&EPA

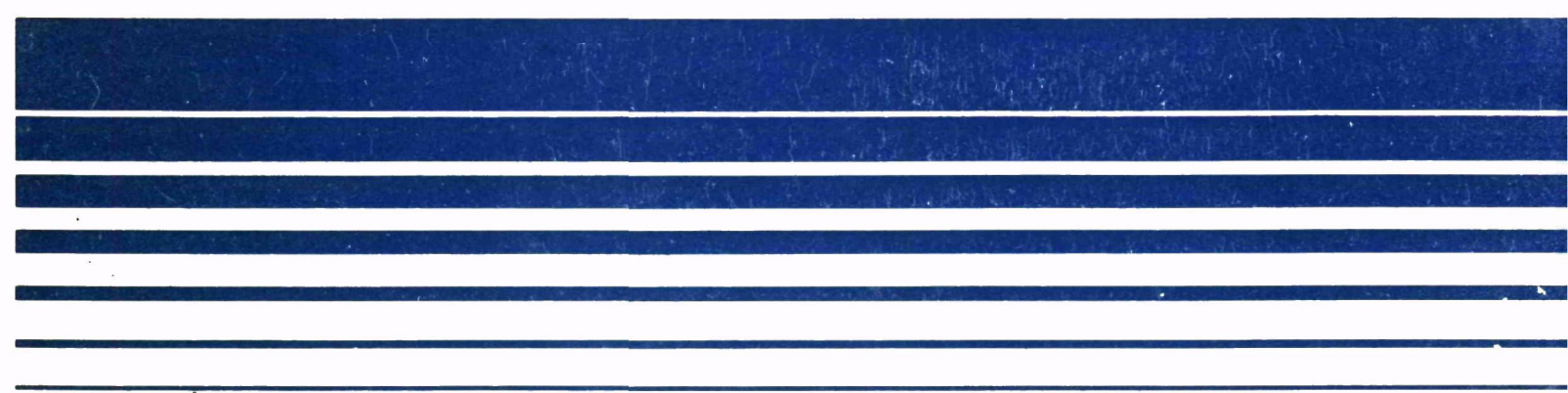# APTI
Course 474
Continuous Emission Monitoring

Student Workbook

Air

APTI
Course 474
Continuous Emission Monitoring

Student Workbook

Notice

This is not an official policy and standards document. The opinions and selections are those of the authors and not necessarily those of the Environmental Protection Agency. Every attempt has been made to represent the present state of the art as well as subject areas still under evaluation. Any mention of products or organizations does not constitute endorsement by the United States Environmental Protection Agency.

Availability

This document is issued by the Manpower and Technical Information Branch, Control Programs Development Division, Office of Air Quality Planning and Standards, USEPA. It was developed for use in training courses presented by the EPA Air Pollution Training Institute and others receiving contractual or grant support from the Institute. Other organizations are welcome to use the document.

This publication is available, free of charge, to schools or governmental air pollution control agencies intending to conduct a training course on the subject covered. Submit a written request to the Air Pollution Training Institute, USEPA, MD 20, Research Triangle Park, NC 27711.

Others may obtain copies, for a fee, from the National Technical Information Service (NTIS), 5825 Port Royal Road, Springfield, VA 22161.

Overview

This course provides an in-depth discussion of the field of continuous source emission monitoring. The course begins with a review of the regulatory basis for continuous monitoring, and then presents the operating principles of opacity monitors, extractive monitors, and in-situ monitors. Emphasis is placed on the selection of systems for given applications. Performance Specification Test procedures and Quality Assurance procedures necessary for high system availability are explained in detail.

How to Use This Workbook

This workbook is to be used during the course offering. It contains a chapter corresponding to each of the lessons.

Each chapter contains a listing of the lesson goal, the lesson objectives, and any special references that might be helpful to you. Each chapter also contains several pages of black-and-white line-art reproductions of selected lecture slides. These reproductions are intended to generally follow the slide presentations given in the lecture. However, the instructor may on occasion change the order or present new material not included in the workbook. It is therefore recommended that the student take notes throughout the course and not rely on the graphic reproductions as representing the total course content.

Table of Contents

Chapter 1
Course Goals and Objectives

Course Goals

1. To provide you with an understanding of the continuous emission monitoring regulations for the New Source Performance Standards as given in the June 6, 1975 Federal Register (40 CFR 46240).
2. To provide you with a knowledge of the physical and chemical bases of operation of the presently available particulate and gaseous emission source monitors.
3. To enable you to make judgements in selecting and evaluating continuous monitors with regard to the requirements of the Federal regulations and the needs of the industry.
4. To enable you to recognize the problems associated with the use of continuous monitors, particularly with respect to interfacing systems, sample extraction, calibration procedures, quality assurance, and data handling systems.

Course Objectives

Upon completion of this course, you should be able to:
1. identify the existing sources and new sources which are covered by the continuous monitoring regulations promulgated October 6, 1975. The student will also be able to identify the pollutants which are to be monitored from each source.
2. distinguish the important differences between the Part 60 New Source Performance Standards and the Part 51 State Implementation Plan requirements for continuous monitoring.
3. explain what is required in the State Implementation Plans and recall the time frames for revision requirements.
4. describe the instrument specification requirements for opacity monitors, SO_2 and NO_x monitors, and O_2 or CO_2 monitors. The student will be able to distinguish the differences between each set of specifications.
5. discuss the requirements for the proper installation of continuous monitoring systems.
6. discuss the characteristics of the electromagnetic spectrum, identify the wavelength ranges of visible, infrared and ultraviolet light, and identify the principal regions in which pollutants will absorb or scatter light.

7. recognize and employ terms used to describe advanced electro-optical devices. These include terms such as: optical filter, diffraction grating, correlation cell, chemiluminescence, fluorescence, dispersion, wavenumber, and wavelength.

8. define and use terms associated with continuous stack monitoring instrumentation, such as, sampling interface, span, calibration error, relative accuracy, response time, and stratification.

9. distinguish between the three classes of continuous monitoring instrumentation available for measuring concentration levels of gaseous pollutants.

10. discuss the physical or chemical principles of operation of the most common types of continuous monitoring instruments available on today's commercial market. Such a discussion would include opacity and gas monitors.

11. discuss the relationships between optical density and mass loading and the limitations to such relationships.

12. describe the characteristics of extractive systems for continuous monitors and list their advantages and disadvantages.

13. distinguish between and discuss the advantages and disadvantages of chart recording systems and automated systems.

14. describe the data reporting requirements for continuous monitoring systems.

15. apply the performance specification test procedures to an extractive continuous monitoring system either as an observer or as the equipment operator and carry out the performance specification test with such a system. The student will also be able to discuss the differences between in-situ and extractive monitoring systems with regard to the performance specification test.

16. use the performance specification test forms given in the October 6, 1975 Federal Register.

17. analyze data obtained in the performance specification test procedure, i.e., the student will be able to understand and use such statistical concepts as standard deviation, confidence interval, and t-test. The student will be able to compute a confidence interval for a set of experimental data and will understand the difference between precision and accuracy.

18. calculate emissions in terms of $lbs/10^6$ Btu heat input, using F factors. The student will understand the derivation and be able to discuss the limitations of the F factor procedure.

19. apply the knowledge obtained concerning continuous monitoring systems by being able to evaluate the commercially available systems with respect to source limitations, instrument performance, and regulation requirements, for eventual use on a given source.

Chapter 2
Introduction to Continuous Monitoring

Lesson Goal

To present to you an overview of the continuous emissions monitoring course and the course objectives.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. list the major course objectives.
2. list advantages of continuous monitoring for source operations.
3. list advantages of continuous monitors for air pollution agencies.
4. list four ways to measure emissions from a source.

Reference

Lillis, E. J. and Schueneman, J. J. 1975. "Continuous Emission Monitoring: Objectives and Requirements." *J. Air Poll. Control Assoc.* 35:804-809.
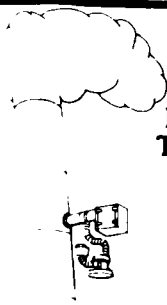
INTRODUCTION TO CONTINUOUS EMISSIONS MONITORING

SOURCE OPERATOR BENEFITS

- monitor process and emission control
- evaluate source operating efficiency
- determine maintenance needs
- improve design information

SOURCE OPERATOR BENEFITS (continued)

- provide control equipment efficiency guarantees
- reduce number of manual tests
- provide protection in legal issues

CONTROL AGENCY BENEFITS

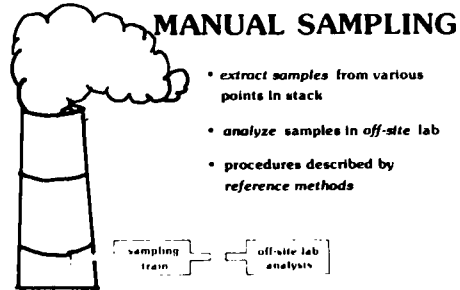- improve and expand enforcement
- develop comprehensive air resources management program
- improve emission data base
- improve dispersion models

CONTROL AGENCY BENEFITS (continued)

- develop new regulations
- improve nuisance control
- provide input for episode control plans
- augment VE observations

METHODS FOR
MEASURING EMISSIONS

- **Manual Sampling**

- **Visual Emissions Observation**

- **Continuous Monitoring**
  - **extractive**
  - **in-situ**

- **Remote Sensing**

MANUAL SAMPLING

- *extract samples from various points in stack*

- *analyze samples in off-site lab*

- *procedures described by reference methods*

sampling train → off-site lab analysis

CONTINUOUS MONITORING
OF SOURCE EMISSIONS

- extractive

- in-situ
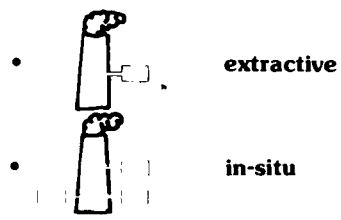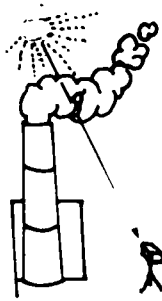
REMOTE SENSING

- *monitor at ground level —* some distance from stack

- *no* sample *extraction*

- *point or integrated* samples

- *on-site analysis* by the device

USES OF DATA OBTAINED

- Manual Sampling
  - to determine compliance status

- VE Observation
  - to determine compliance status

USES OF DATA OBTAINED (continued)

- Continuous Monitoring
  - to meet NSPS requirements
  - to determine compliance status (Bay Area only)

- Remote Sensing
  - to determine compliance status (possibly in future)

Chapter 3

Continuous Emission Monitoring Regulations—I: Federal Requirements

Lesson Goal

To familiarize you with Federal regulations which require the installation of continuous emission monitoring systems and the documents in which these regulations are contained.

Lesson Objectives

Upon completion of this lesson, you should be able to:

1. explain the relationship of the Federal Register to the Code of Federal Regulations and understand the regulatory reference format for each.
2. understand the distinction between Part 51 and Part 60 of the Code of Federal Regulations and explain what distinguishes a new source from an existing source.
3. explain what is located in the subparts of Part 60 of the CFR and what is located in the appendices of Part 60 of the CFR.
4. a. list at least four new source categories required to continuously monitor SO_2.
   b. list at least four new source categories required to continuously monitor opacity.
5. state when a new FFFSG is not required to monitor NO_x.
6. locate Federal Register announcements pertinent to continuous emission monitors.
7. contrast the CEM philosophy of control equipment monitoring as given in the October 6, Federal Register with the CEM philosophy of continuing compliance given in the June 11, 1979 Federal Register.

CONTINUOUS EMISSION MONITORING REGULATIONS I:

Federal Requirements

- yearly publication
- 40 CFR Part 60
- 40 CFR 60.12

- daily update
- 46 FR 8352 (1981)

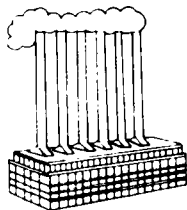## Significant Dates

December 23, 1971
- initial requirements for continuous monitoring

October 6, 1975
- Performance Specification Tests (PST) promulgated

40 CFR

Part 51   Part 60
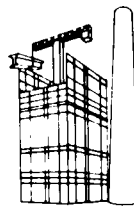
Existing Sources   New Sources

40 CFR

Part 51	Part 60
Existing Sources	**New Sources**
• deals with State SIPs	• deals with new or modified sources
• standards must meet minimum Federal requirements	• source categories are specified
• standards may be more stringent than Federal requirements	

Regulations

Proposed
Regulation

versus

Proposed
* open to discussion and comment
* not law

Promulgated
* law
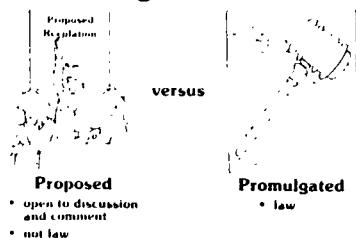
New/Modified Sources
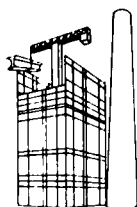
* **construction (or modification) initiated after a standard is proposed**

NSPS Source Categories
Required to Monitor Emissions

Subpart	Source Category	Opacity Standard
D	FFFSG	20%
D$_a$	Utilities	20%
J	Petroleum Refineries	30%
PQR	Cu, Zn, Pb Smelters	20%
Z	Ferroalloy Facilities	20%
AA	Iron and Steel Plants	20%
BB	Kraft Pulp Mills	35%
HH	Lime Manufacturing Plants	10%

NSPS Source Categories
Required to Monitor SO$_2$

Subpart	Source Category
D	FFFSG • Coal Fired Boilers • Oil Fired Boilers
D$_a$	Utilities • Coal Fired Boilers • Oil Fired Boilers
H	H$_2$SO$_4$ Plants
J	Petroleum Refineries
PQR	Cu, Zn, Pb Smelters

NSPS Source Categories
Required to Monitor NO$_x$

Subpart	Source Category
D	FFFSG • Coal - Oil - Gas
D$_a$	Utilities
G	Nitric Acid Plants

Other Pollutants Required to be Monitored on a Continuous Basis

Subpart	Source Category	Pollutant
J	Petroleum Refineries	
	• Catalyst Regenerators	CO
	• Fuel Gas Combustion Device	H_2S
J	Petroleum Refineries	
	• Claus Sulfur Recovery Plants	Reduced Sulfur H_2S
BB	Kraft Pulp Mills	TRS

NSPS Source Categories Required to Monitor Process Parameters

Subpart	Source Category	Process Parameters
N	Iron and Steel Plants	• scrubber pressure loss
O	Sewage Treatment Plant	• mass or volume of sludge
TUVWX	Phosphate Fertilizer Plants	• pressure drop across scrubber
Y	Coal Preparation Plants	• temperature • scrubber pressure loss • water pressure

Subpart	Source Categories	Process Parameters
Z	Ferroalloy Facilities	• flow rate monitoring in hood
AA	Iron and Steel Plants	• flow rate monitoring in hood • pressure monitoring
BB	Kraft Pulp Mills	• scrubber pressure loss
HH	Lime Manufacturing Plants	• scrubber pressure loss • scrubber liquid flow rate • electric current

Use of Data

Control Equipment Evaluation   **Enforcement of Compliance**

CFR 1975

FR Oct.6 1975

Existing Sources Part 51 Appendix P

New Sources Part 60 Appendix B

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                    ┌─────────────────┐
                    │       FR        │
                    │ October 6,1975  │
                    └────────┬────────┘
              ┌──────────────┴──────────────┐
        ┌─────┴──────┐      ┌───────────────┴───────────────┐
        │            │      │           Part 60             │
        │  Part 51   │      ├──────────┬──────────┬─────────┤
        │            │      │ Preamble │ Subparts │Appendix │
        └────────────┘      └──────────┴──────────┴─────────┘
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Part 60		
Preamble 46250	**Subparts** 46254	**Appendix B** 46259
	• amendments • additions	• Performance Specifications Tests
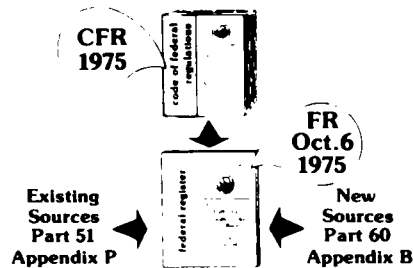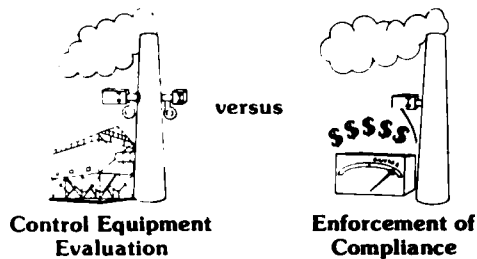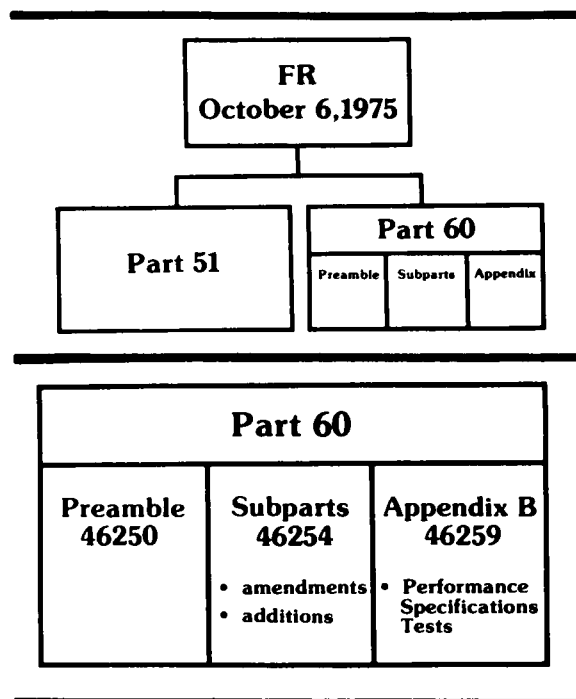
Subparts

