergone various revisions including reorganization of each of these tests, improved descriptions of CEM location requirements for PS1, clarification of calibration drift (CD) and relative accuracy (RA) test requirements in PS2 and PS3, and an increased reliance on the RA test results for assessing CEMS performance in PS2. Finally, since 1975 three additional performance specification tests have been promulgated. They are CO (PS4) which was published on August 5, 1985 total reduced sulfur (TRS) (PS5) which was published on July 20, 1983, and Continuous Emission Rate Monitoring Systems (CERMS) (PS6) which was published on March 9, 1988. The reader should note that PS6 involves Performance Specifications Tests for equipment required for the determination and recording of a pollutant mass emission rate (in terms of mass per unit time). CERMS are not the subject of this course and PS6 will not be discussed in this lesson.

In this lesson, we will explore the technical requirements of *Appendix* B. In particular, we will discuss the performance specification tests for continuous gas emission monitors, define some of the important terms used in this appendix, describe the CEM parameters (calibration drift and relative accuracy) which are required to be tested and the acceptable specification test values, discuss the specifications for locating and installing a CEM, and discuss the methods used for determining the calibration drift and relative accuracy.

Overview of Appendix B

Table 12-1, lists the topics covered in performance specification tests, numbers 2-5, for CEM equipment used to monitor SO_2 and NOx (PS2), CO_2 and O_2 (PS3), CO (PS4), and TRS (PS5). It should be noted, that specification tests 3-5 use almost the same procedures outlined in specification test 2. Because of this, the following discussions focus on specificiation test number 2. We will first address *Section* 2.0, Definitions.

Performance specifications tests 2-5 have several key terms in common and these terms are important to learn in order to understand each test procedure. The terms we will address are: 1) Span Value, 2) Relative Accuracy (RA), 3) Calibration Drift (CD), and 4) Reference Methods (RM).

Span Value refers to the full range of the monitoring system and is defined as "The upper limit of a gas concentration measurement range specified for affected source categories in the applicable subpart of the regulations".

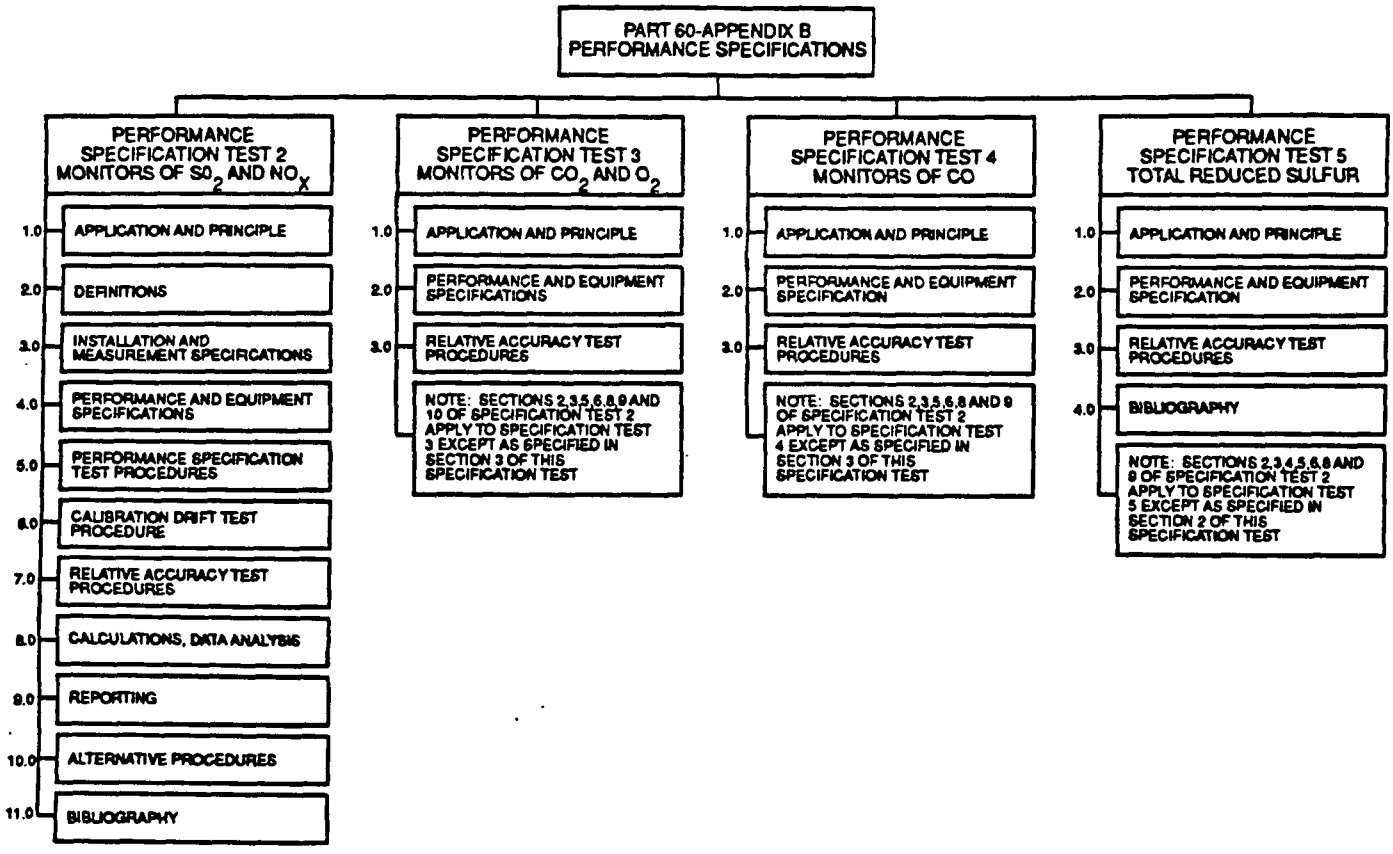


TABLE 12-1 CODE OF FEDERAL REGULATIONS, TITLE 40, PART 60, APPENDIX B PERFORMANCE SPECIFICATION TEST PROCEDURE SECTIONS (SPECIFICATION TESTS #2, #3, #4, AND #5

The Relative Accuracy (RA) of a gas CEM is the percent difference in the continuous monitor's measurement of the pollutant versus the value of the measurement as a result of using an EPA Reference Method. Because the accuracy of the monitoring system is determined by the use of a second, independent measurement and not by a known or actual value, the term Relative Accuracy and not, Accuracy, is used.

The Calibration Drift (CD) refers to the comparison of the monitor's response to a known concentration of gas. If the continuous emission monitoring system has a separate pollutant and diluent monitor, then the CD test must be performed separately for each monitor. We will discuss the difference between a pollutant and a diluent monitor later.

The Reference Method is a way to sample and analyze for an air pollutant. These methods are found in *Appendix* A of Part 60 and are required to be used in the performance specification test procedures of *Appendix* B. For the most part, these reference methods rely on equipment specifications, but a few of the methods do rely on performance criteria. That is to say, some reference methods have established performance criteria by which any system design can be used as long as it meets the criteria.

It is important to note, that whenever source owners are required to perform specification tests on newly installed CEM equipment, the regulatory agency will appoint a representative to observe the tests in order to ensure

that they are performed in accordance with the specification requirements. A detailed explanation of the required specification test(s) as well as specific instructions and recommendations for the test report which the observer must file are contained in an EPA document entitled, "Performance Specification Tests for Pollutant and Diluent Gas Monitors: Reporting Requirements, Report Format, and Review Procedures," EPA-340-1/83-013. These regulatory personnel can be from the state control agency or the EPA regional office and must be specifically trained to work with CEMS.

Tables 12-2 through 12-5 provide a basic overview of the accepted specification test values for zero drift,calibration drift and relative accuracy, as well as the period of time required for performing a calibration drift test. Each table is specific to a different specification test. The applicable Part 60 *Appendix* A Reference Method(s) required to be used for each of the gases monitored in either specification test #2, #3, #4, or #5 are displayed in *Table* 12-6. The reader should be aware that some Subparts to 40 CFR 60 may contain alternate Reference Methods to those contained in *Table* 12-6 which may be used in conducting a performance specification test.

Since the Reference Methods procedures are designed to analyze the gas pollutants on a dry basis, a correction factor to account for moisture is necessary if the CEM system being tested is not corrected for this factor. Reference

Table 12-2 Performance Specification for SO_2 / NO_x System Specification Test #2

PARAMETER	SPECIFICATION
ACCURACY*	< 20% of the mean value of the reference method test data or 10% of the applicable standard, whichever is greater. **
ZERO DRIFT	2.5% of Span Value***
CALIBRATION DRIFT	2.5% of Span Value ***
CALIBRATION DRIFT TEST PERIOD	168 hours, minimum (at 24 hour intervals for 7 consecutive days)

* Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests.

** Span values are as specified in the applicable regulations and are a function of the type of fuel burned.

*** For SO_2 emission standards between 0.30 and 0.20 lb/MMBtu, use 15% of the applicable standard; below 0.20 lb/MMBtu use 20% of the emission standard.

Method #4 is used to provide this moisture correction and is used concurrently with the regular gas pollutant measurement methods.

CEM Installation and Measurement Location

Section 3.0 performance specification test #2 of *Appendix* B describes th specifications for installing the monitoring system and selecting locations where representative measurements can be taken. It is the source owners' responsibility to assure that the CEM is located in such a position which will yield a representative concentration

Table 12-3 Performance Specification for O_2 and CO_2 Specification Test #3	
PARAMETER	**SPECIFICATION**
ACCURACY*	< 20% of the mean reference method test data or 1.0% O_2 or CO_2 of the applicable standard, whichever is greater
CALIBRATION DRIFT	<0.5% O_2 or CO_2 from reference value of gas, gas cell, or optical filter
CALIBRATION DRIFT TEST PERIOD	168 hours, minimum (at 24 hour intervals for 7 consecutive days)

* Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests.

Table 12-4 Performance Specification for CO Specification Test #4	
PARAMETER	**SPECIFICATION**
ACCURACY*	<10% of the mean reference method test data value or 5% of applicable standard, whichever is greater
CALIBRATION DRIFT	<5% of established span value for 6 out of 7 test days from reference value of gas cylinder, gas cell or optical filter (Subpart J facilities use 1000ppm as span values)**
CALIBRATION DRIFT TEST PERIOD	168 hours, minimum (at 24 hour intervals for 7 consecutive days)

* Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests.

** Span values are as specified in the applicable regulations and are a function of the type of fuel burned.

Table 12-5 Performance Specification for TRS Specification Test #5	
PARAMETER	SPECIFICATION
ACCURACY*	< 20% of the mean value of reference method test data or 10% of applicable standard, whichever is greater
CALIBRATION DRIFT	<5% (1.5PPM) of established span value of 30ppm for 6 out of 7 test days **
CALIBRATION DRIFT TEST PERIOD	168 hours, minimum (at 24 hour intervals for 7 consecutive days)

* Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests.

** Span values are as specified in the applicable regulations and are a function of the type of fuel burned.

or can be corrected to yield a representative concentration of the total emissions from that facility. As indicated earlier, the specifications listed in *Section* 3.0 (i.e., performance specification test 2) are also used in the other CEM system performance specifications.

In general, the suggested CEM location (i.e., where the sample taken will most likely provide data which meets the RA requirements) should be at least two equivalent diameters (i.e., at a distance two times the diameter of the stack or duct) downstream from the nearest control device, the point of pollutant generation or other point at which a change in the pollutant concentration or emission rate occurs, and at least 0.5 equivalent diameters upstream from the effluent exhaust or control device. It is worthy to note that some individual subparts of Part 60 may contain additional requirements. For example, steam generating facilities must locate the CEM downstream of the air preheater.

Section 3.2 of *Appendix* B addresses the sample locations for the Reference Method (RM) measurement locations and traverse points during the relativeaccuracy tests. Basically, this section states that in performing the relative accuracy test, the RM sample is taken by traversing the measurement line at three points. If the measurement line is 2.4 meters long and stratification is not a problem (discussed below), the sample points may be located on this line at 0.4, 1.2 and 2.0 meters from the stack or duct wall. If the measurement line is longer than 2.4 meters, then the sample points can be located at 16.7, 50 and 83.3 percent of the length of the measurement line.

It should be noted that the CEM measurement location and the Reference Method traverse location need not be the same for determining the relative accuracy. For example, the CEM may be located in the exhaust duct of a control device because it is an accessible location, but the area may not contain ports for taking Reference Method samples. The Reference Method sample could then be taken further downstream where ports would be present and which would meet the requirements of the performance specifications. The CEM results are still compared to results obtained by using the Reference Methods in determining the relative accuracy.

Personnel who perform the performance specification test, need to be aware of the problem of stratification. Stratification refers to the amount of variation in pollutant emission rates at the Reference Method measurement locations. Stratification results from the mixing of two dissimilar gases immediately upstream of the measurement

location. A specific example of where stratification can occur is when a CEM is located in duct work which provides better accessibility for maintenance and repair purposes. In this situation, by-passed gas can be mixed with cleaned or scrubbed gas for reheating purposes. Another example of where stratification occurs is due to poor scrubber operation especially where plugging of gas passageways and liquid-slurry spray nozzles has occurred. Stratification involving poor scrubber operation is very difficult to measure and is often temporally variable.

TABLE 12-6 APPLICABLE REFERENCE METHODS FROM 40 CFR PART 60, APPENDIX A

PERFORMANCE SPECIFICATION TEST	APPLICABLE REFERENCE METHOD(S)	TITLE
2	Method 3	Gas analysis for the determination of dry molecular weight
	Method 3B	Gas analysis for the determination of emission rate correction factor or excess air
	Method 4	Determination of moisture content in stack gases
	Method 6	Determination of sulfur oxide emissions from stationary sources
	Method 7	Determination of nitrogen oxide emissions from stationary sources
3	Method 3	Gas analysis for the determination of dry molecular weight
	Method 3B	Gas analysis for the determination of emission rate correction factor or excess air
4	Method 10	Determination of carbon monoxide emissions from stationary sources (Note: Section 10.1 of method 10 specifies the use of an alternative interference trap when using nondispersive infrared CEMS)
	Method 10A	Determination of CO emissions in certifying continuous emission monitoring systems at petroleum refineries
	Method 10B	Determination of CO emissions from stastionary sources
5	Method 16	Semicontinuous determination of sulfur emissions from stationary sources
	Method 16A	Determination of total reduced sulfur emissions from stationary sources (Impinger Technique)

(Note: Some Subparts to 40 CFR Part 60 may contain alternate reference methods which may be used instead of those methods listed in this table.

Under conditions where stratification is evident, the Reference Method sampling points should be taken along a line perpendicular to the line of such gas mixing. There are methods for locating the sample points whenever stratification is suspected for both rectangular and circular ducts. These procedures are outlined in an EPA

document entitled "Gaseous Continuous Emission Monitoring Systems - Performance Specification Guidelines for SO_2, NO_x, CO_2, O_2 and TRS", EPA-450/3-82-026. Interestingly enough, it has been shown that taking the RM samples at three points along the traversed measurement line will yield good results even if stratification is a problem.

Calibration Drift, Relative Accuracy, Test Methods and Procedures

Section 4.0 of performance specification test #2 in *Appendix* B, addresses relative accuracy and the calibration drift (CD) requirements for CEMs. The actual procedures for performing the calibration drift test and the relative accuracy test are contained in sections 6 and 7, respectivley. As stated earlier, if a CEM has both a pollutant and a diluent monitor, then the calibration drift test must be performed separately for each monitor. According to *Appendix* B, a pollutant monitor is one which measures the concentration of the pollutant gas and will display an output which is proportional to the concentration of the gas being sampled. A diluent monitor is used to measure the concentration of the diluent gas which is either O_2 or CO_2. These gases are measured concurently with SO_2 or NO_x gases in order that the pollutant gas concentrations can be converted from parts per million (ppm) to pounds of pollutant per million Btu heat input (lb/MMBtu). This type of conversion is usually required for electric utility steam generators and may be required for additional sources such as sulfuric acid plants. A diluent monitor is required to comply with performance specification test #3. *Section* 5.0 of performance specification test #2 of *Appendix* B gives the required time period for performing both calibration drift and relative accuracy tests. The minimum required operation time for performing these tests is 168 hours. These tests are performed for 7 consecutive days at 24 hour intervals.

Sections 7.5 and 8.0 of performance specification test #2 describe the necessary calculations and the equations which are used in reporting the relative accuracy results. In addition to the equation for relative accuracy, *Section* 8.0 gives the equations for computing the standard deviation and the confidence coefficient.

Calibration Drift

The calibration drift test is done by using cylinder gases, gas cells or optical filters. This test is performed over a period of seven consecutive days (per *Section* 5.0) and involves the introduction of a zero and a span gas of known concentrations into the system. The system output readings are then compared to the known values (certified by the National Institute of Standards and Technology (NIST) of the calibration gases. During this test, the CEM recorder is usually preset at 5% or 10% offset to detect negative drift. A 24-hour drift test involves 8 sets of zero and span measurements correlated with 7 days of zero and calibration drift measurements. The zero drift values are determined by taking the difference between the zero value recorded after each 24 hour period and substracting the correct zero value. The calibration drift value is the span value measured at the end of each 24 hour period minus the correct span value. Following each zero and span measurement, a corresponding zero and span value adjustment is required. If the zero value adjustment is made before the span reading is made, then the effects of zero drift are removed and the span measurement adjustment is not necessary. Mathematically, the calibration drift is expressed in terms of the monitor span value for each individual day in the following manner:

(Eq. 12-1)

$$\text{Calibration Drift (\%)} = \frac{(S_r - S_v) \times 100}{(Sv)}$$

where: S_r = the monitor span reading (ppm), and
S_v = the monitor span value (ppm).

The calibration drift data should be recorded in a form similar to that as displayed in *Figure* 12-1. This format is the type as suggested in *Appendix* B.

