United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-453/B-94-057
September 1994

Air

EPA

High Capacity Fossil Fuel Fired Plant Operator Training Program

Instructor's Guide

EPA-453/B-94-057

HIGH CAPACITY FOSSIL FUEL-FIRED PLANT OPERATOR TRAINING PROGRAM

INSTRUCTOR'S GUIDE

U. S. Environmental Protection Agency
Industrial Studies Branch/ESD
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

September 30, 1994

NOTICE

This Instructor's Guide is part of a model state training program which addresses the training needs of high capacity fossil fuel-fired plant (boiler) operators. Included are generic equipment design features, combustion control relationships, and operating and maintenance procedures which are designed to be consistent with the purposes of the Clean Air Act Amendments of 1990.

This training program is not designed to replace the site-specific, on-the-job training programs which are crucial to proper operation and maintenance of boilers.

Proper operation of combustion equipment is the responsibility of the owner and operating organization. Therefore, owners of boilers and organizations operating such facilities will continue to be responsible for employee training in the operation and maintenance of their specific equipment.

DISCLAIMER

This Instructor's Guide was prepared by the Industrial Studies Branch, Emission Standards Division, U. S. Environmental Protection Agency (USEPA). It was prepared in accordance with USEPA Contract Number 68-D1-0117, Work Assignment Number 68.

Any mention of product names does not constitute an endorsement by the U. S. Environmental Protection Agency.

The U. S. Environmental Protection Agency expressly disclaim any liability for any personal injuries, death, property damage, or economic loss arising from any actions taken in reliance upon this Handbook or any training program, seminar, short course, or other presentation based on this Instructor's Guide.

AVAILABILITY

This Instructor's Guide and the accompanying Student Handbook are issued by the Office of Air Quality Planning and Standards of the U.S. Environmental Protection Agency. These training materials were developed, as required by the Clean Air Act Amendments of 1990, to assist operators of high capacity fossil fuel-fired plants in becoming certified as may be required by state regulatory agencies.

Individual copies of this publication are available to state regulatory agencies and other organizations providing training of operators of high capacity fossil fuel-fired plants. Copies may be obtained from the Air Pollution Training Institute (APTI), U.S. EPA, MD-17, Research Triangle Park, NC 27711.

TABLE OF CONTENTS

COURSE MATERIALS INTRODUCTION

The course materials were developed by the U. S. Environmental Protection Agency (USEPA) as the model State program for training boiler operators on the effects their actions have on the air pollution emitted from the boiler. The USEPA was required to develop a model State training program for high-capacity fossil fuel-fired plant operators under Title III, Section 129 of the Clean Air Act Amendments of 1990.

The Instructor's Guide and the corresponding Student Handbook make up the materials for the training program. The course presents the fundamentals of boiler operation, typical boiler designs, the fundamentals of air, water and solid waste pollution and the corresponding control technologies.

The Instructor's Guide presents information required by course directors and instructors, including course preparation instructions, a program agenda, specific objectives of each chapter, and masters for making overhead projection transparencies or slides.

The Student Handbook contains the detailed discussion of the course topics with an outline for the material to be presented at the beginning of each chapter and a copy of the figures and tables which will be presented by the instructor.

Training Program Goals

The primary goal of the training program is to provide an adequate level of understanding to boiler operators of the effects their actions have on the air pollution emitted from the boiler as well as the proper operation of boilers and the associated pollution control equipment. Fundamental information is related to general applications and to the operator's own work experiences. Trainees are encouraged to comment and ask questions during the training program.

The program was designed to augment, not substitute for, the normal site-specific, on-the-job and supervised self-study training programs which are provided by the vendor, owner or operating company.

Training Program Intended Audience

The training program addresses a wide range of boiler sizes and applications. Specifically, the program addresses gas, oil, and coal fired boilers ranging in size from 10 million BTU per hour heat input up to the large utility boilers. Therefore, boiler operators of these types of units are the intended audience for this training program.

Other persons who are expected to be trainees in this program include boiler operating management staff members, technical managers, mechanics and maintenance personnel, instrument and control technicians, general engineers and design engineers.

Course Limitations

Detailed administrative and legal aspects of unit operation are not emphasized in the program because the regulations under which units operate will vary with location and time. Operators are urged to obtain specific regulatory information and permit requirements from the owner/operator organization.

COURSE PREPARATION INSTRUCTIONS

This course requires 4 days for a complete presentation. Planning and administrating the activities are the responsibilities of the course director. This includes making provision for activities before and during the course as follows:

1. Making arrangements for scheduling and announcing the course.

2. Recruiting an appropriate group of instructors who have:

   a. Knowledge of the design principles and operational aspects of boilers and specific expertise in their assigned topical area.

   b. Knowledge of the job requirements of boiler operators.

   c. Relevant practical and operational experience.

   d. A positive attitude about environmental management.

3. Briefing of the instructors before the course and providing feed-back during the course.

4. Maintaining continuity and coordination throughout the course, such as asking questions and leading discussions with the participants, requesting course critique, and preparing certificates of course completion.

5. Arrange for the preparation and distribution of the course materials (agenda, Student Handbook, roster, course critique forms)

6. Provide appropriate lecture materials.

7. Managing and confirming course registration.

8. Arranging for accommodations, including proper classroom size and seating, projection equipment, and possible provisions for breaks and meals.

COURSE AGENDA

The course is designed to be a 4-day sequence of learning units in which the agenda follows the sequence in the Student Handbook. However, the course agenda can be rearranged to accommodate the special scheduling needs of the speakers. The following is proposed agenda which follows the outline sequence of the handbook.

AGENDA FOR BOILER OPERATOR TRAINING PROGRAM

Day & Time		Subject
DAY 1		
8:00 - 8:30		Registration
8:30 - 9:15	1.	Introduction and Pre-Test
9:15 - 10:00	2.	Water and Steam Circuit
	Break	
10:15 - 10:45	3.	Combustion Gas Circuit
10:45 - 11:30	4.	Fossil Fuels
	Lunch	
12:30 - 1:45	5.	Combustion Principles
1:45 - 3:00	6.	Air Pollution Fundamentals
	Break	
3:15 - 4:15	7.	Natural Gas Fired Boilers
4:15 - 5:00	8.	Oil Fired Boiler

AGENDA FOR BOILER OPERATOR TRAINING PROGRAM

Day & Time		Subject
DAY 2		
8:00 - 8:45	9.	Pulverized Coal Boilers
8:45 - 9:30	10.	Stokers
	Break	
9:45 - 10:45	11.	Fluidized-Bed Boilers
10:45 - 11:45	12.	Gas Turbine with Heat Recovery Steam Generator
	Lunch	
12:45 - 1:15	13.	Package Boilers
1:15 - 2:15	14.	Normal Operation
	Break	
2:30 - 3:30	15.	Automatic Control Systems
3:30 - 4:00	16.	Instrumentation: General Measurements
4:00 - 5:00	17.	Electrical Theory

AGENDA FOR BOILER OPERATOR TRAINING PROGRAM

Day & Time		Subject
DAY 3		
8:00 - 8:45	18.	Turbine Generator
8:45 - 9:30	19.	Preventative Maintenance
	Break	
9:45 - 10:30	20.	Safety
10:30 - 11:45	21.	Air Pollutants of Concern
	Lunch	
12:45 - 1:30	22.	Environmental Regulations
1:30 - 2:45	23.	Continuous Emission Monitoring
	Break	
3:00 - 3:45	24.	Particulate Control
3:45 - 4:30	25.	Nitrogen Oxides Control
DAY 4		
8:00 - 9:00	26.	SO_x Control
9:00 - 9:45	27.	Water Pollution
	Break	
10:00 - 10:30	28.	Wastewater Treatment
10:30 - 11:00	29.	Solid Wastes
11:00 - 11:30	30.	Solid Waste Management
	Lunch	
12:30 - 2:00	Post-Test and Course Closure	

BOILER OPERATOR TRAINING
PRE-TEST

Instructions The entire test is to be taken as a closed book test.
Write in your answer or circle the best answer on this sheet

1. Identify which of the following that is not a fossil fuel boiler design
   a. fluidized bed
   b. watertube
   c. stoker
   d. firetube
   e. carnot

2. The fuel delivery system for a fossil fuel boiler
   a. only delivers fuel to the burners
   b. prepares fuel for combustion
   c. prepares fuel for combustion and transports it to the steam generator
   d. transports steam to the steam turbines.

3. The three most common fuels used in steam production are:
   a. natural gas, fuel oil and kerosene
   b. natural gas, kerosene and wood
   c. natural gas, wood and coal
   d. natural gas, fuel oil and coal

4. Name three air pollutants of concern generated by fossil fuel fired boilers.

   a. ________________
   b ________________
   c. ________________

5. A boiler is an open vessel in which water is transformed into steam under pressure by the application of heat.

   T
   F

6. In a natural draft furnace, the amount of draft , or movement of air, is determined by the height of the stack, the difference between the inside and outside temperatures, and the draft losses.

   T
   F

7. What is the density of a fuel oil at 60 F if its specific gravity is 0.842, given that the density of water is 8.328 lb/gal at 60 F and 8.335 lb/gal at 32 F? _______ lb/gal

8. A lean fuel mixture will produce an oxidizing flame

T
F

9. An HRT boiler is a watertube boiler

T
F

10. In a watertube boiler the ______ pass(es) through the tubes and the ______ pass(es) across the outside surface of the tubes.

11. Boiler efficiency is defined as the ratio of energy output to energy input expressed as a percentage.

T
F

12. Fuel oil grades are designated by No ____ for the lightest grade of fuel oil through No. ____ for the heaviest grade of oil.

a. 1; 6
b. 6; 1
c. 1; 4
d. 2; 6

13. Heavy grade fuel oils have low viscosity and a low pour point.

T
F

14. Natural gas combustion can never produce soot or black smoke. Even when operated with insufficient oxygen or incomplete combustion.

T
F

15. The two general types of stoker boiler are the ______ stoker and the ______ stoker.

a. overfeed, underfeed
b. massfeed, tuyere feed
c. spreader, pulverized coal
d. none of the above.

16. Stoker boilers are uniquely different from pulverized coal burners in that the fuel particle size is ______ for stokers.

a. smaller
b. much smaller
c. larger
d. much larger

17. Two advantages of fluidized-bed combustion is that the system can be operated at low combustion temperatures. and higher heat transfer rates from the fuel to the watertubes can be achieved

T
F

18. Since gas turbine power is based on mass through-put, the power output of a gas turbine will decease from the use of water or steam injection for NO_x control.

T
F

19. An explosion is usually less disastrous in a firetube boiler than in a watertube boiler.

T
F

20. O_2, SO_2, and CO are used to measure the efficiency of the combustion process and the thermal heat transfer between the hot flue gasses and the steam.

T
F

21. Flame appearance is a good way to adjust the air to the furnace.

T
F

22. A flame scanner is a photo-electric eye connected to the air supply trip.

T
F

23. An RTD senses temperature by generating a milli-volt output that varies with temperature

T
F

24. Use Ohm's law to determine the current through a device with a resistance of 16 ohms when a voltage of 24 volts is applied. The current would be ____.
a. 384 amps
b. 0.67 amps
c. 1.50 amps
d. 36 amps

25 Using the above information, what is the power consumed by the device?
   a 36 watts
   b. 24 watts
   c. 10.67 watts
   d. 384 watts

26. Transformers are designed to increase or decrease voltage in AC circuits

   T
   F

27. The boiling temperature of water decreases as pressure decreases.

   T
   F

28. Critical turbine speed is the optimum speed for low turbine maintenance and long life.

   T
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29. The goal of preventative maintenance is
   a. maximize unit reliability.
   b. minimize total operating costs.
   c. enhance equipment life.
   d. all of the above.

30. Carbon monoxide enters the bloodstream through the lungs in the same manner as oxygen.

   T
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31. MSDSs should only be available to supervisors and managers.