- **Subpart Q**
- **Subpart F**
- **Subpart D - F Factors introduced**

Appendix B

- **Performance Specification Test Procedures**
  - Opacity Monitors
  - SO_2 and NO_x Monitors
  - CO_2 and O_2 Monitors

- **Ambient Air Monitors**
  - specific instrument models approved by EPA

- **Source Emission Monitors**
  - individual instruments approved only by passing a PST

- **source emission monitors approved on a case-by-case basis after installation**
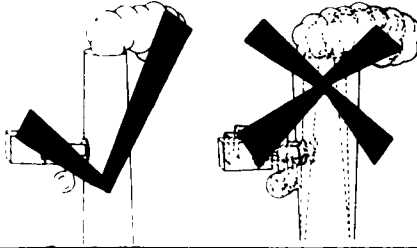
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987

October 12, 1976 FR

Wet F Factors

1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987

January 31, 1977 FR

Revisions to
October 6, 1975

1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987

May 23, 1977 FR

Opacity
Monitor Data

1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987

December 5, 1977

Revision of Reporting
Requirements for Opacity

1975	
1976	
1977	
1978	**June 11, 1979 etc.**
1979	
1980	
1981	**Promulgation of Subpart**
1982	**D$_a$ - NSPS for Electric**
1983	**Utility Generating Units**
1984	
1985	
1986	
1987	

1975	
1976	
1977	
1978	**August 8, 1979**
1979	
1980	
1981	**ANPR for Part 51**
1982	
1983	
1984	
1985	
1986	
1987	

1975	
1976	
1977	
1978	**October 10, 1979**
1979	
1980	
1981	**Revisions to Performance**
1982	**Specifications (Proposed)**
1983	
1984	
1985	
1986	
1987	

1975	
1976	
1977	
1978	**December 1979**
1979	
1980	
1981	**Ex. Ex. Method**
1982	
1983	
1984	
1985	
1986	
1987	

1975	
1976	
1977	
1978	**February 1980**
1979	
1980	
1981	**PST 4 for CO**
1982	**Monitors (Proposed)**
1983	
1984	
1985	
1986	
1987	

January 26, 1981

**PST 2 and 3
Revisions Re-proposed**

Chapter 4
Continuous Emission Monitoring Regulations—II: Existing Sources

Lesson Goal

To introduce to you the current activities and methods used by the States to establish continuous monitoring requirements for existing stationary sources.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. list at least three EPA divisions or laboratories currently involved in continuous emission monitoring.
2. explain the importance to the State Implementation Plan of the October 6, 1975 Federal Register.
3. understand the difference between **minimum** requirements set forth by EPA in 40 CFR 51 and the **actual** regulations included in the SIP.
4. list the four source categories required by 40 CFR 51 to install CEM systems, and detail the exceptions for NO_x monitoring for existing sources.
5. explain the features of the EPA minimum requirements for State CEM regulations—including the importance of the reporting requirements and the use of the specification tests as given in 40 CFR 60 Appendix B.
6. list at least three ways in which a State may require an existing source to install a CEM system.
7. assess the current status of CEM activity in the regions and States.
8. recognize the changing nature of CEM activity for existing sources and list at least three potential developments in this area.

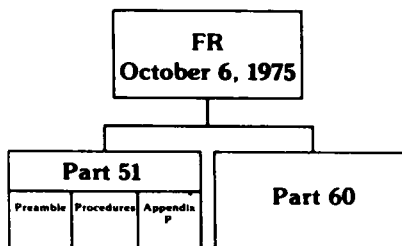## CONTINUOUS EMISSION MONITORING REGULATIONS II: Existing Sources