FIGURE 12-1 DATA SHEET USED FOR RECORDING CALIBRATION DRIFT MEASUREMENTS

	DAY	DATE & TIME	CALIBRATION VALUE	MONITOR VALUE	DIFFERENCE	PERCENT OF SPAN VALUE
LOW LEVEL						
HIGH LEVEL						

NOTE: LOW-LEVEL AND HIGH-LEVEL REFER TO THE PERCENTAGE OF CEM DATA RECORDED FULL SCALE WHERE THE CALIBRATION DRIFT MEASUREMENTS ARE MADE. AN ACCEPTABLE TEST WOULD BE TO DETERMINE THE CALIBRATION DRIFT BETWEEN TEN AND TWENTY PERCENT OF THE HIGH-LEVEL VALUE FOR THE LOW-LEVEL TEST AND AT A VALUE BETWEEN FIFTY AND ONE-HUNDRED PERCENT OF THE HIGH-LEVEL VALUE FOR THE HIGH-LEVEL TEST. SECTION 4.1 (PERFORMANCE AND EQUIPMENT SPECIFICATIONS) APPENDIX B, 40 CFR PART 60, DESCRIBES THE METHOD WHICH THE SOURCE OWNER OR OPERATOR MAY USE IN CHOOSING THE DESIRED HIGH-LEVEL VALUE.

Relative Accuracy

The relative accuracy test involves the use of the specified EPA Reference Methods which are delineated in *Appendix* A to 40 CFR Part 60. This test is essentially a comparison between a CEM's measurement of a pollutant and the value of the pollutant's concentration as determined by an EPA Reference Method. Because a second (the reference method) independent measurement is used to assess the accuracy of the

monitor, this test is referred to as a relative accuracy test. This test requires a series of nine sets of measurements. However, the source owner may choose to perform more than nine sets of measurements. If this option is chosen up to three sets of data comparisons can be rejected as long as a minimum of nine sets of measurements are used in calculating the relative accuracy. All data, including the data sets which were rejected, are reported. The measurements are taken at three points along the cross-section of the duct or stack. There are three terms which are used in calculating the relative accuracy (expressed as a percent). They are: 1) the algebraic mean difference between the recorded concentrations of the monitor and those as determined by the Reference Method procedure, 2) the 95% confidence interval associated with the determination of the mean difference, and 3) the mean concentrations as determined by the Reference Method used. We can mathematically express this relationship in equation 12-2 as follows:

(Eq. 12-2)

$$\text{Relative Accuracy (\%)} = \frac{\overline{|d|} + C.C._{95\%} \times 100}{[RM_{avg}]}$$

where:

$\overline{|d|}$ = the absolute mean difference between the monitor value and reference method value, corrected for O_2 or CO_2,

$C.C._{95\%}$ = the 2.5 percent confidence coefficient, (the 95% confidence interval associated with the observered differences) and

$[RM_{avg}]$ = the average result of the Reference Method used for a series of test, corrected for O_2 or CO_2.

Section 8 presents the equation used for determing the value of d, its associated standard deviation, and the confidence coefficient, CC. Equation 12-3 is the equation used for determining the mean difference between the Reference Method data and t he CEMS data and is expressed as follows:

(Eq. 12-3)

$$\overline{d} = \frac{1}{n}\sum_{i=1}^{n}(Xi - Yi) = \frac{1}{n}\sum_{i=1}^{n} d_i$$

$\overline{d}$	=	arithmetic mean,
n	=	number of data points,
X_i	=	concentration from reference method, ng/J,
Y_i	=	concentration from the CEMS, ng/J
d_i	=	signed difference between individual pairs, X_i and Y_i, ng/J, and
Σd_i	=	algebraic sum of the individual differences, d_i, ng/J.

In order to calculate the 2.5 percent confidence coefficient, we must first calculate the standard deviation S_d using Equation 12-4 as follows:

(Eq. 12-4)

$$S_d = \sqrt{\frac{1}{n-1}\left(\sum_{i=1}^{n} d_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} d_i\right)^2\right)}$$

The 2.5 percent (error) confidence coefficient, CC, is also presented in *Section* 8 and is calculated using *Equation* 12-5 as follows:

$$\textit{(Eq. 12-5)} \qquad CC = t_{0.975} \frac{S_d}{\sqrt{n}}$$

where $t_{0.975}$ = A statistic which represents a 95% probability that the sample value is correct within a particular sample population. A standard table of t-values is contained in *Section* 8 of *Appendix* B. This table is presented in *Table* 12-7 below.

TABLE 12-7 VALUE OF T FOR 95 PERCENT PROBABILITY

[a]n	$t_{0.975}$	n[a]	$t_{0.975}$	n[a]	$t_{0.975}$
2	12.706	7	2.447	12	2.201
3	4.303	8	2.365	13	2.179
4	3.182	9	2.306	14	2.160
5	2.776	10	2.262	15	2.145
6	2.571	11	2.228	16	2.131

[a]The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of individual values.

The reader should note that the values obtained from the monitor and the Reference Methods need to be corrected for O_2 or CO_2 (either correction is applicable) in determining the relative accuracy in PS2 and PS4 for combustion sources, and that an O correction is necessary in performing PS5. Performance Specification Test #3 does not require this correction.

Basically, the smaller the RA value, the more accurate the monitor. Performance Specification Test #2 requires that the RA value be less than 20% in order for the CEMs to be acceptable for use. This required value differs slightly for Performance Specification Tests #3 and #4 (see *Tables* 12-2 - 12-5). The reader should note

differs slightly for Performance Specification Tests #3 and #4 (see *Tables* 12-2 - 12-5). The reader should note that the relative accuracy results can be affected by errors in both the monitor data and the Reference Method data due to the variations in the ability of the individual(s) performing these tests. These types of errors cannot be quantified and the cause of an excessive RA value (e.g., poor testing practices or poor CEM performance) is difficult to determine. Therefore, an acceptable RA value may demonstrate the adequacy of a CEMS, but an unacceptable value does not necessarily mean that the CEM is providing inaccurate data.

Now that we have presented the methodology for determining the RA, we will perform an example calculation. The SO_2 emission standard for Electric Utility Steam Generating Units (listed in 40 CFR Part 60 Subpart Da) which burn solid solvent refined coal (SRC-I) is 520 ng/J. Let's say that during a Performance Specification Test at one of these facilities using PST, the nine sets of data (corrected for O_2 or CO_2) yielded the following results contained in *Table* 12-8 .

TABLE 12-8 ***Example Performance Specification Test Results***

TEST	MONITOR DATA (ng/J)	REFERENCE METHOD DATA (ng/J)	SIGNED DIFFERENCE (ng/J)
1	420	425	+5
2	440	436	- 4
3	450	444	- 6
4	479	484	+5
5	485	490	+5
6	490	482	- 8
7	435	445	+10
8	550	565	+15
9	460	480	+20
	$[RM_{Avg}]$ =	472.3	$\overline{\lvert d \rvert}$ = 8.67
			Σd_i = 78
			Σd_i^2 = 916

As we can see from *Table* 12-8, we now have two values (e.g., $\overline{\lvert d \rvert}$ and $[RM_{avg}]$ which will be used in the equation for determining the RA. However, we still need to determine the value of the 2.5 percent confidence coefficient, $C.C._{95\%}$). As we just learned, the confidence coefficient is determined as follows:

1. first of all, determine the standard deviation using *equation* 12- 4:

$$S_d = \sqrt{\frac{1}{9-1}\left[916 - 1/9\,(78^2)\right]} = 5.48 \text{ng/J}$$

2. next, determine the value for the 2.5% confidence coefficient as follows:

$$C.C._{95\%} = 2.306 \left[\frac{5.48}{\sqrt{9}} \right] = 1.83 \text{ ng/J}$$

Now that we have determined the value for $C.C._{95\%}$, we can determine the RA which is shown below:

$$RA = \frac{8.67 + 1.83}{472.3} \times 100\% = 2.2\%$$

Since the value for RA is well below the allowable level (<20%) as specified in *Appendix* B, the CEM passes the Performance Specification Test.

In situations where the value for (RM_{avg}) is very small, a higher RA value will result which may fall outside of the acceptable range for RA. This could happen in a situation where the desired values for the monitor and Reference Method (i.e., in ppm) are very low. To obtain the desired results, an alternative mathematical expression can be used. This mathematical relationship is expressed in *Equation 12-6* as follows:

(*Eq.* 12-6)

$$\text{Relative Accuracy (\%)} = \frac{|X| + C.I._{95\%} \times 100}{\text{Applicable Standard}}$$

The Applicable Standard would be in units applicable to a specific source category. The reader should note that this alternate method for expressing the RA is only reserved for sources whose actual emissions are $\leq$ 50% of the emissions standard. Additionally, the RA is required to be $\leq$ 10% using this mathematical expression. In this situation, the concern is not to determine whether or not the emissions standard has been exceeded but rather to ensure that the CEM is producing accurate and reliable data.

Figure 12-2 Show the suggested Appendix B data sheet which is used for recording the relative accuracy values from each test run.

FIG 12-2 DATA SHEET USED FOR RECORDING RELATIVE ACCURACY MEASUREMENTS

RUN NO.	DATE & TIME	SO_2			NO_x[b]			CO_2 or O_2[a]		SO_2[a]			NO_x[a]		
		RM	M	DIFF	RM	M	DIFF	RM	M	RM	M	DIFF	RM	M	DIFF
		PPM[c]			PPM[c]			%[c]	%[c]	MASS/GCV			MASS/GCV		
1															
2															
3															
4															
5															
6															
AVERAGE															
CONFIDENCE INTERVAL															
ACCURACY															

[a] FOR STEAM GENERATORS; [b] AVERAGE OF THREE SAMPLES; [c] MAKE SURE RM & M DATA ARE ON CONSISTENT BASIS, EITHER WET OR DRY.

RM - EPA REFERENCE METHOD DATA
M - CEM MONITOR DATA
GCV - GROSS CALORIFIC VALUE

Reporting

Section 9.0 of performance specification test #2 of *Appendix* B, gives the minimum requirements for reporting the test results for both relative accuracy and calibration drift. *Appendix* B requires that the results of both the calibration drift test and the relative accuracy test must be summarized in tabular form and all data sheets used, calculations, monitor charts showing the CEM's response, cylinder gas concentration certifications and calibration cell response certifications (if applicable) must be reported to ensure the adequacy of the performance specification test.

Alternative Procedures

Sources whose emissions are well below the applicable standards may petition the EPA Administrator for permission to use an alternative relative accuracy procedure. This alternative procedure is explained in *Section* 10 of performance specification test #2 of *Appendix* B, and applies to SO_2, NO_x, O_2, and CO_2 CEMS. In this alternative test, RA is the difference between the monitor response and the calibration gas or cell value. *Table* 12-9 delineates the accepted values for the relative accuracy, zero drift, calibration drift and operational period obtained by using the alternative performance specification test procedures specified in *Section* 10.0 for SO_2 and NO_x. The reader should note that diluent monitors, which (as we discussed earlier) are operated concurrently with SO_2 and NO_x monitors, are subject to the requirements of performance specification test 3. The alternative procedures are applicable to performance specification test 2 and 3. In this alternative procedure, the response of the CEM is checked at two measurement points within the ranges specified in *Table* 12-10 on both the pollutant and diluent monitors. The RA difference is expressed as a percent difference for SO_2 and/or NO_x and as an absolute difference for CO_2 or O_2.

Table 12-9
ALTERNATIVE PERFORMANCE SPECIFICATIONS FOR SO_2/ NO_X SYSTEMS

ACCURACY*	< 15% of span gas or cell
DILUENT MONITOR ACCURACY	<0.7% O_2 or CO_2
ZERO DRIFT	2.5% of span value **
CALIBRATION DRIFT	2.5 % of span value **
OPERATIONAL PERIOD	168 hours, minimum

* Expressed as sum of absolute difference between monitor response and cylinder gas or calibration value.

** Span values are as specified in the applicable regulations and are a function of the type of fuel burned.

Preparing for the Performance Specification Test

Now that we have discussed the various sections to *Appendix* B, let us say a few words regarding the necessary steps involved in preparing for the performance specification test. Several steps should be considered. First of all, the performance specification test requirements should be carefully reviewed and if necessary, the control agency should be contacted if there are any problems encountered in the proper interpretation of these require-

used in the test. Lastly, all parties involved in the performance specification test should meet prior to the actual test in order to discuss such issues as test scheduling, agency participation, alternative procedures to be used, and the performance specification test procedures to be employed. Participants who would be involved in such a meeting would include representatives from the company (source), control agency, the testing contractor (if such a company is used), and the CEM vendor.

Table 12-10

MEASUREMENT RANGES FOR RELATIVE ACCURACY DETERMINATIONS FOR SO_2, NO_x, CO_2 AND O_2

		Dilute Monitor	
Measurement Point	Pollutant Monitors	CO_2	O_2
1	20 to 30% of span value	5 to 8% by volume	4 to 6% by volume
2	50 to 60% of span value	10 to 14% by volume	8 to 12% by volume

Summary

The requirements for performance specification tests for continuous gas emission monitors are contained in *Appendix* B to 40 CFR Part 60. These tests are performed on a one time basis (or as required by the EPA pursuant to *Section* 114 of the U.S. Clean Air Act) in order to ensure that the CEMS are acceptable for determining regulatory compliance by the source. There are performance specification tests for SO_2 and NO_x (PS_2), CO_2 and O_2 (PS3), CO (PS4) and TRS (PS5).

Most of the test procedures for PS2 are the same procedures which are used for PS3, PS4 and PS5. These procedures require the measurement of two parameters: 1) calibration drift (CD), and 2) relative accuracy (RA). The calibration drift is determined by comparing the monitor's response to a known concentration of gas. The relative accuracy is a percent difference between the measurement of the stack gas concentration obtained by the monitor versus the same concentration obtained by using an EPA Reference Method. These Reference Method procedures are contained in *Appendix* A to Part 60. In some cases, an alternative relative accuracy procedure may be approved by the EPA for sources which emit below the applicable standards. This procedure applies to SO_2, NO_x, CO_2 and O_2 CEMS.

Performance specification test #2 describes the methods used in installing the CEM and when/how Reference Method measurements are taken. Both the CEM measurement location and the Reference Method measurement location need not be the same. The Reference Method measurements are taken by traversing the stack or duct cross-section at three points. Stratification involves the mixing of two dissimilar gases and can cause significant differences in the amount of pollutant gas measured at the Reference Method measurement locations.

Preparing for the performance specification test at a source facility requires the development of a written work plan and cooperation between the company, control agency, the test contractor (if applicable) and the CEM vendor.

Finally, the reader is advised to obtain copies of both *Appendix* A and *Appendix* B to 40 CFR Part 60 in order to become familiar with the methods and requirements contained in both of these Appendices.

REVIEW EXERCISES	
1. True or false. *Appendix* B is contained in 40 CFR Part 60 and provides alternate reference method procedures which can be used during a performance specification test.	
2. True or false. Performancespecification tests are used to evaluate a CEM's performance over an extended period of time.	1. False
3. True or false. Unless otherwise stated, the procedures delineated in the sections to performance specification test #2 are applicable to performance specifications test #3-5.	2. False
4. The term Span Value refers to: a. The upper limit of a gas concentration measurement range specified for affected source categories in the applicable subpart of the regulations. b. The lower limit of a gas concentration measurement range specified for affected source categories. c. The Upper and Lower Limit of a gas concentration measurement range specified for affected source categories in the applicable subpart of the regulations. d. Can be all of the above.	3. False
5. True or false. An alternative mathematical expression for determining the relative accuracy may be used whenever the actual emissions from a source are $\leq$ 50% of the emissions standard.	4. a
6. What section of performance specification test #2 of Appendix B, describes the specifications for installling a CEM system.	5. True

7. "Stratification": a. results from the mixing of two dissimilar gases immediately upstream of the measurement location. b. is the non-uniform distribution of pollutant gas along a given length of a stack or duct. c. refers to the amount of variation in pollutant emission rates at the Reference Method measurement locations. d. Both a and c.	6. Section 3-D
8. The minimum period of time required in testing a continuous emission monitor for calibration drift is: a. 8 hours b. 24 hours c. 14 hours d. 168 hours	7. d
9. True or false. The equation used for determining relative accuracy can be found in *Section* 8.0 of performance specification Test #2 *Appendix* B.	8. d
10. The terms used to calculate the relative accuracy of a continuous monitor are: a. the algebraic mean difference between the recorded concentrations of the monitor and those as determined by the Reference Methods. b. the 95% confidence interval associated with the determination of the mean difference. c. the mean concentation as determined by the Reference Methods. d. all of the above.	9. True
	10. d

REFERENCES

1. *Code of Federal Regulations*, Title 40 Part 60 *Appendix* B. PerformanceSpecifications.

2. Environmental Protection Agency, 1986. *The Quality Control Handbook for Air Pollution Measurement Systems* Volume III. Stationary Source Specific Methods. *Section* 3.0.9., *Continuous Emission Monitoring (CEM) Systems Good Operating Practices*. EPA-600/4-77-02b.

3. Environmental Protection Agency. 1983. *Guidelines for the Observations of Performance Specification Test of Continuous Emission Monitors*. EPA 625/6-79-005.

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LESSON 13

The Requirements of Appendix F Quality Assurance Requirements for Continuous Gas Emission Monitors

Lesson Goal and Objectives

Goal

To describe the requirements of the Code of Federal Regulations, Title 40 Part 60 *Appendix* F, Procedure 1 - Quality Assurance Requirements for Continuous Gas Emission Monitoring Systems.