   T
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32. ______ were established by the U. S. Environmental Protection Agency to establish air quality standards for pollutant species that impact public health and welfare.
   a. SIPs
   b. Public health service
   c. PSD
   d. NAAQS

33. Critical factor to determining hazardousness of particulate matter is (are)
   a. particle size.
   b. particle type.
   c. aerosol concentration.
   d all of the above.

34 Nitrogen oxides result from the combustion of all fossil fuels

T
F

35 NSPS applies to all fossil fuel boilers in existence in the U. S.

T
F

36. An opacity monitor measures the amount of exhaust gases exiting the stack.

T
F

37. Calibration of CEMS analyzers is only performed upon installation.

T
F

38. Cyclones are very effective at removing both particulate matter and sulfur dioxide.

T
F

39. Which of the following is not a particulate control device?
   a. cyclone
   b. electrostatic precipitator
   c. wet scrubber
   d. SCR device

40. Combustion of chemically-bound nitrogen in the fuel can form
   a. fuel NO_x.
   b. thermal NO_x.
   c. prompt NO_x.
   d. both "a" and "c"

41. Three techniques to reduce NOx in fossil fuel fired boilers are

   a. ______________.
   b. ______________.
   c. ______________.

42. Utilities are given allowances to emit a certain number of tons of SO_2 in a year and can also buy additional SO_2 allowances at the Chicago Board of Trade to cover their actual emissions, or sell their unused allowances.

T
F

43 The EPA does not regulate discharges of waste water from utility and industrial boilers

T
F

44. Sunlight is an agent available for dechlorination of water and waste water

T
F

45. The air heater flyash hopper in a utility boiler typically collects ____ of the total ash produced.
   a. about 5%
   b. 10 to 20%
   c. 20 to 40%
   d. 50 to 70%

46. High ash fusion temperature will generally indicate low slagging potential.

T
F

47. Contamination of ground water from pollutants released from landfills when rain water infiltrates the landfill and seeps into the ground water is
   a. leaching.
   b. sedimentation.
   c. settling.
   d. desulfurization

48. More than the optimum amount of preventative maintenance will result in
   a. a substantially improved unit availability.
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   c. increased operating and maintenance costs.
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   a. water is acidic and potential tube corrosion will be a problem
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   c. water is basic but water tube corrosion problems are probably under control
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50. A properly operating in situ monitor indicates 200 ppm of SO_2 in the flue gas, and the moisture in the flue gas is known to be 15%. If an extractive instrument which has an in-line dryer indicated 235 ppm of SO_2, then
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BOILER OPERATOR TRAINING
PRE-TEST
Answer Key

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4. Name three air pollutants of concern generated by fossil fuel fired boilers
- a. ***nitrogen oxides*** ***carbon monoxide***
- b. ***sulfur oxides*** ***particulate matter***
- c. ***hydrocarbons***

5. A boiler is an open vessel in which water is transformed into steam under pressure by the application of heat.

False

6. In a natural draft furnace, the amount of draft , or movement of air, is determined by the height of the stack, the difference between the inside and outside temperatures, and the draft losses.

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7. What is the density of a fuel oil at 60 F if its specific gravity is 0.842, given that the density of water is 8.328 lb/gal at 60 F and 8.335 lb/gal at 32 F? ***7.01*** lb/gal

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12. Fuel oil grades are designated by No. ____ for the lightest grade of fuel oil through No ____ for the heaviest grade of oil.
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41. Three techniques to reduce NOx in fossil fuel fired boilers are

- a. ***low NOx burners***
- b. ***low excess air operation***
- c. ***reduced air preheat***
- d. ***reburning***
- e. ***burners out of service operation***
- f. ***flue gas recirculation***
- g. ***overfire air***
- h. ***selective catalytic reduction***
- i. ***selective non-catalytic reduction***

42. Utilities are given allowances to emit a certain number of tons of SO_2 in a year and can also buy additional SO_2 allowances at the Chicago Board of Trade to cover their actual emissions, or sell their unused allowances.

True

43. The EPA does not regulate discharges of waste water from utility and industrial boilers.

False

44. Sunlight is an agent available for dechlorination of water and waste water.

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a ***the two instruments are reading consistently.***
b. the extractive instrument is reading too high.
c. the extractive analyzer is reading too low.

LESSON PLAN

CHAPTER 1. INTRODUCTION

Goal: To give the participant an overview of the objectives of the course and a general description of issues related to operating a steam generator system.

Objectives:

Upon completion of this unit, an operator should be able to:

1. Describe the basic components of a steam generator system.
2. List the Federal Acts which address emissions standards for a steam generator system.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What kind of steam generating facilities do you have experience working at?

Do you know what emissions restrictions are imposed on your facility?
What are they?

Presentation Outline:

1.1 Purpose of Course

1.2 Steam Generators

1.3 Regulatory Requirements

1.4 Course Overview

Pre-Test

Pre-Test Answers

CHAPTER 1. INTRODUCTION

1.1 Purpose of Course

1.2 Steam Generators

1.3 Regulatory Requirements

A. NAAQS

B. NSPS

C. SIPs

D. NESHAPS

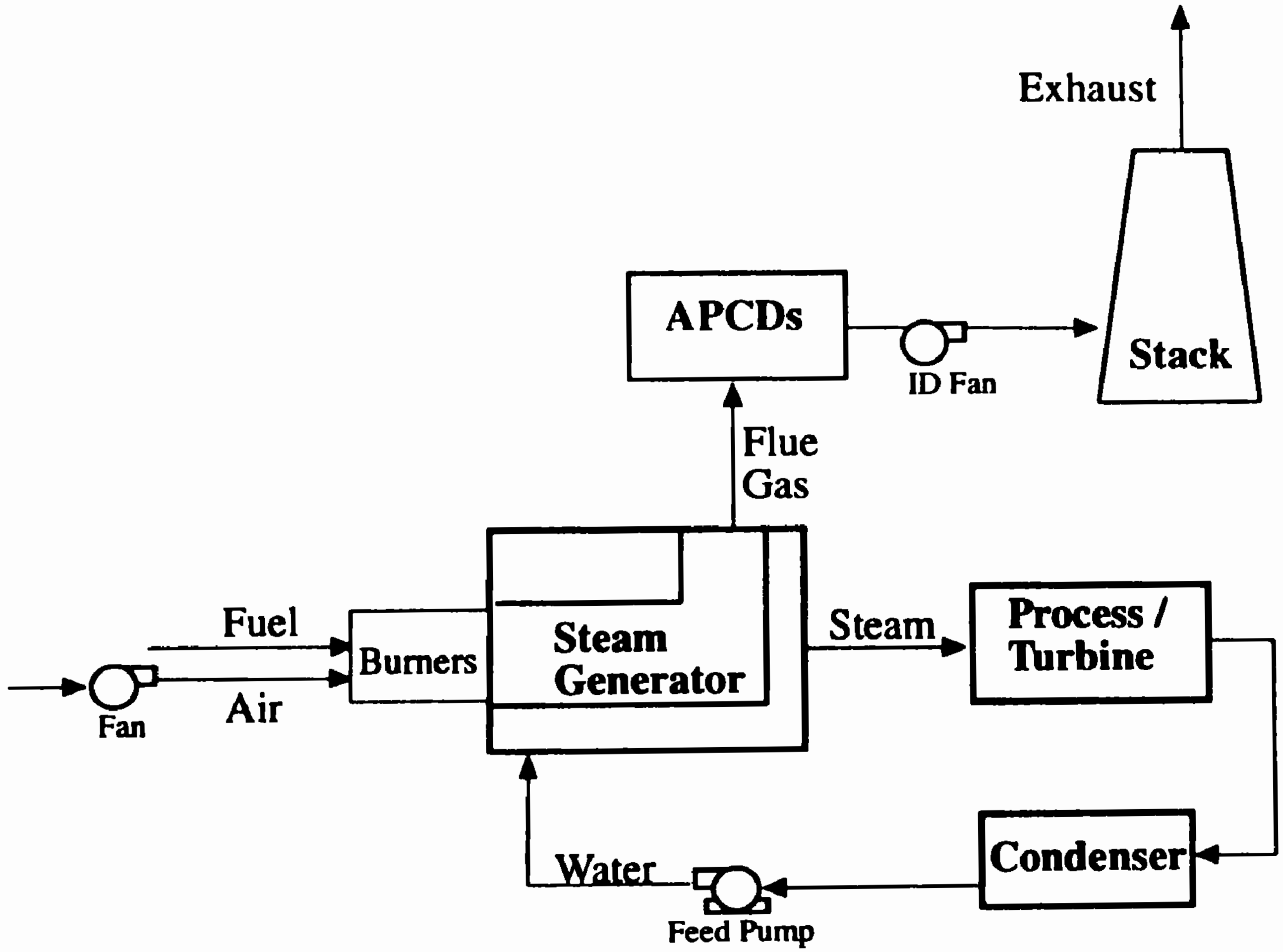
F. Clean Air Act Ammendments

1.4 Course Overview

COURSE OBJECTIVES

1. Effects of Operation on Emissions
2. Boiler Operation and Maintenance
3. APCD Operation and Maintenance
4. Auxiliary Systems Operation

GENERAL SCHEMATIC FOR A STEAM GENERATOR SYSTEM



Slide 1 - 3

CLEAN AIR ACT STANDARDS

- National Ambient Air Quality Standards (NAAQS)
- New Source Performance Standards (NSPS)
- State Implementation Plan (SIP)
- National Emission Standards for Hazardous Air Pollutants (NESHAPs)

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

Limit ambient concentration of air pollutants

Concentration limits based on health risk data

Covered Pollutants called "Criteria Pollutants"
- **Sulfur Oxides (SOx)**
- **Nitrogen Oxides (NOx)**
- **Carbon Monoxide (CO), and**
- **Particulate Matter**

Standards apply to geographical areas or basins

NEW SOURCE PERFORMANCE STANDARDS

Apply to New Units or Significantly Modified Units

Regulations Established for different Groupings of Pollutant Emission Sources

- **Utility Boilers**
- **Industrial Boilers**
- **Gas Turbines**

Established Stack Emissions Limits for Criteria Pollutants

Limits must be based on Demonstrated Performance of Control Technologies

STATE IMPLEMENTATION PLANS (SIPs)

- **Plans for Implementing the Requirements of the Clean Air Act at the State level**
- **SIPs provide the road map for States to meet NAAQS**
- **Regulations may apply to New and Existing sources**
- **Regulations may be More Stringent than NSPS**
- **SIPs must be reviewed and approved by Federal EPA**

Clean Air Act Amendments of 1990 Titles with Impact on Boiler Operation

Title I: Attainment and Maintenance of NAAQS

Title III: Hazardous Air Pollutants

Title IV: Acid Deposition Control

COURSE ORGANIZATION

LESSON PLAN

CHAPTER 2. WATER AND STEAM CIRCUIT

Goal: To give the participant an overview of the basic designs and operational issues related to water and steam circuits in boilers.

Objectives:

Upon completion of this unit, an operator should be able to:

1. Describe the process of the transformation of water into steam.
2. Understand the meaning and significance of the various physical qualities of steam formation, such as sensible heat, latent heat, superheated steam, and saturated steam.
3. Describe the basic designs of firetube and watertube boilers.
4. Discuss the steam-water circuit in a boiler and the related system components.
5. Discuss water treatment and properties related to boiler water.
6. Describe the major steam-side components.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What is the difference between firetube and watertube boiler designs?

What is "foaming" in a boiler water circuit?

Presentation Outline:

2.1. Steam Fundamentals

2.2. Boiler Fundamentals

2.3. Water - Steam Circuit

2.4 Water Treatment

References for Presentation Slides

Slide 2-4	Wilson, Dean R., *Boiler Operator's Workbook,* American Technical Publishers, Inc., 1991.
Slide 2-5	Elliott, Thomas C., *Standard Handbook of Powerplant Engineering,* McGraw-Hill Publishing, 1989.
Slide 2-7	Ibid.