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Cast of Characters

EPA Divisions

- DSSE
- CPDD
- QAD

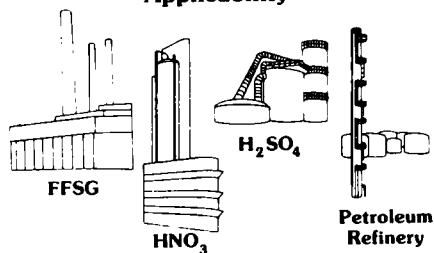- ESRL
- IERL
- ESED

Industry Activities

- EPRI
- UARG

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              ┌──────────────────┐
              │        FR        │
              │ October 6, 1975  │
              └──────────────────┘
```

Part 51			Part 60
Preamble	Procedures	Appendix P	

Part 51		
Preamble 46240	Procedures 46247	Appendix P 46247
	• source surveillance procedures	• minimum emission monitoring requirements for States

Appendix P

Paragraph 1:
Applicability

FFSG

H_2SO_4

HNO_3

Petroleum
Refinery

Paragraph 2:
Minimum Monitoring Requirements

> 73 MW — opacity
SO_2 — only if FGD
NO_x — if in AQCR
  and 70% of standard
  and 1000 x 10^6 Btu/hr heat input

> 300 t/d production

> 300 t/d production

> 20,000 bbl/d production
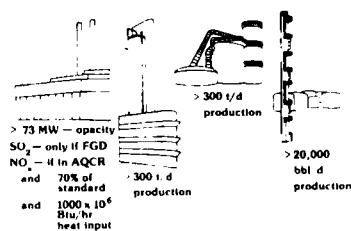
Paragraph 3:
Performance Specifications

• same as in Part 60, Appendix B

Appendix B

• **Performance Specification
  Test Procedures**
  • Opacity Monitors
  • SO_2 and NO_x Monitors
  • CO_2 and O_2 Monitors

Paragraph 4:
Minimum Data Requirements

- excess emissions to be reported quarterly
- data to be kept for two years

Paragraph 5:
Data Reduction

- F factors to be used for FFFSGs
- conversion factors to be used for sulfuric acid plants and nitric acid plants

Paragraph 6:
Special Considerations

- alternative monitoring requirements may be provided on case-by-case basis
  - physical plant limitations
  - extreme economic reasons

- Appendix P gives minimum requirements
- actual requirements may be more stringent
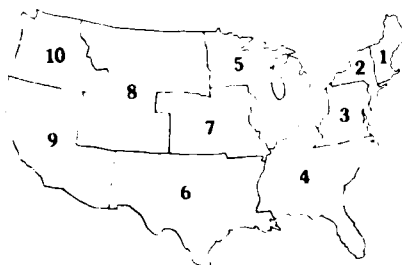
Regulatory Mechanisms
for Using CEMs

- Appendix P (SIP)
- permits
- direct compliance
  orders
- variances

Chapter 5
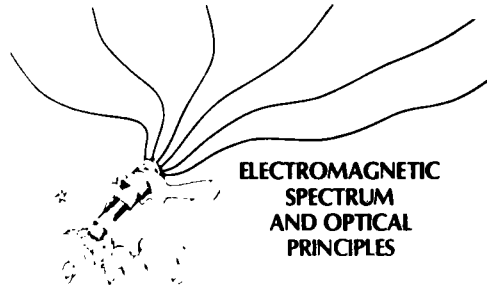## Review of the Electromagnetic Spectrum and Optical Principles

Lesson Goal

To review the basic principles of light and energy associated with the electromagnetic spectrum, and to show how these are related to the design of source emission monitors.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. define wavelength, frequency, and wavenumber.
2. explain how light frequency is related to energy.
3. describe what happens when a molecule absorbs light energy in the infrared and ultraviolet regions of the electromagnetic spectrum.
4. write the Beer-Lambert law.
5. list the essential components of a device designed to measure light absorption.

**ELECTROMAGNETIC
SPECTRUM
AND OPTICAL
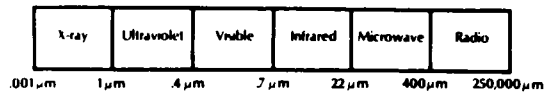PRINCIPLES**

**NATURE OF THE
ELECTROMAGNETIC SPECTRUM**

Wavelength (nm)
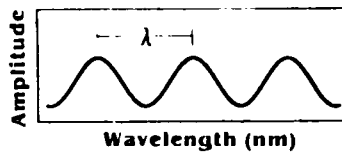
PLANCK'S CONSTANT (h)

$$E = h \cdot \upsilon$$

E represents the exact amount
of energy required for a
transition to occur

ELECTROMAGNETIC SPECTRUM
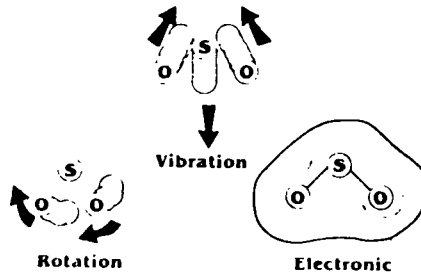
X-ray	Ultraviolet	Visible	Infrared	Microwave	Radio

.001 μm   1 μm   .4 μm   .7 μm   22 μm   400 μm   250,000 μm

$$E = h \upsilon$$

$$= h\left(\frac{c}{\lambda}\right)$$

ELECTRONIC TRANSITION
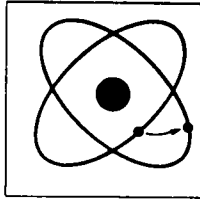
- quantum amount of energy necessary

Vibration

Rotation

Electronic

APPLICATIONS

- NDIR
- NDUV
- Fluorescence
- Chemiluminescence
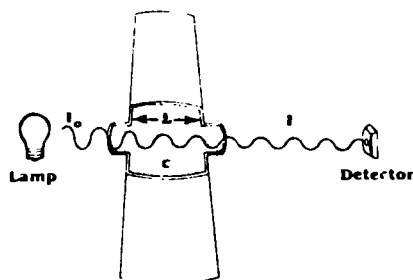
Beer-Lambert Law

$$I = I_o e^{-acl}$$

I = intensity of radiation through the sample

I_o = intensity of radiation with $c = 0$ or $a = 0$

a = absorption coefficient

c = gas concentration

l = pathlength of radiation through the gas

Lamp

Detector

Chapter 6

## Extractive Continuous Monitoring Systems Design

Lesson Goal

To provide you with an understanding of the fundamental design considerations for installing an extractive continuous monitoring system and the components that make up the system.

Lesson Objectives

Upon completion of this lesson, you should be able to:

1. list the necessary system functions of an extractive continuous monitoring system.
2. list the procedures involved in designing an extractive sampling system.
3. recall the important factors in selecting sampling system components.
4. list at least seven components that make a properly designed extractive system.
5. draw a schematic of a typical extractive system for three gas analyzers used to monitor a coal-fired power plant stack.
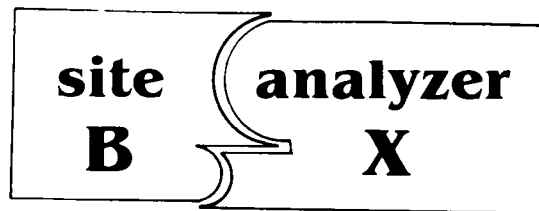6. name some advantages and disadvantages of extractive continuous monitoring systems.

extract calibrate analyze

transport condition
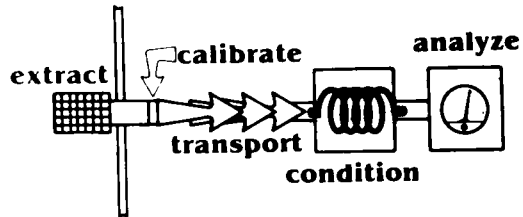
DESIGN INTENT

- Minimum System
- Minimum Initial Investment
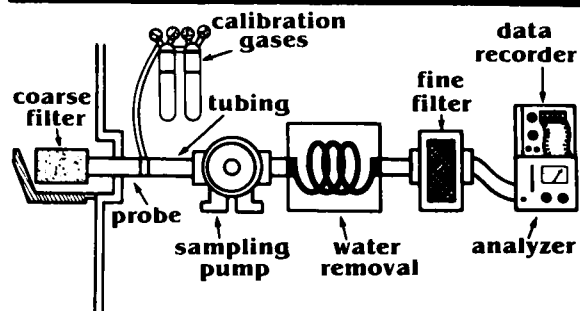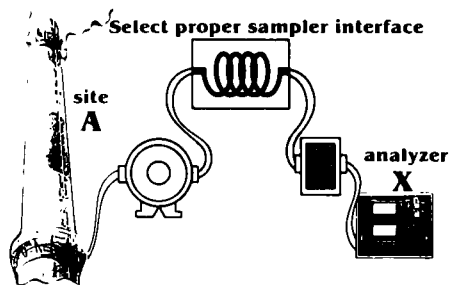- Minimum Operating
  and Maintenance Cost

Read regulations

Review product literature
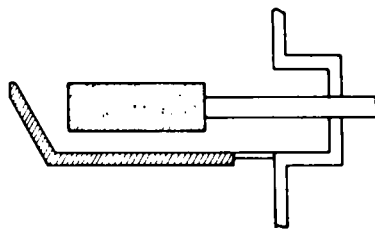
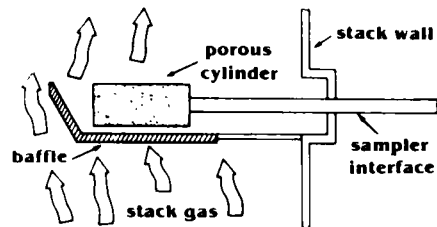**Determine gas stream parameters**

Select best sample site

site B **analyzer X**

Select compatible analyzer

Select proper sampler interface

site A

analyzer X

calibration gases

data recorder

coarse filter

fine filter

tubing

probe

sampling pump

water removal

analyzer

COARSE FILTER

EXTERNAL

porous cylinder

stack wall

baffle

sampler interface
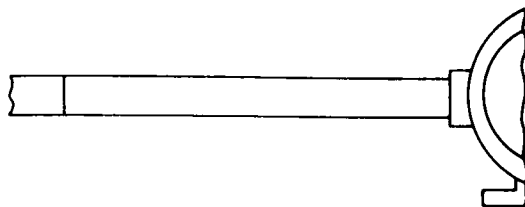
stack gas
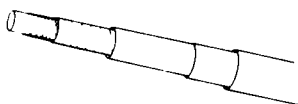
INTERNAL

stack wall

tube

nozzle

filter

stack gas
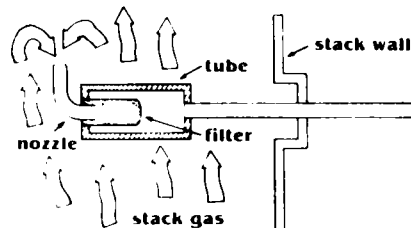
GAS TUBING

GAS TUBING TYPES

- **Stainless Steel**
- **Teflon**
- **Polyethylene**
- **Polypropylene**

HEATED SAMPLING LINE

- provides uniform heat to gas sample
- prevents vapors from condensing in sample line

SAMPLING PUMP

sampling pump   **fine filter**

water removal system

**water
removal
system**

**sampling
pump**
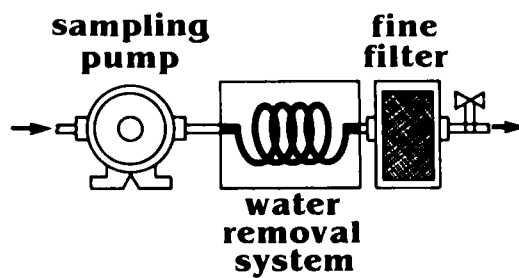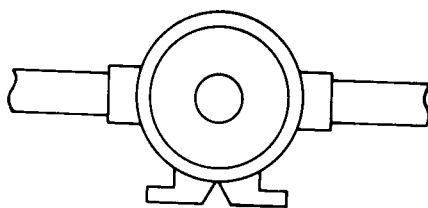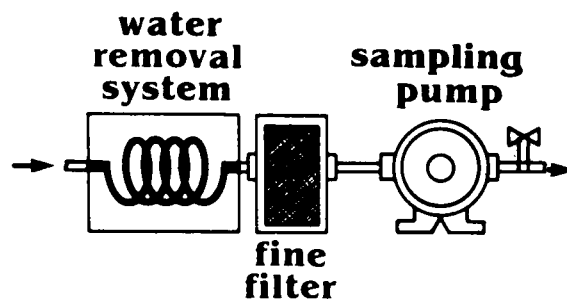
**fine
filter**

FINE FILTER

SURFACE FILTER

particles <
1 micron

gas stream

clean gas

DEPTH FILTER

particles <
1 micron

gas stream

clean gas
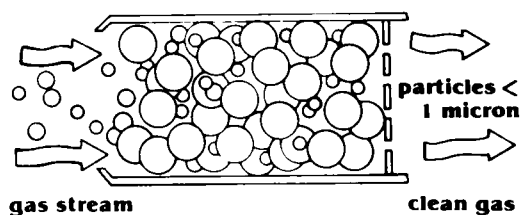
WATER REMOVAL
SYSTEM

PERMEATION DRYER

wet purge
gas outlet

dry gas
outlet

wet feed
inlet

dry purge
gas inlet
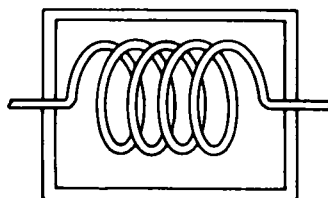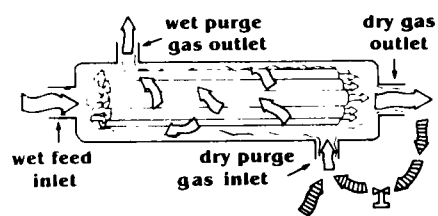
DILUTION SYSTEM
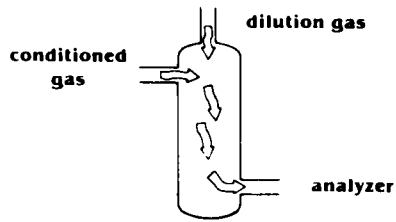
CONTROLS

- **Temperature**
- **Pressure**
- **Flow Rate**
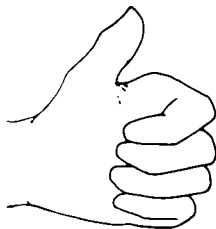
- can time-share analyzer

- can zero and calibrate with cylinder gas — better quality control

- may not require special training for maintenance of analyzer

- probe plugging common

- chance of altering gas sample

- long sample lines — longer response time

Chapter 7
Operating Principles of Extractive Gas Monitors

Lesson Goal

To present the basic operating principles of extractive gas monitors and to show the commercial systems currently available.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. maintain an understanding and overview of the previous day's lecture material concerning:
   a. regulations
   b. spectroscopic principles, and
   c. extractive system design
2. list at least five different operating principles used in current extractive monitors.
3. define the term *NDIR* and diagram a typical NDIR monitoring system.
4. explain how the process of differential adsorption is used to measure pollutant gases.
5. define the term *luminescence*.
6. describe how UV fluorescence is used to detect SO_2.
7. write down the chemical reaction which occurs in a chemiluminescence analyzer.
8. explain how electrons flow through the cell and the measuring circuitry of a polarographic analyzer.
9. list at least three applications of a polarographic analyzer.

Amplitude

λ

Wavelength (nm)

Vibration

Rotation

Electronic
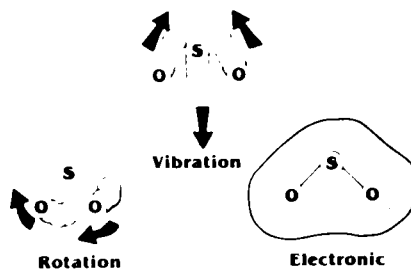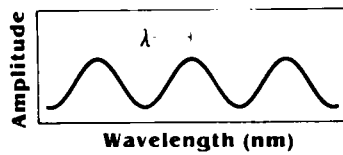
Normal Vibrations of SO₂

λ = 8.69 μm
ṽ = 1150.5 cm⁻¹

λ = 7.48 μm
ṽ = 1336.0 cm⁻¹

λ = 19.1 μm
ṽ = 524.5 cm⁻¹
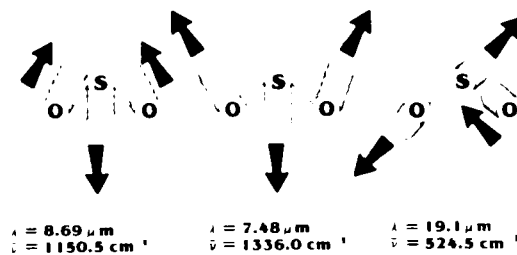
Molecular Species Absorb Specific Wavelengths

Molecular Species
Absorb Specific
Wavelengths
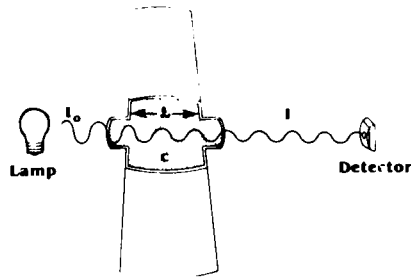
Lamp   Detector

Beer-Lambert Law

$$I = I_o e^{-\alpha c \ell}$$

I = intensity of radiation through the sample

I_o = intensity of radiation with $c = 0$ or $\alpha = 0$

α = absorption coefficient

c = gas concentration

ℓ = pathlength of radiation through the gas

Calibrating a Spectrometer
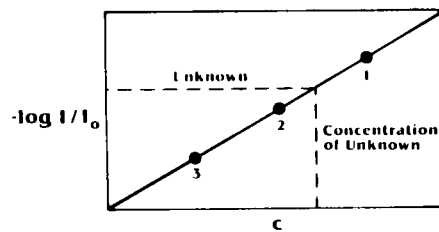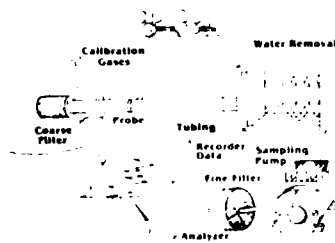
-log I/I_o

Unknown

1

2

Concentration of Unknown

3

c

Gaseous Emission Monitors
Extractive Systems

- **Absorption Spectroscopy**
  - nondispersive infrared
  - differential absorption

Absorbance vs. Wavelength (nm)

SO$_2$ NO$_2$

280   436   578

Measuring Photomultiplier Tube

Beam Splitter

Sample In

Sample Out

Bandpass Filter

Calibration Filter

UV Lamp

Electronics

Bandpass Filter

Reference Photomultiplier Tube

Recorder
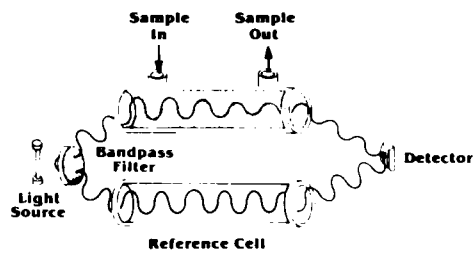
Gaseous Emission Monitors
Extractive Systems

- **Absorption Spectroscopy**
  - nondispersive infrared
  - differential absorption

- **Luminescence Methods**
  - chemiluminescence (NO$_x$)
  - fluorescence (SO$_2$)
  - flame photometry

SO$_2$ Absorption Spectrum

SO$_2$ Fluorescence Emission Spectrum

Wavelength (nm)
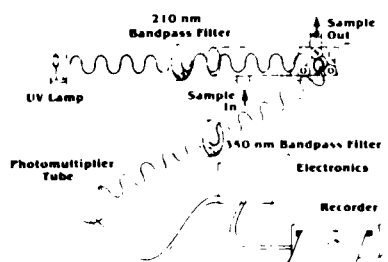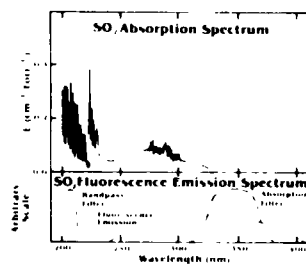
Twenty-one Percent O$_2$ Calibration
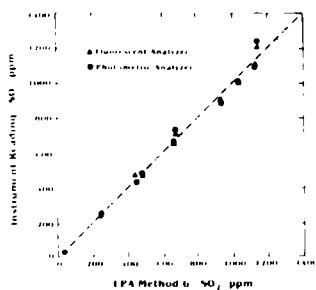
SO$_2$ in Nitrogen Span Gas

Step 1
NO + NO$_2$
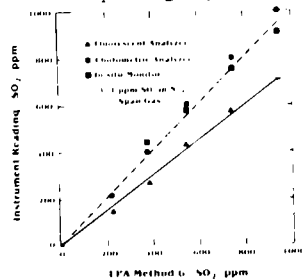
Chemiluminescence Analyzer
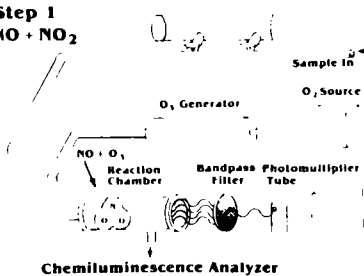
Step 2
NO + NO
(Converted from NO$_2$)

Chemiluminescence Analyzer
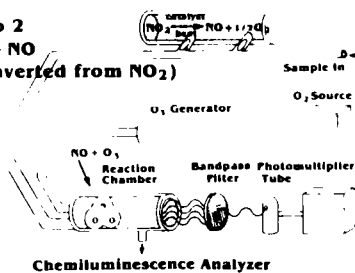
NO$_2^*$ Chemiluminescent Emission Spectrum

Gaseous Emission Monitors
Extractive Systems

- **Absorption Spectroscopy**
  - nondispersive infrared
  - differential absorption

- **Electroanalytical Methods**
  - polarography
  - electrocatalysis (O_2)

- **Luminescence Methods**
  - chemiluminescence (NO_x)
  - fluorescence (SO_2)
  - flame photometry

  - conductivity
  - paramagnetism (O_2)

Polarographic Analyzer
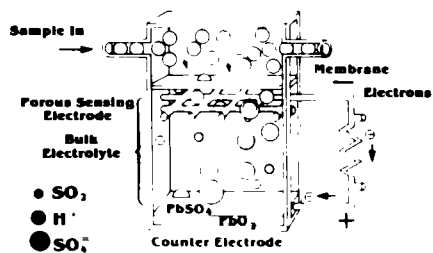
Chapter 8
Opacity Monitors

Lesson Goal

To provide you with an understanding of the basic technical and operational characteristics of opacity monitoring systems.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. define the terms *opacity* and *optical density*.
2. explain the importance of the optical density, and explain why optical density is proportional to particulate concentration.
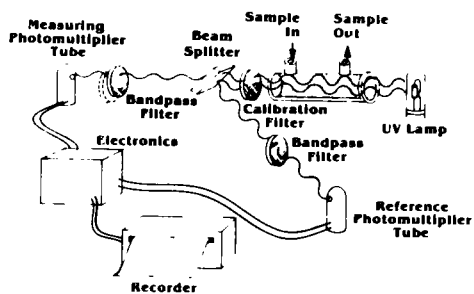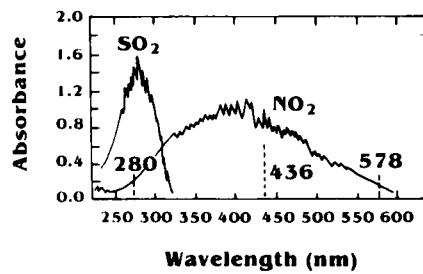3. explain the difference between single pass and double pass transmissometers and list at least two advantages for each type.
4. illustrate how a Datatest transmissometer can meet the EPA system zero and span check requirements.
5. trace the passage of light beams through the Lear Siegler optical system and explain the function of each component of the system.
6. explain the function of the chopper wheel used in the Contraves Goerz transmissometer.
7. explain the function of the alternating shutter in the EDC/Esterline Angus opacity monitor.
8. demonstrate how the three detectors in the Dynatron opacity monitor are used to perform a calibration check.

I. Introduction

   A. Opacity measurement—need no more than lamp and detector—however, have to specify certain aspects of the system

   B. Definitions

      1. Opacity—the fraction of incident light that is attenuated due to light scattering and absorption by particulate matter in flue gas

      2. Optical density—a logarithmic measurement—a measure of the ability of particulate matter to attenuate light

         a. Obtained from the Beer-Lambert-Bouguer relationship
$$T = e^{-naq\ell}$$

         b. Go through derivation

$$\ell n\ T = -naq\ell$$

$$-\ell n\ (1 - O) = naq\ell$$

$$\ell n \left(\frac{1}{1 - O}\right) = naq\ell$$

$$2.303 \log \left(\frac{1}{1 - O}\right) = naq\ell$$

$$OD = \log \left(\frac{1}{1 - O}\right) = kn\ell$$

very important—optical density is proportional to both particulate concentration and pathlength

         c. Optical density can be used for a number of purposes

           (1) OD, grain loading correlations

           (2) stack exit correlations

$$OD_1 = \frac{L_1}{L_2}\ OD_2$$

           (3) Used by most instrument manufacturers

II. Transmissometer—basic types and features

   A. Single pass systems

      1. Send light from source to detector
      2. Inability to check zero and calibration without having down stack
      3. Simple and relatively inexpensive
      4. Used for baghouse monitoring, etc.

   B. Double pass systems

      1. Send light from source to retroreflector and back to detector
      2. Can get *pseudo*-zero and span check
      3. More expensive, but well made—more options
      4. Standard use in power plant monitoring

C. Light used — visible

    1. Light in visible region of spectrum is used — i.e., between 400 and 700 nm

    2. Used because measures smaller sized particles, not sensitive to water vapor, more closely reproduces what humans see

    3. In actual use — photopic (i.e., visible) regions obtained by combination of lamps, filters, and detector

    4. Actual response curve may not be completely symmetric

III. Commercial transmissometers — single pass systems

    A. List of vendors

        1. Some marginal — may no longer be in business

    B. Datatest

        1. Single pass with light pipe — meets EPA requirements for zero and calibration check

        2. Diagram
            a. Note coding wheel
            b. Note zero and filter wheel on light paper
            c. Note other features such as alignment bulls-eye, detector, lenses and filters

IV. Commercial transmissometers — double pass systems

    A. List of vendors

        1. Changes from time to time — companies get bought out or consolidate

    B. Lear Siegler

        1. Double pass system — enables zero and span check

        2. Photos of LSI-RM4 and LSI-RM41

        3. Diagram
            a. Coding wheel — codes light so instrument insensitive to ambient light
            b. Light goes through half-silvered mirror to retroreflector, back to half-silvered mirror to detector
            c. Chopper moves into place — beam reflects off chopper and to detector to get I_o value
            d. Note — alignment mirror and bulls-eye
            e. Note — zero reflector and calibration filter
        4. Photo of internal system
        5. Photo of transportable system

C. Contraves Goerz
1. Photos of monitor — note rotary wheel
2. Diagram