Objectives

At the end of this lesson you should be able to -

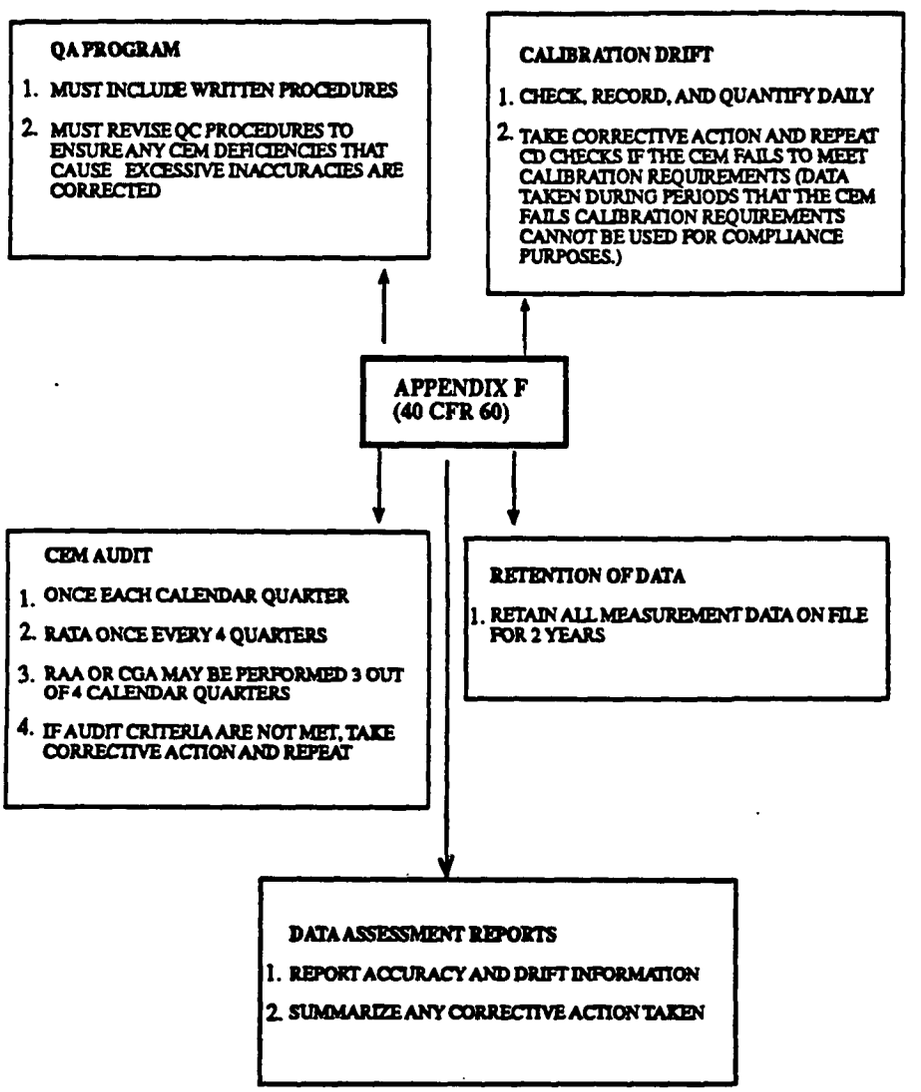
1. define the two functions of the quality control (QC) procedures required in Procedure 1 of *Appendix* F,
2. describe the minimum QC requirements which source owners must implement in their continuous emission monitoring program,
3. define the criteria for determining excessive drift in a continuous emission monitoring system (CEMS), and
4. describe the three acceptable methods for performing Data Accuracy Assessments.

Introduction

In the last lesson, we learned about the regulatory requirements of *Appendix* B (Specification Test Procedures) of Part 60 of Title 40 of the Code of Federal Regulations. In this lesson, we will explore the requirements in *Appendix* F of Part 60. *Appendix* F is entitled "*Appendix* F - Quality Assurance Procedures, Procedure 1 - Quality Assurance Requirements for Gas Continuous Emission Monitoring Systems for Compliance Determination" and was promulgated at 52 FR 21007 on June 4, 1987. These procedures apply to steam generating units which are

subject to the requirements of 40 CFR 60 Subparts Da and Db. *Appendix* F requires that the source implement written quality assurance procedures, states the acceptable values in performing calibration drift assessments and data accuracy assessments, and gives the requirements for reporting the data to the regulatory agency. The requirements of *Appendix* F are summarized in *Figure* 13-1.

FIGURE 13-1 AN OVERVIEW OF THE REQUIREMENTS OF APPENDIX F



In this lesson, we will take a look at each of the following sections of *Appendix* F:

- Applicability and Principle (*Section* 1),
- Definitions (*Section* 2),
- Quality Control Requirements (*Section* 3),

- Calibration Drift (CD) Assessment (*Section* 4),
- Data Accuracy Assessment (*Section* 5),
- Calculations for CEMS Data Accuracy (*Section* 6), and
- Reporting Requirements (*Section* 7).

Applicability and Principle - Section 1

Section 1.0 , Procedure 1 of *Appendix* F, sets forth procedures for evaluating the effectiveness of quality assurance/quality control procedures as well as evaluating the quality of data produced by CEMS that are used for determining compliance with emission standards.

This section also states that the QC procedures required by Procedure 1 have two distinct but equally important functions. The first function is assessment of CEMS data quality by estimating the accuracy of the monitor. The second function is that of control and improvement of data from a continuous emission monitor (CEM) through the implementation of QC policies and corrective actions. A control loop is formed through the interaction of these two functions as follows; whenever the assessment function demonstrates that the data quality is inadequate, the control effort has to be increased until the quality of the data is acceptable.

Section 1 also specifies the methods for assessing response drift and accuracy of the CEM and these methods are based on methods found in *Appendix* B, Part 60. Procedure 1 allows source owners a great deal of latitude in the development of QC procedures in order for these to be as effective and efficient for source specific situations. In some circumstances, source owners may specify certain sections of the CEMS instrument manual (i.e., the manual which is published by the manufacturer) as their written procedures.

Definitions - Section 2

Section 2 provides the definitions of several terms and continuous emission monitor (CEM) parameters. They are:

1. continuous emission monitoring system;
2. diluent gas;
3. span value;
4. zero, low-level and high-level values;
5. calibration drift (CD); and
6. relative accuracy (RA).

The definitions for CEMS, calibration drift, relative accuracy and span value are the same as those contained in *Appendix* B of Part 60. These terms were discussed in the last lesson. A "diluent gas" is defined as a major gaseous constituent in a gaseous pollutant mixture. CO_2 and O_2 are the major gaseous constituents of interest for combustion sources. "Zero, low-level and high-level values" refer to the CEMS response value as it relates to the source-specific span value. Procedures for determining these values are presented in the appropriate performance specification tests in *Appendix* B.

Quality Control Requirements - Section 3

Section 3 requires source owners to develop and implement a quality control program which, as a minimum, must include detailed procedures for the following activities:

1. calibration of the CEMS;
2. calibration drift determination and adjustment of the CEMS;
3. preventive maintenance of the CEMS (which includes maintaining a spare parts inventory);
4. data recording, calculations, and reporting for emissions and QA data;
5. accuracy audit procedures which includes sampling and analysis methods; and
6. the program of corrective action for the malfunctioning CEMS.

The reader should note that *Section* 3 does not provide detailed discussion of these activities. The following sections to *Appendix* F contain requirements for these activities:

- *Section* 4 - Calibration drift determination and adjustment of the CEMS, corrective action for the malfunctioning CEMS, and data recording;
- *Section* 5 - Accuracy audit procedures and corrective action for the malfunctioning CEMS;
- *Section* 6 - Data recording and calculations; and
- *Section* 7 - Reporting requirements for emissions and QA data.

Since none of the sections in *Appendix* F specifically address calibration of a CEMS, we will briefly mention this term. The calibration of a CEM refers to the adjustment of the instrument relative to specified gas standards or independent effluent measurements. Written procedures for calibrating a CEM are required and each source may develop its own procedures. As stated earlier in *Section* 1, applicable sections of an instrument's operating manual may suffice for these written procedures. The reader should take note that there are no current regulations regarding specific calibration frequencies or specific criteria for initiating calibration procedures. Therefore, sources should implement their own procedures for determining the calibration frequency and criteria for calibrating a CEM based on operating experience or manufacturer's recommendations.

Preventive maintenance is also not addressed in detail in *Appendix* F. Preventive maintenance consists of such activities as routine maintenance and repairs and instrument adjustments performed on an as-needed basis. We will talk more about maintenance for continuous gas emission monitors in Lesson 15.

Finally, *Section* 3 states that if excessive inaccuracies in data occur for two consecutive quarters, then the source owner must either revise the current written procedures or modify or replace the CEMS in order to correct this deficiency. Written QC procedures must be kept on file and must be available for inspection by the regulatory agency. In the next lesson, we will talk about quality control in more detail.

Calibration Drift (CD) Assessment - Section 4

This section discusses the requirements for performing the calibration drift (CD) assessment tests. As we learned in Lesson 12, "calibration drift" refers to the difference between the CEMS output reading and a reference value after a period of operation during which no unscheduled maintenance, repair, or adjustment took place. Part 60.13 of Title 40 of the Code of Federal Regulations, requires that daily zero (or low-level) and span drift checks be performed. These same two checks are also used to fulfill the CD assessment requirements of *Appendix* F. Written procedures are required for specifying how the zero and span calibration drift determinations will be performed. Also, these procedures must be consistent with the methods prescribed by the CEM vendor.

Table 13-1 is a compilation of the performance specification criteria and the required response by the source owner or operator if the zero and span calibration drift exceeds the allowed limit. It should be noted that a source may develop response requirements more stringent than those as stated in this table. The written procedures for the performance of calibration drift, should incorporate the criteria for adjusting the CEMS should the calibration drift test show that the instrument is out of line. Making corrections for excessive drift involves any type of

Table 13-1
CEMS CALIBRATION DRIFT CRITERIA

PARAMETER	CRITERION*	ACTION REQUIRED
Zero (or low) level calibration drift	CD> 2 x (Spec)**	Adjust CEMS for calibration drift
	CD> 2 x (Spec) for 5 consecutive 24-hour periods	CEMS out-of control period begins at end of 5th day the CD exceeds 2 x (Spec); perform corrective action and repeat CD check
	CD> 4 x (Spec)	CEMS out-of-control period begins at the time corresponding to the completion of the last acceptable CD check preceding the CD check which exceeds 4 x (Spec); perform corrective action and repeat the CD check
Span calibration drift	CD> 2 x (Spec)**	Adjust CEMS for calibration drift
	CD> 2 x (Spec) for 5 consecutive 24-hour periods	CEMS out-of-control period begins at end of 5th day the CD exceeds 2 x (Spec); perform corrective action and repeat CD check
	CD> 4 x (Spec)	CEMS out-of-control period begins at the time corresponding to the completion of the last successful CD check preceding the CD check that exceeds 4 x (Spec); perform corrective action and repeat the CD check

* Spec refers to the applicable performance specification 40 CFR Part 60, Appendix B, Performance Specification. Example - In Performance Specification Test 2 (for SO NO Systems), the calibration drift must not deviate from the reference standard by more than 2.5% of the span value. Hence 2 x (spec) = 2x 2.5%=5%.

** This is the minimum criterion for adjustment of the CEMS. More stringent criteria, which may be preferred by many sources, are also acceptable.

adjustments which the CEM operator deems necessary in order to correct the observed drift. Activities such as routine checks and adjustments of calibration and sample gas flow rates, pressures, filter elements and moisture removal systems; verification of the status of monitor-specific auxiliary monitoring parameters (i.e., sample cell temperature and pressure, gas flow capillaries, detection optics and electronics, temperature compensation, linearization signal output circuitry); and adjustments of zero and/or span potentiometers are included in the procedure for compensating for excessive drift. The source owner should have written procedures for performing drift adjustments and these procedures should include the criteria for demonstrating that the adjustments that were made are adequate.

If the zero (low-level) or the span (high-level) values exceed four times the applicable drift specification as stated in *Appendix* B, the CEM is considered to be out-of-control. Whenever this happens, *Appendix* F requires that corrective action be taken. The type of action taken will depend on the nature of the problem. Written procedures are required to be available for addressing instrument start-up and trouble shooting. CEM instrument operation and/or repair manual sections applicable to out-of-control problems will suffice for these written procedures. It is also suggested that additional quality assessment procedures be written for the purpose of verifying that the CEMS is in control following any repair or adjustment. Alternative methods used for monitoring emissions during the out-of-control period should be listed in these quality assessment procedures. These procedures should also list the office or individual responsible for handling an out-of-control event. Such a listing would include the personnel in charge of approving the corrective action to be taken, and procedures for determining when alternative methods for emission monitoring should be performed. The criteria for determining that a CEMS is out of control must include the procedure from *Appendix* F for determining excessive drift and excessive inaccuracy.

Section 4 of *Appendix* F also states requirements for CEMS that have automatic adjustments for resetting the CD. Such systems must be programmed to record the unadjusted concentration measured in the CD prior to resetting the calibration if performed, or record the amount of adjustment (e.g., a microprocessor control would do this).

Lastly, *Section* 4 states that all measurements from the CEMS are required to be retained on file for at least two years as required in 40 CFR Part 60.7(d). However, emission data recorded on each day that the CEMS is out-of-control need not be included in the daily data requirement of the applicable subpart in Part 60.

Data Accuracy Assessment - Section 5

Appendix F became effective on December 4, 1987 and the first required relative accuracy test was to be performed by March 4, 1988 or by the date a CEMS initial performance test was required by the applicable regulation, whichever date was later.

This section lists the three acceptable techniques which can be used for performing an audit on the CEM. Audits are required to be performed at least once each quarter. The three acceptable techniques are:

1. Relative Accuracy Test Audits (RATA),
2. Cylinder Gas Audits (CGA), and
3. Relative Accuracy Audits (RAA).

In addition to these procedures, *Appendix* F states that the EPA may approve alternative procedures to be used during three of the four calendar quarters. However, one RATA is required at least once every four calendar quarters. The reader should note that currently, there have been no alternative procedures approved by the EPA and only one procedure for an RAA test for in-situ systems is currently under review.

A CEMS which does not demonstrate adequate accuracy during any quarterly audit test is considered to be out-of-control with corrective action necessary. As we learned in *Section* 3, if the CEMS does not demonstrate an acceptable accuracy for two consecutive quarters, then either the QA program must be revised or the CEMS must be replaced or modified. *Table* 13-2 delineates the specific requirements and performance criteria for each of the three acceptable audit techniques. *Appendix* F requires that the QC program must have written sampling and analysis procedures to be used during the required quarterly accuracy audits.

Table 13-2.
Requirements and Criteria for Appendix F, Procedure 1 Audit Techniques

TECHNIQUE	REQUIREMENTS	PERFORMANCE CRITERIA	WHEN REQUIRED
Relative Accuracy Test Audit	Conduct as per applicable performance specification (PS) in 40 CFR Part 60 Appendix B, performance specifications (e.g., PS 2 for SO and NO) Analyze appropriate performance audit samples from EPA	Relative accuracy must not exceed 20% or 10% of applicable standard, whichever is greater For SO_2 standards from 0.20 to 0.30lb / million Btu, relative accuracy must not exceed 15% of the standard For SO_2 standards below 0.20 lb/10^6 Btu, relative accuracy must not exceed 20% of the standard	Once every four calendar quarters
Relative Accuracy Audit	Conduct as per applicable PS in Appendix B except only 3 runs are required Use relative difference between the mean reference method values and the mean of the CEMS responses to assess the accuracy of the CEMS data	Inaccuracy must not exceed ± 15% or 7.5% of the applicable standard, whichever is greater	May be performed in three of the four calendar quarters
Cylinder Gas Audit	Challenge both pollutant and dilutant channels (if applicable) of CEMS three times at the two points specified in Procedure 1 Use gases that have been certified by comparison to NBS SRM's or NBS/EPA approved gas manufacturer's CRM's Operate analyzer in normal sample mode Use average difference between actual gas value and concentration indicated by CEMS to access accuracy	Inaccuracy must not exceed ± 15%	May be performed in three of the four calendar quarters

As stated earlier, *Appendix* F requires that these accuracy audits be performed once each calendar quarter. Additionally, successive audits must occur no closer than two months apart and must be conducted as follows:

1. The RATA test must be performed once every four calendar quarters. This test is performed the same way that the performance specification test #2 (for SO_2 and NO_x) as outlined in *Appendix* B is done. However, *Appendix* F also requires that EPA performance audit samples be taken sequentially (i.e., shortly before or after) with the RATA samples. Both the EPA audit sample and the RATA sample must be analyzed by the same person. The logic behind conducting these two tests sequentially is that the RATA will approximate the "truth" by the Reference Method test results which are then checked for analytical accuracy by the EPA audit method.

   The EPA audit samples are performed the same way that the applicable Reference Methods (e.g., Methods 6 for SO_2 and 7 for NO_x) as delineated in Part 60 *Appendix* A, are performed. The EPA audit samples and the data samples are concurrently analyzed in the same manner in order to determine that the technique of both the sample analyst and the audit sample preparation are effective. The results of the EPA audit sample must agree within five percent of the audit concentration on each of two SO_2 audit samples or within ten percent of each other on each of two NOx samples.

2. Where applicable, a CGA may be performed in three of the four calendar quarters. An example of a situation where a CGA could not be performed would be in the case of a path in-situ monitor which could not undergo this test unless a flow-through cell is used.

   This audit is performed by checking the CEMS (both pollutant and diluent monitors, if applicable) with an audit gas following EPA Traceability Protocol No. 1 (see citation in the Reference section). An audit gas must be certifiable through comparison with a National Institute of Standards and Technology -Standard Reference Materials (NIST-SRM) gaseous reference or NIST/EPA-approved gas manufacturers CRM Certified Reference Material (CRM). This audit gas of a known concentration is used to check the CEM at two points within the following ranges:

Audit range			
		Dilute monitors for - -	
Audit	**Pollutant monitors**	**CO_2**	**O_2**
1	20 to 30% of span value	5 to 8% by volume	4 to 6% by volume
2	50 to 60% of span value	10 to 14% by volume	8 to 12% by volume

It should be noted that a separate audit gas cylinder must be used for each point checked. This cylinder gas cannot be diluted. Check the CEM at each point three times and use the average response value for computing the accuracy. Also, each point should be sampled long enough to assure absorption-desorption of the CEMS sample transport surfaces has stabilized. Audit each monitor in its normal sampling mode (i.e., allow the audit gas to pass through all filters, scrubbers, conditioners as well as the other components used during normal sampling and as much of

the sampling probe as possible). The audit gas should be injected at the connection between the probe and the sample line. The accuracy is the difference between the concentration of the audit gas and the concentration as indicated by the monitor.

3. The RAA test may be performed three of the four calendar quarters. This test is performed the same way in which the relative accuracy test of *Appendix* B is performed with two exceptions; 1) only three sets of measurements are required, and 2) EPA performance audit samples are required to be analyzed concurrently with the RAA samples. The EPA audit sample and the RAA test sample must be taken by the same person. The CEMS accuracy is determined by the relative difference between the mean of the CEMS values (in terms of the standard) and the mean of the Reference Method results. That is to say, the audit sample verifies the accuracy of the *Appendix* B Reference Method test used, then the Reference Method test is used to "audit" the CEM.

The data accuracy assessment is an important check of the CEMS ability to produce accurate emissions data over time. One should not expect that accuracy will remain constant over each quarter because of changes in calibration gases, analysts and environment.