CHAPTER 2. WATER AND STEAM CIRCUIT

2.1. Steam Fundamentals

2.2. Boiler Fundamentals

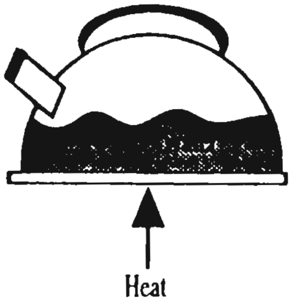
2.3. Water - Steam Circuit

- A. Circulation
- B. Water-Side Components
- C. Steam-Side Components

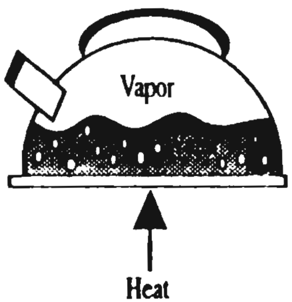
2.4 Water Treatment

- A. Mechanical Treatments
- B. Chemical Treatments

TRANSFORMATION OF WATER INTO STEAM

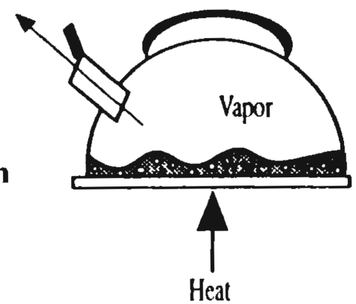


- Sensible Heat Addition
- Heat increases the water temperature to the Saturation Temperature

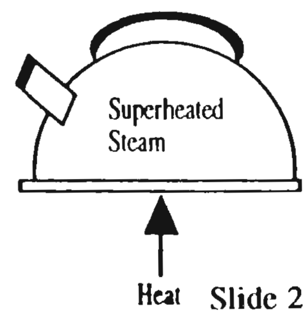


- Heat added at the Saturation Temperature produces water vapor or saturated steam

- Pressure increases as more steam is produced
- Pressure is relieved by lid opening to release the steam from the kettle



- Additional heat applied to a closed kettle with saturated steam produces superheated steam at a higher temperature and pressure



STEAM FUNDAMENTALS

Sensible Heat

Saturation Temperature

Change of Phase

Latent Heat

Saturation Steam

Superheated Steam

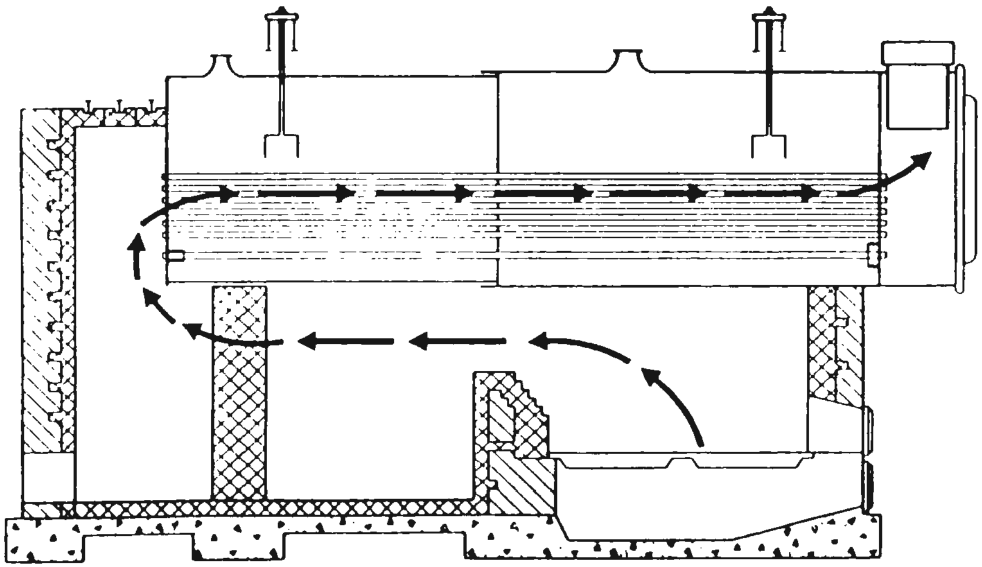
Steam Quality

Pressure = [Force ÷ Area] (psi)

Atmospheric Pressure (14.7 psi)

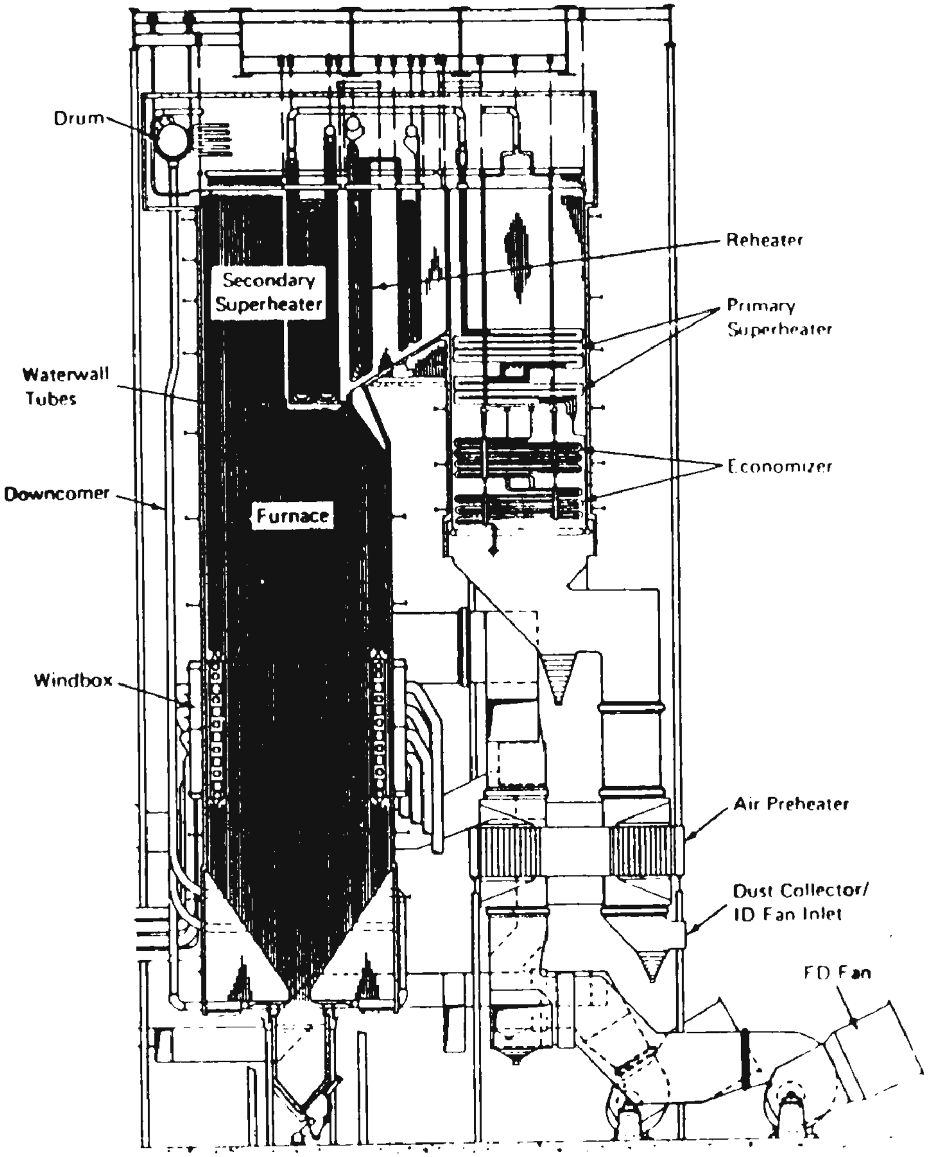
Maximum Allowable Working Pressure (MAWP)

FIRETUBE BOILER



Slide 2 - 4

WATERTUBE BOILER



Slide 2 - 5

CONVECTION PASS COMPONENTS

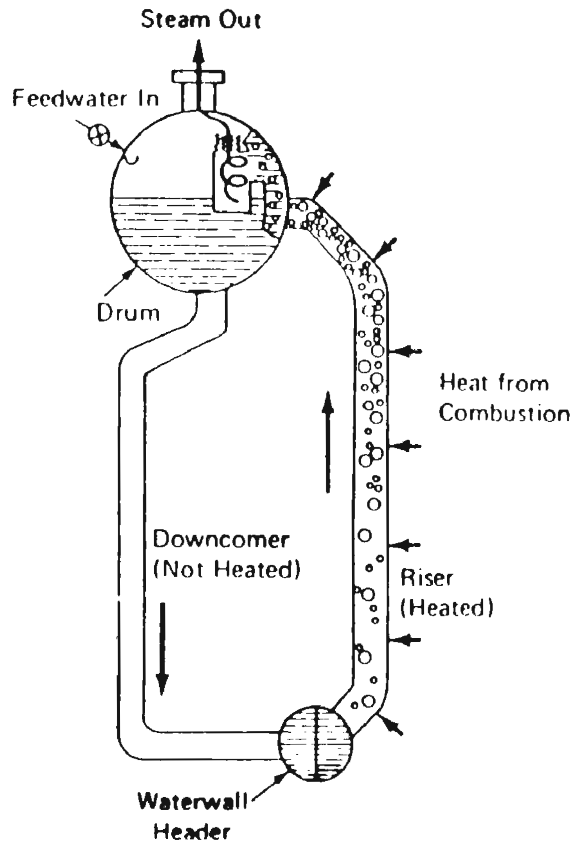
Superheaters

Reheater

Economizer

Air Heater

NATURAL CIRCULATION IN A BOILER



Slide 2 - 7

WATER-SIDE COMPONENTS

Feedwater pump

Waterwalls

Drum

Downcomers

Risers

STEAM-SIDE COMPONENTS

Steam Drum

Superheater

Desuperheater

Reheater

Safety Valves

STEAM-SIDE COMPONENTS SCHEMATIC

Steam Drum

Superheater

Desuperheater

Reheater

WATER IMPURITIES AND MEASUREMENTS

Dissolved Solids

Dissolved Gases

Suspended Solids

Hardness

pH

MECHANICAL WATER TREATMENTS

Technology	Primary Application	Devices
Pretreatment	Removal of debris	Rakes, gates
Cooling	Regulation of water temperature	Cooling tower, canals
Clarification	Removal of large suspended matter	Sedimentation tanks, horizontal clarifier tanks, vertical clarifiers
Filtration	Removal of remaining suspended matter	Screens, beds of rigid or granular material
Aeration	Removal of dissolved iron & manganese	Rotor brush aerators, aerator towers
	Stripping of dissolved gases (CO_2, H_2S)	Rotor brush aerators, aerator towers
Demineralization	Removal of remaining dissolved matter	Flash distillation units, semipermeable membranes, reverse osmosis unit, ion exchange resins

DEMINERALIZATION TECHNIQUES

Evaporation

Membrane Treatments

Reverse Osmosis

Ion Exchange

CHEMICAL WATER TREATMENTS

Chemical	Application
Sodium hydroxide (caustic soda)	Increases pH, precipitates magnesium
Sodium carbonate	Increases pH, precipitates calcium
Sodium phosphate	Precipitates calcium
Sodium aluminate	Precipitates calcium and magnesium
Chelants	Controls scale by forming heat stable soluble compounds
Tanins, starches, lignin	Prevents water deposits by coating scale to produce a sludge that does not adhere as readily to pipe surfaces
Polymers, copolymers	Disperses sludge, prevents scale, prevents fouling by corrosion products
Sodium sulfite	Prevent O_2 corrosion
Hydrazine	Prevent O_2 corrosion
Ammonia	Adjusts pH
Filming amines	Control return line corrosion by forming protective film on metal surfaces
Neutralizing amines	Controls return line corrosion by adjusting condensate pH
Sodium nitrate	Inhibits caustic embrittlement
Anti-foams	Reduces foaming tendency of high solids boiler water
Chlorine	Removal of dissolved gases by oxidation, control of slime and algae
Potassium permanganate	Control of slime and algae
Coagulants	Causes suspended matter to coagulate, used in conjunction with clarification
Calcium hydroxide (lime)	Adjusts pH

LESSON PLAN

CHAPTER 3. COMBUSTION GAS CIRCUIT

Goal: To discuss the combustion process, heat transfer from fossil fuels and combustion products flowpath for steam generating units.