   a. Light goes to mirror through coding wheel to half-silvered mirror — $\frac{1}{3}$ of cycle goes to retroreflector and back to detector — $\frac{1}{3}$ bounces off of chopper to detector for a zero measurement — other $\frac{1}{3}$ for a calibration measurement
   b. Get continual zero, calibration, and measurement zero and cal readings given as a call-out
   c. Contraves — control unit — note modular approach

D. Thermo Electron/EDC/Esterline Angus
1. Instrument has long history
   a. Durag → Intertech → Esterline Angus → EDC → TECO
2. Diagram
   a. Note special feature here — mode shutter flicks in and out Ref/Measurement separate cycles. Every two minutes for a period of two seconds, the reference beam is directed to the photodiode and its intensity stored in the microprocessor → I_o value
   b. Coding chopper
   c. Filter selection

E. Dynatron
1. Electronic system — no moving parts
2. Diagram
   a. Note three lamps and three detectors
   b. Light goes from lamp at bottom to half-silvered mirror, across stack to retroreflector — back through half-silvered mirror to detector. Next, measuring lamp turns off and reference lamp 1 turns on. Get comparative reading for filter 1 between measurement and reference detector. Do the same for reference lamp 2. Get system calibration check
   c. Note detector at window to stack and detector at reference beam reflector — both used as part of automatic dirty window compensation circuit
3. System photos

V. Transmissometer applications
A. Satisfy EPA continuous opacity monitoring requirements
B. Process performance data — maintenance and repair indicator, process improvement
C. Control equipment operation — ESP tuning, broken bag detector
D. Correlation with particulate matter concentration
E. Maintenance of a continuous emissions record

OPACITY

- the fraction of incident light
  that is attenuated due to
  light scattering and absorption
  by particulate matter in flue gas
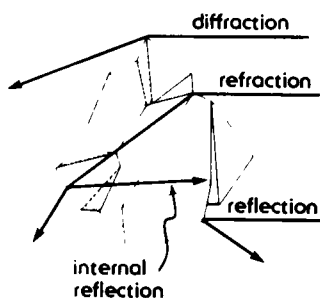
$$\frac{I}{I_o} = T = e^{-naQL}$$

Where:

T = fraction of light transmitted
(transmittance)

n = number of particles per unit volume

a = mean particle projected area

Q = particle extinction coefficient

L = length of effluent path

e = base of natural logarithm

OPTICAL DENSITY
(a logarithmic measurement)

- a measure of the ability of
  particulate matter to attenuate light

$$\text{Optical Density} = \log_{10} \frac{1}{1 - \text{Opacity}}$$

KRAFT RECOVERY FURNACE
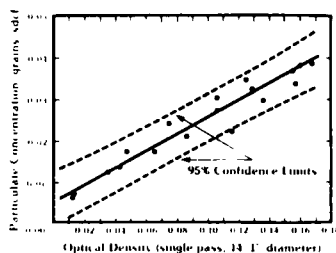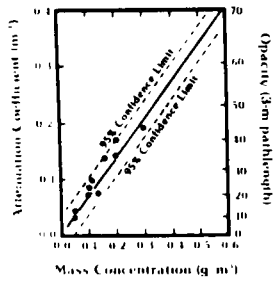
CEMENT PLANT -
WET PROCESS

$$OD_1 = \frac{L_1}{L_2} OD_2$$

$$O_1 = 1 - (1 - O_2)^{L_1/L_2}$$

Where,

L_1 emission outlet pathlength

L_2 monitor pathlength

O_1 emission opacity

O_2 monitor opacity

TRANSMISSOMETER DESIGN SPECIFICATIONS

SPECTRAL RESPONSE:

The system must project a beam of light
with the wavelength of maximum
sensitivity lying between 500 and
600 nm. Also, no more than 10% of
this peak response can be outside of
the range of 400 to 700 nm.
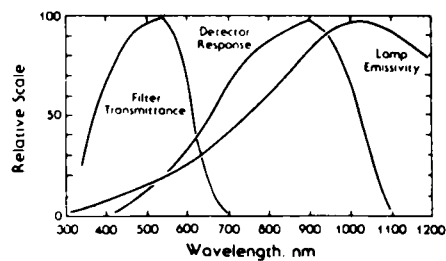
INSTRUMENT SPECTRAL RESPONSE
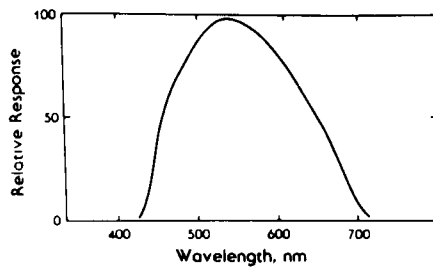
SINGLE PASS SYSTEM
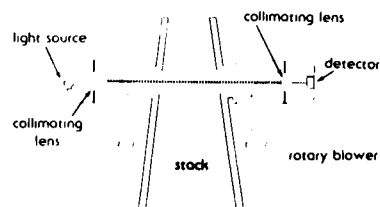
VENDORS OF SINGLE PASS TRANSMISSOMETERS
Cost Range $1,500 to $9,000

- Bailey Meter
- Cleveland Controls, Inc.
- De-Tec-Tronic Corp.
- Reliance Instrument Manufacturing
- HADCO
- Leeds and Northrop

- Photomotion, Inc.
- Preferred Utilities Manufacturing
- Electronics Corp. of America
- Robert H. Wager
- Datatest
- Anderson 2000
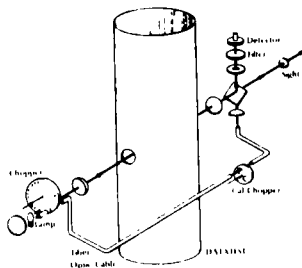
VENDORS OF DOUBLE PASS
TRANSMISSOMETERS
Cost Range $8,000 to $16,000

- Lear Siegler
- Contraves Goerz
- Environmental Data Corp.
- Dynatron
- Datatest

DOUBLE PASS SYSTEM

stack   rotary blower

24 - HOUR CHECK

calibration
source lens   check   zero mirror

light →   stack

beam splitter   detector

24 - HOUR CHECK

calibration
source lens   check   zero mirror

light →   stack

beam splitter   detector

BEAM SPLITTER

CORNER CUBE
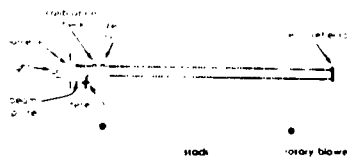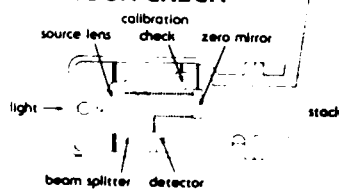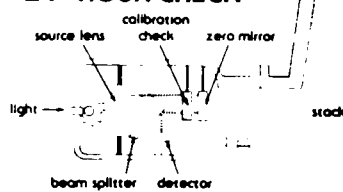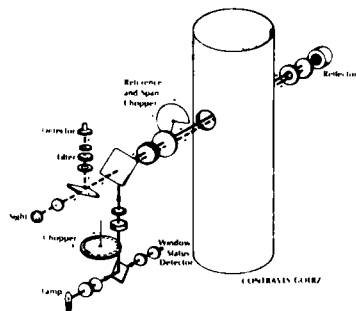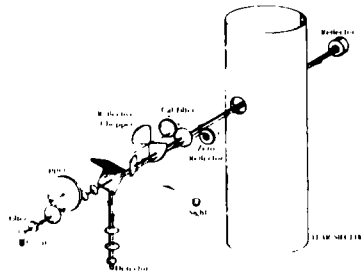
TRANSMISSOMETER APPLICATIONS

- Satisfy EPA continuous opacity monitoring requirements
- Process performance data - - maintenance and repair indicator, process improvement
- Control equipment operation - - ESP tuning, broken bag detector
- Correlation with particulate concentration
- Maintenance of a continuous emissions record

Chapter 9

Performance Specification Test 1— Opacity Monitors

Lesson Goal:

To recognize the performance test specifications for opacity monitors and to be conversant with the test procedures.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. explain why design specifications are required for opacity monitors, and list at least four design specifications.
2. list two reasons why opacity monitors must use light in the photopic region of the spectrum for measuring opacity.
3. define *angle of view* and *angle of projection*.
4. explain how a double-pass opacity monitor meets the system operation check design specification.
5. list the performance specifications for opacity monitors.
6. list the four steps which are followed in a response time test.
7. list at least two installation requirements for transmissometers.
8. define *plane of the bend*.
9. state at what times the optics of a transmissometer are to be cleaned during the 24-hour drift test.
10. perform the calculations for the zero drift specification.
11. perform the calculations for the 24-hour drift specification.

I. Introduction

    A. Performance specification tests for continuous emission monitors

        1. Will have two lectures—first on Performance Specification Test 1 for opacity monitors; second on Performance Specification Tests 2 and 3—gas monitors

        2. Performance Specification Test 1—opacity monitors

            a. Performance specifications required so that have control over quality of monitors installed on sources

            b. Case-by-case basis—source monitors not approved like ambient air monitors

            c. No such thing as an EPA-approved line of instruments—must be checked individually through performance specification test

    B. Lecture topics

        1. Students should be able to list the design specifications for opacity monitors

        2. Students should be able to list the installation requirements for opacity monitors

        3. Students should be able to list the performance specifications for opacity monitors

        4. Students should be able to perform the calculations involved in the evaluation of performance specification tests for opacity monitors

II. Design specifications for opacity monitors

    A. Introduction

        1. Design specifications required since can't use EPA Reference Method 9 for accuracy comparisons

            a. EPA Method 9 uses transmissometer for calibration

            b. Comparison would be transmissometer versus transmissometer

        2. Design specifications—each instrument must be designed in a certain manner

        3. One monitor of each month's production must be checked to see if it meets required design specifications—40 CFR 60 Appendix B paragraph 6.2

    B. Photopic response design specification

        1. Opacity monitor must have peak spectral response of between 500 and 600 nm. Response below 400 or above 700 nm must be less than 10% of peak response

        2. Mean spectral response shall be between 500 and 600 nm

        3. Specification given for a number of reasons

            a. Want transmissometer to "see" in visible region, where human eye sees—correlate with EPA Reference Method 9

      b. Have absorption by H_2O and CO_2 in IR
        (1) Positive interference
      c. Light of shorter wavelengths is attenuated better by small particles than is light of longer wavelengths
        (1) Want to monitor < 1 μm particles since they contribute greatly to plume opacity

C. Angle of projection — angle of view specification

1. Angle of projection — angle of the light cone emitted from the system. Is limited to $5°$
2. Angle of view — angle of the cone of observation of the photodetector assembly. Is limited to $5°$
3. Specifications are given since at wider angles, light can scatter back into the detector and give readings lower than true

D. System operation check

1. Found in 40 CFR 60.13d2 — design specification not in the body of Performance Specification Test 1
2. The monitor system is to include a means of checking the "active" elements of the system in the zero and calibration procedures
3. Double-pass systems can satisfy specification; single-pass systems generally cannot (except for Datatest monitor)
4. Can insert mirror in path and reflect light back to detector in double-pass system to satisfy regulation

E. Sampling requirements

1. Monitoring system is required to complete a minimum of one measuring cycle every ten seconds and one data recording cycle every six minutes
2. Requirement easily satisfied by commercial monitors

F. Design specification certification

1. Design specification procedures need not be performed by agency or source operator, however, certification of monitor meeting specifications should be supplied
2. Vendor must check one monitor at random of each month's production and certify that it meets all specifications
3. See 40 CFR Appendix B Paragraph 6.2; a revision appears in 42 FR 5937 January 31, 1977

III. Calibration and response time tests for opacity monitors

A. Tests to be performed with instrument set up at actual measuring distance (transceiver to retroreflector)

1. Tests may be done at source by source engineer, etc.
2. Vendor may perform tests and supply certification to operator and agency

B. Calibration error test

   1. Specification — using neutral density calibration filters, the instrument is limited to an error of 3% opacity

   2. Filters

     a. Must be within ± 3% of their given opacity values

     b. Filters should be checked with a well collimated photopic transmissometer

     c. All filters used must block the entire optical volume of the transmissometer

     d. Filters to have low, midrange, and high values with respect to the applicable standard for the source (found in the appropriate subpart)

   3. Procedure

     a. Filters to be placed alternately into monitor beam, and readings taken

     b. Five sets of data to be taken for each filter

     c. Calibration error for each filter to be determined from five data points each

   4. Calculating the calibration error

     a. Obtain difference values by subtracting

$$\text{Transmissometer \% opacity} - \text{Known filter opacity} = x_i \text{ difference } (+ \text{ or } -)$$

     b. Take arithmetic average of difference values keeping + and − signs

$$|\bar{x}| = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Where: $|\bar{x}|$ = the absolute mean value of the difference

           $n = 5$

           x_i = difference values

     c. October 6, 1975 Federal Register incorrectly stated that the average was to be made using the *absolute* values of the difference values. This is statistically incorrect and is not supported by the background documentation. As of June 1981, however, this error has not been corrected in a CFR revision, although it has been corrected in the performance specification test revision proposals of October 10, 1979 and January 26, 1981

     d. Confidence interval calculation

$$CI_{95} = \frac{t_{0.975}}{n\sqrt{n-1}} \sqrt{n(\Sigma x_i^2) - (\Sigma x_i^2)}$$

Where: $t_{0.975}$ = tables obtained in 40 CFR Appendix B

           $n = 5$

     e. Calibration error

$$|\bar{x}| + CI_{95} = \text{calibration error}$$

sum of the absolute mean value and the confidence interval calculations

      f. Comments — absolute mean value can be zero, but confidence interval calculation would have some value indicating degree of precision

C. Response time test

  1. Response time defined as the time interval required to go from an opacity value of zero to 95% of the value of a step change — limited to 10 seconds

  2. Procedure:

    Step 1: Place upscale filter in path

    Step 2: Record time for 95% response

    Step 3: Take filter out

    Step 4: Record time for 95% downscale response

  3. Calculation method

    a. $\dfrac{\text{sum of 5 upscale tests} + \text{sum of 5 downscale tests}}{10} = \text{mean response time}$

    b. Mean response time must be less than 10 seconds

IV. Installation requirements

A. Question of where to locate monitor is a difficult one

B. Stratification testing for particulate matter

  1. Number of ways to check — looking for a representative location for the monitor

  2. Check with pitot tube velocity traverse — particulate matter may not follow streamlines

  3. Check with portable opacity monitor — monitor may not check entire stack diameter

  4. Check using manual reference method — time consuming and expensive

C. Plane of the bend

  1. Monitor shall be located as far from bends and obstructions as practical

  2. Following a bend, the opacity monitor shall be installed in the plane defined by the bend

    a. This plane, formed by the intersection of two ducts or stacks is defined as the *plane of the bend*

  3. Particulate matter stratifies — want to measure through any stratification

D. Accessibility

  1. Monitors should be installed in an accessible location

  2. May contradict other requirements

  3. Accessibility for maintenance purposes can be more important than representativeness

E. Zero alignment

1. Requirement found in 40 CFR 60 Appendix B 8.2.1.2
2. When monitor installed — true down-stack zero and simulated zero must be made to correspond
3. Zero alignment must be done once each year (40 CFR 60 Appendix B 8.2.1)
4. Procedure can be done with monitor off the stack if transceiver and retroreflector are at stack measuring distance

V. Performance specification test procedures and calculations

A. Performance specification test for opacity monitors

1. Relatively simple compared to Performance Specification Test 2 and Performance Specification Test 3
2. Two tests — 24-hour zero and calibration drift tests
   a. Take seven sets of data — one set each 24 hours
   b. Monitor must run without breakdown for 168 hours

B. Zero drift test

1. Procedure — day 1: clean external optics, adjust instrument to zero and write down zero
2. Procedure — day 2: 24 hours later take zero reading, write it down, then clean optics and adjust instrument back to zero
3. Obtain x_i values for seven days