Calculations For CEMS Data Accuracy - Section 6

This section gives the types of calculations necessary to assess the accuracy of the CEM. For the RATA relative accuracy calculation, the equations used are contained in *Section* 8 of *Appendix* B, Performance Specification Test 2. We talked about these equations in the last lesson. Before proceeding any further in this section, the reader may wish to go back to Lesson 12 and review these equations. While the RATA and RAA must be calculated in units of the applicable standard (e.g., lb./million BTU), the CGA must be calculated in units of the appropriate concentration (i.e., ppm SO_2 or percent O_2).

Equation 13-1 can be used by combustion sources to convert a pollutant concentration to units of the applicable standard as follows:

(*Eq.* 13-1) $$E = CF \left[\frac{20.9}{20.9 - \text{percent } O_2} \right]$$

where

E = pollutant emission, ng/J (1b/million Btu),
C = pollutant concentration, ng/dsm³ (lb/dscf)*
F = factor representing a ratio of the volume of dry fuel gas generated to the caloric value of the fuel, dsm³/J (dscf/million Btu),
20.9 = a constant which refers to the amount (percent) of O_2 in the ambient air.

Percent O_2 = oxygen content by volume (expressed as percent), dry basis in the sample stream.

* dsm = Dry Standard Cubicmeter
dscf = Dry Standard Cubic Feet

Data from CEMSs are sometimes collected on a wet basis. When comparing the CEM data with the Reference Method data it is necessary to convert the wet basis data to a dry basis. This conversion can be done as shown in *equation* 13-2:

(*Eq.* 13-2)

$$X_{ppm,\,dry} = \frac{X_{ppm,\,wet}}{1 - B_{ws}}$$

where:

X = Concentration from the CEMS

B_{ws} = Moisture fraction of the CEMS gas sampled. This value is determined by using Part 60 *Appendix* A, Method 4.

Part 60, *Appendix* A, Method 19 presents a complete explanation of equations 13-1 and 13-2.

As we stated earlier, the RATA relative accuracy is determined by using the equation contained in *Section* 8 of *Appendix* B, Performance Specification Test 2. The RAA test accuracy and the accuracy of the CEM per the CGA method are calculated by using the same equation. Equation 13-3 is the mathematical expression used for determining both the RAA and the CGA and is presented as follows:

(*Eq.* 13-3)

$$A = \frac{C_m - C_a}{C_a} \times 100$$

where:

A = The accuracy of the CEMS (percent),

C_m = average CEMS response during audit in units of applicable standard, (for RAA), or

C_a = average audit value (CGA certified value or three - run average for RAA) in units of the applicable standard or appropriate concentration.

Reporting Requirements - Section *7*

The results of each CEMS accuracy audit must be reported in the form of a Data Accuracy Report (DAR). After each quarterly audit, one copy of the DAR must be submitted to the state regulatory agency or in some cases the EPA Regional Office along with a report of emissions required under the applicable regulation (i.e., the requirements of subparts Da and Db in Part 60). The minimum information required to be submitted with a DAR is as follows:

1. Source owner or operator name and address.

2. Identification and location of monitors in the CEMS.

3. Manufacturer and model number of each monitor in the CEMS.

4. Assessment of CEMS data accuracy and date of assessment as determined by a RATA, RAA or CGA, including the relative accuracy for the RATA, the accuracy for the RAA or CGA, the Reference Method results, certified values for the cylinder gases, the CEMS responses, and the CEMS accuracy

calculation results. If the accuracy audit results show the CEMS to be out-of-control, the CEMS operator shall report both the audit results showing the CEMS to be out-of-control and the results of the audit following corrective action showing the CEMS to be operating within specifications.

5. Calibration drift (CD) assessment results.

6. Results from the EPA performance audit samples.

7. Summary of all corrective actions taken when the monitor was determined out-of-control.

Figure 13-2 is an example of what a DAR form looks like.

Figure 13-2 ***Example format for data assessment report (DAR).***

Period ending date _____ **Year** _____
Company name _____
Plant name _____ **Source unit no.** _____
CEMS manufacturer _____ **Model no.** _____
CEMS serial no. _____ **CEMS type (e.g., in-situ)** _____
CEMS sampling location (e.g., control device outlet) _____
CEMS span values as per the applicable regulation, SO_2 ppm _____
O_2 _____ **percent,** **NO_x** _____ **ppm,** **CO_2** _____ **percent**

I. *Accuracy assessment results (Complete A, B, or C below for each CEMS or for each pollutant and diluent analyzer, as applicable.) If the quarterly audit results show the CEMS to be out-of- control, report the results of both the quarterly audit and the audit following the corrective action showing the CEMS to be operating properly.*

A. *Relative accuracy test audit (RATA) for* _____ (e.g., SO_2 in ng/J).
1. Date of Audit _____.
2. Reference methods (RM's) used _____ (e.g., Methods 3 and 6).
3. Average RM value _____ (e.g., ng/J, mg/dsm³, or percent volume).
4. Average CEMS value _____.
5. Absolute value of the mean difference |d| _____.
6. Confidence coefficient |CC| _____.
7. Percent relative accuracy (RA) _____ percent.
8. EPA performance audit results:

a. Audit lot number	(1) _____	(2) _____
b. Audit sample number	(1) _____	(2) _____
c. Results (mg/dsm³)	(1) _____	(2) _____
d. Actual value (mg/dsm³)*	(1) _____	(2) _____
e. Relative error*	(1) _____	(2) _____

B. *Cylinder gas audit (CGA) for* _____ (e.g., SO_2 in ppm).
1. Date of audit _____.

	Audit point 1	Audit point 2	
2. Cylinder ID number	_____	_____	
3. Date of certification	_____	_____	
4. Type of certification	_____	_____	(e.g., EPA Protocol 1 or CRM).

Figure 13-2 (Continued)

5. Certified audit value _____ (e.g., ppm).
6. CEMS response value _____ (e.g., ppm).
7. Accuracy _____ percent.

C. *Relative accuracy audit (RAA) for* _____ (e.g., SO_2 in ng/J).

1. Date of audit _____ .
2. Reference methods (RM's) used _____ (e.g., Methods 3 and 6).
3. Average RM value _____ (e.g., ng/J).
4. Average CEMS value _____ .
5. Accuracy _____ percent.
6. EPA performance audit results:

a. Audit lot number	(1) _____	(2) _____
b. Audit sample number	(1) _____	(2) _____
c. Results (mg/dsm³)*	(1) _____	(2) _____
d. Actual value (mg/dsm³)*	(1) _____	(2) _____
e. Relative error*	(1) _____	(2) _____

D. *Corrective action for excessive inaccuracy.*

1. Out-of-control periods.
   a. Date(s) _____ .
   b. Number of days _____ .

2. Corrective action taken _____

3. Results of audit following corrective action. (Use format of A, B, or C above, as applicable.)

II. Calibration drift assessment.

A. Out-of-control periods.
   1. Date(s) _____ .
   2. Number of days _____ .

B. Corrective action taken _____

**To be completed by the Agency*

Summary

The requirements of Part 60 of Title 40 *Appendix* F, Procedure 1 apply to steam generating units listed in Part 60 Subparts Da and Db. *Appendix* F requires that these sources implement written quality control procedures for evaluating the quality data produced by continuous emission monitoring systems. In particular, the source is required to perform calibration drift (CD) tests (i.e., daily zero and scan value checks.) Both the zero and span values cannot exceed the applicable drift specifications as stated in *Appendix* B to Part 60 and the measurement data must be retained on file for two years except in cases where the CEM is deemed out-of-control.

The source is also required to perform quarterly audits of the CEM. The three acceptable audits which can be used are the relative accuracy test audit (RATA), which must be performed at least once ever four calendar quarters, the relative accuracy audit (RAA), and the cylinder gas audit (CGA). Both the RAA and CGA may be

performed in three of the four calendar quarters. The RATA and RAA are performed in the same manner which the relative accuracy test as required by Part 60 *Appendix* B are performed. The RAA test only requires that three sets of data be used as opposed to taking nine sets of data which *Appendix* B requires. Additionally, EPA audit samples must be analyzed sequentially with the RATA and/or RAA test samples. The CGA test is performed by checking the CEM at two point within specific ranges with an audit gas.

The results of CEMS accuracy tests must be recorded on a Data Accuracy Report (DAR) form each quarter and a copy of this form along with a report of source emissions required under Subparts Da and Db must be submitted to the regulatory agency.

REVIEW EXERCISES	
1. True or false. The two distinct but equally important functions of the QC procedures required by *Appendix* F are to 1) assess the quality of the CEMS data by estimating the monitors accuracy, and 2) to control and improve the quality of the CEMS data through the implementation of QC policies and corrective actions.	
2. True or false. The inclusion of a spare parts inventory is one of the several QC requirements which source owners must implement in their CEMS program.	1. True
3. True or false. *Appendix* F states that if excessive inaccuracies in data occur for two consecutive quarters, then the source owner shall replace the CEMS.	2. True
4. In performing the daily calibration drift test for both zero and span drift, the CEMS is considered to be out-of-control if: a. The CD > 4x the allowable limit b. The CD > 2x the allowable limit c. The CD > 5x the allowable limit d. The CD > 10x the allowable limit	3. False
5. True or false. The RAA Test requires that only 3 sets of measurements be taken.	4. a
6. True or false. A CGA Test may be performed in any of four calendar quarters.	5. True
7. The audit gas used in performing the CGA Test is used to check the CEM at _____ point(s) within the specified ranges.	6. False
8. The RAA Test may be performed during _____ of the four calendar quarters.	7. Two

9. The performance criteria for the RATA Test requires that the RA must not exceed ____ or ____ of the applicable standard, whichever is greater. a. 20% or 10% b. 10% or 15% c. 20% or 15% d. 5% or 10%	8. Three
10. True or false. The equation used to convert a pollutant concentration to units of the applicable standard is as follows: $E = CF \left[\frac{20.9}{20.9 - \text{percent } O_2}\right]$ The percent O_2 in this equation is the oxygen content by volume (expressed as percent), wet basis in the sample stream.	9. a
	10. False

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UNIT 5

CONTINUING OPERATIONS

LESSON 14

Quality Assurance/Quality Control and Audit Programs for Continuous Gas Emission Monitors

Lesson Goal and Objectives

Goal

To gain an understanding of the basic components of a quality assurance/quality contol (QA/QC) program and the importance of an audit program.

Objectives

At the end of this lesson you should be able to -

1. define the following terms:
   - quality control
   - audit
   - interlaboratory audit
   - level system inspection program
   - level audit procedure
   - quality assurance
   - intralaboratory audit
   - schedule system inspection program
   - phase audit procedure
2. Describe quality assurance procedures associated with purchase and installation of a continuous emission monitoring system (CEMS),
3. list objectives of a QA program for continuous emission monitoring,
4. define the three levels of a QA program and the three stages of a QC program for CEMSs, and
5. describe the types of audits used in a QA program.

Introduction

In the last three lessons, we have learned about some of the regulatory requirements involved with the use of continuous gas emission monitors. One way to ensure that a continuous emission monitor (CEM) is maintained in a manner which provides assurance to the source owner that the system is in regulatory compliance, is through

the establishment and implementation of a good, sound quality assurance program. In the past, much confusion has come about regarding the application of quality control methods to CEMSs. This was because there were three groups involved with these types of procedures. These three groups were:

- the regulatory agency which required the air emissions monitoring,
- the source owner or operator responsible for purchasing and installing the CEM, and
- the CEM manufacturer.

Although each group wants the system to perform at a satisfactory level, there is some uncertainty about each participant's role in ensuring the success of the CEM.

It is always important to remember that unless the source has entered into a service contract with a vendor the CEM belongs to the source owner. However, once the unit has been purchased from the vendor, that party has lost control of it. Also, the regulatory agency has very little control over the unit even though the agency required the source to install it. Normally, the source owner will not allow the vendor or the agency to touch the unit unless they have been contracted. It is therefore the responsibility of the source to design and implement a satisfactory quality assurance/quality control program which will enable the source to operate the CEM to the satisfaction of the regulatory agency, meeting the manufacturer's specifications. Quality control refers to activities which will provide a quality product and quality assurance refers to activities which will provide assurance that the quality control program is performing in a satisfactory manner.

There are three phases involving the development of a continuous emission monitoring program. They are:

1. purchasing an instrument that meets design specifications,
2. installing and testing the performance of the new instrument, and
3. ensuring continued operation of the monitoring system in accordance with the specifications and regulatory requirements.

Figure 14-1 shows a basic overview of these three phases. For the first two phases, there are quality assurance procedures and techniques which can be applied in order to ensure that these phases are performed adequately. For the third phase, two types of quality assurance programs are involved. The first type of program is designed by the source to ensure the continuous operation of the CEM as well as to audit the system. The second type of program is designed by the regulatory agency in order to inspect the CEM. This lesson will provide an overview of these quality assurance/quality control programs and will provide a discussion of audits which are a necessary element in ensuring that the QA/QC program is performing up to standards and the CEM is displaying accurate and reliable data.

Quality Assurance Involving the Purchase and Installation of Continuous Gas Emission Monitors

Procuring a CEM must be done on a case-by-case basis. This is because a CEM which functions well at one plant may not be suitable at another facility due to the differences in the design parameters at each of the two

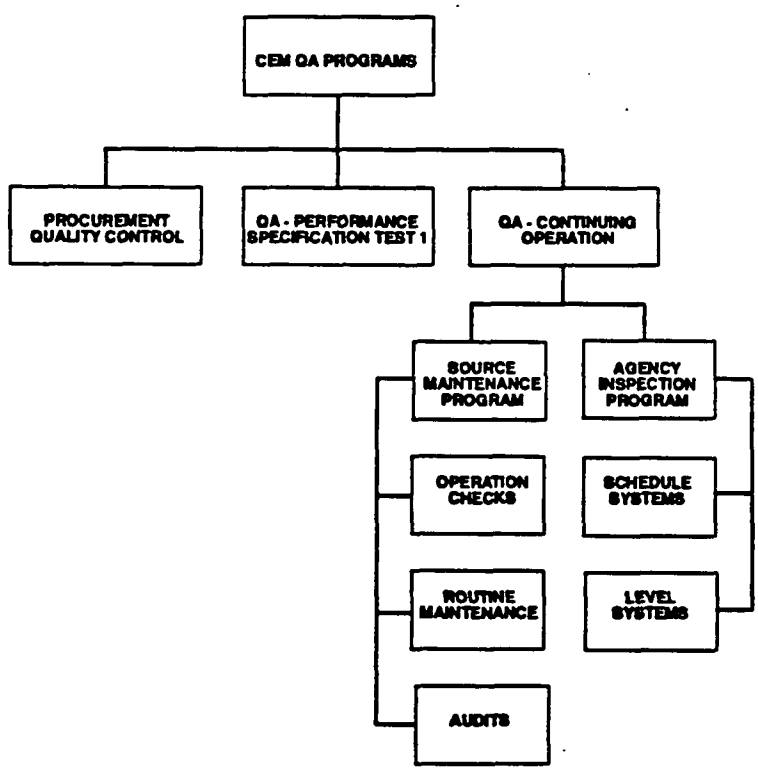
facilities. In purchasing a CEM, there are three areas which should be incorporated into a quality control program. They are:

- prepurchase evaluation/selection,
- writing of the purchase contract specification, and
- recordkeeping.

A discussion of these three areas follows below.

Prepurchase Evaluation/Selection

FIG 14-1 TYPES OF QUALITY ASSURANCE PROGRAMS FOR CONTINUOUS MONITORING SYSTEMS



CEMs which are available on the market should be compared according to instrument specifications, evaluated according to their operational design with respect to the installation site, and compared by contacting owners of systems which are already installed and field tested if possible (this is recommended for multiple purchases). An instrument which does not meet the required specifications is probably not designed for regulatory purposes.

In making comparisons of operational designs, methods used in performing zero and calibration checks, vulnerability to vibration and temperature extremes, and data processing options should be considered in selecting a system based on the installation site, the data requirements and plant management systems.

Source owners who are currently using CEMs should be consulted both for their experiences and suggestions about the equipment. This information is quite useful in evaluating available systems even though differences in installation may result. It is also advisable to field test a system if the source wishes to make a multiple purchase. If a source were to purchase a dozen or so units at a reduced cost (a so called package deal) and, after installing the first unit, unresolvable problems were to result, the source would be stuck with a number of units, all which would be incompatible for use at that facility. At that point, it would be difficult to back out of an agreement with the vendor.

Writing the Purchase Contract

There are several features which should be incorporated into a contract with the vendor:

1. the performance specifications for the selected CEM should be guaranteed (i.e., the manufacturer's test data which demonstrates that the system meets the required design and performance test specifications should be included in the contract);

2. the payment or a substantial part of the payment is not due until the CEM passes the performance test;

3. a minimum of a one-year warranty should be given which should not start until the CEM has passed an acceptance test conducted by the purchaser;

4. the operating manual supplied with the CEM must be consistent with the equipment purchased;

5. operator training should be provided by the vendor;

6. the vendor of the CEM must subject the monitor to a burn-in procedure to detect immediate malfunctions due to defective components or poor assembly, and

7. a two-year supply of spare parts and analyzer consumables (listed in the operating manual) should be furnished with the purchase.

Such specifications as shipping costs, service fees, and manpower requirements can be included in the contract but these specifications are usually verbally negotiated.

Recordkeeping

In the area of recordkeeping, a file system should be maintained which covers the entire lifetime of the CEM. Such items as vendor literature, phone logs, meeting notes and financial records should be included in this file. Also, the results of performance specification tests, copies of quarterly excess emission report, and instrument log books should be kept on file so that if there is ever a change in personnel, or a failure of memory, the company will have on file documentation of the experiences gained from the use of the system.

Quality Assurance for Performance Specification Tests

The design specifications for a newly purchased CEM are normally checked by the CEM vendor and a contractor usually performs the Performance Specification Test. Both of these parties should have an established

quality assurance program for doing these tests. Unless the CEM is not functioning properly, the Performance Specification Test (which gives specific data and reporting requirments should) yield good quality results.

Quality assurance techniques which are not specifically addressed in the specification tests but which may be used as part of the testing program are as follows:

1. strip chart recorders may be run at a faster rate during the test to aid the operator in reading the data;

2. after a series of zero and span readings have been taken, both plant and agency representatives can initial the results in order to demonstrate agreement between the two parties;

3. a separate (portable) monitoring system can be run in parallel with the system undergoing the test to aid in verifying the data produced by this system; and

4. audit devices can be used before and after the performance tests to uncover any inconsistences in the system.