Objectives:

Upon completion of this unit, an operator should be able to:

1. Describe the basic components of the combustion process in a fossil fuel boiler.
2. Discuss both forced draft and natural draft in boiler design.
3. Describe the components of a combustion gas circuit in a steam generating system.
4. Describe the design features of air preheaters and typical fan types.
5. Discuss the modes of heat transfer.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

Does your facility use a natural draft or forced draft system?

Who can describe the difference between conduction and convection?

Presentation Outline:

3.1 Introduction

3.2 Combustion Process
- A. Burner Arrangements
- B. Fuel System
- C. Primary Air
- D. Secondary Air

3.3 Heat Transfer
- A. Radiation
- B. Conduction
- C. Convection

Presentation Outline (Continued):

3.4 Combustion Gas Flow Path
  A. Furnace
  B. Convection Pass

3.5 Flue Gas Treatment

References for Presentation Slides

Slide 3-4 Wilson, Dean R., *Boiler Operator's Workbook,* American Technical Publishers, Inc., 1991.

Slide 3-5 Ibid.

Slide 3-6 Ibid.

Slide 3-7 Perry, Robert H. and Green, Don, *Perry's Chemical Engineers' Handbook*, Sixth Edition,McGraw-Hill Publishing Co., 1984, p. 6-22.

Slide 3-10 Wilson.

CHAPTER 3. COMBUSTION GAS CIRCUIT

3.1 Introduction

3.2 Combustion Process

- A. Process Components
- B. Furnace Draft

3.3 Heat Transfer

- A. Radiation
- B. Conduction
- C. Convection

3.4 Combustion Gas Flow Path

- A. Furnace
- B. Convection Pass

3.5 Flue Gas Treatment

COMBUSTION GAS CIRCUIT FUNCTIONS

1. **Release of heat from the Combustion Process**

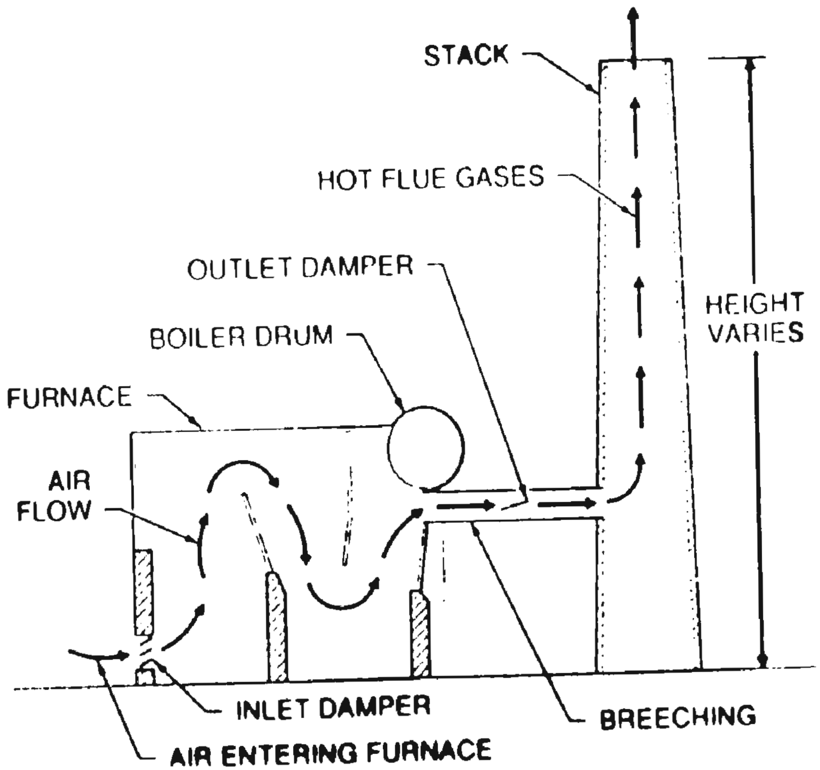
2. **Heat Transfer to Steam-Water Circuit**

3. **Flue Gas Treatment for Pollution Control**

COMBUSTION PROCESS COMPONENTS

- Fuel
- Primary Air
- Secondary Air
- Combustion Chamber
- Burners
- Fans

NATURAL DRAFT FURNACE[1]



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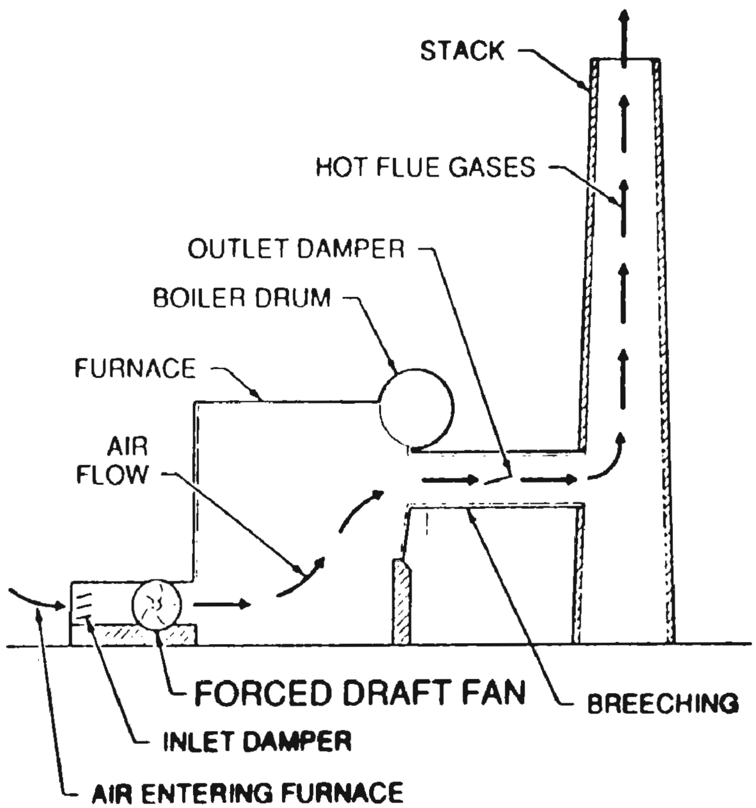
FORCED DRAFT FURNACE[1]



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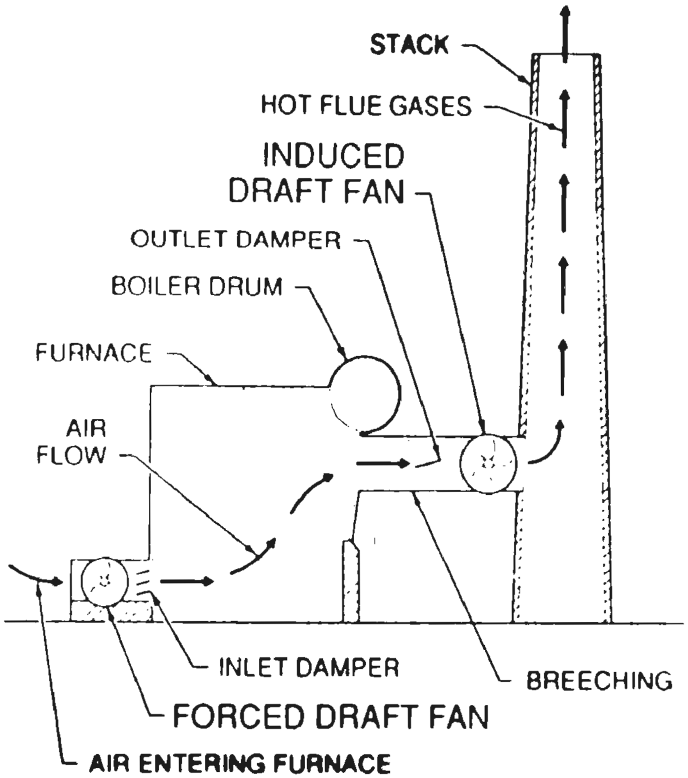
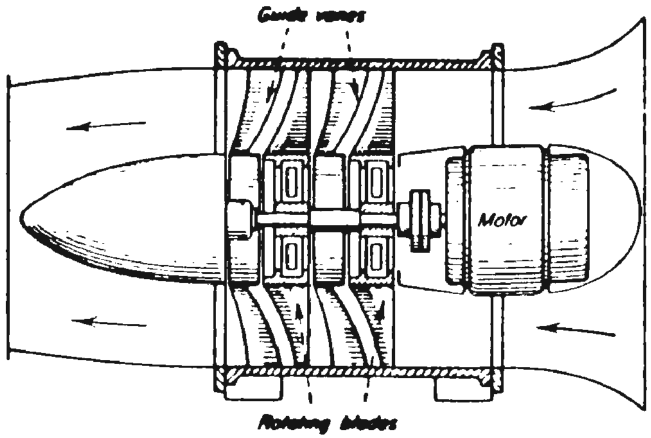
BALANCED DRAFT FURNACE[1]

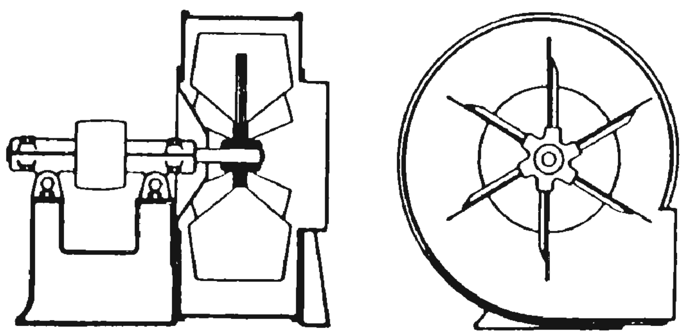


TYPICAL FAN DESIGNS[3]