$$\begin{pmatrix} \text{zero reading} \\ \text{after cleaning} \\ \text{optics} \end{pmatrix} - \begin{pmatrix} \text{zero reading before} \\ \text{cleaning optics 24} \\ \text{hours later} \end{pmatrix} = x_i \, (+ \text{ or } -)$$

C. Calibration drift test

1. Procedure — day 1
   a. Clean optics and adjust to zero
   b. Calibrate instrument and write down value
2. Procedure — day 2
   a. Clean optics and adjust to zero
   b. Obtain reading for calibration filter and write it down
   c. Recalibrate instrument
3. Obtain x_i values for seven days

$$x_i \, (+ \text{ or } -) = \begin{pmatrix} \text{span reading} \\ \text{after cleaning} \\ \text{optics and zero} \\ \text{adjustment} \end{pmatrix} - \begin{pmatrix} \text{span reading} \\ \text{after cleaning optics} \\ \text{and zero adjustment,} \\ \text{but before span} \\ \text{adjustment 24 hours} \\ \text{later} \end{pmatrix}$$

D. Calculations

1. Similar to previous calculations using the confidence interval
2. Absolute mean value

$$|\bar{x}| = \frac{1}{n} \sum_{i=1}^{n} x_i$$

3. Confidence interval calculation

$$CI_{95} = \frac{t_{0.975}}{n\sqrt{n-1}} \sqrt{n(\Sigma x_i^2) - (\Sigma x_i^2)}$$

4. Performance parameters given by

$$|\bar{x}| + CI_{95} = \text{24-hour zero drift}$$
$$\text{or 24-hour calibration drift}$$

5. Closing slide—will continue with performance specification tests—Lecture 11, Performance Specification Tests 2 and 3

Chapter 10

Performance Specification Tests 2 and 3

Lesson Goal

To introduce to you the procedural requirements of Performance Specification Tests 2 and 3 for SO_2/NO_x monitors and O_2/CO_2 continuous emission monitors.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. define stratification as applied to continuous emission monitors.
2. list at least two installation requirements for an SO_2/NO_x CEM system.
3. explain what is meant by a representative location for a gaseous CEM installation.
4. list at least five of the eight performance specifications for an SO_2/NO_x CEM.
5. explain how a calibration error test is performed.
6. perform the calculations required in Performance Specification Tests 2 and 3.
7. describe how the relative accuracy test is performed and why it is important for gaseous monitor certification.
8. outline, step-by-step, the procedures involved in performing the 2-hour and 24-hour zero and calibration drift tests for an SO_2/NO_x monitor.
9. list at least three of the performance specification requirements for a diluent gas monitor.
10. describe the procedure that is to be followed in lieu of a relative accuracy test for a diluent gas monitor.

I. Introduction (Performance Specification Tests 2 and 3)

A. Points that will emphasize

1. Installation requirements
2. Test procedures
3. Performance specification calculations

B. Doing the test

1. Carried out by source or contractors
2. Involves many people — agency observer should be present for part of test
3. Scheduling important — what is to be done when should be agreed upon by all parties prior to test
4. Any modifications to test procedures should be approved by administrator prior to test

II. Installation requirements

A. Representative location

1. Installation specifications given in 40 CFR 60 App. B Performance Specification Test 2 Par. 4
2. Require CEM sample to be representative of what is emitted from stack
   a. Sample to be directly representative
   b. Can correct unrepresentative measurements

B. Stratification

1. Gases can stratify — a situation which may make it difficult to achieve representativeness
2. Stratification (EPA definition): a condition identified by a difference in excess of 10% between the average concentration in the duct or stack and the concentration at any point more than 1.0 meter from the duct or stack wall
3. Stratification testing
   a. Use a portable monitor to check across the diameter
   b. Can use reference methods to check
4. If a sampling location is 8 or more duct diameters (equivalent diameters) downstream of any air in-leakage, the effluent gas can be assumed to be nonstratified (cannot apply this upstream of an air preheater, however)
5. For sampling locations where effluent gases are demonstrated or may be assumed to be nonstratified (8 diameters) a point or path of average concentration may be monitored

C. Other requirements

1. Single point sampling systems must monitor at a point greater than 1 meter from the stack wall

2. May use multipoint sampling system, sampling rake, or path in-situ monitor in cases of stratification—may require data to substantiate representativeness

3. If the pollutant and diluent monitor are not of the same type (both extractive or in-situ), the extractive systems must use a multipoint probe

III. Test procedures (Performance Specification Test 2)

   A. Performance specifications

      1. Relative accuracy test required
         a. ±20% of the mean value of the reference method test data
         b. Relative accuracy test only required for SO_2/NO_x monitors
         c. Most important part of performance specification test procedure

      2. Calibration error
         a. Must be ≤5% of a 50% calibration gas mixture or internal calibration cell value
         b. Must be ≤5% of a 90% calibration gas mixture or internal calibration cell value

      3. Zero drift (2-hour)—2% of the span value
      4. Zero drift (24-hour)—2% of the span value
      5. Calibration drift (2-hour)—2% of the span value
      6. Calibration drift (24-hour)—2.5% of the span value
      7. Response time limited to a maximum of 15 minutes
      8. Operational test period—instrument must operate a minimum of 168 hours without breakdown

   B. Calibration error test

      1. Calibration gases
         a. Must be prepared two weeks prior to performance specification test using EPA Reference Methods 6 or 7
         b. Each sample test result must be within 20% of the average or the tests are to be repeated
         c. NBS certified gases may be used if administrator approves

      2. Test procedure—introduce gases into extractive monitor system

         a. Fifteen nonconsecutive tests
         b. Alternate between 0, 50%, and 90% gases
         c. Obtain five values for each gas

      3. Test procedure—in-situ systems
         a. Insert two or more certified calibration gas cells
         b. Follow instrument vendor's procedure

4. Calculations
   a. Same method as in Performance Specification Test 1
   b. Obtain difference x_i values

$$\left(\begin{array}{c}\text{monitor reading}\\\text{ppm}\end{array}\right) - \left(\begin{array}{c}\text{reference method}\\\text{ppm gas value}\end{array}\right) = x_i\,(+\text{ or }-)$$

   c. Calculate absolute mean value

$$|\bar{x}| = \frac{1}{n}\sum_{i=1}^{n} x_i$$

   d. Compute confidence interval

$$CI_{95} = \frac{t_{.975}}{n\sqrt{n-1}}\sqrt{n(\Sigma x_i^2)-(\Sigma x_i)^2}$$

   e. Compute calibration error

$$\frac{|\bar{x}|+CI_{95}}{\left[\begin{array}{c}\text{average calibration}\\\text{gas reading}\end{array}\right]} \times 100 = \text{calibration error}$$

C. Relative accuracy test

   1. Most important part of performance specification test
   2. Probe for manual sample to be at same location as monitoring system
   3. SO_2 — 9 samples, 1 each hour
   4. NO_x — 9 data sets, 3 samples within a 3-minute interval, once each hour
   5. Calculations — similar to others
      a. Difference values

$$\left(\begin{array}{c}\text{instrument test period}\\\text{average}\\\text{(ppm)}\end{array}\right) - \left(\begin{array}{c}\text{reference method}\\\text{(ppm)}\end{array}\right) = x_i\,(+\text{ or }-)$$

      b. Relative accuracy

$$\frac{|\bar{x}|+CI_{95}\%}{\begin{array}{c}\text{average}\\\text{reference}\\\text{method (ppm)}\end{array}} \times 100 = \%\,\text{relative accuracy}$$

      c. [**NOTE:** as source concentration of pollutant decreases, becomes more difficult to pass relative accuracy test]

D. Response time test

   1. To be tested for the system, not just analyzer
   2. If time sharing analyzer, must repeat for each point
   3. Zero instrument with zero gas and inject pollutant gas
   4. Obtain three upscale and three downscale readings

5. Calculations: find the averages

$$\left(\sum_{i=1}^{3} \frac{\text{upscale}}{3}\right) \text{ and } \left(\sum_{i=1}^{3} \frac{\text{downscale}}{3}\right)$$

6. The response time is the lowest average

7. The two averages must not differ by more than 15% of the lowest average, or

$$\frac{\sum\limits_{i=1}^{3} \dfrac{\text{upscale}}{3} - \sum\limits_{1}^{3} \dfrac{\text{downscale}}{3}}{\text{slower time}} \times 100 \leq 15\% \text{ of slower time}$$

E. Zero and calibration drift tests

1. Seven 24-hour zero and calibration drift tests required
2. Fifteen 2-hour zero and calibration drift tests required
3. To obtain 2-hour drift data

   a. $\begin{pmatrix} \text{zero set} \\ \text{(ppm)} \end{pmatrix} - \begin{pmatrix} \text{zero reading} \\ \text{2 hours later} \end{pmatrix} = x_i = \Delta \text{ zero}$

   b. Add these and average to obtain $|\bar{x}|$ for 2-hour zero drift

4. To obtain 2-hour calibration drift

   a. Step 1: $\begin{pmatrix} \text{calibration} \\ \text{set (ppm)} \end{pmatrix} - \begin{pmatrix} \text{calibration reading} \\ \text{2 hours later} \end{pmatrix} = \Delta \text{ span}$

   b. Step 2: correct for any zero drift

   $\Delta \text{ span} - \Delta \text{ zero} = x_i \ (+ \text{ or } -) \text{ for calibration drift}$

   c. Step 3: use x_i values in step 4b to obtain $|\bar{x}|$ for 2-hour calibration drift

5. Calibration/zero drift computation

   a. Computation similar to others

   $$\frac{|\bar{x}| + \text{CI}_{95}}{\text{(instrument span)}} \times 100$$

   b. Must be less than 2% of span

6. To obtain 24-hour zero drift

   a. Step 1: $\begin{pmatrix} \text{zero set} \\ \text{ppm} \end{pmatrix} - \begin{pmatrix} \text{zero reading 24 hours} \\ \text{later prior to adjustment} \\ \text{(ppm)} \end{pmatrix} = x_i \text{ (zero drift)}$

   b. Step 2: use x_i values for computation of $|\bar{x}|$

7. To obtain 24-hour calibration drift

   a. Step 1: adjust zero reading back to zero if any drift occurred

b. Step 2:

$$\begin{pmatrix} \text{calibration set} \\ \text{ppm} \end{pmatrix} = \begin{pmatrix} \text{calibration reading} \\ \text{24 hours later after} \\ \text{zero adjustment} \\ \text{(ppm)} \end{pmatrix} = x_i \begin{pmatrix} \text{calibration} \\ \text{drift} \end{pmatrix}$$

c. Step 3: adjust calibration to correct value if there was any drift and use x_i values to compute $|\bar{x}|$

8. Calculation for the performance parameter

$$\frac{|\bar{x}| + CI_{95}}{\text{instrument span}} \leq \begin{array}{l} 2\% \text{ (24-hour zero drift)} \\ 2.5\% \text{ (24-hour calibration drift)} \end{array}$$

IV. Procedures for certification of diluent monitors (Performance Specification Test 3)

A. Introduction

1. Have installation requirements, test procedures, and calculations similar to those of Performance Specification Test 2
2. No relative accuracy test required

B. Performance specifications

1. Zero drift (2-hour) $\leq 0.4\%$ O_2 or CO_2
2. Zero drift (24-hour) $\leq 0.5\%$ O_2 or CO_2
3. Calibration drift (2-hour) $\leq 0.4\%$ CO_2 or CO_2
4. Calibration drift (24-hour) $\leq 0.5\%$ O_2 or CO_2
5. Response time 10 minutes maximum

C. Gases for determining calibration drift

1. Require midrange and 90% gases
2. Must check calibration gases by Orsat within two weeks prior to performance specification test
3. If span is higher than 21%, may use ambient air

D. Calibration check

1. Establish a calibration curve for the continuous monitoring system using zero, midrange, and span concentration mixtures
2. Compare calibration curve to that provided by vendor
3. If expected curve is not produced, steps should be taken to verify the instrument response

V. Special comments

A. Performance specification test revisions

1. October 10, 1979 — not promulgated (in regulatory handbook)
2. January 26, 1981 — not yet promulgated

B. Care should be taken in applying proposed regulations since they are technically not legally binding

C. The October 6, 1975 performance specification test procedures are the only ones promulgated and included in the Code of Federal Regulations as of February 1982.

Chapter 11
In-situ Monitors

Lesson Goal

To describe the configuration of and operational principles of in-situ gaseous emission monitors.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. define the term *in-situ* and distinguish between *cross-stack* and *in-stack* monitors.
2. explain how and why the technique of differential absorption spectroscopy can be used in in-situ monitors.
3. describe what a gas filter correlation cell is, how it is used in an in-situ monitor, and why the technique is insensitive to particulate matter.
4. list three ways to check the calibration of a Lear Siegler SM810 analyzer.
5. describe why the method of second derivative spectroscopy can be used for in-situ gas analysis.

IN-SITU MONITORS

IN-SITU MONITORS

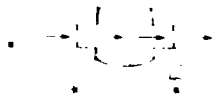Cross-Stack (path)   In-Stack (point)

Single Pass   Double Pass

IN-SITU ELECTRO-OPTICAL MONITORING PRINCIPLES

- Differential Absorption
- Gas Filter Correlation
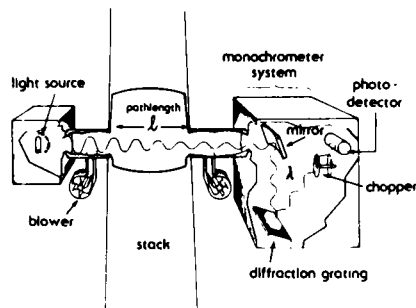- Second Derivative Spectroscopy

Cross-Stack Monitors

EDC
Cross-Stack
Monitor

Differential Absorption

	SO_2	NO	CO_2
Reference Wavelength	310 nm	228 nm	2100 nm
Measurement Wavelength	309 nm	226 nm	2000 nm

EDC Light Source Assembly
(external view)

EDC Light Source Assembly
(internal view)

EDC Analyzer
Assembly
(internal view)

• gases measured in presence of particulate matter

$$I_p = K I_{wp}$$

$$I_{op} = K I_{owp}$$

$$\frac{I_p}{I_{op}} = \frac{K I_{wp}}{K I_{owp}} = \frac{I_{wp}}{I_{owp}}$$

Where:

K   fraction of light attenuated by particulate matter in gas stream

I   intensity

Calibration Cells

EDC Zero Pipe

IN-SITU ELECTRO-OPTICAL
MONITORING PRINCIPLES

- Differential Absorption
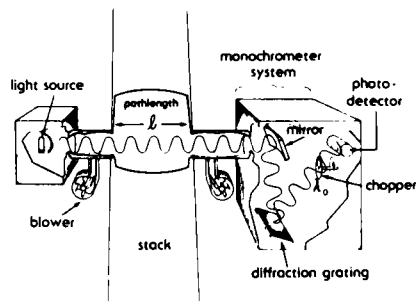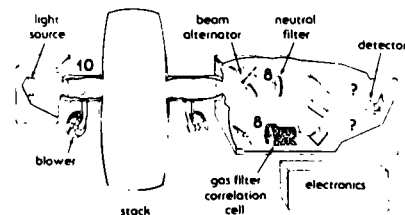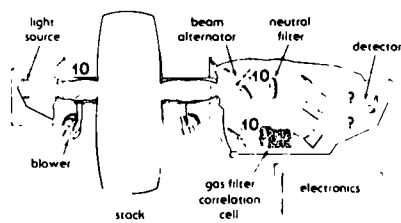- Gas Filter Correlation
- Second Derivative
  Spectroscopy

Contraves Goerz Analyzer

light source · beam alternator · neutral filter · detector · blower · gas filter correlation cell · electronics · stack

light source · 10 · beam alternator · neutral filter · 10 · detector · 10 · blower · gas filter correlation cell · electronics · stack

light source · 10 · beam alternator · neutral filter · detector · 8 · blower · 8 · gas filter correlation cell · electronics · stack

light source   beam alternator   neutral filter   detector   blower   stack   gas filter correlation cell   electronics

Neutral Beam   Gas-Filter Cell Beam

Absorpiton, percent

No SO$_2$ in Stack