Techniques such as these can be used by the instrument operator, the independent contractor (if one is employed) or the CEM vendor if they are present during these tests.

Quality Assurance for Continuing Operation and Maintenance

Quality Assurance versus Quality Control

So far, we have used the terms quality assurance and quality control interchangeably. Both fall under the overall quality assurance program for a source. *Figure* 14-2 shows an overview of such a program. Quality control involves "Activities" which will provide a quality product (i.e., adequate CEM data) while quality assurance involves "actvities" which will ensure an adequate quality control program.

Objectives of a Source Quality Assurance Program

What then, is the primary objective of a quality assurance program? The primary objective of such a program is to ensure that all data collected are precise, meaningful and accurate within stated acceptance criteria. A quality assurance program should be rigid enough so that all established procedures are strongly adhered to and flexible enough to allow a continual evaluation of the adequacy and effectiveness of the implemented procedures. The objectives of a quality assurance program can be summarized as follows:

- to monitor routine performance of personnel and/or equipment;

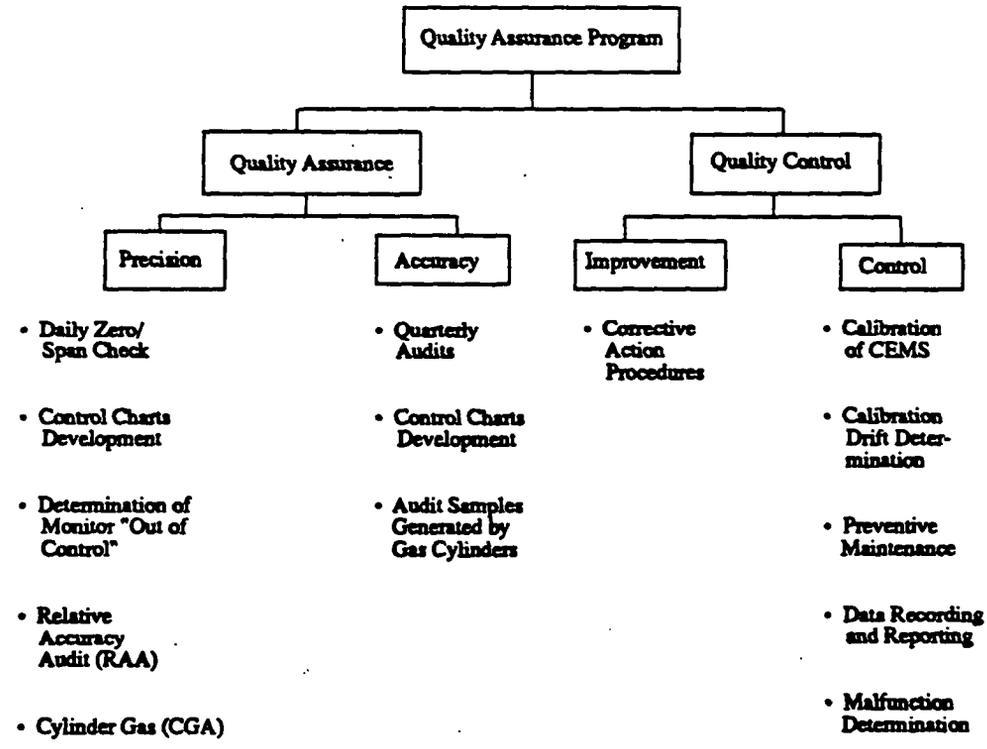
- to provide for prompt detection and correction of conditions that contribute to the collection of poor quality data, and

- to collect and supply information necessary to describe the quality of the data.

A good sound quality assurance program must contain the following elements:

- routine training and/or evaluation of operators,
- routine monitoring of the variables and/or parameters which may have a significant effect on data quality,
- development of techniques to detect defects,
- development of methods and written procedures to qualify data, and
- action strategies to increase the level of precision in the reported data and/or to detect equipment defects or degradation in equipment performance.

Figure 14-2 **Source Specific Quality Assurance Program**



Overall, quality assurance program involves the incorporation of three general categories. These categories are; 1) management, 2) measurement and documentation, and 3) data reduction, validation, analysis and statistics. Let us take a moment and comment on each of these categories.

Management

The first category pertains to the development of written policies concerning the use of quality assurance procedures as a part of the management effort. Also, any administrative procedures relevant to all measurement systems would be incorporated in this category. These procedures should comply with current EPA regulations. QA reports and graphics which would demonstrate data quality of CEMs should be summarized on a routine basis in order that the QA coordinator may distribute them for internal review. Cost-effectiveness considerations for obtaining high quality data at the least cost should be incorporated here as well.

Measurement and Documentation

The second category to consider in developing a QA program, measurements and documentation includes a QA manual which delineates step-by-step procedures for the following: CEM start-up, calibration, internal QA checks on each CEM, performance audits, system audits, calibration standards certification, CEM certification, data validation, maintenance (non-routine and scheduled) and intralaboratory quality assessment activities. Procedures which incorporate the requirements of *Appendix* F, Procedure 1 should be a part of this document.

A document control system should also be implemented. Such a system would consist of the identification of and revisions to all QA documents associated with CEMS. A numbering system should be used in order to identify all log books used. Types of log books used should include the following: monitor log books, procurement log books, calibration standards log books, laboratory log books, excess emission log books, daily monitor log books, and periodic audit log books. Also the document system should provide for maintaining records of monitoring equipment (by manufacturer's serial number and monitor location), spare parts inventory, the status of all CEM components (e.g., return to vendor, discarded, under repair, etc.) and all QA audit standards (National Institute of Standards and Technology (NIST) traceable, recertified date). Finally, the source owner should develop a document distribution system that provides the most current procedures to concerned personnel for review and implementation.

Data Reduction, Validation, Analysis and Statistics

Finally, the third category incorporates the methods for data reduction and calculations so that the data can be represented in units of the applicable standard. The use of statistics in a quality assurance program is essential in that it provides assurance that the CEM is performing to the required specifications and that the data obtained is valid. These statistics are also used to develop control charts which are then used to detect and assess long-term trends. From these trends, such items as out-of-control criteria limits and confidence limits used to identify any significant changes from past CEM performance are established.

Developing and Implementing a Quality Assurance Program

In developing the QA program, the following questions need to be answered:

- How does the CEM system work?
- What possible things can go wrong?
- How does one determine that something has gone wrong?

The person developing the QA program has various sources to consult. These sources include the operation and maintenance manuals, the service department of the vendor who supplied the CEM, technical personnel who work for the source and who are familiar with the system, and outside contractors who have experience with such systems. Remember that a quality assurance program is source specific and that a program developed for one source may not be applicable to another source's needs. The developer of the QA program will need to determine which CEM parameters need to be tested and how often these tests should be performed. Several issues must be taken into consideration when designing test programs:

- the probability of the CEM parameter changing,
- the impact such a change would have on the quality of the CEM data,
- the degree of difficulty that would be encountered in checking the CEM parameter, and
- any additional reasons for documenting specific CEM parameters.

Once these issues have been resolved, the next step is to determine at what frequency certain CEM parameters should be checked. Certain parameters will require testing on a daily or more frequent basis while others may be checked periodically. It is probably best to divide these frequencies up into weekly, monthly and quarterly checks and then determine which frequency category each parameter test should belong to.

In determining the optimum frequency for performing various CEM activities, it is best to implement a trial period whereby the CEM parameter would be checked more often. After a period of time, the source would have a large enough data base for use in determining this optimum frequency.

It is also a good idea to get representatives of each department which would be involved in or affected by the CEM program, active in the development of the QA program. The input and suggestions received by the various departments will be most useful in developing and implementing a successful QA program.

Once the QA program has been drafted and is approved, it should be implemented on a trial basis. In doing so, such problems as wasted motion, inadequate documentation and confusing instructions which were not apparent during the development of the QA program, will be clearly recognized.

Finally, a QA program needs to undergo a periodic review either once a year or twice a year to determine any necessary changes in the program which would reflect changes in the CEM's reliability due to instrument age or other factors, changes in repair personnel, changes in manpower availability or source operating practices. Such a review would include an inspection of the daily QA checks, periodic checks and corrective action logs. This review would act to fine tune the frequency with which the various CEM parameters would need to be tested. For example, if several months of data indicated that certain daily checks were shown to be quite stable, these checks could then be performed on a less frequent basis.

Overview of a Quality Assurance Document

Figure 14-3 gives an outline of a written quality assurance program document for stationary source testing. We will discuss those sections that are relevant to this lesson. They are, *Section* 1.0, Introduction, *Section* 2.0, Quality Assurance Overview, *Section* 3.0, Organization and Individual Responsibility, *Section* 4.0 Quality Assurance/Quality Control and *Section* 7.0 Quality Assurance Audits. The basic content which should be found in the first three of these sections, is described below. The other two sections (i.e., *Section* 4.0 to 7.0) are discussed in subsequent parts of this lesson.

In the introduction, a commitment by the source to maintain the QA program in compliance with all existing environmental rules and regulations should be stated. Also, a commitment should be made to acquire CEM data of the highest quality possible and to maintain documentation of system performance.

In the QA overview section, the specific objectives of the quality assurance program should be clearly stated. We have already discussed these objectives. Such activities as designation of responsible individuals, assurance of data integrity, documentation, training programs and corrective action activities should be discussed.

The section on organization and individual responsibilities should discuss the key personnel involved in the CEM QA program and provide an organization chart of personnel and activities associated with the major elements of the program. This section should include a definition of all QA/QC maintenance, data reduction, recordkeeping and communication activities and then assign these responsibilities to the appropriate personnel (by job category and name). Also, the mechanisms used for initiating each activity should be defined and the specific frequency for performing certain activities (i.e., preventive maintenance and QA audits) should be stated.

Figure 14-3

EXAMPLE OUTLINE
Source Quality Assurance Program
Written Document

1.0 Introduction

2.0 Quality Assurance Overview
- 2.1 General
- 2.2 Specific

3.0 Organization and Individual Responsibility
- 3.1 Personnel Assignments and Responsibilities
  - 3.1.1 Organization
  - 3.1.2 Program Management
  - 3.1.3 Field Operations
  - 3.1.4 Laboratory Operations
  - 3.1.5 Data Management
- 3.2 QA Responsibilities
  - 3.2.1 Quality Assurance Coordinator
  - 3.2.2 Field Personnel

4.0 Quality Assurance/Quality Control
- 4.1 Quality Assurtance
  - 4.1.1 Activities
  - 4.1.2 Personnel Responsibilities
- 4.2 Quality Control
  - 4.2.1 Recordkeeping
  - 4.2.2 Activities/Corrective Action

5.0 Data Handling, Validation and Reporting
- 5.1 Data Logistics
- 5.2 Data Handling and Statistical Analysis
- 5.3 Control Charts
- 5.4 Data Validation Criteria
- 5.5 Data Reporting
- 5.6 Data Forms

6.0 Operation and Maintenance Program
- 6.1 General
- 6.2 Preventive Maintenance
- 6.3 Corrective Maintenance
- 6.4 Spare Parts Inventory
- 6.5 Maintenance Documentation

7.0 Quality Assurance Audits
- 7.1 Self Auditing
- 7.2 Corporate Auditing
- 7.3 Performance Audit
- 7.4 Data Quality Audits

8.0 Recordkeeping and Reporting Requirements

This section on organization and individual responsibilities should also define the department responsible for initiating any malfunction activities. Such activities include instrument repair, QA audits following maintenance, and operating alternative measurement methods. Additionally, this section should contain flow charts which indicate the flow of information between parties involved in the QA program and a table which identifies all responsible personnel involved in the CEM program and lists these individuals by name, title, address and

telephone number as well as each participant's individual role. An example of a flow chart demonstrating the flow of activities between the various departments involved in a CEM QA program is shown in *Figure* 14-4.

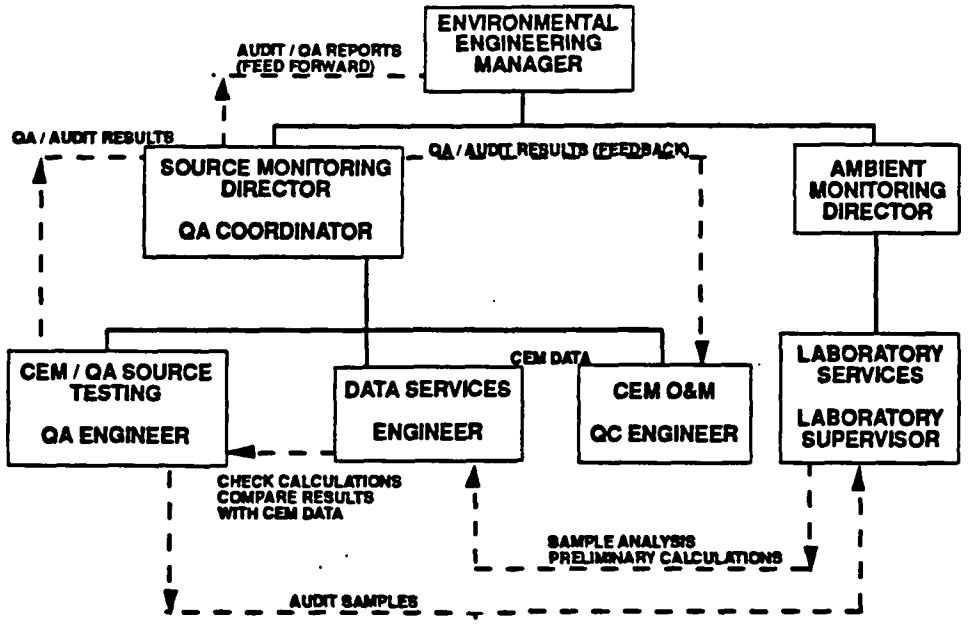


FIGURE 14-4 PERSONNEL FLOW CHART WITHIN SOURCE QA PROGRAM

The Three Levels of a Quality Assurance Program

QA programs contain at least three different levels, Level I, Level II, and Level III QA functions. *Table* 14-1 is a summary of the key responsibilities of the three QA levels. The following discussion summarizes the role of each level.

Level I

The Level I function involves the implementation and support of the QA program. Such duties as administering company QA policy, administrative support, local assistance, development of strategies, system analysis, promulgation of permit requirements and interfacing between the company and the regulatory agency are some of the functions of Level I QA.

Level II

The responsibility of implementing the QA program lies within Level II. Personnel involved with Level II QA are responsible for developing and implementing the QA/QC programs which includes statistical procedures and techniques necessary to meet the regulatory requirements. The scheduling and performance of non-routine and quarterly audits, the evaluation of new QA procedures for applicability, the evaluation of data quality and maintenance of QC charts and records are all a part of the Level II QA responsibilities. Also, Level II QA is

responsible for responding to QC problems and coordinating such activities with Level I QA. The Level II QA coordinator should summarize in monthly and quarterly reports the status of the reliability of the CEM system and its components, the quality of generated data, any CEM problem areas, any corrective actions taken and their results, and quarterly excess emission reports (EER). Such information is fedback to Level I QA for approval and distribution.

TABLE 14-1

RESPONSIBILITIES OF LEVELS I, II, AND III IN A SOURCE QA/QC PROGRAM

LEVEL I AND LEVEL II	LEVEL II AND LEVEL III	LEVEL III
SUPERVISOR & COODINATOR	SUPERVISOR & OPERATOR	OPERATOR
• Document Control/Revisions; • QA Policy & Objective; • Organization; • Quality Planning; • Training; • Quality Cost; • Interlaboratory Testing • Audit Procedures; • Data Validation; and • Quality Reports to Management.	• Corrective Action; and • Procurement Quality Control.	• Preventive Maintenance; • Data Reporting; • Calibration; and • Document Control.

Level III

Level III QA consists of ensuring that good quality data are obtained from instrument operation. Level III QA activities are the responsibility of the CEM operator. Such responsibilities as the daily QA zero/span checks and subsequent recordkeeping, preventive maintenance procedures, sample collection and data reporting are a part of this QA level.

Three Stages of Quality Control Involved in a CEMS Program

In developing a quality assurance program for a continuous gas emission monitoring system, there are three basic stages of quality control which need to be addressed. These three stages are:

1. operation checks (daily checks, observations and adjustments),

2. routine (periodic preventive maintenance) and corrective maintenance, and

3. performance audits.

The operation checks involve daily or routine checks of the monitoring system to ensure that the equipment is performing adequately. Perhaps the most common QA/QC check involves checking the zero and span drift on a daily basis. Other operation checks include checking the reference signals from control panels, flow rates, pressures, vacuum levels, other gauges, valves and temperature settings. These types of checks can compare results to baseline values and control limits. If deficiencies are found, corrective action should be taken.

Routine maintenance is performed at regular intervals. This type of maintenance includes preventive maintenance which involves such activities as the replacement of filters, lamps, motor bearings and other parts. Electronic and optical system checks may also take place. The purpose of this type of maintenance is to prevent problems before they arise or find incipient problems and resolve them before they produce out-of-control situations. Corrective maintenance is performed whenever there is a malfunction in the monitoring system and there is a need to bring it back into proper operation. Corrective maintenance is also called non-routine maintenance which refers to an unscheduled repair. We will talk more about these types of maintenance programs in the next lesson.

Performance audits are performed in order to check the operation of the system, identify any operational problems, identify the need to improve preventive maintenance schedules/procedures, or identify the need for corrective maintenance. We will talk more about audits later.

A Quality Assurance Perspective for Regulatory Agency Inspections

In past lessons, we have learned that federal, state and local agencies require that a source install, calibrate and maintain CEMS in order to demonstrate that it is maintaining compliance with the established air quality standards. The regulatory agency has the right to conduct periodic inspections of a source in order to ensure that the monitoring system being used at a plant is operating in a satisfactory manner. Control agencies which have good inspection procedures for performing audits of a source's CEM program will have a higher percentage of CEMSs which demonstrate good QA/QC practices within their jurisdiction because these CEMs will be maintained and operated in a manner necessary to produce accurate and reliable air quality data. Agency inspection programs are necessary in order to stimulate sources to establish and implement a sound CEM program as well as good quality assurance procedures. The source will find it much easier to maintain a monitoring system than to constantly end up in court due to a poor inspection record. With that in mind, there are two types of agency inspection programs. They are:

- schedule system programs, and

- level system programs.