Two-stage Axial Fan



Straight-Blade Centrifugal Fan



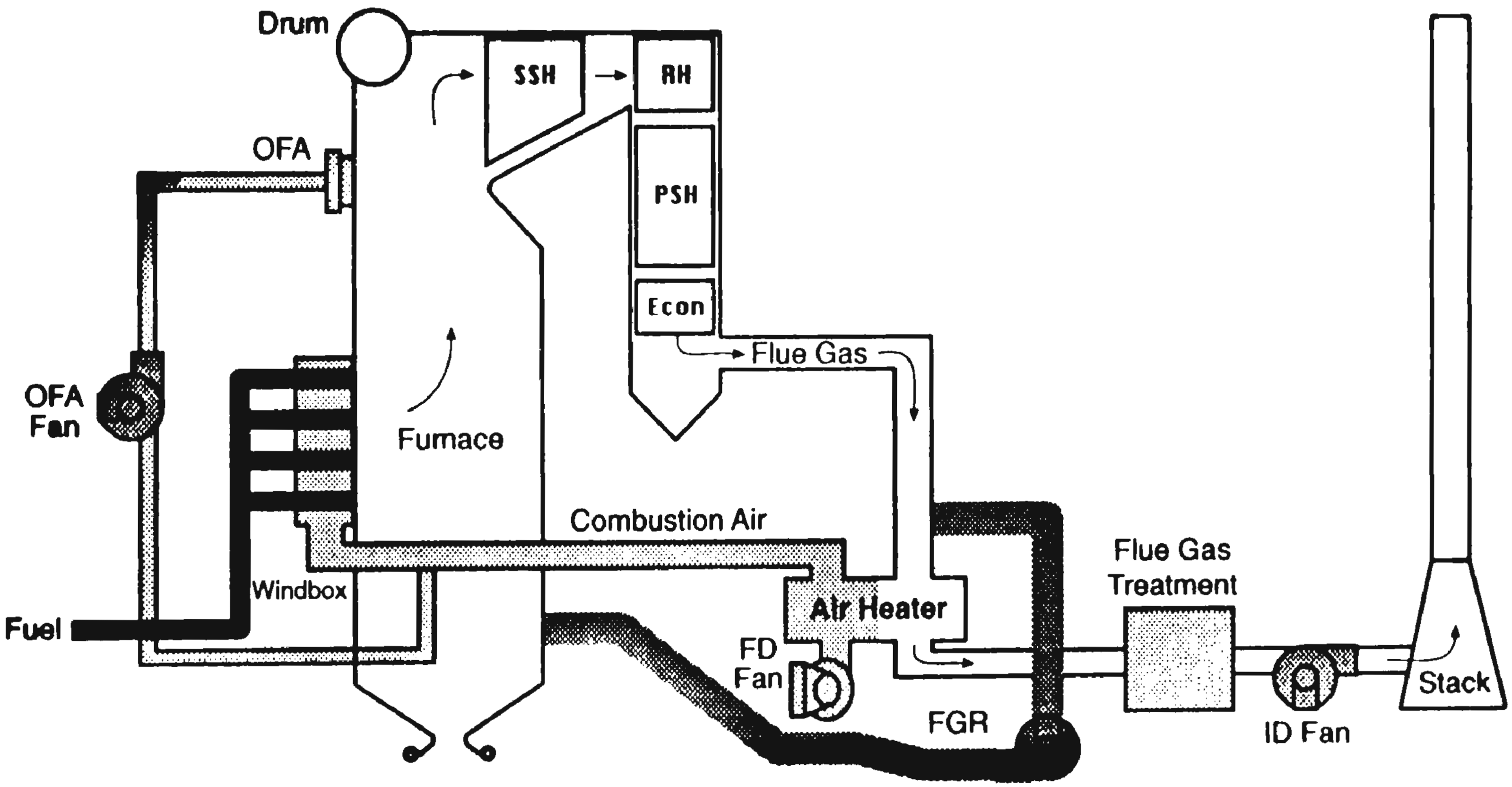
HEAT TRANSFER MODES

Radiation

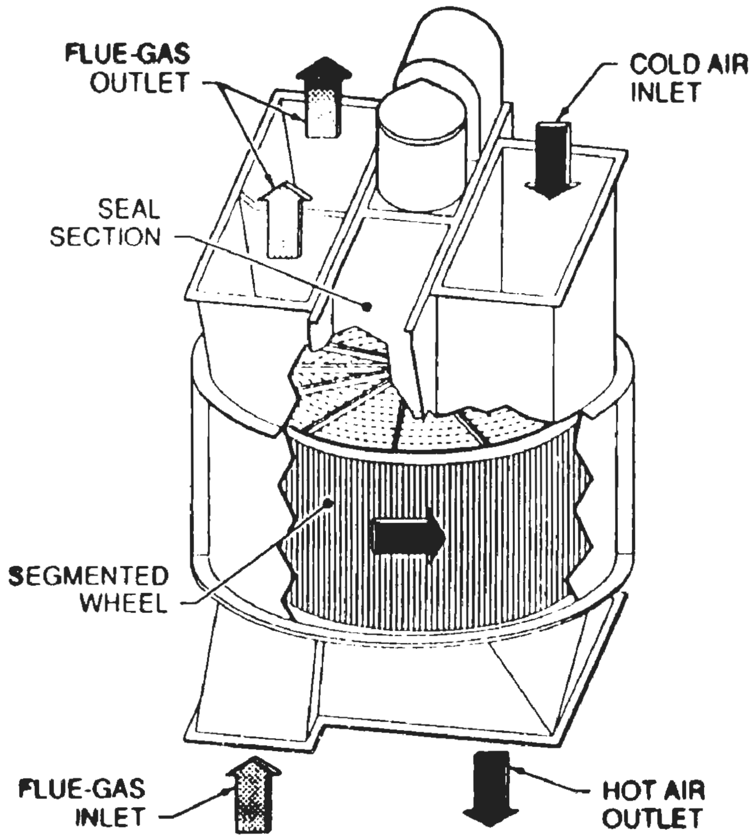
Conduction

Convection

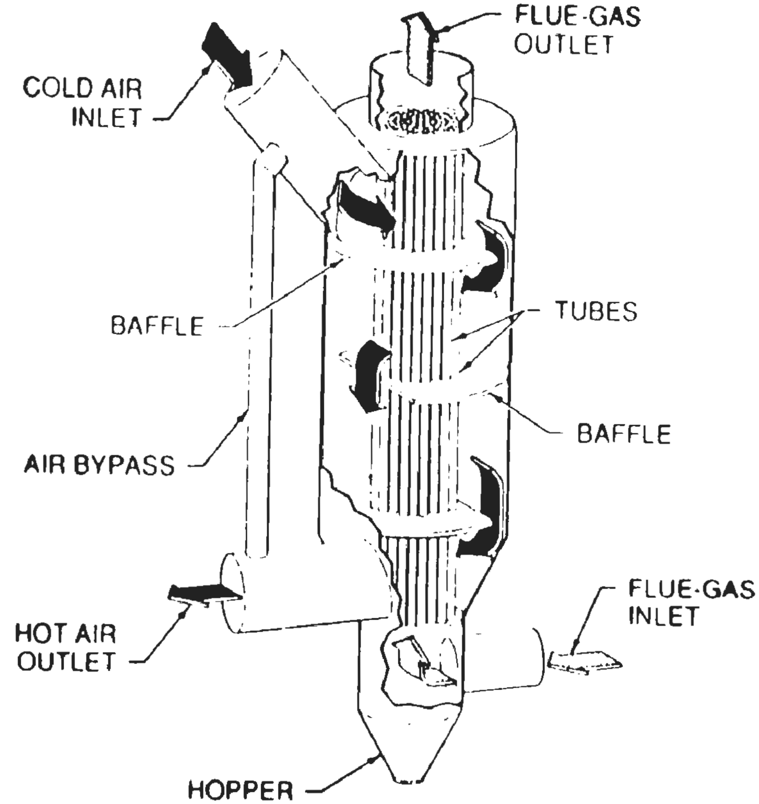
COMBUSTION GAS CIRCUIT



AIR PREHEATERS



Regenerative



Tubular

Slide 3-10

LESSON PLAN

CHAPTER 4. FOSSIL FUELS

Goal: To introduce the participants to the classifications and characteristics of fossil fuels used in boiler operations.

Objectives:

Upon completion of this unit, an operator should be able to:

1. Identify the three classifications of fossil fuels
2. Discuss the importance of each of the characteristics of gaseous fuels.
3. Understand why fuel analyses are important and why they are needed.
4. Understand the difference between higher heating value and lower heating value
5. Understand the concept of specific gravity and how it is related to the various fuel classifications
6. Understand the difference between ultimate and proximate analyses of coal.
7. Name the four classes of coal and identify the dominant characteristics
8. Calculate fixed carbon and Volatile matter percent on a mineral matter free basis using a typical coal analysis.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What are some possible problems or consequences that could arise as a result of switching to a new fuel at your facility?

Presentation Outline:

4.1 Introduction

4.2 Natural Gas
- A. Gaseous Fuel Characterization
- B. Natural Gas Properties

Presentation Outline (Continue):

4.3 Fuel Oil
- A. Fuel Oil Grades
- B. Liquid Fuel Characterization
- C. Fuel Oil Properties

4.4 Coal
- A. Formation of Coal
- B. Classification of Coal
- C. Coal Characterization
- D. Items of Proximate Analysis
- E. Items of Ultimate Analysis
- F. Example Coal Analysis

References for Presentation Slides

Slide 4-5 Singer, J. G., *Combustion: Fossil Power Systems*, 3rd edition, Combustion Engineering, Inc., 1981.

Slide 4-12 *Steam, Its Generation and Use*, 40th edition, Babcock and Wilcox Company, 1992.

CHAPTER 4. FOSSIL FUELS

FOSSIL FUELS

Natural Fuels
- Natural gas
- Fuel oils
- Coal

Byproduct Fuels
- Residual oils

Manufactured Fuels
- Coke
- Char, tar
- Chemical and industrial gases, etc...

GASEOUS FUEL CHARACTERIZATION

- Gas Analysis
- Heating Value
- Specific Gravity
  - Direct Weighing Method
  - Pressure Balance Method
  - Displacement Balance Method

NATURAL GAS PROPERTIES

Composition of Natural Gas
Dry and Wet Natural Gas
Sweet and Sour Natural Gas
Heating Value
Specific Gravity

TYPICAL NATURAL GAS ANALYSES[1]

Constituents (% by volume)

	A	B	C	D
CO_2	5.50	3.51	26.2	0.17
N_2	-----	32.00	0.70	87.69
H_2S	7.00	0.50	-----	-----
CH_4	77.73	52.54	59.20	10.50
C_2H_6	5.56	3.77	13.9	1.64
C_3H_8	2.40	2.22	-----	-----
C_4H_{10}	1.18	2.02	-----	-----
C_5H_{12}	0.63*	3.44*	-----	-----
Density				
(lb/ft^3)	0.0562	0.0661	0.0675	0.0712
High Heating Value				
Btu/ft^3†	1,061	874	849	136
Btu/lb	18,880	13,220	12,580	1,907

* All hydrocarbons heavier than C_5H1_2 are assumed to be C_5H_{12}

† If gas is saturated with moisture at 60°F and 30.0 in. Hg, reduced by 1.74%.

FUEL OIL GRADES

Distillate Fuel Oils

- **Fuel Oil No. 1**
- **Fuel Oil No. 2**

Residual Oils

- **Fuel Oil No. 4**
- **Fuel Oil No. 5**
- **Fuel Oil No. 6**

LIQUID FUEL CHARACTERIZATION

Ultimate Analysis
Specific Gravity
Heating Value
Viscosity
Pour Point
Flash Point, and
Water and Sediment

TYPICAL ANALYSES AND PROPERTIES OF FUEL OILS*

Grade	No. 1 Fuel Oil	No. 2 Fuel Oil	No. 4 Fuel Oil	No. 5 Fuel Oil	No. 6 Fuel Oil
Type	Distillate	Distillate	Residual	Very Light Residual	Light Residual
Color	Light	Amber	Black	Black	Black
API gravity, 60°F	40	32	21	17	12
Specific gravity, 60/60°F	0.8251	0.8654	0.9279	0.9529	0.9861
Density, lb/U.S gal, 60°F	6.870	7.206	7.727	7.935	8.212
Viscos., centistokes, 100°F	1.60	2.68	15.00	50.00	360.00
Viscos. SSU, 100°F	31	35	77	232	-------
Viscos., SSF, 122°F	--------	--------	--------	--------	170
Pour point, °F	Below zero	Below zero	10	30	65
Temp. for pumping, °F	Atmospheric	Atmospheric	15 min.	35 min.	100
Temp. for atomizing, °F	Atmospheric	Atmospheric	25 min.	130	300
Carbon residue, %	Trace	Trace	2.5	5.0	12.0
Sulfur, %	0.1	0.4–0.7	0.4–1.5	2.0 max.	2.8 max
Oxygen and nitrogen, %	0.2	0.2	0.48	0.70	0.92
Hydrogen, %	13.2	12.7	11.9	11.7	10.5
Carbon, %	86.5	86.4	86.1	85.55	85.7
Water and sediment, %	Trace	Trace	0.5 max.	1.0 max.	2.0 max.
Ash, %	Trace	Trace	0.02	0.05	0.08
Heating Value, Btu/gal	137,000	141,000	146,000	148,000	150,000