SO$_2$ in Stack

Particulate Matter in Stack

Wavelength   Wavelength

Contraves Goerz
Optical Assembly

Measurement Cycle

Reference Cycle

reference source

gas cell

detector

calibration cell

gas cell

calibration source

stack

Calibration Cycle

reference source

gas cell

calibration cell

gas cell

calibration source

stack

LSI GM 21
SO$_2$ - NO$_2$ - Opacity Monitor

zero mirror

filter

beam splitter

src

retroreflector

UV lamp

lens

436 nm

546 nm

filter wheel

313 nm

phototube

GFC - CO Monitor

air purge

IR source

mirror   GFC cell   detector

GFC - CO Monitor

mirror   GFC cell   detector

IR source

In-Stack Monitors

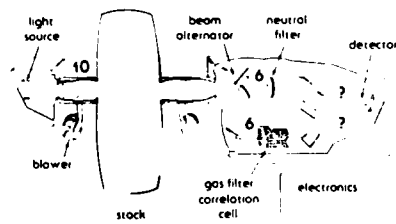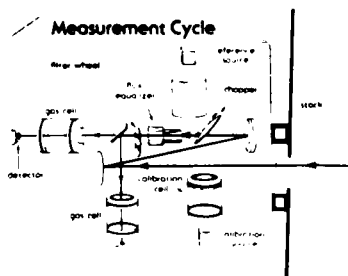## IN-SITU ELECTRO-OPTICAL MONITORING PRINCIPLES

- Differential Absorption
- Gas Filter Correlation
- Second Derivative Spectroscopy

Lear Siegler SM810
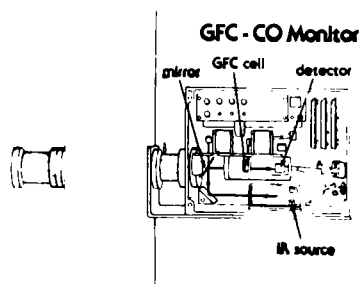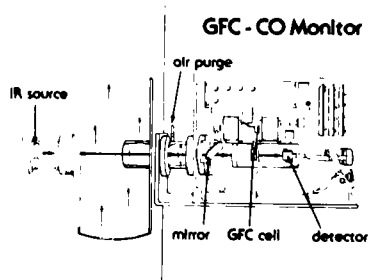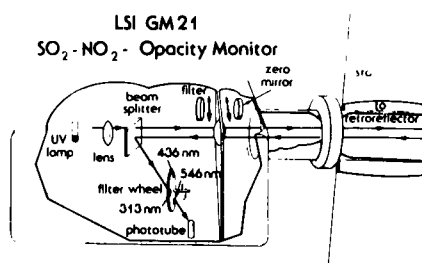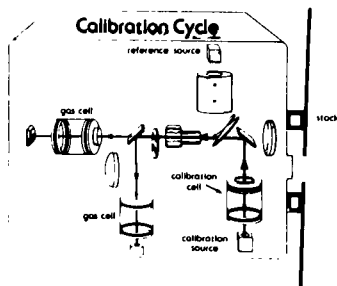

Second Derivative Spectrometer

Measuring Cavity

window   thermocouple   porous filter

retroreflector
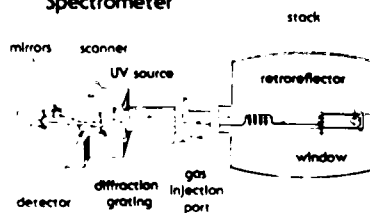
calibration gas line
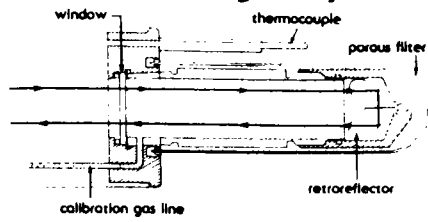
Calibration Checks
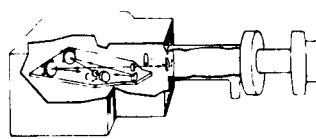
• calibration cell in analyzer

Calibration Checks
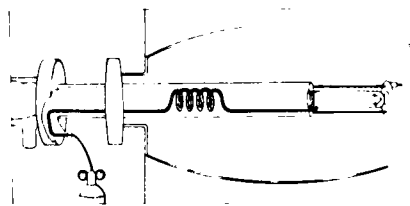
• calibration gas injected into probe

Calibration Checks
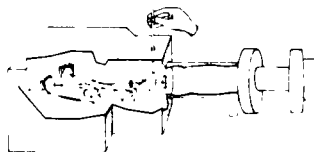
• Independent calibration cell

Linear Absorption

Absorption, percent

0

100

217.8 ← 218.5 → 219.2
Wavelength, nm

Curve   **First Derivative**

I λ_0 λ

$\dfrac{dI}{d\lambda}$ λ_0 λ

Second Derivative

$\dfrac{d^2I}{d\lambda^2}$ $\left(\dfrac{d^2I}{d\lambda^2}\right)_{\lambda_0}$ λ_0 λ
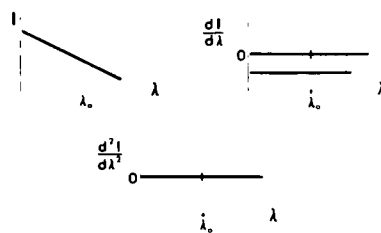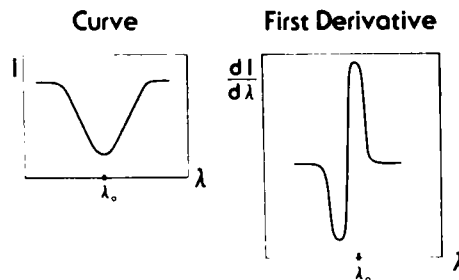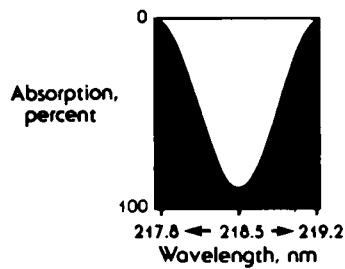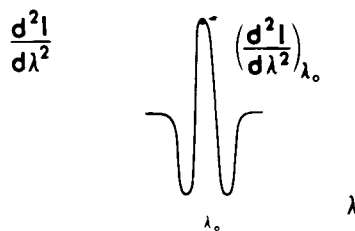
The second derivative spectrometer extracts a signal, S
d = scanning range (nm)

$$S = \frac{d}{4}\left(\frac{d^2I}{d\lambda^2}\right)_{\lambda_0}$$

Taking the derivatives of Beer's Law,

$$\frac{d^2I}{d\lambda^2} = -c\ell\frac{d^2a}{d\lambda^2}I$$

Substituting,

$$S = \frac{-c\ell d^2}{4}\frac{d^2a}{d\lambda^2}I \quad \text{or} \quad S/I = kc\ell$$

Lear Siegler SM810
(cutaway)

IN-SITU MONITORS

- EDC - differential absorption, gas filter correlation

- Contraves Goerz - gas filter correlation

- Lear Siegler SM810 - second derivative spectroscopy

- Lear Siegler - light absorption

- Land CO Monitor - gas filter correlation

Chapter 12
Analyzers for Measuring O_2 and CO_2

Lesson Goal

To describe the methods used to monitor oxygen in flue gases and to review the methods used to monitor CO_2.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. explain what a diluent monitor is and why it may be necessary in a continuous monitoring application.
2. list at least two methods used for measuring oxygen.
3. explain how the effect of paramagnetism can be used to construct an oxygen analyzer. (Describe at least one of three methods.)
4. describe why a porous ZrO_2 solid electrolyte can be used to measure oxygen in an electrocatalytic analyzer system.
5. describe two ways in which an electrochemical O_2 analyzer can be constructed.
6. list the types of CO_2 monitors available for monitoring flue gases.

ANALYZERS
FOR
MEASURING
O_2 AND CO_2

DILUENT MONITORS

OXYGEN
ANALYZERS

CARBON
DIOXIDE
ANALYZERS
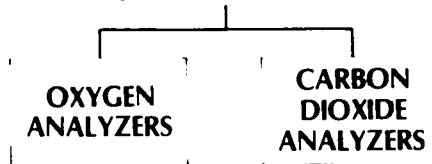
OXYGEN ANALYZERS

Electrocatalytic　Paramagnetic　Membrane
Polarographic
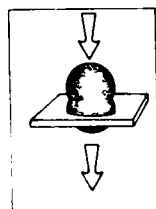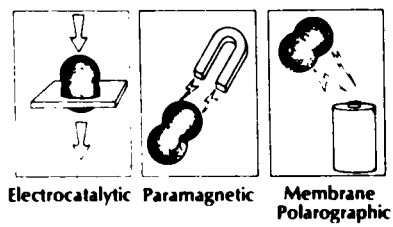
Electrocatalytic Analyzers

- In-Situ
- Extractive

Electrocatalytic Oxygen Analyzer
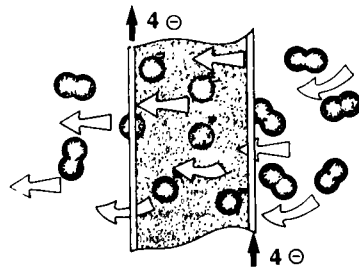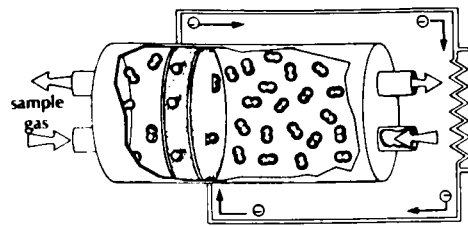
$$EMF = \frac{RT}{4F} \ln \frac{P_{reference}(O_2)}{P_{sample}(O_2)}$$

zirconium oxide
electrolyte

heater   porous filter

instrument
air
(reference)

P (O₂)   P (O₂)
reference   sample
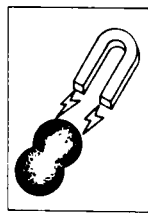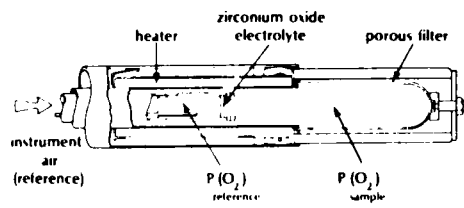
Paramagnetic Analyzers

- **Extractive**
  - Thermomagnetic
  - Magnetodynamic
  - Paramagnetic Pressure

Paired Electrons
(spinning in opposite
directions)

no attraction
to magnetic field
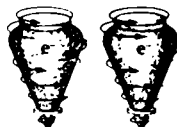
Unpaired Electrons
(spinning in same direction)

attracted to magnetic field

Paramagnetism

Magnetic Wind
Analyzer
(Thermomagnetic)

oxygen out

magnet

cross tube

oxygen in

Torque

N

sample gas

S

feedback
circuit

detector

lamp

Torque

e⁻   O₂

Quinke Analyzer
(Paramagnetic Pressure)

reference gas (N_2)

flow sensor

measuring chamber

No O_2 Present

magnet

reference gas

sample gas

flow sensor

measuring chamber

O_2 Present

magnet
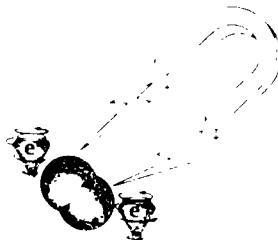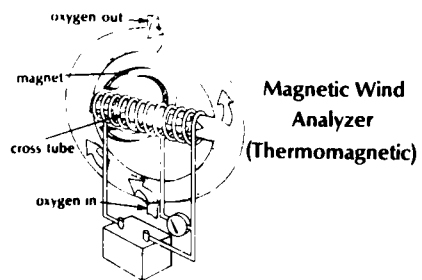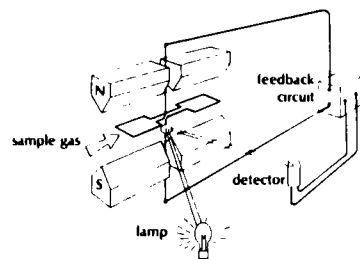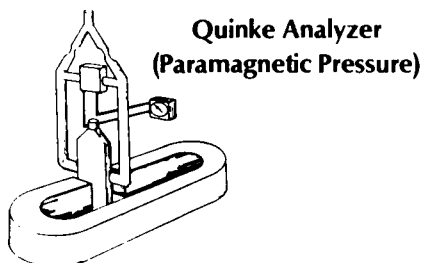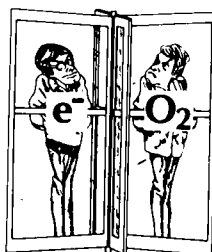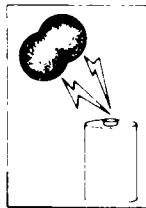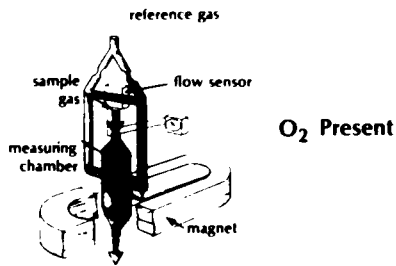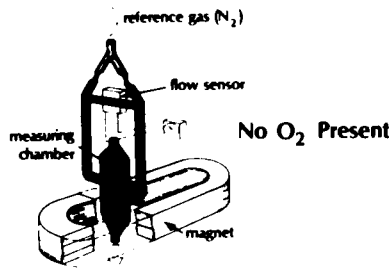
Membrane Polarographic Analyzers

- **Extractive**
  - Internal Voltage Bias
  - External Bias
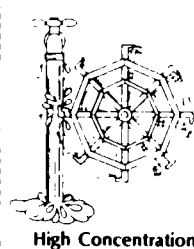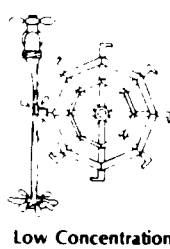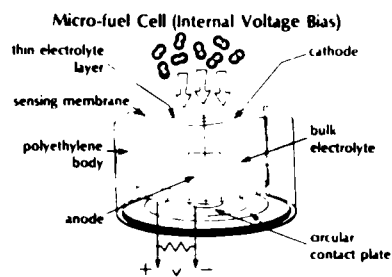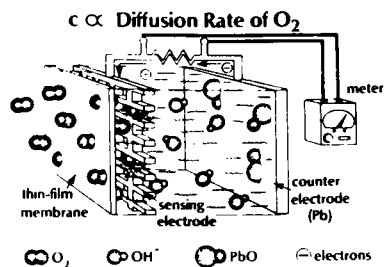
Micro-fuel Cell (Internal Voltage Bias)

thin electrolyte layer

cathode

sensing membrane

bulk electrolyte

polyethylene body

anode

circular contact plate

+ V −

Low Concentration

High Concentration

c ∝ Diffusion Rate of O_2

Sensing Electrode

$$4e^- + 2H_2O + O_2 \rightarrow 4OH^-$$

Counter Electrode

$$4OH^- + 2Pb \rightarrow 2PbO + 2H_2O + 4e^-$$

Sensing Electrode

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Reference Electrode

$$4Ag + 4Cl^- \rightarrow 4AgCl + 4e^-$$

DILUENT MONITORS

OXYGEN ANALYZERS

CARBON DIOXIDE ANALYZERS

Electro-catalytic | Paramagnetic | Membrane Polarographic | Infrared | Membrane Polarographic
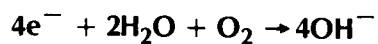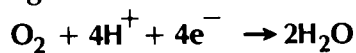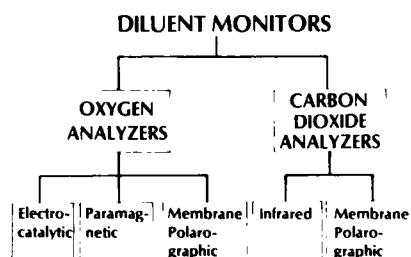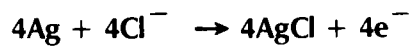
Chapter 13
F Factors—Units of the Standard

Lesson Goal

To review the F factor methods used to calculate pollutant emission rates from combustion sources.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. define the F factor.
2. discuss how the F factor can give a value for the emission rate.
3. describe the requirements for using the F factor in continuous emission monitoring.
4. describe the use of the wet F factor method.

I. Emissions in terms of lbs/10^6 Btu heat input

A. Previously expressed emissions in terms of
[**NOTE**: write equation on board]

$$E = \frac{pmr_s}{Q_H} = \frac{C_s Q_s}{Q_H} = \frac{\dfrac{lbs}{\cancel{ft^3}} \cdot \dfrac{\cancel{ft^3}}{\cancel{hr}}}{10^6 \ Btu/\cancel{hr}}$$

$$= \frac{lbs}{10^6 \ Btu}$$

B. Problems

1. Uncertainty in Q_H. What is Q_H?
   (Fuel feed rate) × (fuel heating value)
   Does EPA have a standardized fuel truck to check fuel feed meters?
   No. — have uncertainty here that can't check
2. Too many variables in the equation for continuous monitoring applications

II. F factor method

A. Alternate approach [**NOTE**: write on board)

$$E = C_s F \begin{pmatrix} dilution \\ correction \\ term \end{pmatrix}$$

B. Definition of the F_d factor

1. $F_d = \dfrac{\begin{matrix} volume\ of\ theoretical\ dry \\ combustion\ products/lb \end{matrix}}{\begin{matrix} 10^6\ Btu/lb\ heating\ value \\ of\ fuel\ combusted \end{matrix}}$

   $= \dfrac{ft^3}{10^6\ Btu}$

   dimensionally, then

2. The emission rate from A, is then

   $$E = \frac{\cancel{ft^3}}{10^6 \ Btu} \cdot \frac{lbs}{\cancel{ft^3}} = \frac{lbs}{10^6 \ Btu}$$

   dilution correction term is dimensionless

3. F factors are relatively constant values for specific categories of fuels

13-2

C. F_d factor method

1. $E = \bar{c}_s F_d \left[\dfrac{20.9}{20.9 - \%O_2} \right]$

    uses $\%O_2$ for dilution correction
2. This is the equation must use in EPA Method 5
3. Examples of F factors

    Note more extensive list in manual — numbers in parentheses, give % deviation from the mean of data sets for which the F factors were calculated
4. EPA Method 5 and the F_d factor method

    [NOTE: Point out the small deviations]

    Required to use this calculation method. Also, required to perform oxygen traverse while doing Method 5 test.

D. F_c factor method

1. $F_c = \dfrac{\begin{array}{c}\text{volume of theoretical } CO_2 \\ \text{generated by combustion/lb}\end{array}}{\begin{array}{c}10^6 \text{ Btu/lb heating value} \\ \text{of fuel combusted}\end{array}}$

    [NOTE: These are important for continuous monitoring, but not for Method 5]
2. The F_c factor method

    $E = \bar{c}_s F_c \dfrac{100}{\%CO_2}$

E. Using F_d factor to calculate E from data given on a wet basis

$E = c_{ws} F_d \left[\dfrac{20.9}{20.9(1 - B_{ws}) - \%O_{2(w)}} \right]$

[NOTE: Define $O_{2(w)}$ — oxygen concentration on a wet basis]

B_{ws} = functional moisture content of stack gas

F. Wet F factor method F_w

$E = \bar{c}_{sw} F_w \left[\dfrac{20.9}{20.9(1 - B_{wa}) - \%O_{2(w)}} \right]$

Where: B_{wa} = fractional moisture content in air

Method used on continuous monitoring applications.

B_{wa} can be determined by several methods

Chapter 14
Measuring, Recording, Averaging, and Reporting

Lesson Goal

The purpose of this lesson is to familiarize you with the basic CEM recording and reporting requirements and to review three methods of recording CEM data.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. explain how the processes of measuring, recording, averaging, and reporting continuous CEM data differ from each other.
2. list the time intervals over which opacity, SO_2, and O_2 monitors are required to measure data for NSPS FFFSG sources.
3. list the averaging periods for recorded opacity, SO_2, and O_2 data.
4. define *excess* emissions for opacity and SO_2 analyzers.
5. explain the phrases *average of three contiguous 1-hour periods* and *30-day rolling average based on 24-hour periods*.
6. list three types of instruments that can be used to record CEM data.
7. list at least three types of analog recorders (i.e., circular chart, single pen strip chart, multiplier strip chart, field recorder, etc.).
8. discuss the advantages and disadvantages of data logging recording systems.
9. list at least two advantages of using a computer system with a CEM system.

I. Measuring and recording — averaging — reporting

   A. Distinction

      1. All measured data are not required to be recorded
      2. All recorded data are not required to be reported

   B. Averages

      1. Recorded data can be averages of measured data
      2. Reported data are averages of recorded data
      3. Have two types of averages in NSPS for FFFSG sources

   C. In this lecture, will talk about recording and reporting requirements for NSPS FFFSG sources. Requirements for other source categories will differ

II. Measuring and recording

   A. Instruments

      1. Have talked about instruments which do this throughout the course
      2. Instruments give analog instantaneous, sequential, or integrated signals

   B. Opacity monitors

      1. Measuring requirement — must complete one cycle of sampling and analysis every 10 seconds
      2. Regulation found in 40 CFR 60.13e1
      3. Each 10-second measurement is also to be recorded

   C. SO_2 and NO_x monitors

      1. Measuring requirement — must complete one cycle of sampling and analysis at least every 15 minutes
      2. Regulation found in 40 CFR 60.13e2
      3. Each 15-minute reading is also to be recorded

III. Averaging requirement

   A. Reduction of data

      1. Measured data reduced or averaged
      2. Integrated values can be used — don't have to use specific data points

   B. Opacity monitors

      1. Must average a minimum of 24 equally spaced data points taken over six minutes
      2. Holdover to EPA Method 9, where calibrated eyeballs measure every 15 seconds
      3. Can take $360/10 = 36$ data points or integrated average for the six-minute reading
      4. Found in 40 CFR 60.13h

C. SO$_2$, NO$_x$ monitors

    1. Must average a minimum of four equally spaced data points taken over an hour

    2. Can use integrated data or arithmetic average of all data

    3. Found in 40 CFR 60.13h

IV. Reporting requirements

  A. Excess emissions and reporting

    1. Only data in excess of the standard are to be reported

    2. Use averaged data to compute possible excess emissions

    3. All excess emissions are to be computed in units of the standard

    4. Data not reported need not be reduced into units of the standard

  B. Excess emissions defined for opacity monitors

    1. Defined in 42 FR 61537 December 5, 1977 and 40 CFR 60.45g1

      [**NOTE**: this left as reserved in October 6, 1975 FR]

    2. Any six-minute period during which the average opacity or emissions exceeds 20%, except that one six-minute average of up to 27% opacity need not be reported

    3. Exclusion is based upon an allowance for soot-blowing. One two-minute period at 40% opacity. Get 27% by averaging

$$\frac{40 + 20 + 20}{3} = 27$$

    4. Note that the six-minute averages are those which were obtained previously — an average of at least 24 data points taken over six minutes

    5. Note also that these are integral six-minute periods — data not rolling or contiguous

  C. Excess emissions defined for SO$_2$ and NO$_x$ monitors

    1. Defined as any three-hour period during which the average emissions (arithmetic average of three contiguous one-hour periods) of sulfur dioxide or nitrogen oxides exceed the applicable standard

    2. Defined in 40 FR 46257 October 6, 1975 and 40 CFR 60g2 and 3

    3. Contiguous period means a rolling average: average over three hours — next period, drop off first hour and add next hour's data. Can get 24 possible excess emissions in a day, not just eight

    4. Note that each hour's data are averages of a minimum of four data points taken over that hour

  D. Excess emissions defined for SO$_2$ emissions from FFFSG utility sources constructed after September 18, 1978

    1. Excess emissions defined differently than for NSPS sources built between August 17, 1971 and September 18, 1978

2. Purpose here is for *compliance* monitoring—not control equipment monitoring

3. Here, compliance standard is based on a 30-day rolling average

4. 30-day average computed on average of at least 22 days worth of data. Each day's data computed as an average of at least 18 hours of data. Each hour of data consists of an average of at least two data points