The schedule system program involves the periodic inspection of a given source at various time intervals. This type of inspection program involves more manpower and resources than does a level system inspection program. Schedule system inspection programs may call for quarterly or yearly inspections and may be announced (i.e., the actual date of the inspection is known to the source) or can be unannounced (i.e., the source may know that an agency inspection will be conducted within a given year, but not know the specific date). During the actual course of the inspection, the content may vary. The inspection may only consist of the inspector's use of a checklist to determine the condition of the monitoring system with such items as strip chart records, meter readings and computer outputs reviewed. Such checklists have been developed by the EPA Stationary Source Compliance Division. Some inspections, however, may require the use of audit devices to check the performance of the CEM in the presence of the inspector. Usually, the agency will hire an independent contractor to perform these audits.

The level system inspection program relies on the required quarterly excess emission report (EER) requirements contained in the applicable subparts of 40 CFR Part 60. For both new and existing sources, the information required to be contained in this report includes details on exceedences of emissions standards; the nature and cause of the excess emissions; and periods during which the CEM was inoperative and during which calibration checks, adjustments and maintenance were performed. Because the specific format for reporting the excess emissions varies from one agency to the next, it is a good idea to contact the agency prior to developing any software for handling and reporting this type of data.

The excess emission report is reviewed by the agency once received, and a determination made as to the status of the control equipment and monitoring system performance. Enforcement action may result if these reports reveal extensive periods of excess emissions. Depending on the severity of the problems noted in these reports, the agency will determine the next level of action to take. This action may be in the form of an agency call (or a letter) to the plant asking for clarification as to why the monitoring system malfunctioned, or it may require an agency inspection visit to the plant in order to review data and calibrations using checklists as previously described. If this level of review does not determine the nature of the problem, a full scale audit or a repeat of parts of the performance specification test (Part 60, *Appendix* B) may be required. Although a level system inspection program requires less manpower, this type of program may encounter problems. Such problems include sources going for years before undergoing an independent audit or agency inspection, and excess emission reports that may mask actual problems in the monitoring program.

Audits

Overview

Earlier in this lesson, we discussed the three levels of quality control used in CEM programs. As you may recall, one of those levels involved the use of performance audits. In general, audits are independent checks of the monitoring system by someone other than the day-to-day instrument operator. These audits are usually performed by an outside consultant, someone from a different facility or someone in the quality assurance group of the company. The audit is performed in addition to the normal quality control checks of the monitoring system using audit standards/devices different from those used in the normal day-to-day calibration checks.

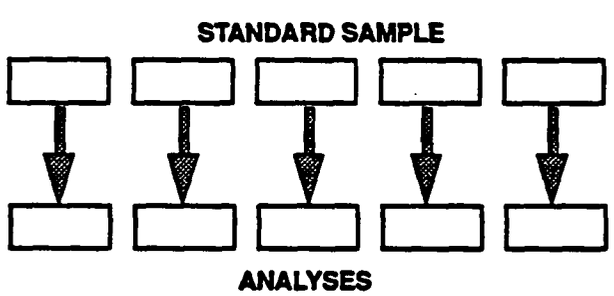
The audit will provide an independent means for determining if the reported data (from day-to-day) are precise and accurate, that the QA and maintenance programs are adequate and quality control is satisfactory. The audit should be performed while the monitoring system is operating under normal conditions (i.e., without any special preparation or adjustments) and both announced and unannounced audits should be scheduled.

In the last lesson, we talked about the requirements of Part 60 *Appendix* F. This type of audit as you may recall, is required on a quarterly basis for regulatory purposes. It should be noted that while a CEM calibration is the most important part of quality control, the audit program is the most important part of quality assurance. Basically, there are two types of laboratory audit programs:

- intralaboratory
- interlaboratory

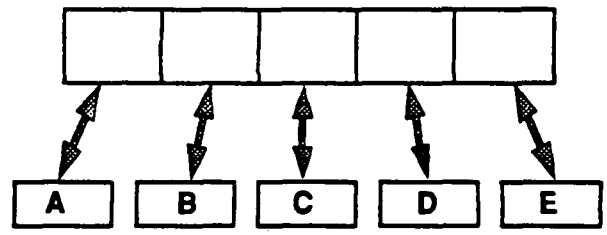
Intralaboratory program audits, involves the analysis of standard samples using the same procedures that are used for analyzing the actual air samples. Each standard sample would contain the same concentration and therefore, each participating laboratory should obtain the same results as long as each lab uses the same identical procedure. The intralaboratory audit is performed by the same CEM technician who also performs the daily CEM checks (i.e. calibration drift test). The CGA test which we learned about in Lesson 13 (e.g., Part 60 Appendix F requirements) is an example of an intralaboratory audit because this test is usually performed by the same person who performs all daily CEM checks. *Figure* 14-5 shows a general diagram which exemplifies the intralaboratory audit method.

FIGURE 14-5 INTRALABORATORY AUDIT (STANDARD SAMPLE)



The Interlaboratory Program audit includes the performance audit which provides a quantitative assessment of the monitoring system in order to verify the adequacy of the quality assurance procedures used to determine adequate CEM performance. In performance audit surveys, a single source will send samples to various participating laboratories with instructions on how to analyze the samples. Each laboratory will send their sample analysis results to the source for evaluation. The Interlaboratory audit is performed by personnel not involved in the CEM program (e.g., by source QA personnel not involved with the CEM program or outside contractors). An example of this type of audit is the RATA test requirement of Part 60 *Appendix* F. As we will learn in the next subsection, performance audits may comprise only a part of a source's audit program. *Figures* 14-6 shows a general diagram which demonstrates the performance audit method.

FIGURE 14-6 INTERLABORATORY AUDIT (PERFORMANCE AUDIT SURVEY)



Types of Audits Incorporated In A Source Quality Assurance Program

From a QA standpoint, a source may incorporate four different types of audits in its CEM program. The four types of audits are:

- Management Systems Audits (MSA),
- Technical Systems Audits (TSA),
- Performance Audits (PA), and
- Data Quality Audits (DQA).

The management system audit provides an evaluation of the role of management in the QA program. This type of audit is conducted to determine if the company's management policy includes quality assurance in the normal plant activities, if plant personnel involved in the QA program have job descriptions and performance standards, if adequate resources have been appropriated to the QA program, if the QA program has an adequate system for document control involved in audits and other QA projects, and if there is a satisfactory program for ensuring that QA training programs and communications are adequate and upgraded when necessary. It is the source which determines the specific criteria for an MSA and incorporates this into its QA program.

A technical systems audit evaluates qualitatively, the total measurement system which includes selection and use of the monitoring system, (both in the field and laboratory). This type of audit is intended to ensure that the source has adequate sampling and data analysis techniques, that personnel have adequate training and are routinely evaluated, that the equipment and facilities used in the CEM program are satisfactory and that written procedures, recordkeeping, calibration and equipment maintenance are all adequate to produce data of acceptable quality and minimize out-of-control conditions. The QA program should establish the necessary criteria for the TSA and guidelines for developing this type of audit program may come from federal, state or local regulations.

As we have just learned, a performance audit is a quantitative assessment of the monitoring system for demonstrating adequate QA procedures used in verifying adequate CEM performance. The performance audit provides this quantitative assessment of the monitoring system by using reference samples of known concentrations or replicate samples. We also stated that the RATA test requirement of Part 60 *Appendix* F is an example of a

performance audit. In addition, the "Quality Assurace Handbook for Air Pollution Measurement Systems" consisting of five volumes, contains the EPA's Quality Assurance program. The reader should note, that of these five volumes, only volume 3 pertains to source CEM programs. Volume 3 gives quality assurance procedures for specific source categories and provides audit procedures for some of the reference methods (RM) which we mentioned in Lesson 12. Basically, a good performance audit will answer several questions. These are:

1. What is the accuracy of the CEM at the time of the audit?

2. Is the system operating within the established control limits?

3. Are QC data obtained in routine system operations correctly reflecting the quality of data generated from the system?, and

4. How do these data compare to that generated from previous audits?

The PA results can sometimes be used to determine corrective action for out-of-control situations. However, if this cannot be done, a technical systems audit may be needed in order to determine such corrective action needed as a result of an out-of-control situation. In this case, the TSA may determine that there is an insufficient documentation of procedures and the next step would be to conduct a data quality audit.

The data quality audit evaluates the documentation which is used to show that the data obtained is of a known quality. Essentially, this audit ensures that quantitative and qualitative indicators of data quality are available in the QA program. Several questions need to be answered in order to determine if these indicators are present:

- Are monitoring procedures documented in such a way that they could be used by personnel (with similar technical qualifications) other than the original data collector(s)?

- Did personnel involved in sampling sign the appropriate documents which demonstrates that the required procedures were used?

- Does the data obtained contain enough information (i.e., such indicators as precision, bias, and representativeness) so that the limitations of the data can be evaluated and if the intended use of the data is appropriate?

A successful QA program should implement all four of these audit types at some point in time. Only the performance audit provides a quantitative assessment of precision and bias in the measurement of CEM parameters.

Audit Procedures Used By The Regulatory Control Agency

A regulatory agency may use an inspection audit program consisting of the administrative "phase" and technical CEM evaluation "levels". Let us discuss each of these approaches.

The "phase" approach consists of the administrative activities involved with the initial CEM system application, performance testing and final approval. This will allow the agency to approve the CEM through established certification procedures. The "phase" approach consists of these activities:

1. Phase I - the control agency grants the initial approval of the source CEM application as required through the source permit,

2. Phase II - the control agency observes the performance specification testing (PST) of the installed CEM, and

3. Phase III - the control agency reviews the PST report and gives approval or disapproval.

The "level" approach begins after the completion of the administrative phases. This approach extends from a relatively simple to a more complex evaluation of the source's CEM program. The lowest level would consist of source records review and the highest level would consist of stack testing compliance determinations. This approach involves the inspection program which determines or confirms compliance and identifies causes of excess emissions. The level approach consists of four levels and the activities at each level are as follows:

1. Level I - agency review of records including excess emission reports, previous inspection reports, source "working" file and permits;

2. Level II - on-site inspections involving review of monitor recordkeeping (maintenance, monitor and control equipment logs), monitor fault indicator, monitor internal zero/span check, strip chart review and electronic checks;

3. Level III - evaluation of the source CEM through external audit evaluation involving the use of neutral density filters for opacity monitors and gas cylinders/permeation tubes for gas monitors; and

4. Level IV - a comparative evaluation of the source CEM through performance testing utilizing federal Reference Methods or portable CEMS (e.g., this level involves a recertification of the CEM).

The regulatory audit procedure using the "phase" and "level" approach was designed so that by completing an activity, it can be known whether or not the CEM has achieved the necessary stage of compliance before starting the next level or phase.

Additional information regarding specific audit procedures and techniques used by regulatory field inspectors is contained in an EPA document entitled "Field Inspections Audit Techniques", EPA 340/1-89-003.

Summary

A successful QA/QC program for a CEM involves considerations in the purchasing, installation and testing, and the continual operation of the monitoring system. Quality control refers to methods used to assure a quality product. Quality assurance is used to ensure the adequacy of the quality control program. The overall objective of a quality assurance program is to ensure that CEM data are precise, meaningful and accurate within given acceptance criteria. QA involves the implementation of four general categories, namely management, measurement, documentation and statistics. There are three levels involved in a quality assurance program. The first level involves the implementation and support of the QA program, the second level is program implementation and the third level involves the duties of the CEM operator. The three levels of CEM quality control are operation checks, routine and corrective maintenance and performance audits.

Regulatory agencies may use either a schedule system inspection program involving the periodic inspections of sources or may use a level system program which relies on required quarterly excess emission reports from the source. A good agency inspection program will yield a high number of sources which have an adequate QA/QC program for their CEM systems.

An audit provides a means (outside of the QA program) for the source to ensure that its monitoring system is providing accurate and reliable data. Intralaboratory audits involve using the same personnel and procedures for analyzing both standard and actual air samples while interlaboratory audits employee personnel outside of the CEM program to analyze the air samples in order to compare the results of the independent laboratory to those obtained by the source. Regulatory agencies may use a "phase" and "level" audit procedure approach in order to ensure that a sources CEM program is in regulatory compliance.

REVIEW EXERCISES

1. In conducting a prepurchase/ evaluation of a CEM, a source owner needs to consider which of the following: a. Having the CEM field tested (if purchasing multiple units.) b. The operational design with respect to the installation site, c. Contacting the owners who have already installed that particular CEMS model. d. All of the above.	
2. True or false. A minimum warranty of one year should be included in a CEM purchase contract. This warranty should not begin until after the CEM passes an acceptance test conducted by the purchaser.	1. d
3. True of false. Quality control refers to activities which will provide a quality product and quality assurance refers to activities which provide assurance that the quality control program is satisfactory.	2. True
4. Which of the following is not a primary objective of a quality assurance program: a. Collect and supply information necessary to describe the quality of the data. b. Provide routine performance evaluation of personnel and/or equipment. c. Provide for prompt detection and correction of conditions that contribute to the collection of poor quality data. d. Provide an initial screenning of new personnel through the use of a lie detector system.	3. True
5. True or false. A quality assurance program consists of the incorporation of three general categories: 1. Management 2. Measurement and documentation, and 3. Data reduction, validation, analysis and statistics.	4. d
6. The person made responsible for developing a CEM QA program should consider which of the following questions: a. How does one determine that the CEM is malfunctioning? b. How does the CEM work? c. What possible things can go wrong with the CEM? d. All of the above.	5. True

7. True or false. The person developing a CEM QA program will need to consider testing CEM parameters on both a daily and a periodic basis.	6. d
8. True or false. Once a CEM QA program has been implemented and has undergone an acceptable trial review, there is usually no need to review the program adequacy on a periodic basis.	7. True
9. In a quality assurance program, the Level III function involves which of the following activities: a. the overall implementation of the QA program. b. the duties of the CEM operator. c. Administering company QA policy. d. procuring operating permits from the regulatory agency.	8. False
10. The three stages of quality control in a CEMS program are _____, _____ and _____.	9. b
11. True or false. A level system inspection program used by a regulatory agency involves the periodic inspection of a given source at various time intervals.	10. Operation checks, routine and corrective maintenance, performance audits.
12. True or false. Audits are independent checks of the monitoring system, are performed in addition to the normal quality control checks, and are performed by some person other than the normal day-to-day instrument operator.	11. False

13. A technical systems audit: a. Provides a quantitative assessment of the monitoring system using reference samples of known concentrations or replicate samples. b. Provides an evaluation of the managements role in the QA program. c. Evaluates the total measurement system which includes selecting the CEM, ensuring adequate written procedures, and adequately trained personnel. d. None of the above.	12. True
14. The _____ audit will provide a quantitative assessment of precision and bias in the measurement of CEM parameters.	13. c
15. True or false. In a regulatory agency's inspection audit program, the "phase" approach consists of administrative activities involved with the initial CEM system application, performance testing and final approval.	14. Performance
	15. True

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LESSON 15

Maintenance Procedure - Problems and Troubleshooting for Continuous Gas Emission Monitoring Systems

Lesson Goal and Objectives

Goal

To describe the recommended maintenance activities for continuous gas emission monitors and to discuss the potential problems with their use and suggested solutions to these problems.

Objectives

At the end of this lesson, you should be able to -

1. describe some of the activities involved in preventive maintenance, routine maintenance, and corrective maintenance programs;
2. describe the three basic problem areas encountered in a continuous emission monitor (CEM) maintenance program;
3. describe some of the activities specific to preventive maintenance, routine maintenance, and corrective maintenance programs for extractive monitoring systems; and
4. describe some of the activities specific to preventive maintenance, routine maintenance, and corrective maintenance programs for in-situ monitoring systems.

Introduction

In Lesson 13, we discussed the requirements of *Appendix* F to Part 60 which involved the quality assurance procedures that sources subject to subparts Da and Db of Part 60 must incorporate into their monitoring programs. As you may recall, one of the requirements called for written procedures for performing preventive maintenance activities to the monitoring system. A successful maintenance program for continuous gas emission monitors can mean the difference between "life and death" to the monitoring program. These instruments are complex, electro-optical systems which are operated in a variety of adverse environments. It is no wonder why a successful maintenance program must include procedures for maintenance to be performed at certain intervals in order to ensure that the system does not fail for (short or) extended periods of time.

This lesson presents a basic overview of a complete maintenance program which includes the three types of maintenance programs used. This lesson also describes the maintenance programs which are specific to both extractive and in-situ type monitoring systems.

A Basic Overview of Maintenance Programs For Continuous Emission Monitors

There are three types of maintenance programs. They are preventive maintenance, routine maintenance, and corrective maintenance. Preventive maintenance involves any activities which are designed to detect and prevent the development of monitoring problems. This would include daily operational checks of the CEM. A preventive maintenance program is important because it reduces the overall maintenance of the system and increases the continuous emission monitors (CEMs) ability to obtain reliable data. In the development of a preventive maintenance program, there are a number of factors to consider. They are:

1) providing the CEM with adequate protection against environmental effects such as heat, cold, dust, rain, and flue gas;

2) locating vibration-free locations for installation in order to minimize damage to mechanical components and electrical connections;

3) installing the CEM in an accessible location for convenience to maintenance personnel;

4) providing a stable power supply which is relatively free of electrical noise;

5) providing a system air supply which is adequate to prevent filter and sample line pluggage;

6) installing CEMs in areas which avoid extreme flue gas conditions such as high temperature flue gases, in areas of high particulate loading, and areas with a high moisture content (especially entrained droplets);

7) providing adequate mountings for on-stack CEM components to eliminate stack movement (expansion/ contraction) and vibration;

8) selecting the appropriate in-stack components (e.g., selecting components made of the appropriate alloys) depending on the CEMS location;

9) maintaining maintenance records which are adequate to determine problem trends which could help in identifying system weaknesses; and

10) selecting a CEM which is appropriate to the application (e.g., using path in-situ systems in gas streams which contain entrained water droplets is not recommended).

All of these considerations will be important in determining the types of, and frequency for performing CEM maintenance. Routine maintenance is actually a part of a preventative maintenance program and involves the periodic inspection and/or replacement of worn or damaged CEM components. Corrective maintenance involves the correction of any immediate malfunctions in the monitoring system (i.e., on an as-needed basis). Troubleshooting the monitoring system whenever something goes wrong is an integral part of a corrective maintenance program. As you may recall, in the last lesson we defined the three levels of quality control for CEMs and we briefly discussed each. Two of these levels were operation checks (routine maintenance) and preventive/ corrective maintenance.