*Data from Exxon Corporation

CALCULATING API GRAVITY FROM SPECIFIC GRAVITY

Given: Sp. Gr. (60/60°F) = 1.000

°API = 141.5/(Sp. Gr. (60/60°F)) - 131.5
= 141.5/(1) - 131.5
= 10°

CALCULATING DENSITY FROM SPECIFIC GRAVITY

Given: Sp. Gr. (60°F) of oil = 0.973
Water Density (60°F) = 8.328 lb/gal

Oil Density (60°F) = 0.973 x 8.328
= 8.099 lb/gal

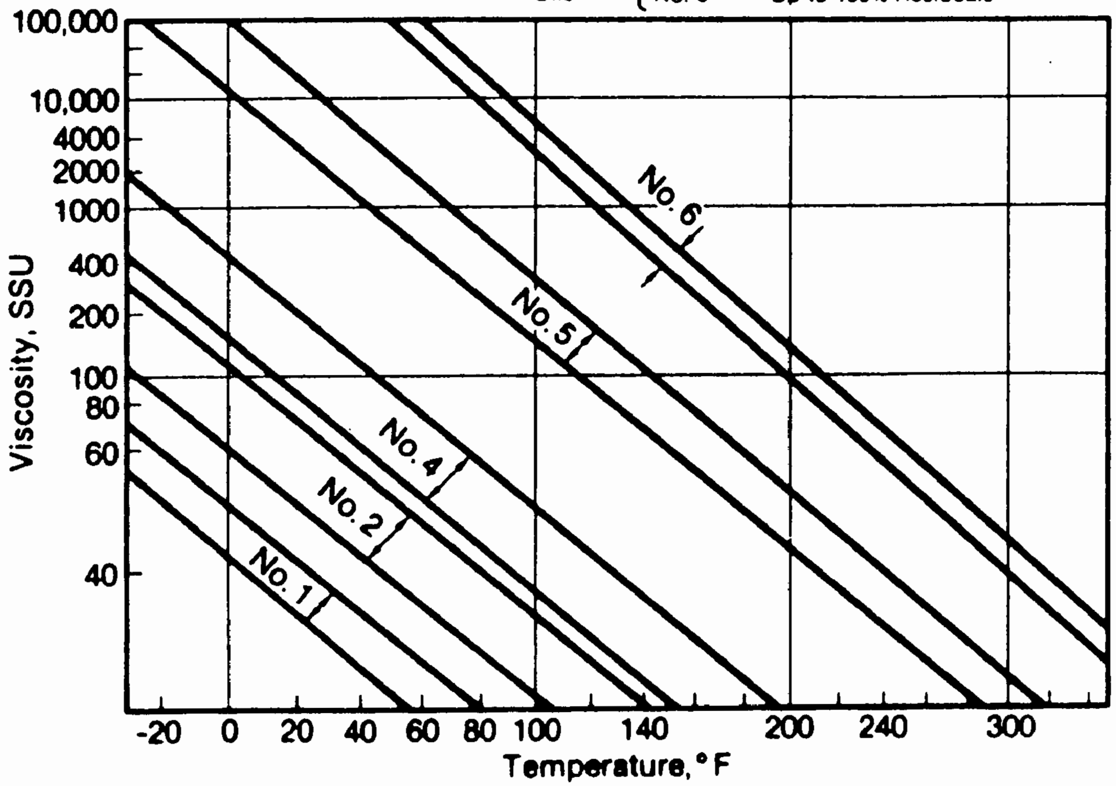
VISCOSITY RANGES FOR FUEL OILS

ASTM Std Viscosity - Temperature Charts for Liquid Petroleum Products (D 341)

SSU = Saybolt Universal Viscosity

Viscosity Ranges for Fuel Oils

	Fuel Oil	Composition
Distillate Oils	Kerosene	Straight
	No. 1	Kerosene Plus 5% No. 2
	No. 2	Straight
	No. 4	Straight and Up to 15% Residuals
Residual Oils	No. 5	Heavy Distillates Plus Up to 40% Residuals
	No. 6	Up to 100% Residuals



Slide 4 - 10

CLASSIFICATION OF COAL BY RANK[a]

Class and Group		Fixed Carbon Limits, % (Dry, Mineral-Matter-FreeBasis) Equal or Greater Than	Less Than	Volatile Matter Limit,s, % (Dry, Mineral-Matter-Free Basis) Equal or Greater Than	Less Than	Calorific Value Limits, Btu/lb (Moist[b], Mineral-Matter-Free Basis Equal or Greater Than	Less Than	Agglomerating Character
I.	Anthracite							
1.	Meta-Anthracite	98	-----	-----	2	-----	-----	Nonagglomeratıng
2	Anthracite 92	98	2	8	-----	-----		
3	Semı-Anthracite[c]	86	92	8	14	-----	-----	
II.	Bituminous Coals							
1	Low-volatile	78	86	14	22	-----	-----	
2	Medium-volatile	69	78	22	31	-----	-----	
3	High-volatıle A	-----	69	31	-----	14,000[d]	-----	Agglomeratıng[e]
4.	High-volatıle B	-----	-----	-----	-----	13,000[d]	14,000	
5	High-volatıle C	-----	-----	-----	-----	11,500	13,000	
						10.500	11,500	Agglomeratıng
III.	Subbituminous							
1	Subbituminous A coal	-----	-----	-----	-----	10,500	11,500	
2	Subbituminous B coal	-----	-----	-----	-----	9,500	10,500	Nonagglomertıng
3.	Subbituminous C coal	-----	-----	-----	-----	8,300	9,500	
IV	Lignite							
1.	Lignite A -----	----	-----	-----	6,300	8,300		
2.	Lignite B -----	-----	-----	-----	-----	6,300		

Slide 4 - 11

PARR FORMULAS[2]

$$\text{Dry, mineral-free FC} = \frac{FC - 0.15S}{100 - (M + 1.08A + 0.55S)} \times 100$$

$$\text{Dry, mineral-free VM} = 100 - \text{Dry, mineral-free FC}$$

$$\text{Moist, mineral-free Btu} = \frac{Btu - 50S}{100 - (1.08A + 0.55S)} \times 100$$

APPROXIMATION FORMULAS[2]

$$\text{Dry, mineral-free FC} = \frac{FC}{100 - (M + 1.1A + 0.1S)} \times 100$$

$$\text{Dry, mineral-free VM} = 100 - \text{Dry, mineral-free FC}$$

$$\text{Moist, mineral-free Btu} = \frac{Btu}{100 - (1.1A + 0.1S)} \times 100$$

Where:

Btu = Heating value per lb,
FC = Fixed carbon, %
VM = Volatile matter, %
M = Bed moisture, %
A = ash, %
S = Sulfur, %

COAL CHARACTERIZATION

Proximate Analysis
Ultimate Analysis
Bases of Analyses
- **As–received basis**
- **Dry basis**
- **Dry mineral–matter free basis**

ITEMS OF PROXIMATE ANALYSIS

- Moisture
- Volatile Matter
- Fixed Carbon
- Ash
- Heating Value
- Ash Fusion Temperature
- Free Swelling Index
- Grindability

ULTIMATE ANALYSIS

Carbon
Hydrogen
Nitrogen
Sulfur
Oxygen
Washability

EXAMPLE COAL ANALYSES

Coal: Eastern Bituminous

Proximate Analysis (as rec'd)

Total Moisture	17.80
Volatile Matter	34.04
Fixed Carbon	39.38
Ash	8.78

Ultimate Analysis (as rec'd)

Moisture	17.80
Carbon	57.76
Hydrogen	3.99
Oxygen	7.51
Nitrogen	1.16
Sulfur	3.00
Ash	8,78

Higher Heating Value 10,406 Btu/lb

Ash Analysis (as rec'd)

SiO2	50.65
Al2O3	13.91
TiO2	0.89
Fe2O3	18.88
CaO	6.26
MgO	0.85
Na2O	1.36
K2O	1.52
P2O5	0.18
SO3	5.72

Ash Fusion Temperatures (°F)

	Reducing	Oxidizing
Initial Deform temp.	1,930	2,230
Softening temp.	2,000	2,400
Hemispherical temp.	2,150	2,480
Fluid temp.	2,260	2,580

Slagging Index	Medium
Fouling Index	High

Hardgrove Grindability Index 58

LESSON PLAN

CHAPTER 5. COMBUSTION PRINCIPLES

Goal: To present the participant with the fundamental laws and calculations for the combustion and heat transfer processes.

Objectives:

After completing this chapter the participant should be able to:

1. Describe the basic elements of the combustion process.
2. Explain the influence of excess air on a combustion system.
3. Understand the concept of the mole, molecular weight.
4. List the fundamental laws governing combustion and understand the interrelationship between Avogadro's Law and the Ideal Gas Law through the Mole–Volume relationship.
5. Balance a stoichiometric combustion equation and calculate theoretical air requirements.
6. Calculate actual air for an excess % air requirement.
7. Describe the difference between conduction, convection and radiation heat transfer.
8. Be familiar with the concepts of heat transfer.

Lesson Time: Approximately 75 minutes.

Suggested Introductory Questions:

How is the heat context of a fuel released?

How much air creates an excess air condition when burning a given fuel?

Presentation Outline:

5.1 Basic Combustion Concepts
- A. Combustion Processes
- B. Composition of Combustion Air

5.2 Air-Fuel Mixture

5.3 Combustion Equations
- A. Concept of the Mole
- B. Fundamental Laws
- C. Balancing Combustion Equations

5.4 Combustion Calculations
- A. Molar Evaluation of Combustion
- B. Calculating Theoretical Air
- C. Calculating Excess Air
- D. Calculating Percent Excess Air

5.5 Heat Transfer Fundamentals
- A. Basic Modes of Heat Transfer
- B. Heat Transfer Parameters

CHAPTER 5. COMBUSTION PRINCIPLES

SIMPLIFIED COMBUSTION PROCESSES

Reactants				**Products**	
carbon	+	oxygen	--->	carbon dioxide	+ heat
hydrogen	+	oxygen	--->	water vapor	+ heat
sulfur	+	oxygen	--->	sulfur dioxide	+ heat

COMPOSITION OF COMBUSTION AIR

Dry Atmospheric Air

	Volume %	Mol. Wt.
Nitrogen	78.09	28.02
Oxygen	20.95	32.00
Argon	0.93	39.94
Carbon dioxide	0.03	41.01

COMBUSTION TERMS

Excess Oxygen
Excess Air
Stoichiometric
Lean Mixture, Oxidizing Flame
Rich Mixture, Reducing Flame
Oxygen Supply
Time, Turbulent, Temperature

CONCEPT OF THE MOLE

- A mole always contains the same number of particles
- Pound mole (mole) is molecular weight expressed in pounds.
- Example:
  1 mole of CO_2 weighs 44 lbs
  1 mole of H_2O weighs 18 lbs

FUNDAMENTAL LAWS

Conservation of Matter
Conservation of Energy
Law of Combining Weight
Avogadro's Law
Ideal Gas Law

IDEAL GAS LAW

This law state that the volume of an ideal gas is directly proportional to its absolute temperature and inversely proportional to its absolute pressure. The proportionality constant is the same for one mol of any ideal gas, so this law may be expressed as:

$$R = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Where:

R = universal gas constant, 1545 ft lb/mol R.

V = molar volume, ft^3/mol

P = absolute pressure, lb/ft^2

T = absolute temperature, R = °F + 460

Most gases involved in combustion calculations can be approximated as ideal gases.

COMBUSTION EQUATIONS

Combustibles	Reaction		
Carbon	$C + O_2$	--->	CO_2
Hydrogen	$H_2 + 1/2O_2$	--->	H_2O
Sulfur	$S + O_2$	--->	SO_2
Methane	$CH_4 + 2O_2$	--->	$CO_2 + H_2O$
Ethane	$C_2H_6 + 7/2O_2$	--->	$2CO_2 + 3H_2O$
Propane	$C_3H_8 + 5O_2$	--->	$3CO_2 + 4H_2O$

FORMS OF COMBUSTION EQUATIONS

C	+	O_2	=	CO_2
1 molecule C	+	1 molecule O_2	=	1 molecule CO_2
1 mol C	+	1 mol O_2	=	1 mol CO_2
12 lb C	+	32 lb O_2	=	44 lb CO_2
1 ft^3 C [1]	+	1 ft^3 O_2	=	1 ft^3 CO_2

[1] If C were an ideal gas instead of solid, 1 ft^3 of C combines with 1 ft^3 of O_2 to form 1 ft^3 of CO_2.