5. Compute rolling average by dropping off first day's 24-hour average and adding on next 24-hour average

6. Get 30 possible violations per month, not just one

7. Method allows source to average periods of upsets. Less stringent than if used no rolling average

V. Recording instrumentation

A. Introduction and review

1. Three things being done
   a. CEMs measure
   b. Recorders record and possibly average
   c. People or data processors report

2. Can record data either on analog or digital basis

3. Can have dedicated CEM data processors or in-plant computers to compute into units of the standard, flag excess emissions, etc.

4. Recording instrumentation—will discuss three systems
   a. Analog chart recorders
   b. Data loggers
   c. Microprocessor—computer systems

B. Analog chart recorders

1. Have number of types
   a. Circular, field recorders, single pen, multipen
   b. Circular chart recorders not advisable—charts frequently written over
   c. Multipen recorders with 10 to 12-inch scales best for CEM applications

2. Example of recorders in the field
   a. Field recorder on left used for opacity data
   b. Multipen recorder used for gas data, but have only 3-inch scales

3. Example of data

4. Example of horizontal mount—Lear Siegler recorder installed in system

5. Strip charts for a Bendix system

6. Multipen strip chart recorder

7. Molytek recorder with explosion proof housing

8. State-of-the-art Molytek recorder with internal microprocessor and pull-out keyboard. Thirty-two trace capability with thermal print

C. Data loggers
   1. Digital data
      a. Like a digital watch—prints numbers instead of giving a trace
      b. Easy to read exact numbers
      c. Easier than analog signals to interface with computers
      d. Difficult to detect trends
      e. Can have problems if have high noise levels—can't detect average unless damp noise out
   2. Lear Siegler data logger
   3. Meloy—digital meter with digital printout in analyzer

D. Microprocessor and computer systems
   1. Microprocessors have variety of functions—can merely compute in units of the standard, print excess emissions, or be programmed—slide of monitor labs microprocessor
   2. Dedicated computer systems
      a. Many companies make computer systems for their monitoring equipment (LSI, EDC, Contraves Goerz, etc.)
      b. Lessen problems with interfacing
      c. Easier to deal with vendor service personnel
      d. As of 1981—generally takes one year to debug any of these systems
      e. Slide of LSI-DP30 dedicated computing system with keyboard, deck, and cassette magnetic tape recording
   3. In-plant computers
      a. Plant may wish to interface CEM system with existing computers—can save money
      b. Advantage since can incorporate into overall plant control system
      c. Problems with interfacing and programming
      d. If do not have in-house programmer, costs are comparable to dedicated systems since may need to hire consultants ($30,000 or more)

Chapter 15

Quality Assurance Programs and Field Inspection Procedures

Lesson Goal

To describe elements of quality assurance and inspection programs which can be developed by agencies and by sources.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. list at least four quality assurance checks that one could perform during a performance specification test.
2. describe where responsibility lies in maintaining continuing operation of emission monitoring equipment.
3. list at least three elements that should be contained in the source quality assurance program.
4. list two types of agency inspection programs.
5. define *traceability protocol*.
6. diagnose some typical instrument problems, given strip chart data.
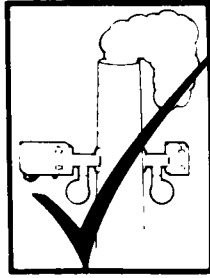
QA PROGRAMS AND FIELD INSPECTION PROCEDURES

CEM QA PROGRAMS
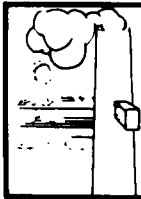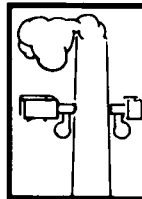
| Procurement Quality Control | QA - Performance Specification Test | QA - Continuing Operation |

PROCUREMENT QUALITY CONTROL

- Prepurchase Evaluation/Selection
- Writing of Purchase Contract Specifications
- Record Keeping

Prepurchase Evaluation/Selection

- Analyze performance parameters
- Assess analyzers
- Contact users for opinions
- Field test
- Assess site

- Analyze performance parameters
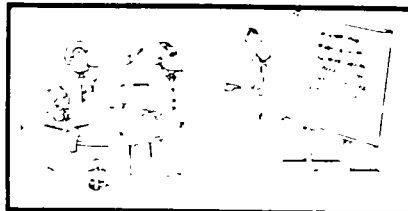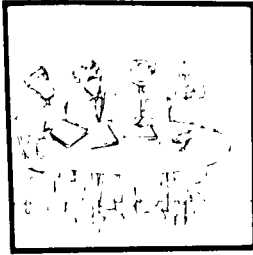
- Assess analyzers
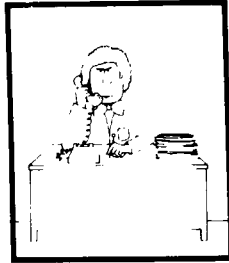
- Contact users for opinions
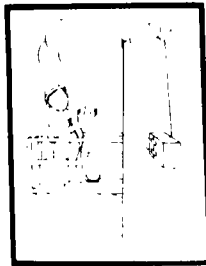
- Field test

- Assess site
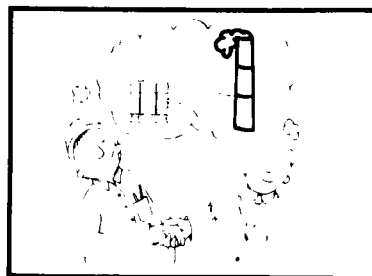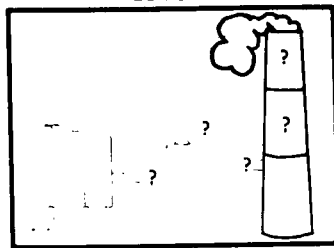
PROCUREMENT QUALITY CONTROL

- Prepurchase Evaluation/Selection
- Writing of Purchase Contract Specifications
- Record Keeping

Writing Purchase Contract Specifications

Requiring the following:

- test data documenting that analyzer meets performance specifications
- payment contingent upon successful PST
- warranty
- consistent operating manuals
- operator training
- consumables and spare parts

PROCUREMENT QUALITY CONTROL

- Prepurchase Evaluation/Selection
- Writing of Purchase Contract Specifications
- Record Keeping

Record Keeping

QA - PERFORMANCE SPECIFICATION TEST

- Reference Method QA
- CEM QA - Cross Checks
- Special Techniques

Reference Method QA

- EPA Quality Assurance Manual
  Volume III. EPA-600/4-77-027b
  Institute Procedures

- EPA SO_2 and NO_x audit samples
  to check technique

CEM QA - Cross Checks

Special Techniques
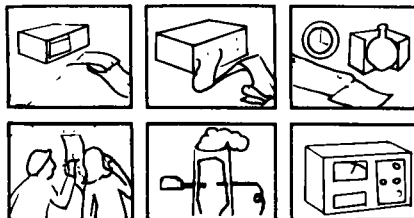
QA - CONTINUING OPERATION

- Source Maintenance Program
- Agency Inspection Program
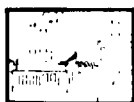
Source Maintenance Program

- Assign responsibility
- Provide operator training
- Keep a logbook
- Maintain spare parts inventory
- Ensure security

- Establish maintenance schedules
- Perform periodic audits
- Define:
  - Calibration Procedures
  - Fault Procedures
  - Data Handling Procedures

- **Assign responsibility**
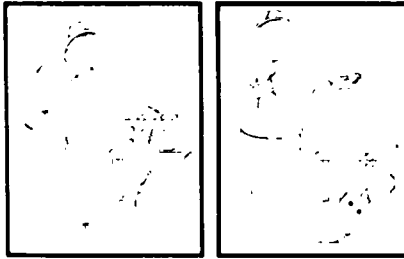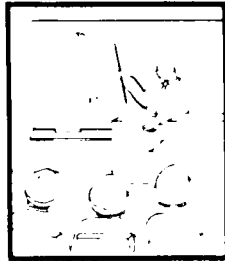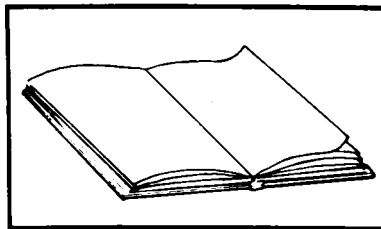
- **Provide operator training**

- **Keep a logbook**

- Maintain spare parts inventory

- **Ensure security**

- Establish maintenance schedules
- Perform periodic audits

• Define:
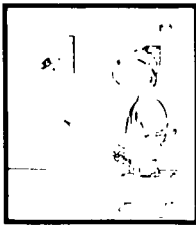
Instrument Problems
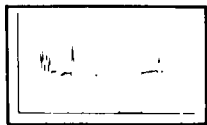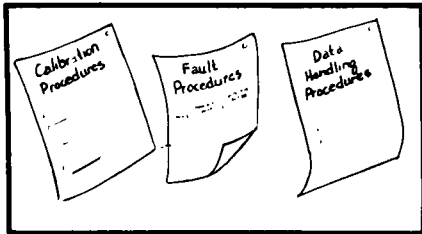
correct damping/gain

low gain/over damped   high gain/under damped
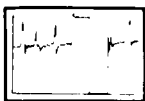
Recorder Problems

paper movement problem
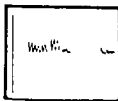
inking problem   over inking
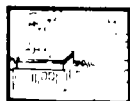
Source Maintenance Program

- Assign responsibility
- Provide operator training
- Keep a logbook
- Maintain spare parts inventory
- Ensure security

- Establish maintenance schedules
- Perform periodic audits
- Define:
  - Calibration Procedures
  - Fault Procedures
  - Data Handling Procedures

15-7
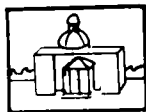
Agency Inspection Program

- Schedule Systems
- Level Systems

Schedule Systems

- Routine Audits or Inspections
- Random Periodic Audits
- Repeat of Performance Specification Tests

Level Systems

Field Test Audit

CEM System Site Inspection

Phone or Letter Communication

EER Evaluation

EER Evaluation

- periods and magnitudes of excess emissions
- nature and causes of excess emissions
- periods during which CEM system was inoperative
- record of calibration checks, adjustments, and maintenance
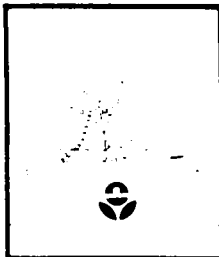
Phone or Letter Communication
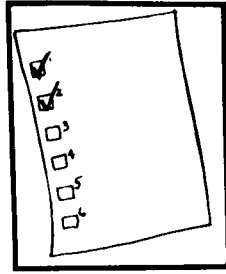
CEM System
Site Inspection

Field Test Audit

Options:

1. Check CEM with calibration gas or calibrated filters
2. Check CEM with agency inspection monitors
3. Check CEM with EPA reference methods
4. Redo performance specification test
5. Combinations of 1-4 or other procedures

Consequences

* enforcement action possible

CEM QA Programs

Procurement Quality Control

QA Performance Specification Test

QA-Continuing Operation

Assess Analyzer

Reference Method QA

CEM QA Cross Checks

Special Techniques

Source Maintenance Program

Agency Inspection Program

Assess Site

Contract Specifications

Schedule Systems

Level Systems
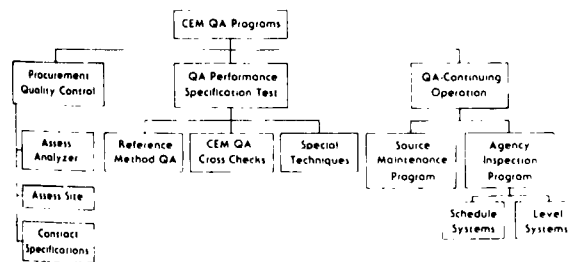
Chapter 16

Recent Developments in Emission Monitoring

Lesson Goal

To introduce to you new methods and concepts in emissions monitoring, such as remote sensing and continuous mass monitoring.

Lesson Objectives

Upon completion of this lesson, you should be able to:
1. describe at least two new methods used for source emissions monitoring that are currently in a research stage.
2. list at least two instrument methods that can be used for continuously monitoring source particulate mass emissions.
3. define, and distinguish between, *active* and *passive* modes of remote sensing.
4. list at least three types of methods used in remote sensing.
5. describe at least three applications for remote sensing techniques.
6. discuss the regulatory implications of new emission measurement techniques.

References

Environmental Protection Agency (EPA), C. B. Ludwig and M. Griggs, June 1976. *Application of Remote Techniques in Stationary Source Monitoring*, EPA-340/1-76-005.

Environmental Protection Agency (EPA), February 1979. *Proceedings: Advances in Particle Sampling and Measurement, Asheville, NC*, May 1978. EPA-600/7-79-065.

Herget, W. F. and Conner, W. D., "Instrumental Sensing of Stationary Source Emissions", *Environmental Science and Technology*, Vol. 11, 962-967 (1977).

Hartt, E. I. "An Evaluation of Continuous Particulate Monitors at a Secondary Lead Smelter", Environment Canada Report No. O.R.,-16.

RECENT DEVELOPMENTS IN
EMISSIONS MONITORING

| Neu | Continuous | Remote |
| Methods | Mass Monitoring | Sensing |
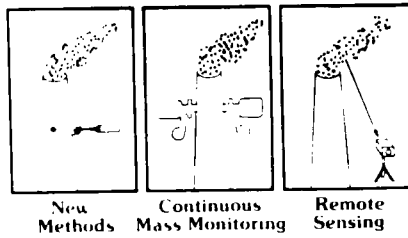
NEW METHODS
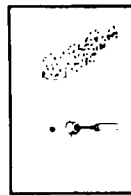
- Diode Laser
- H_2SO_4 Measurement
- Organics
- Others

IN-STACK SO$_2$ MONITORING
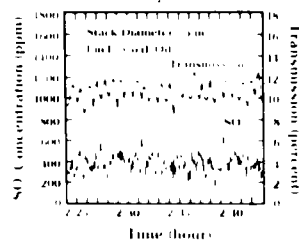
CONTINUOUS MASS MONITORING
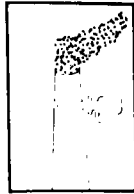
- Light Attenuation
- Light Scattering
- Charge Transfer
- Beta Radiation Attenuation

KRAFT RECOVERY FURNACE
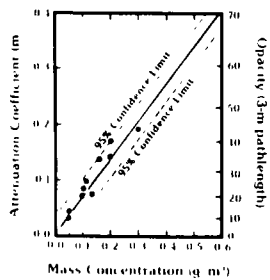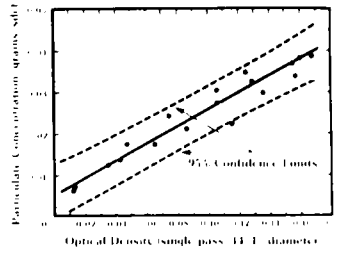
CEMENT PLANT WET PROCESS
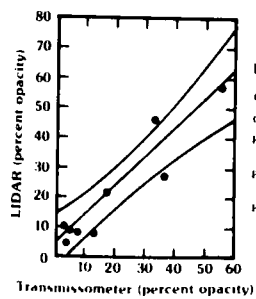
Data From.

Coal Fired Power Plants

Oil Fired Power Plants

Phosphate Plant Rock Dryer

Paper Mill Kraft Recovery Furnace

Portland Cement Plant

16-3

LIGHT SCATTERING

CHARGE TRANSFER

BETA RADIATION
ATTENUATION

REMOTE SENSING

- LIDAR
- ROSE
- COSPEC
- Others

REMOTE MEASUREMENT
METHODS

LIDAR

GCA

EPA
ROSE
SYSTEM

COSPEC

RESEARCH VENTURES, INC.

JRB

Chapter 17
Homework Problems

Homework Questions
Set 1

1. What is the value of 5.3 μm when converted to wavenumbers?
   a. 1.766×10^{-16} cm^{-1}
   b. 5.7×10^{15} cm^{-1}
   c. 1886 cm^{-1}
   d. 18.86 cm^{-1}

2. What would be the frequency, ν, of light having a wavelength of 5.3 μm?
   a. 5.7×10^{13} sec^{-1}
   b. 1886 sec^{-1}
   c. 5.7×10^{12} sec^{-1}
   d. 1.766×10^{14} sec^{-1}

3. Calculate the energy, $\Delta\epsilon$, of light having a wavelength of 5.3 μm.
   [**NOTE:** Planck's constant, h $= 6.625 \times 10^{-27}$ erg-sec]
   a. 1.77×10^{-14} ergs
   b. 3.74×10^{-12} ergs
   c. 1.25×10^{-23} ergs
   d. 3.74×10^{-13} ergs

4. What is the value of 2138 Å when converted to wavenumbers?
   a. 4677 cm^{-1}
   b. 1.403×10^{5} cm^{-1}
   c. 1.408×10^{15} cm^{-1}
   d. 46,772 cm^{-1}

5. What would be the frequency, ν, of light having a wavelength of 2138 Å?
   a. 4677 cm^{-1}
   b. 1.4×10^{15} sec^{-1}
   c. 9.8×10^{-12} sec^{-1}
   d. 1.4×10^{13} sec^{-1}

6. Calculate the energy, $\Delta\epsilon$, of light having a wavelength of 2138 Å.
   a. 9.29×10^{-12} ergs
   b. 2.118×10^{-13} ergs
   c. 9.29×10^{-10} ergs
   d. 1.46×10^{-23} ergs

7. Which light of the two considered above carries more energy?
   a. 5.3 μm
   b. 2138 Å

8. In what region of the electromagnetic spectrum does light of 5.3 μm occur?
   a. UV
   b. IR
   c. Visible
   d. Vacuum UV

9. What type of process would you expect to occur if light at 2138 Å happened to be a wavelength at which SO_2 absorbed energy?
   a. rotational transition
   b. vibrational transition
   c. electronic transition
   d. dissociation

10. List four existing source categories which are presently required to continuously monitor some type of emitted pollutant and state which pollutant(s) are required to be monitored.
    (1)_____
    (2)_____
    (3)_____
    (4)_____

11. What are two conditions which a new coal-fired steam generator must meet before being required to monitor NO_x?
    (1)_____
    (2)_____

12. What are three conditions that an existing coal-fired boiler should meet before being required by a State to monitor NO_x?
    (1)_____
    (2)_____
    (3)_____

13. Where would one find the continuous monitoring requirements for a new petroleum refinery?
    a. 40 CFR 60 Appendix B
    b. 40 FR 46250 October 6, 1975
    c. 40 CFR 51 Appendix P
    d. 40 CFR 60 Subpart J
    e. 40 CFR 60 Subpart D

14. You are given a Thermo Electron extractive SO_2 analyzer. Draw a diagram of an extractive system which would provide a representative sample to the analyzer (Stack temperature = 250°F, moisture content = 10% H_2O, grain loading = 0.95 lbs/10^6 Btu. Port exists at 150 ft level of stack. Thirty-foot breeching leads into the stack).

Homework Questions
Set 2

1. A coal-fired power plant with 500×10^6 Btu/hr heat input was constructed in Emit, North Carolina. It began operation in 1960. The boiler combustion gases were ducted into a 750-foot tall 40-foot diameter at the stack exit masonry stack. A transmissometer was located on the duct work. Increasing power demands created the need for an additional 500×10^6 Btu/hr boiler completed in 1969. The plant built separate duct work for the boiler sending effluent up the existing masonry stack. The easy maintenance afforded by placing a transmissometer on the duct work rather than on the stack led the plant to install the transmissometer for the new boiler on the duct work. The actual layout is shown in the diagram:
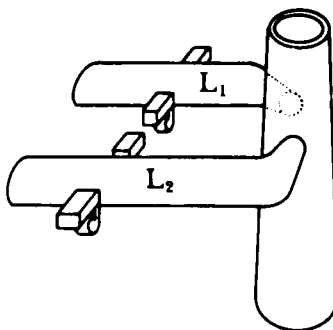
Two ducts entering common stack in Emit, N.C.

Each transmissometer has a pathlength of 15 ft (the ducts have identical dimensions) and gas velocities in the ducts are the same. What would be the stack plume exit opacity when the L_1 transmissometer showed 18% opacity and the L_2 instrument indicated 12% opacity?
   a. 35.3%
   b. 30%
   c. 18%
   d. 15%