Maintenance Providers

The maintenance program can be carried out either under a maintenance contract with a service contractor or CEM supplier, by plant personnel trained in CEM maintenance, or by a combination of contract maintenance and plant personnel. If a full-service maintenance contract is used, it is a good idea to have several plant employees trained in the maintenance of the system since it will allow these people to conduct basic checks of the CEM. Also, they will be able to notify the maintenance contractor whenever non-scheduled maintenance is necessary.

On the other hand, if an in-house maintenance program is used, the required level of effort will depend on such factors as type of system(s) used at the facility, the number of and locations of the monitoring systems, and local conditions (e.g., the plant environment).

The training of in-house personnel for performing CEM maintenance should be provided by the CEM supplier or manufacturer. Individuals to be trained for an in-house maintenance team should ideally have experience with CEMs, or should have a technical background and mechanical and electronic maintenance skills. The reader should note that continuous emission montioring systems (CEMS) contain complex electronic components and some systems incorporate mechanical components which are highly sophisticated in design. It will take an individual with a strong technical background to learn and perform some of the more difficult maintenance tasks.

Problem Areas

Recent surveys have showed that there are three basic problem areas which can be found in a CEM maintenance program. These areas are spare parts, emergency service, and data handling systems.

Obtaining spare parts has been shown to be one of the most persistent and recurring problems encountered in a maintenance program. The most obvious way around this type of problem is to always maintain a large in-house inventory especially if a facility installs several monitoring systems of the same type. By having spare parts available, monitor down time is minimized.

Emergency service is also a problem since it is often difficult to obtain a quick response from a vendor, and sometimes the person(s) who has been called to perform the maintenance may not be very proficient in diagnosing the problem and performing the repair in a timely manner. A possible solution to this problem is to specify certain plant personnel to be responsible for CEM maintenance and to provide these people with vendor training on instrument diagnosis and repair. Another possible solution would be to initiate a service contract with someone, other than the CEM vendor, who has the capability to provide qualified service technicians on an on-call basis.

The problems associated with automated data handling systems are 1) the lack of software support by vendors, and 2) the use of inappropriate calculation parameters. The lack of software support by vendors makes it difficult for the CEM user to make the necessary modifications to their software programs which are usually required after the initial installation of the program. Many times, the vendor will lose the original program documentation whenever there has been a change-over in programming personnel. One way to overcome this type of problem is for the source owner to employ in-house information specialists or consultants to provide constant surveillance over the computer programming system used at the facility. The second problem involving automated data handling systems, pertains to the use of generic equations that contain process specific conversion factors. For example, the F-factor (EPA Method 19) that converts the pollutant concentration in parts per million (ppm) to units of the emission standard in pounds per million Btu for combustion sources, is different depending on the type of fuel burned. When the data handling system is installed, the F-factor in the generic equation must be checked to ensure that it corresponds with the fuel burned at the facility.

Finally, the reader should note that these automated data handling systems require stable environments (i.e., clean, dry and temperature controlled). Additionally, the power supply used for these systems must be stable and free of electrical interferences. A faraday cage is a good preventive maintenance device to use in situations where the data system is subjected to strong radio frequency signals.

Now that we have discussed the basic types of CEM maintenance, considerations to be addressed in developing a maintenance program and problem areas encountered in maintenance programs, the remainder of this lesson will focus on maintenance programs which are specific to 1) extractive monitoring systems, and 2) in-situ monitoring systems.

Recommended Maintenance For Extractive Monitoring Systems

Preventive Maintenance

Daily operation checks should be performed by a qualified and trained instrument operator who is capable of recognizing problems from these daily checks. The use of automatic check systems, which are incorporated into many types of extractive monitoring systems for performing daily zero and calibration drift checks as well as other internal self-checks without the need of the operator, reduce the level of operator attention. However, this lack of attention can cause small problems to develop into much larger ones. This type of problem can be alleviated to a certain extent by using CEMS which have incorporated a more intelligent system which monitors key system parameters and will report an out-of-control situation at a remote panel.

The first item which should be observed during a daily operation check is the strip chart record and/or other data recording devices. All pertinent information for calibration purposes, the time/date of the readings, the name of the person recording the information and chart recorder settings, should be written directly onto the chart. Always check the paper in the recorder or printer (if applicable) to ensure that there is an ample supply of paper for the next 24-hour run. If the data obtained by the monitoring system are both checked and adjusted automatically (by the appropriate calibration factors) by means of a microprocessor controller, the controller unit will have to be preprogrammed to record the unadjusted values before the CEM is adjusted to the required values. If both a strip chart recorder and a microprocessor are used together, the adjusted data should be recorded on both the strip chart and the microprocessor printer output. The problem involved in this case is that sometimes the microprocessor is programmed to record the adjusted number only, without physically adjusting the CEM. When this happens, the CEM meter readings and strip chart readings will differ from the microprocessor reading making data interpretation very difficult.

Once the strip chart recorder has been checked, the next thing to inspect is the indicator lights on the system or monitor control panel. The indicator lights system will alert the operator whenever an out-of-control situation or other problems occur. These problems need immediate attention since subsequent data may be in error. If reset buttons designed to override the indicator lights are installed on the monitoring system, they should not be used until the problem has been corrected. It is advisable to record the system status in ink in a hardbound logbook. Additionally, all other maintenance, including unscheduled repairs or system modifications should also be recorded in this logbook. This book is useful for tracking the long-term performance of the CEM and will allow other system maintenance personnel to become more familiar with the monitoring system. The status of other system indicators should also be recorded at this time. These would include vacuum, or pressure gauges, sample flow rates, and lamp and detector reference levels (if applicable).

The daily monitoring system check should also include a visual inspection of the conditioning system (moisture removal) purge cycle. The proper operation of all valves and verification that the condenser system has been completely drained is the focus of this inspection.

A calibration check of the system should be performed next. We have already discussed the regulatory requirements for performing calibration checks on continuous emission monitoring systems (CEMs) in Lessons 12 and 13. We also discussed the required performance specifications (i.e., *Appendix* B and *Appendix* F to Part 60). In performing a calibration check it is desirable to inject the calibration gas at a point in the monitoring system where many of the conditioning system components will be checked. In some extractive systems, this can be performed at the probe itself with the advantage of allowing the system to be tested for sample line losses. The reader should note some of the problems involved with the injection of calibration gases. First of all, the use of gas cylinders for injecting the gas has a tendency to pressurize the system. When this happens, the flow rate of the gas into the analyzer sample cell may differ from the flow rate of the extracted stack gas. Secondly, cylinder gas is a dry gas and does not contain any moisture. The calibration process can be affected if flow rates and moisture content of the calibration gases entering the analyzer sample cell are not similar to the sample gas. Thirdly, whenever the system is pressurized, system leaks will go undetected because ambient air is prevented from entering the system as it might otherwise if there were a leak during normal monitoring procedures. Finally, the reader should recall from Lessons 12 and 13 that gases which are used for performing these daily checks should be either EPA certified gas concentrations or validated against certified calibration gases.

Figure 15-1 shows a suggested format (from the EPA's "Quality Assurance Notebook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods") for recording the daily checks for an extractive monitoring system.

Routine Maintenance

For CEMs which have just been installed, it is recommended that routine maintenance be performed on each system every 30 days. As more experience with each system is gained, the period for such maintenance can be modified for either shorter or longer periods of time depending on the specific problems encountered with each system type. These maintenance intervals may reflect maintenance frequencies for subsystems or individual components.

Conditioning System

It is the sample conditioning system rather than the analyzer system that is of most concern with extractive monitoring systems. Before the analyzer receives the gas sample, the conditioning system filters remove particulate matter and water vapor. These filters must be periodically cleaned or replaced. For condensing-type moisture removal systems, the condensed water must be drained.

CEM Plumbing

All plumbing associated with the CEM should be periodically checked for corrosion and leaks. This includes an inspection of all fittings, valves and gas regulators. If solenoid valves are used to automate the system, these valves should be checked to ensure that they move freely and on command as these types of valves are prone to sudden failure. Motorized or air-activated rotary valves have been used on extractive systems in order to reduce

FIGURE 15-1 EXAMPLE FORMAT FOR EXTRACTIVE GAS MONITORING SYSTEM DAILY QC SHEET

PLANT _____ DATE _____ TIME _____

UNIT _____ NAME _____

GAS MONITORED _____ PHONE _____

ANALYZER I. D. _____ ZERO OFFSET VALUE _____

SPAN VALUE _____ DATE CERTIFIED _____

CALIBRATION GAS VALUE _____ PAPER STATUS:

ZERO GAS VALUE (AIR, N_2, OTHER) _____ STRIP CHART _____

HOURS OPERATING IN PERIOD _____ PRINTER _____

PART 1 INDICATORS

INDICATOR LIGHTS/GAUGES	STATUS	PROBLEM/ACTION TAKEN
SAMPLE PRESSURE/VACUUM		
SAMPLE FLOW		
LAMP		
DETECTOR		

PART 2 CALIBRATION CHECK

UNADJUSTED READING	TIME	METER	STRIP CHART	DIGITAL PRINTER
ZERO (LOW-LEVEL) GAS				
CALIBRATION (HIGH-LEVEL) GAS				
STACK CONCENTRATION				

PART 3 ZERO & SPAN ADJUSTMENT (IF OUTSIDE OF CONTROL LIMITS)
CONTROL LIMIT ? _____ PPM

ADJUSTED READING	TIME	METER	STRIP CHART	DIGITAL PRINTER
ZERO (LOW-LEVEL) GAS				
CALIBRATION (HIGH-LEVEL) GAS				
STACK CONCENTRATION				

OPERATOR SIGNATURE _____ DATE _____ SUPERVISOR SIGNATURE _____ DATE _____

the frequency of valve failure. It is not a good idea to design a system which utilizes too many valves as the more valves involved, the more valves there are to be checked. Always maintain a sufficient supply of valves in the spare parts inventory.

Electrical System

It is important to frequently inspect the CEMS electrical system which includes all electrical cables and heat-traced lines. The electrical system is always prone to damage in the plant environment through either normal operations or construction projects. The deterioration of electrical insulation is common in the ambient atmosphere near such areas as where flue-gas leakage occurs or in stack down-wash areas. Also, both electrical fittings and plumbing may become corroded whenever acid gases are circulating near the stack. Finally, many CEMS are equipped with electrical test points located on the back panel or on circuit boards. These test points are used in conjunction with a voltmeter or an oscilloscope to check the electrical system for possible problems. This should also be done on a periodic basis.

Pumps and Chiller Units

Since pumps and chiller units on extractive monitoring systems operate on a 24 hour basis, these must be checked on a regular basis for excess wear in motor brushes, for pump diaphragm breakage, or other parts which require oiling.

Overall Cleanliness

Since particulate matter from flue-gas has a tendency to settle in unwanted locations, the overall cleanliness of the system should be inspected. For systems which are located outside, near a stack, all sensitive components should be installed inside a dust-free cabinet. These cabinets should never be opened whenever fly-ash is in the ambient air.

Lamps and Bulbs

There are certain components of extractive monitoring systems which have limited lifetimes. Such components include lamps and bulbs. These components should be replaced before their lifetime expires because a weakened bulb can produce erroneous results. Since monitoring systems are designed to operate within a given range of lamp intensities, a bulb which is below this intensity range will not respond well to incoming signals. In addition to replacing bulbs, detectors sometimes need replacement but this is not done very often.

Figure 15-2 shows an example of a check sheet format (from the EPA's "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods") which could be used for recording routine maintenance checks. Depending upon factors such as the adequacy of vendor instruction manuals to provide routine maintenance information and experience with the system itself, it may take up to a year to design such a check sheet. The reader should keep in mind that the system's logbook is a very good reference to use in developing these routine maintenance check sheets.

Corrective Maintenance

As we stated earlier, any individual involved with CEM maintenance must have a good technical background and be well trained on the monitoring system. This is particularly true in the case where something goes wrong and the technician is left with the task of locating the problem and solving it.

With extractive monitoring systems, maintenance problems generally occur in the gas transport and the gas conditioning components. If routine maintenance is not performed on valves, fittings, tubing and filters, then acid gases, particulate matter and continuous vibration will take their toll on the system. A good quality control/quality assurance program can minimize the need for corrective maintenance. *Table* 15-1 provides a listing of some of the common problems encountered with extractive monitoring systems. These problems range from physical problems associated with the conditioning system to problems associated with the analyzer. These problems are sometimes caused by a failure of the CEM manufacturer to understand problems regarding constraints imposed by the plant environment and stack conditions. Additionally, the plant may have provided inadequate specifications to the vendor at the time of purchase. Corrective maintenance problems are difficult to foresee and often times the monitoring system must be redesigned so that the frequency of any corrective maintenance can be minimized.

FIGURE 15-2 EXAMPLE FORMAT FOR EXTRACTIVE GAS MONITORING SYSTEM
30-DAY ROUTINE MAINTENANCE CHECK SHEET

PLANT _____ DATE _____ TIME _____
UNIT _____ NAME _____
SYSTEM I. D. _____ PHONE _____
ANALYZER I. D. _____ GAS _____
ANALYZER I. D. _____ GAS _____
ANALYZER I. D. _____ GAS _____

REQUIRED MAINTENANCE CHECKS

EXTRACTIVE SYSTEM	STATUS	ACTION
PROBE FILTER		
FINE FILTER		
CONDENSATION SYSTEM DRAIN		
HEAT TRACE CONTINUITY		
PUMP - BEARING NOISE		
PUMPING LEAK CHECK - VACUUM		
PRESSURE		
CABLE INTEGRITY		
CLEANLINESS		
CORROSION LEVELS PROBE		
SOLENOID PERFORMANCE		

REGULATOR PRESSURES		
AIR-OPERATED VALVES		
AIR PURGE/BLOWBACK		
ZERO GAS		
CALIBRATION GAS		

ANALYZERS		
LAMP		
SENSOR		
TEST POINTS		
CHOPPER MOTOR		
OPTICAL WINDOW STATUS		

OPERATOR SIGNATURE _____ DATE _____ SUPERVISOR SIGNATURE _____ DATE _____

TABLE 15-1

Extractive Monitoring System Problems and Possible Solutions

COMMON PHYSICAL PROBLEMS	POSSIBLE CORRECTIVE ACTION
A. Conditioning Systems Probe plugging	Install blowback system, increase blowback frequency proble shield. Relocate. Change probe design. Change system design. Enter probe at downward angle.
Probe/filter corrosion	Relocate probe. Obtain corrosion-resistant alloy for probe construction.
Probe breakage (due to vibration or embrittlement from chloride)	Support probe. Shorten. Select resistant alloy.
Condensation in sample lines	Resize heaters. Don't let heat go off on heat trace. Use backup power. Avoid shorts - don't loop lines. Install thermal conductivity sensor if continuing problem. Remove water at stack probe. Filter at lower temperaturte (acid may be condensing) - increase temperature or heat.
Inadequate water removal	Improve chiller design. Connect two chillers in series. Back up chiller with Permapure dryer (but heat front end of Permapure). Dilute the gas stream to lower moisture content.
Dirt in sample lines, plugged values, plugged samples lines	Decrease pore size of probe filter. Increase sample flow rate to fine filter. Increase diameter of line. Use clear Teflon tubing to detect areas of accumulation. Redesign to reduce number of valves. Use redundant filters.
Leaks in sample lines/fittings	Reduce number of fittings as much as possible. Detect leaks by pressurizing system and using soap bubble indicator. Check for leaks in gas regulators. Don't wrench down on compression fittings too severely. Don't use glue, paint, glyptal, etc., to cover leaks - rebuild system if necessary.
Pump failure	Perform routine maintenance - check brushes periodically. Check diaphragms of diaphragm pumps.
B. Analyzers	
Internal corrosion/damage	Check moisture removal system for failure. Build redundancy in system. Add extra chiller. Put thermal conductivity sensor in line to stop pump when moisture breaks through. When moisture breaks through, dismantle sample cell, clean, and dry. May have to replace entire cell in some models. Clean and dry all sample lines.
Poor response time (False positive zero values or poor calibration check values)	Check sample line length. Shorten line or increase flow rate. Some analyzers have slow response times. Increase time for calibration gas flow during daily checks.
Excessive drift	Check fouling of sample cell for dirt or water. Electrical problems. Passivation of cell surfaces. Lamp weakening - light levels too low. Detector problems. Electronic problems. Erratic power supply.
Component failures Lamps, fan, chopper motors	Check component wear. Check and replace on regular schedule.
Electronic problems Loose circuit boards, poor contacts	Check for vibration problems. Install circuit board clamps. Check for SO_2 corrosion in exposed units.
Ground loops and noise	Trace and rewire.
Large voltage drops when plant equipment is started. Spikes in strip chart record.	Install transient suppressor, dedicated power transformer or constant voltage/isolation transformer for monitoring system.
Static electrical charges	Connect probe case to dedicated earth ground.
Burned out electronic circuits from lightning strikes	Add phenolic gaskets between metal stack and probe. Add surge arrestors at junction box.
No output from instrument, no calibration cycle, etc.	Check fuses.
Improper instrument response faulty calibration, improper or no output	Check electronics. Check to see that cards and components are secure. Use trouble-shooting guide supplied by vendor to check electronic test points. Replace approriate components or replace cards. Check software for errors in programming - particularly in calibration adjustment routines.

Reference: Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods, EPA-600/4-77-027b.

Such problems as loss of signal, inconsistent readings and poor calibration response are indications of malfunctions in the CEM system. As we just stated, it is important that the CEM operator have sufficient skill to diagnose these types of problems. The following general guidelines can be used for troubleshooting both mechanical and electrical deficiencies of CEMs.

- Loss of signal or abnormally low values - check conditioning system for plugging, leaks, pump failures.

- Noisy, erratic signals - check for electronic problems, electrical supply problems, weak lamps, moisute condensation, particulate matter in analyzer.

- Loss of linearity - check for sample cell contamination, leaking calibration manifold, incorrect gas cylinder values.

- Slow response - check for leaks, water in lines, measuring cell failures.

A majority of the problems encountered with extractive monitoring systems are in the system's electronics. Normally, if the electronics problem is severe, the instrument is compact enough such that it can be shipped back to the vendor for repair. The instrument's maintenance manual is a good reference to use for troubleshooting problems in circuit boards and components.