BALANCING COMBUSTION EQUATIONS

(unbalanced equation)

C_3H_8 + O_2 ------------------------> CO_2 + H_2O

C_3H_8 + O_2 ------------------------> $3CO_2$ + H_2O

C_3H_8 + O_2 ------------------------> $3CO_2$ + $4H_2O$

(balanced equation)

C_3H_8 + $5O_2$ ------------------------> $3CO_2$ + $4H_2O$

MOLE–VOLUME RELATIONSHIP

Because a mole of every ideal gas occupies the same volume, by Avogadro's law, the mole fraction of a component in a mixture of ideal gases equals the volume fraction of that component.

$$\frac{\text{Moles of component}}{\text{Total moles}} = \frac{\text{Volume of component}}{\text{Volume of mixture}}$$

This is a valuable concept because the volumetric analysis of a gaseous mixture automatically gives the mole fractions of the components.

CONVERTING FUEL ANALYSIS FROM VOLUME BASIS TO MASS BASIS

(1) Element	(2) Moles / 100 moles fuel	(3) lb/mol e	(4) lb/ 100 moles fuel	(5) lb/ lb fuel	(6) lb/ 100 lb fuel
C	110.2	12.01	1323.5	0.729	72.9
H_2	207.5	2.02	419.2	0.231	23.1
O_2	0.7	32.00	22.4	0.12	1.2
N_2	1.8	28.01	50.4	0.28	2.8
Total			1815.5		100.0

THEORETICAL OXYGEN CALCULATIONS

(1) Coal Constit.	(2) % by wt.	(3) Mole wt.	(4) Moles	(5) Comb. Product	(6) Moles theo. O_2 req.
C	63.50	12	5.30	CO_2	5.30
H	4.07	2	2.04	H_2O	1.02
S	1.53	32	0.05	SO_2	0.05
O_2	7.46	32	0.23	–	0.23
N_2	1.28	28	0.05	N_2	0.00
H_2O	15.00	18	0.83	H_2O	0.00
Ash	7.16				
Total	100.00				6.12

CALCULATING PERCENT EXCESS AIR

$$\text{Excess Air, \%} = K \times \frac{O_2}{21 - O_2}$$

Where:

O_2 = Volume percent, dry oxygen in the flue gas

$$K = \frac{100C + 237H + 37.5S + 9N - 29.6O'}{C + 3H + 3/8S - 3/8O'}$$

C = Mass fraction of carbon in the fuel
H = Mass fraction of hydrogen in the fuel
S = Mass fraction of sulfur in the fuel
O' = Mass fraction of oxygen in the fuel
N = Mass fraction of nitrogen in the fuel

(Note that these mass fractions should be given on a dry weight percent basis; lb/lb dry fuel.)

BASIC MODES OF HEAT TRANSFER

Conduction
Convection
Radiation

HEAT TRANSFER PARAMETERS

Heat Transfer Area
Temperature Difference
Conductivity
Diffusivity
Velocity and Turbulence
Relative Positions

UNITS OF HEAT TRANSFER PARAMETERS

Parameter	Symbol	English	SI
Conduction heat flux rate	Q_k	Btu/hr	Watts
Conduction heat flux	q_k	Btu/ft^2 hr	W/m^2
Thermal Conductivity	k	Btu/ft hr °F	W/m K
Length of heat flow path	L	ft	m
Area of heat flow path	A	ft^2	m^2
Temperature difference	ΔT	°F	K
Diffusivity	η	ft^2/hr	m^2/s
Specific heat	c	Btu/lb °F	J/kg K
Density	r	lb/ft^3	kg/m^3
Film Coefficient	h_c	Btu/ft^2 hr °F	W/m^2 K

LESSON PLAN

CHAPTER 6. AIR POLLUTION FUNDAMENTALS

Goal: To introduce the participant to the types and sources of air pollution, and to familiarize them with the terminology and expose them to fundamental air pollutant parameters.

Objectives:

Upon completion of this unit the participant should be able to:

1. Identify the type of pollutants causing different colors of smoke.
2. Convert NO_X and SO_2 ppm concentration to the respective emission factor.
3. Understand the purpose of converting pollutant emissions levels to 0% and 3% O_2 conditions and be able to correct both gaseous and particulate emissions to 3% and 0% O_2, and 12% CO_2.
4. Understand the meaning of combustion efficiency and be able to calculate this quantity for carbon.
5. List the possible sources of heat losses for calculation of efficiency from the heat loss method.
6. Know the difference between heat loss method and heat input-output method for determining boiler efficiency.

Lesson Time: Approximately 75 minutes.

Suggested Introductory Questions:

What is boiler efficiency?

Does anyone know emissions factors imposed on your facility by the EPA?

Presentation Outline:

6.1 Introduction

6.2 Fuel Dependent Air Pollutants

6.3 Combustion Dependent Air Pollutants

6.4 Smoke and Particulate

6.5 Gas Concentrations
- A. Mole Fractions
- B. Parts Per Millions (ppm)

6.6 Emission Factors
- A. Converting ppm to lb/MMBtu

6.7 Correcting Concentrations
- A. Correcting to 3% Oxygen
- B. Correcting to 0% Oxygen
- C. Correcting to 12% Carbon Dioxide
- D. Converting [gr/dscf] to [mg/dscm]

6.8 Excess Air Calculations

6.9 Combustion Efficiency Calculation

6.10 Boiler Calculations
- A. Methods to Calculate Boiler Efficiency
- B. Heat Loss Efficiency
- C. Heat Input–Output Efficiency
- D. Heat Rates
- E. Heat Release Rates

References for Presentation Slides

Slide 6-12 Babcock and Wilcox Company, *Steam, Its Generation and Use*, 40th Edition, 1992.

Slide 6-13 J.T. Beard, F.A. Iachetta, and L.U. Lilleleht, *APTI Course 427, Combustion Evaluation, Student Manual*, U.S. Environmental Protection Agency, EPA-450/2-80/063, February 1980, pp. 5-4 to 5-21.

Slide 6-17 Ibid.

Slide 6-23 Ibid.

Slide 6-10 *Codes of Federal Regulations*, Protection of Environment 40, Parts 53 to 60, Office of the Federal Register National Archives and Records Administration, July 1991, p. 1014.

CHAPTER 6. AIR POLLUTION FUNDAMENTALS

6.1 Introduction

6.2 Fuel Dependent Air Pollutants

6.3 Combustion Dependent Air Pollutants

6.4 Smoke and Particulate

6.5 Gas Concentrations

6.6 Emission Factors

6.7 Correcting Concentrations

6.8 Combustion Efficiency Calculation

6.9 Excess Air Calculation

6.10 Boiler Efficiency Calculations

FUEL DEPENDENT AIR POLLUTANTS

Acid Gases
- Sulfur Oxides
- Nitrogen Oxides (Fuel NO_x)

Toxics and Hazardous Materials
- Lead
- Mercury
- Arsenic
- Beryllium
- Benzene
- Radionuclides
- Vinyl Chlorides

Carbon Dioxide

COMBUSTION DEPENDENT AIR POLLUTANTS

Products of Incomplete Combustion (PIC)

- Particulate
- Carbon Monoxide
- Volatile Organic Compounds (VOC)

Nitrogen Oxides

SMOKE & PARTICULATE

Black Smoke
- Carbon in Particulate

Particulate
- Removed by APCDs

White Smoke
- Condensed Hydrocarbon Gases
- Ammonium Chloride
- Water Droplets (Not Smoke)

Blue Smoke
- Ammonium Sulfate

Brown Smoke
- Nitrogen Oxides

GAS CONCENTRATIONS

Mole Fractions

Parts Per Million (ppm)

STOICHIOMETRIC COMBUSTION

$$C_{1.85}H_{5.4}O_{2.08}N_{.02}S_{.006} + 1.22\ H_20 + 2.165\ O_2 + 8.14\ N_2 \text{-->}$$
$$1.85\ CO_2 + 3.92\ H_2O + 8.15\ N_2 + 0.006\ SO_2$$

Product Gas	Wet Gas Moles	Dry Gas Moles	Dry Gas Mole Frac.	Dry Gas Mole %
CO_2	1.85	1.85	0.185	18.49
H_2O	3.92			
N_2	8.15	8.15	0.814	81.45
SO_2	0.01	0.01	0.001	0.060
Total	13.93	10.01	1.000	100.00

EQUIVALENCE OF GAS CONCENTRATIONS

Mole Fraction x 100 --> Percentage

Mole Fraction x 1,000,000 --> ppm

Percentage x 10,000 --> ppm

EMISSION FACTORS

$$\text{lbs } NO_x/\text{MMBtu} = \frac{\text{lbs of } NO_2 \text{ emitted}}{\text{Millions Gross Btu Fuel Input}}$$

$$\text{lbs } SO_2/\text{MMBtu} = \frac{\text{lbs of } SO_2 \text{ emitted}}{\text{Millions Gross Btu Fuel Input}}$$

CONVERSION OF PPM TO LB/MMBTU

lb NO_x/MMBtu = $1.19 \times 10^{-7} \times F_d \times NO_x$ (ppm @ 3% O_2, dry) x (21/(21-3))

lb SO_2/MMbtu = $1.69 \times 10^{-7} \times F_d \times SO_2$ (ppm @ 3% O_2, dry) x (21/(21-3))

Where: F_d is the dry F factor of fuel

AVERAGE F_d FACTOR FOR VARIOUS FUELS[4]

Coal:	
Anthracite	10,100
Bituminous	9,780
Lignite	9,860
Oil:	
(Crude, residual or distillate)	9,190
Gas:	
Natural gas	8,710
Propane	8,710
Butane	8,710
Wood:	9,240
Wood Bark:	9,600

GAS CONCENTRATIONS AT STANDARD DILUTION

3% O2, dry

or 0% O_2, dry

or 12% CO_2, dry

EQUATION FOR CORRECTING TO 3% OXYGEN[2]

Assume: CO_m is the measured dry gas CO
Expressed as a ppm or %
O_{2m} is the measured dry gas O_2
Expressed as a percentage

Converting:

$$CO\ (@\ 3\%\ O_2) = CO_m \times (21 - 3)/(21 - O_{2m})$$
$$= CO_m \times (18)/(21 - O_{2m})$$

EQUATION FOR CORRECTING TO 0% OXYGEN[1]

Assume: CO_m is the measured dry gas CO
Expressed as a ppm or %
O_{2m} is the measured dry gas O_2
Expressed as a percentage

Converting:

$$CO\ (@\ 0\%\ O_2) = CO_m \times (21 - 0)/(21 - O_{2m})$$
$$= CO_m \times (21)/(21 - O_{2m})$$

PRODUCT GAS ANALYSIS, METHANE @ 20% EXCESS AIR

Gas	Wet Gas Moles	Dry Gas Moles	Dry Gas Mole %
CO_2	1.0	1.0	9.59
H_2O	2.0		
O_2	0.4	0.4	3.84
N_2	9.024	9.024	86.56
CO	0.001	0.001	0.01
Total	12.425	10.425	100.00

EXAMPLE FOR CONVERSION OF GAS CONCENTRATIONS TO 3% OXYGEN

Let: CO_m = 100 ppm

O_{2m} = 3.84% (dry gas)

CO (@ 3% O_2) = CO_m x (21 - 3)/(21 - O_{2m})

= 100 x (18)/(21 - 3.84)

= 104.9 ppm

EXAMPLES FOR CONVERSION OF PARTICULATE TO 3% OXYGEN

Let: PM_m = 0.035 gr/dscf (Particulate Matter)