2. A transmissometer located on a duct (pathlength 18 ft) indicated an optical density through the effluent of 0.0809. The duct gas exits to the atmosphere from a 36-foot diameter stack. What is the plume opacity of the stack exit?
   a. 48%
   b. 17%
   c. 31%
   d. 24%

Table II · Logarithms of Numbers

N	0	1	2	3	4	5	6	7	8	9
1.0	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
1.1	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
1.2	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
1.3	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
1.4	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
1.5	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
1.6	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
1.7	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
1.8	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
1.9	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
2.0	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
2.1	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
2.2	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
2.3	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
2.4	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
2.5	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
2.6	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
2.7	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
2.8	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
2.9	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
3.0	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
3.1	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
3.2	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
3.3	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
3.4	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
3.5	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
3.6	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
3.7	5682	5691	5705	5717	5729	5740	5752	5763	5775	5786
3.8	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
3.9	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
4.0	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
4.1	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
4.2	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
4.3	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
4.4	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
4.5	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
4.6	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
4.7	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
4.8	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
4.9	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
5.0	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
5.1	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
5.2	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
5.3	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
5.4	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396

N	0	1	2	3	4	5	6	7	8	9
5.5	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
5.6	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
5.7	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
5.8	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
5.9	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
6.0	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
6.1	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
6.2	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
6.3	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
6.4	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
6.5	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
6.6	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
6.7	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
6.8	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
6.9	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
7.0	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
7.1	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
7.2	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
7.3	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
7.4	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
7.5	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
7.6	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
7.7	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
7.8	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
7.9	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
8.0	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
8.1	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
8.2	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
8.3	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
8.4	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
8.5	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
8.6	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
8.7	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
8.8	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
8.9	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
9.0	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
9.1	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
9.2	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
9.3	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
9.4	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
9.5	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
9.6	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
9.7	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
9.8	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
9.9	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

Homework Questions
Set 3

1. The October 6, 1975 Federal Register gives design specifications for transmissometer instruments. Which of the following is **not** a design specification listed in the Federal Register?
   a. The instrument must show less than 2% zero drift during the performance specification test.
   b. The instrument must include a system check of the simulated zero and upscale opacity.
   c. The angle of view and angle of projection are limited to a 5° arc.
   d. Instrument response must be within 20% of EPA Reference Method 9 once the instrument is operating on the source.

2. The calibration error test is extremely important for the transmissometer performance specification certification procedure. The reason for this is:
   a. Transmissometer readings may be used as an alternative to the visible emissions observer.
   b. Performance Specification Test 1 does not have a relative accuracy test.
   c. Readings of the neutral density filters taken during the calibration error test will serve to verify proper instrument angle of view and angle of projection.
   d. The response time test is conducted at the same time.

3. Transmissometer instruments must be properly installed at an affected facility. Which of the following is(are) **not** a Federal Register installation requirement?
   a. The instrument must be installed in an accessible location.
   b. The instrument must be located downstream of all particulate control devices.
   c. The transmissometer shall be installed as far from a bend as possible.
   d. Instruments located in the plane of the bend must have a path-length that includes the entire duct diameter.

4. The Federal Register requires an optical and zero alignment of the transmissometer once a year at clean stack conditions. This is done so that:
   a. optics may be cleaned and serviced.
   b. instrument cross stack and simulated zero may be balanced.
   c. angle of view and angle of projection can be made identical.
   d. mechanical stability of the installation can be checked.

5. The calibration gases used in Performance Specification Test 2 must be checked two weeks prior to use by reference method testings. The Federal Register requires:
   a. triplicate reference method tests with each sample test within 20% of the test average.
   b. triplicate reference method tests with all tests within 20% of manufacturer certified value.
   c. triplicate reference method tests with the test average within 20% of an NBS traceable standard.
   d. triplicate reference method tests with a ±20% standard deviation.

6. Performance specification test data for an SO_2 monitor at a fossil-fuel-fired steam generator was as follows:

Test period	Instrument SO_2 value (ppm)	RM6 SO_2 value (ppm)
1	670	678
2	678	685
3	698	700
4	670	665
5	694	703
6	670	675
7	682	688
8	690	693
9	677	682

What is the relative accuracy of the instrument?
a. 11.21%
b. 1.12%
c. 10.12%
d. 2.51%

7. An in-situ SO_2 monitor is installed at a fossil-fuel-fired steam generator. The plant then installed an extractive oxygen monitor at a different location on the duct. The following statements describe the two installations. Which statement shows that the instrument installations do not meet performance specification test guidelines?
a. The extractive system samples at a single point of average concentration and is one meter from the stack wall.
b. The stack gases are nonstratified at both monitor locations.
c. There is no air in-leakage between the two points.
d. The system is 8 duct diameters upstream of the air preheater.

8. Reference Method 6 test data showed an SO_2 concentration in a stack effluent of 3.45 gm/dry m^3. Which of the listed values would be the equivalent readout in ppm from an SO_2 instrument?
a. 1296 ppm
b. 1029 ppm
c. 829 ppm
d. 1926 ppm

Homework Questions
Set 4

1. A fossil-fuel-fired steam generator burned the following combination of fuels:
   Natural gas   30%
   Oil   20%
   Bituminous coal   50%
   Stack testing of the unit yielded this data:
   Particulate concentration $= 1.5 \times 10^{-5}$ lb/dscf
   Diluent gas (dry basis) $= 6.2\%$ O_2
   What is the emission rate in lbs/10^6 Btu?

2. The Bradshaw Furniture Co. has an industrial steam generating unit of greater than 250×10^6 Btu/hr heat input. The unit is bituminous coal fired. It has an extractive carbon dioxide monitor. Recent testing showed an effluent SO_2 concentration of 750 ppm (wet basis)* and 12.8% CO_2 (dry basis). The average stack moisture content is 7% H_2O. What is the emission rate in lb/10^6 Btu?
   a. 1.89 lb/10^6 Btu
   b. 1.20 lb/10^6 Btu
   c. 1.03 lb/10^6 Btu
   d. Not enough information given

3. The operation of a continuous oxygen monitor was compared to Orsat data taken at the same point in the duct. The monitor showed 7.8% O_2 on a dry basis. The Orsat indicated 6.8% O_2 and 12.40% CO_2. The facility burns bituminous coal to produce steam. What data do you believe are correct?
   a. the instrument
   b. the Orsat
   c. neither the Orsat nor the instrument
   d. insufficient information

4. The sulfur dioxide monitor installed at a fossil-fuel-fired steam generator measured an effluent SO_2 concentration of 850 ppm (wet basis). The in-situ oxygen monitor at the plant indicated a 6.2% O_2 (wet basis) concentration. The plant is oil fired. What is the emission rate in pounds/10^6 Btu?
   a. 3.16 lbs/10^6 Btu
   b. 2.16 lbs/10^6 Btu   *NOTE: 454 gms $= 1$ lb; 1 m$^3 = 35.31$ ft^3
   c. 4.16 lbs/10^6 Btu
   d. insufficient data

5. An SO_2 cross-stack in-situ analyzer makes a single-pass measurement over a distance of 10 meters. The instrument contains an internal calibration cell which has a 1-centimeter thick gas space. What would the concentration of SO_2 in the gas cell need to be if a calibration reading of 900 ppm SO_2 is required for the 24-hour calibration check?
   a. 900 ppm
   b. 9%
   c. 90%
   d. 9000 ppm

Group Problem

You are the chief instrumentation engineer at a 420 MW coal-fired steam generating facility located in Emit, NC. The plant began construction October 5, 1971 and began operation September 11, 1978. The source uses high sulfur coal. The following schematic diagram illustrates the boiler layout.
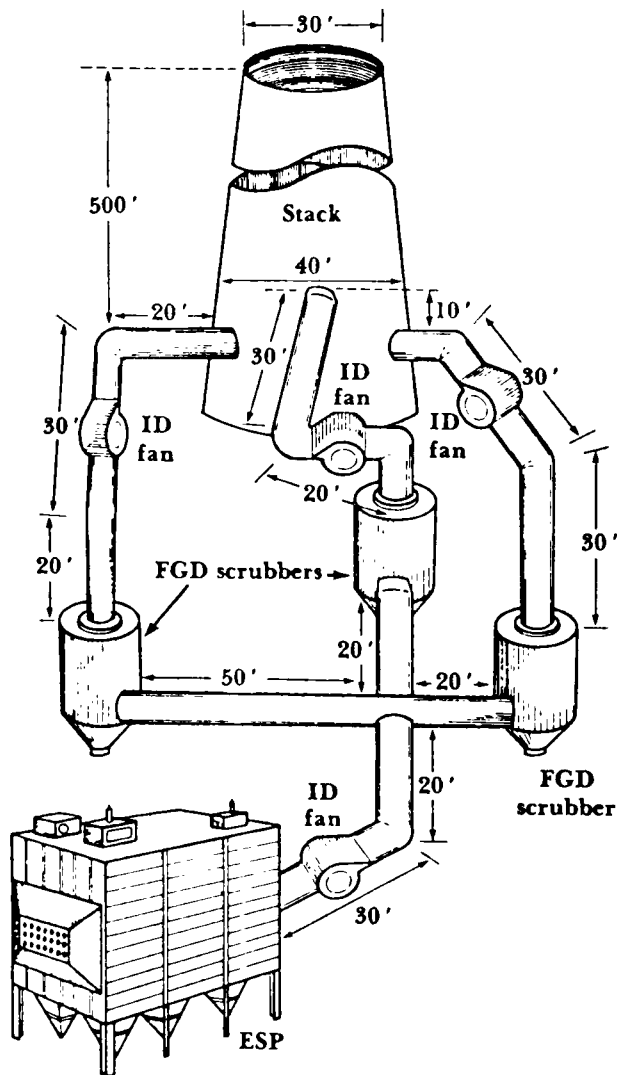
Three ducts lead into the common stack. Ports, walkways, and platforms have not as yet been installed. Each duct is exiting from an FGD scrubber module. Using this information, answer the following questions, filling in the answer sheet provided:

Design a continuous emissions monitoring system for the source that you feel will meet all applicable Federal regulations.* Use the folders supplied for this exercise and your course manual to aide you. You are also to determine a total system cost estimate which includes the following:

a. Instrument purchase prices
b. Platforms, ladders, and port installation costs (note instrument locations on answer sheet)
c. Engineering overhead
d. Performance testing

Also estimate the yearly maintenance costs. Note system locations on the diagram.

Work as a group to solve this problem and hand in one answer sheet for the group on Friday. The group presenting the best overall system will receive a special award.

*Note: 1. *You may not subcontract system design.*
       2. *Remote sensors may not be used.*
       3. *Assume that NO_x emissions are greater than 70% of the standard.*

Data Sheet

Group Number _____

Date_____

No. of monitors	Monitor type	Manufacturer	Operating principal	Estimated cost
Data handling systems				
System costs: calibration gases, plumbing, chillers, etc. (if required)	
Access costs: platforms, ladders, ports, elevators, electricity, etc.	
Engineering overhead	
Performance specification testing	
Total costs	
Yearly operating and maintenance costs	

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE APTI Course 474 Continuous Emission Monitoring Student Workbook		**5. REPORT DATE** August 1982
		6. PERFORMING ORGANIZATION CODE
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9. PERFORMING ORGANIZATION NAME AND ADDRESS Northrop Services, Inc. P.O. Box 12313 Research Triangle Park, NC 27709		**10. PROGRAM ELEMENT NO.** B 18A2C
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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

This student workbook is to be used in conjunction with presentations of
Air Pollution Training Institute Course 474, "Continuous Emission Monitoring".
This publication contains chapters corresponding to lessons given in the
course and includes a chapter containing homework exercises. Each chapter
contains a lesson goal, lesson objectives, and special references that
would provide helpful background material for the subject area covered in
the chapter. Each chapter also contains important black-and-white
reproductions of selected slides used in the training course. In the case
of more difficult material, complete lecture notes are provided.

This publication is intended for use in conjunction with the Instructor's
Guide (EPA 450/2-82-013) and the Student Manual (EPA 625/6-79-005).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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