From a mechanical standpoint, extractive monitoring systems encounter their greatest problems when they are located in severe environments or if the conditioning system fails. In Lesson 8, we mentioned that placing the entire system inside a protective housing was one way to protect the CEM from the operating environment. When the conditioning system breaks down, acid gases and/or moisture may condense in the sample cell and particulate matter may cause blockage of the probe, sample lines, or the analyzer itself. Also, after unconditioned sample gas has entered the analyzer, it can take months before the system will operate properly again. By far, a malfunctioning conditioning system is one of the worst maintenance problems encountered with an extractive monitoring system.

Plugged particulate filters are a prevalent problem with extractive monitoring systems. This can lead to reduced sample flow to the analyzer which will result in component failure and erroneous emissions data. Blockage of particulate filters can be caused by an insufficient backpurge or by an inadequate schedule for filter replacement. Filter blockage is evident whenever a steady drop in the sample flow rate occurs and may be accompanied by a gradual increase in the system vacuum. Backflushing with purge air may slightly improve the situation.

The use of valves which are not properly designed for application to a particular monitoring system are another cause of frequent failures in extractive monitoring systems. Valve failures are sometimes difficult to assess and major maintenance efforts can result. One example of an inappropriate use of a valve type in a system is the use of a solenoid-type valve in a particulate-laden gas stream. In this situation, the particulate matter will eventually wear out the valve seat causing the system to leak. Another problem with the improper use of valves is the use of unsuitable material for frequent operation such as the use of polymeric materials which fail at accelerated operation rates. Additionally, brass valves should not be used in corrosive gas streams. TeflonR and corrosion-resistant steel alloys should be used in most situations.

One other problem encountered with extractive monitoring systems is the failure of heat-traced sample lines which transport moist flue gas to the conditioning system. These lines are heated to prevent condensation from occurring. If a section of the heating element fails, condensation will occur and this can lead to sample gas loss or contamination, and blockage of the sample line. In some instances, these heat-traced lines are not designed to function in adverse environments such as those found in power plants. Providing additional insulation or using a stronger sample line sheath are ways in which this problem can be minimized.

Recommended Maintenance For In-situ Monitoring Systems

Preventive Maintenance

As we just learned, performing the daily operation checks on extractive monitoring systems requires a well trained operator. The same holds true when performing daily checks on in-situ monitoring systems. Also, as with extractive systems, using systems designed with automatic zero and calibration procedures can lead to a false sense of security and additional system failures. However, these problems can be alleviated through the use of more intelligent systems.

Strip chart recordings and computer printouts from the previous 24 hour operation should be reviewed with any discrepancies recorded on both the daily check sheet and instrument logbook. As with extractive monitoring systems, any problems identified by the system indicator lights should be resolved immediately.

Gas cells containing pollutant gas at a known concentration are normally used for calibrating in-situ gas monitors. Optical in-situ analyzers are checked by placing the gas cell into the path of the light beam, and the signal is attenuated by a specific amount. The reader should note that this does not always perform a complete check of the optical system over the full range of concentrations measured in the flue gas. Additionally, the gas concentration of the pollutant gas inside the cells is not normally certified by independent laboratories. These cells are also prone to leakage, and degradation by adsorption and internal reactions which can cause problems when attempting to calibrate these systems.

In-situ point monitors can be calibrated with a cylinder gas which has been certified. This is accomplished by flooding the volume within the ceramic thimble with calibration gas or with a zero gas. In either single-pass or double-pass monitors, a "flow-through" gas cell can be used. This involves flowing gas of a certified concentration through a fixed cell in the instrument. Through this method, a calibration "traceable" to National Institute of Standards and Technology (NIST) or other certified gases can be obtained. However, problems involving the optical system may still be present.

During any of the calibration sequences, the operator should note whether the temperature compensation circuit had been disconnected so that problems in these circuits are not overlooked. This system is used to compensate the temperature for the effects of elevated flue gas temperatures. For in-situ systems which use temperature compensation circuitry, this circuitry must be used during instrument calibrations. If the calibration is performed manually using calibration cells, this circuitry can be bypassed.

In order to ensure proper operation of in-situ monitoring systems, it is important to check the alignment of the optical system on a daily basis. It should be noted that if the system was not designed with an alignment sight, a more detailed electronic or optical check may need to be performed in order to optimize the system alignment.

Figure 15-3 gives an example of a check sheet (from the EPA's "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods) to be used for recording daily operation checks.

FIGURE 15-3 EXAMPLE FORMAT FOR IN-SITU MONITORING SYSTEM DAILY QC CHECKS

PLANT _____ DATE _____ TIME _____

UNIT _____ NAME _____

GAS MONITORED _____ PHONE _____

ANALYZER I. D. _____ ZERO OFFSET VALUE _____

SPAN VALUE _____ DATE CERTIFIED _____

CALIBRATION GAS VALUE (CYLINDER GAS, GAS CELLS) _____ VENDOR _____

ZERO GAS VALUE (AIR, N_2, OTHER) _____ PAPER STATUS:

HOURS OPERATING IN PERIOD _____ STRIP CHART _____

PART 1 INDICATORS PRINTER _____

INDICATOR LIGHTS	STATUS	PROBLEM/ACTION TAKEN
POWER FAILURE		
BLOWER FAILURE		
LAMP FAILURE		
DIRTY WINDOWS		
ALIGNMENT		
ALARM		
OTHER		

PART 2 CALIBRATION CHECK

UNADJUSTED READING	TIME	METER	STRIP CHART	DIGITAL PRINTER
ZERO GAS				
GAS CELL #1				
GAS CELL # 2				
CALIBRATION GAS (IF APPLICABLE)				
STACK CONCENTRATION				

PART 3 ZERO & SPAN ADJUSTMENT (IF OUTSIDE OF CONTROL LIMITS)
CONTROL LIMIT ± _____ PPM

ADJUSTED READING	TIME	METER	STRIP CHART	DIGITAL PRINTER
ZERO GAS				
GAS CELL #1				
GAS CELL # 2				
CALIBRATION GAS				
STACK CONCENTRATION (IF APPLICABLE)				

OPERATOR SIGNATURE _____ DATE _____ SUPERVISOR SIGNATURE _____ DATE _____

Routine Maintenance

Routine maintenance for in-situ monitors should be initially performed every 30 days. There are some manufacturers of in-situ systems who will recommend a routine maintenance period of two or three months, but until the system is "broken in," it is a good idea to perform this maintenance every 30 days.

The first type of routine maintenance consists of ensuring that key system components (e.g., windows, filters, and desiccants) are clean and operational. Whenever cleaning windows or optics, the technician should be very careful as these components can be easily damaged. These components should be cleaned with lens tissue or soft rags along with alcohol or water solutions. If the windows are exposed to flue gas, a mild detergent may have to be used in order to clean these windows. One method which would ensure that optical surfaces are maintained as clean as possible, is to replace purge air blower filters on a periodic basis. If these filters become clogged, particulate matter can scratch the optical surfaces. If stack gas enters the monitor cabinet, electronic components will corrode and fail. The blower filters should be replaced concurrent with cleaning system optics and purge air shutters should be checked at this time. Other optical components such as diffraction gratings are so sensitive that they should never be touched or cleaned in the field. In this case special techniques should be used because fingerprints or traces of cleaning material will severely affect the performance of these components.

As with extractive monitoring systems, the electronics involved with in-situ systems should also be routinely checked for adequate performance. Digital voltmeters and oscilloscopes are used to check the electrical circuits along the various test points. These tests should include checking lamp voltages, power supply voltages, and detector outputs. A well-trained service technician or electronic technician will need to be employed for this maintenance service.

In many in-situ monitoring systems, chopper motors are used in the transceiver assembly to modulate the light beam. Routine maintenance on these motors involves checking the motor bearing for noise or excessive vibration. Motors used for moving mirrors or gas cells into position should be checked by manual means to ensure that the movements are smooth and complete.

A system logbook should be used for recording observations made during routine maintenance checks. This logbook can be used to determine performance trends over a given period of time so that a determination can be made as to the specific frequency for performing certain routine maintenance checks. *Figure* 15-4 gives an example of a check sheet (from the EPA's "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods) which can be used for recording routine maintenance on in-situ monitoring systems.

Corrective Maintenance

In-situ monitoring systems are complex in nature and require a person who has a high degree of troubleshooting skill to perform corrective maintenance. A maintenance technician employed to perform maintenance tasks on in-situ systems should be required to undergo formal training at the vendor's facility. These systems do not share many of the problems associated with extractive monitoring systems but because they are directly mounted inside stacks or ducts they are subjected to harsh environments. In general, such conditions as temperature cycling, acid gases, and vibration can damage optical components, disrupt the optical alignment, and harm electrical components located in the mounted system assemblies.

Recent surveys conducted with utility companies have identified three problem areas relative to locating in-situ monitoring systems. These are:

- ambient dust and severe weather conditions;
- moisture condensation from the effluent stream; and
- sensitivity to vibration.

FIGURE 15-4 EXAMPLE FORMAT FOR IN-SITU MONITOR 30-DAY ROUTINE MAINTENANCE CHECK SHEET

PLANT _____ DATE _____ TIME _____

UNIT _____ NAME _____

MONITOR I. D. _____ PHONE _____

PART 1 REQUIRED MAINTENANCE ACTIONS	STATUS	ACTION
CLEAN OUTER SURFACES		
HOOD		
TRANSMITTER/TRANSCEIVER ASSEMBLY		
LAMP REFLECTOR ASSEMBLY		
PURGE AIR SYSTEM		
CLEAN INNER SURFACES		
HOOD		
TRANSMITTER/TRANSCEIVER ASSEMBLY (UNLATCHED)		
LAMP RETROREFLECTOR ASSEMBLY (UNLATCHED)		
PRESEPARATOR - AIR PURGING SYSTEM		
CLEAN TRANSMITTER/TRANSCEIVER WINDOWS		
CLEAN LAMP/RETROREFLECTOR WINDOWS		
REPLACE PURGE AIR FILTER (OR CLEAN AND REPLACE)		
TIGHTEN HOSE, CLAMPS, CABLES, MOUNTINGS		

PART 2 REQUIRED MAINTENANCE CHECKS	STATUS	ACTION
CHECK ALIGNMENT		
CHECK DESICCANTS		
CHECK CABLES (CONTINUITY, PINCHING, CUTS, CORROSION)		
CHECK HOSES (CONTINUITY, PINCHING, CUTS, CORROSION)		
CHECK SECURITY SEALS		
BLOWER MOTOR (BEARING NOISE)		

OPERATOR SIGNATURE _____ DATE

SUPERVISOR SIGNATURE _____ DATE

The most common problem identified was exposure to ambient dust and severe weather conditions. Electronic drift which will cause erratic operation of the CEM can be caused by extreme fluctuations in ambient temperature and/or cooling caused by wind. Exposure to ambient dust can cause problems with optical surfaces, electronic components and purge air systems if purge air blower filters are not changed periodically. Some in-situ systems are equipped with isolation shutters which protects the system from optical and electronic component damage and should be checked frequently. The construction of an enclosure around the system large enough for maintenance personnel to work on the system is a possible solution to this kind of problem.

Moisture condensation from effluent streams can cause severe problems to exposed optics. The optics can become clouded and this will cause a decrease in light transmittance which could possibly result in the system recording higher pollutant concentration readings. Cleaning these optical surfaces offers only a temporary solution. A longer term solution would be to use heated purge air, especially in colder climates. This air would have to be heated above the dewpoint of the effluent gas and any exposed areas acting as heat sinks would need to be insulated to prevent heat loss. Moisture condensation can also cause corrosion of metal parts (e.g., the reaction of SO_2 and NO_x with water to form an acid solution). This corrosion can cause moving parts to freeze and complete mechanical failure to occur. It is therefore important that fiberglass, teflonR or metal alloys which are resistant to corrosion are used in in-situ systems. Problems involving moisture condensation are encountered mostly whenever the system is mounted in areas downstream of a wet flue-gas desulfurization (FGD) system.

In-situ monitoring systems are very susceptible to vibration. A possible solution to this problem would be to either locate the system in areas away from any stack or duct vibration or to mount the monitor on a floating platform which is attached to a rigid structure (e.g., by placing shock absorbers between the monitor and the platform).

In addition to these three common problems, there is one additional problem which is not as common as the first three. This is the problem of alignment. Whenever stack or duct walls expand or contract, the relative orientation of the transceiver and the retroreflector is changed causing a misalignment ~~of the~~ system to occur. By mounting both ends of the system to fixed platforms and interfacing the system to the stack or duct with flexible seals, this problem can be avoided. Across-stack, in-situ monitors are very sensitive to alignment problems.

Table 15-2 is a listing of some of the common problems associated with in-situ monitoring systems and possible solutions to these problems.

Summary

The three types of maintenance programs are preventive maintenance, routine maintenance and corrective maintenance programs. Preventive maintenance programs involve the daily operational checks of the system in order to prevent long-term problems from occurring. Routine maintenance involves the periodic inspection/ replacement of CEM components and is an integral part of a preventive maintenance program. Corrective maintenance includes troubleshooting the monitoring system whenever a malfunction in the system occurs. Troubleshooting a monitoring system can only be accomplished by a skilled technician who is knowledgeable in the overall operations of the monitor.

There are a number of factors involving the system design as well as environmental factors to consider in the development of a CEM maintenance program. The maintenance of spare parts, obtaining emergency service and data handling systems are three basic problem areas in a CEM maintenance program.

A preventive maintenance program for extractive monitoring systems involves daily operation checks of the system which include strip chart recorders/data handling devices, indicator lights, the conditioning system and a daily instrument calibration. For in-situ systems, daily checks include strip chart recordings and computer applications, instrument calibrations using gas cells, and proper alignment of the optical system. Routine maintenance should be performed every thirty days for both extractive and in-situ monitoring systems. For extractive systems, such components as conditioning system filters, valves, plumbing (for corrosion and leaks),

electrical components, pumps and chillers should be inspected and replaced if faulty operation of any of these components is evident. Routine maintenance for in-situ systems includes an inspection and/or replacement of the optical system components, electrical parts and chopper motors. Corrective maintenance for both extractive and in-situ systems involves a thorough knowledge of all CEM subsystems and a consideration of the severe environmental conditions for which these monitoring systems are required to operate in.

TABLE 15-2 In-situ Gas Analyzer Problems and Possible Solutions

PROBLEM	POSSIBLE CORRECTIVE ACTION
Excessive dirt buildup on windows or thimbles.	Clean blower filters on path systems. Increase blower capacity. Rotate ceramic thimbles on point systems or replace.
Cyclic drift in signal unrelated to plant performance - due to ambient temperature changes. Signal becomes erratic from high temperatures.	Insulate protective hood or install temperature conditioning system about monitor.
Optics misalignment/electrical noise due to stack or dust.	Mount assemblies independently from duct. Use flexible bellows for duct connection. Dampen mountings. Relocate monitor.
Signal becomes erratic at high opacities.	Relocate monitor after control device. Water droplets from scrubber may also cause this problem. In such cases, analyzer may have to be located before the scrubber.
Misaligned system.	Realign, check, and tighten system.
Probe/seal leaks (in-stack monitors).	Return to vendor for repair.
Lightning strikes.	Add phenolic gaskets. Add surge arrestors. Relocate monitor.
Static charge buildup burning out circuit boards.	Run copper cables to earth ground.
Lamp burnout/degradation	Replace on regular schedule. Check lamp power supply for high incidence of lamp failure.
Gas cells unreliable.	Cell leakage, losses to walls - recalibrate cells or replace.
Spurious readings during plant start-up, shutdown, etc.	Install transient suppressor, dedicated transformer for monitoring system.
Improper temperature compensation.	Adjust circuits, recalibrate, or repair or replace boards.
Increased response time.	For in-stack in-situ monitors, check ceramic thimble for plugging. Replace if necessary.

Reference: Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods, EPA-600/4-77-027b

REVIEW EXERCISES	
1. True or false. A corrective maintenance program involves trouble-shooting the monitoring system whenever it breaks down in order to detect the cause of the problem.	
2. True or false. Training in-house personnel for performing CEM maintenance should consist of a thorough study of the CEM owner's manual.	1. True
3. Which of the following has been shown by a recent survey as being problem areas in CEM maintenance programs: a. Data handling systems. b. Spare parts. c. Emergency service. d. All of the above.	2. False
4. Daily CEM operation checks for an extractive monitoring system include which of the following: a. strip charts and/or other data recording devices. b. system indicator lights. c. conditioning system. d. a, b, and c. e. a, b, c, and a calibration check of the system.	3. d
5. The recommended period for performing routing maintenance checks on extractive monitoring systems are every _____ _____.	4. e
6. True or false. Inspecting the overall cleanliness of an extractive monitoring system is really not necessary.	5. 30 days
7. True or false. The majority of monitoring system problems encountered with extractive systems occur in the system electronics.	6. False
8. By far, extractive monitoring systems encounter their greatest mechanical problems in a. heat traced lines. b. the indicator light system. c. the conditioning system. d. none of the above.	7. True

9. True or false. If the system indicator lights on an in-situ monitoring system give the indication of a potential problem, it should be assumed that the light circuit has malfunctioned and the operator may proceed with a daily calibration check of the system.	8. c
10. Gas cells which are used to calibrate in-situ monitors are: a. not normally certified by independent laboratories. b. are always EPA certified. c. are not EPA certified but certified by OSHA. d. certified by both EPA and OSHA.	9. False
11. True or false. If an in-situ monitor is calibrated manually using calibration cells, the temperature compensation circuit can be by-passed.	10. a
12. The three most common problem areas which have been associated with in-situ monitoring systems are: a. 1) plugged filters, 2) moisture condensation, 3) improper CEM design. b. 1) improper CEM design 2) plugged filters, 3) improper stack or duct design. c. 1) ambient dust and severe weather, 2) sensitivity to vibration, 3) moisture condensation. d. In-situ systems are superior in design and never encounter any operational problems.	11. True
	12. c

REFERENCES

1. Electrical Power Research Institute. *1988 Continuous Emission Monitoring Guidelines: Update.* EPRI CS-5998.

2. Environmental Protection Agency. 1985. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods. Section* 3.0.10 Guideline for Developing Quality Control Procedures for Gaseous Continuous Emission Monitoring Systems. EPA 600/4-77-0276.

3. Environmental Protection Agency. 1988. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods. Section* 3.0.9 *Continuous Emission Monitoring (CEM) Systems Good Operating Practices.* EPA 600/4-77-027b.