O_{2m} = 3.84% (Measured Dry Gas O_2)

$$PM\ (@\ 3\%\ O_2) = PM_m \times (21 - 3)/(21 - O_{2m})$$

$$= 0.035 \times (18)/(21 - 3.84)$$

$$= 0.037 \text{ gr/dscf @ } 3\%\ O_2$$

EQUATION FOR CORRECTING TO 12% CO_2[1]

Assume: CO_m is the Measured Dry Gas CO
Expressed as a ppm or %
CO_{2m} is the Measured Dry Gas CO_2
Expressed as a Percentage

Converting:

$$CO\ (@\ 12\%\ CO_2) = CO_m \times (12/CO_{2m})$$

EXAMPLE CORRECTION TO 12% CO_2[1]

Let: CO_m = 100 ppm

CO_{2m} = 9.59% (dry gas)

$$CO\,(@\,12\%\,CO_2) = CO_m \times (12/CO_{2m})$$
$$= 100 \times (12/9.59)$$
$$= 125\text{ ppm}$$

CONVERSION OF [gr/dscf] TO [mg/dscm]

Basic Identities:

1 pound [lb]	=	454 grams [g]
1 gram [g]	=	1,000 milligrams [mg]
1 foot [ft]	=	0.3048 meters [m]
1 pound [lb]	=	7,0000 grains [gr]

For Dry Gases at Standard Conditions:

1 dry standard cubic foot [dscf]

1 dry standard cubic meter [dscm]

1 dscf = 0.0283 dscm

So That:

1 [gr/dscf] = 1 [gr/dscf] x (1 lb/7000 gr) x (454 g/lb) x (1000 mg/g) x (1 dscf/0.0283 dscm)

Therefore:

1 [gr/dscf] = 2,290 [mg/dscm]

EXAMPLE APPLICATION OF THE CONVERSION FACTOR

Factor: 1 [gr/dscf] = 2,290 [mg/dscm]

Given: 34 [mg/dscm]

Therefore:

34 [mg/dscm] x (1 [gr/dscf]/2,290 [mg/dscm]) = 0.015 [gr/dscf]

DETERMINATION OF EXCESS AIR FROM DRY GAS ANALYSIS[1]

Assume:

CO_{2m} = Percent Dry Gas CO_2

CO_m = Percent Dry Gas CO

O_{2m} = Percent Dry Gas O_2

Therefore:

$$N_{2m} = 100 - (CO_{2m} + CO_m + O_{2m})$$

And:

$$EA = (O_{2m} - 0.5\ CO_m)/(.264\ N_{2m} - O_{2m} + 0.5\ CO_m)$$

EXAMPLE DETERMINING EXCESS AIR

Let:	CO_{2m}	=	9.59%
	CO_m	=	0.01%
	O_{2m}	=	3.84%
Therefore:	N_{2m}	=	$100 - (CO_{2m} + CO_m + O_{2m})$
		=	$100 - (9.59 + 0.01 + 3.84)$
		=	86.56
And:	EA	=	$(O_{2m} - 0.5\ CO_m)/(.264\ N_{2m} - O_{2m} + 0.5\ CO_m)$
	EA	=	$(3.84 - 0.005)/(.264 \times 86.56 - 3.84 + 0.005)$
	EA	=	0.20 --> 20%

EQUATION FOR COMBUSTION EFFICIENCY (BASED ON CARBON COMBUSTION TO CO_2)

$$C.E.(\%) = (100\% \times CO_{2m}) / (CO_{2m} + CO_m)$$

or

$$C.E.(\%) = 100\% \times (1 - (CO_m / (CO_{2m} + CO_m))$$

EXAMPLE COMBUSTION EFFICIENCY CALCULATION

Let:	CO_{2m}	=	9.59 Percent
	CO_m	=	0.01 Percent (100 ppm)

$$C.E.(\%) = (100\% \times CO2_m)/(CO_{2m} + CO_m)$$
$$= (100\% \times 9.59)/(9.59 + 0.01)$$
$$= 99.9\%$$

METHODS TO DETERMINE BOILER EFFICIENCY

Heat Loss Method:

$$\eta(\%) = 100 - \text{Net Heat Losses } (\%)$$

Heat Input–Output Method:

$$\eta(\%) = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{\text{Heat absorbed by working fluid(s)}}{\text{Heat in fuel + Heat credits}} \times 100$$

HEAT LOSS EFFICIENCY

Net losses = Loss due to dry gases +
Loss due to moisture in the fuel +
Loss due to hydrogen in fuel +
Loss due to CO in flue gas +
Loss due to unburnt carbon +
Loss due to radiation +
Unaccounted losses

Efficiency = 100 - Net losses

HEAT LOSS DUE TO DRY GASES

$$\text{HL due to dry gases} = \frac{\text{lb dry gas}}{\text{lb fuel fired}} \times 0.24\,(t_g - t_a)$$

Where:

0.24 = Specific heat of gas, Btu/lb °F
t_g = Temperature of gas leaving unit, °F
t_a = Temperature of air entering unit, °F

$$\frac{\text{lb dry gas}}{\text{lb fuel fired}} = \frac{11\,CO_2 + 8\,O_2 + 7\,(N_2 + CO)}{3(CO_2 + CO)} \times \frac{\text{lb C burned}}{\text{lb fuel fired}} + 3/8\,S$$

CO_2, O_2, N_2 and CO are in % by volume of flue gas
S is % by weight of sulfur in fuel

LOSS DUE TO MOISTURE IN FUEL

$$\text{HL due moisture in fuel} = \frac{H_2O}{100} \times (h_g - h_l)$$

Where:

H_2O = % moisture in fuel

h_g = Enthalpy of vapor at 1 psia and t_g

h_l = Enthalpy of liquid at t_a

HEAT LOSS DUE TO HYDROGEN IN FUEL

$$\text{HL due to } H_2 \text{ in fuel} = \frac{9\,H_2}{100} \times (h_g - h_a)$$

Where:

H_2 = % of hydrogen in fuel
h_g = Enthalpy of vapor at 1psia and t_g
h_a = Enthalpy of liquid at t_a

HEAT LOSS DUE TO CO IN FLUE GAS

$$\text{HL due to CO in flue gas} = \frac{CO}{CO + CO_2} \times 10{,}160 \times \frac{\text{lb C}}{\text{lb fuel}}$$

Where:

CO and CO_2 are % by volume in flue gas

10,160 is Btu generated burning 1 lb of CO to CO_2

HEAT LOSS DUE TO UNBURNED CARBON

$$\text{HL due to unburned C} = \frac{\text{lb C in ash}}{\text{lb of fuel}} \times \text{Btu per lb of ash}$$

HEAT INPUT–OUTPUT EFFICIENCY

$$\text{Heat I-O Efficiency} = \frac{W_1(H_1 - h_1) + W_2(H_2 - h_2)}{C} \times 100\%$$

Where:

W_1 = Main steam flow, lb/hr
W_2 = Reheat steam flow, lb/hr
H_1 = Enthalpy of main steam, Btu/lb
H_2 = Enthalpy of reheat steam, Btu/lb
h_1 = Enthalpy of feed water, Btu/lb
h_2 = Enthalpy of steam entering reheater, Btu/lb
C = Total heat input from fuel, Btu/hr

HEAT RATES

Gross Heat Rate
Net Heat Rate

HEAT RATE CALCULATIONS

$$\text{Gross Heat Rate} = \frac{\text{Heat input from fuel}}{\text{Electrical output}}$$

$$= \frac{\text{Fuel flow x HHV}}{\text{MW generated}}$$

$$= \text{Btu/kWh}$$

Slide 6 - 34

EXAMPLE OF HEAT RATE CALCULATIONS

Let:

Coal flow	=	60,000 lbs/hr
Coal HHV	=	10,540 Btu/lb
Gross MW	=	55 MW

$$GHR = \frac{60{,}000 \times 10{,}500}{55} \times \frac{1 \text{ MW}}{1000 \text{ kW}}$$

$$= 11{,}454 \text{ Btu/kWh}$$

HEAT RELEASE RATES

Volumetric Heat Release Rate

Burner Zone Heat Release Rate

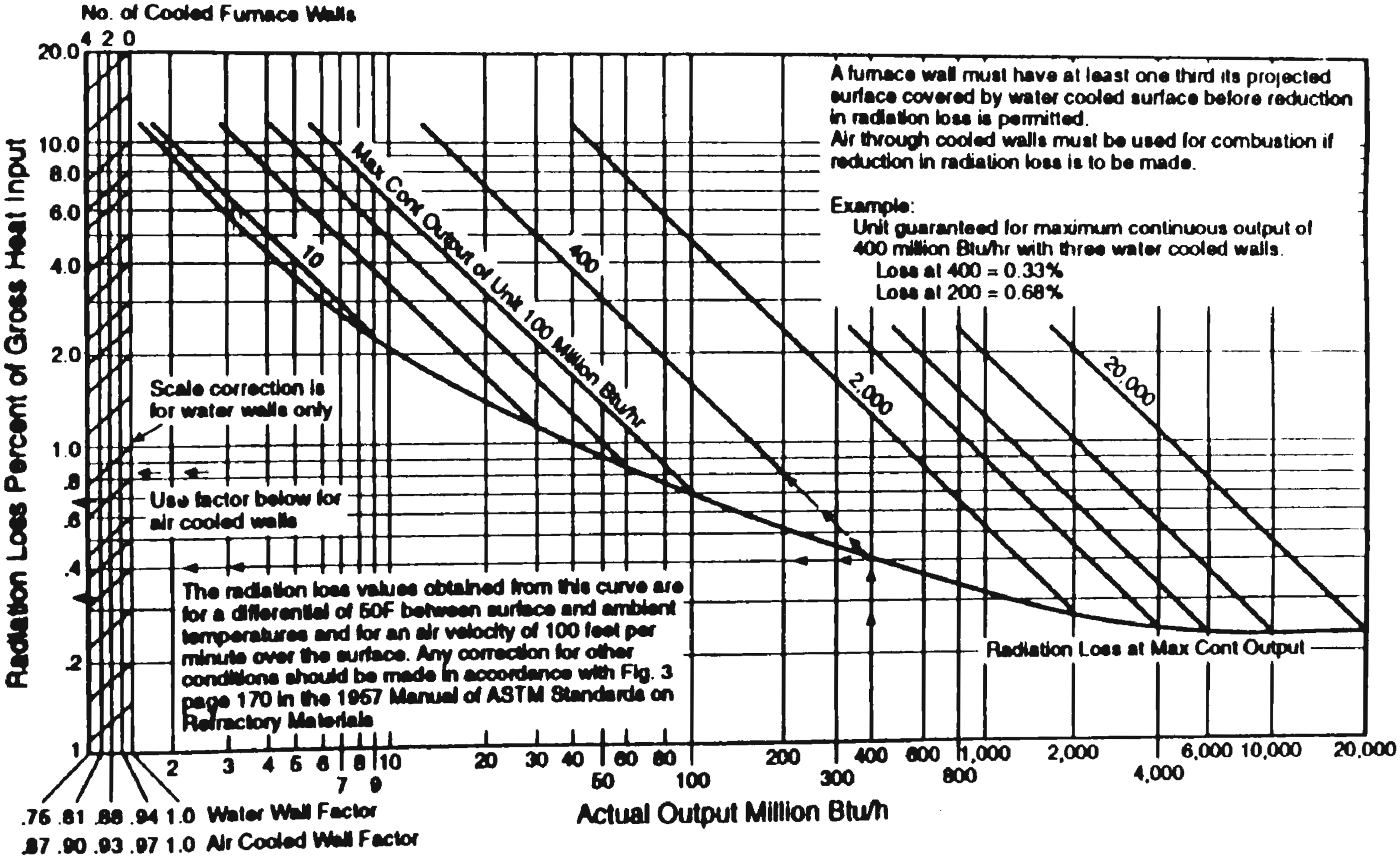


Figure 6-1. Radiation loss in percent of gross heat input (American Boiler Manufacturers Association).

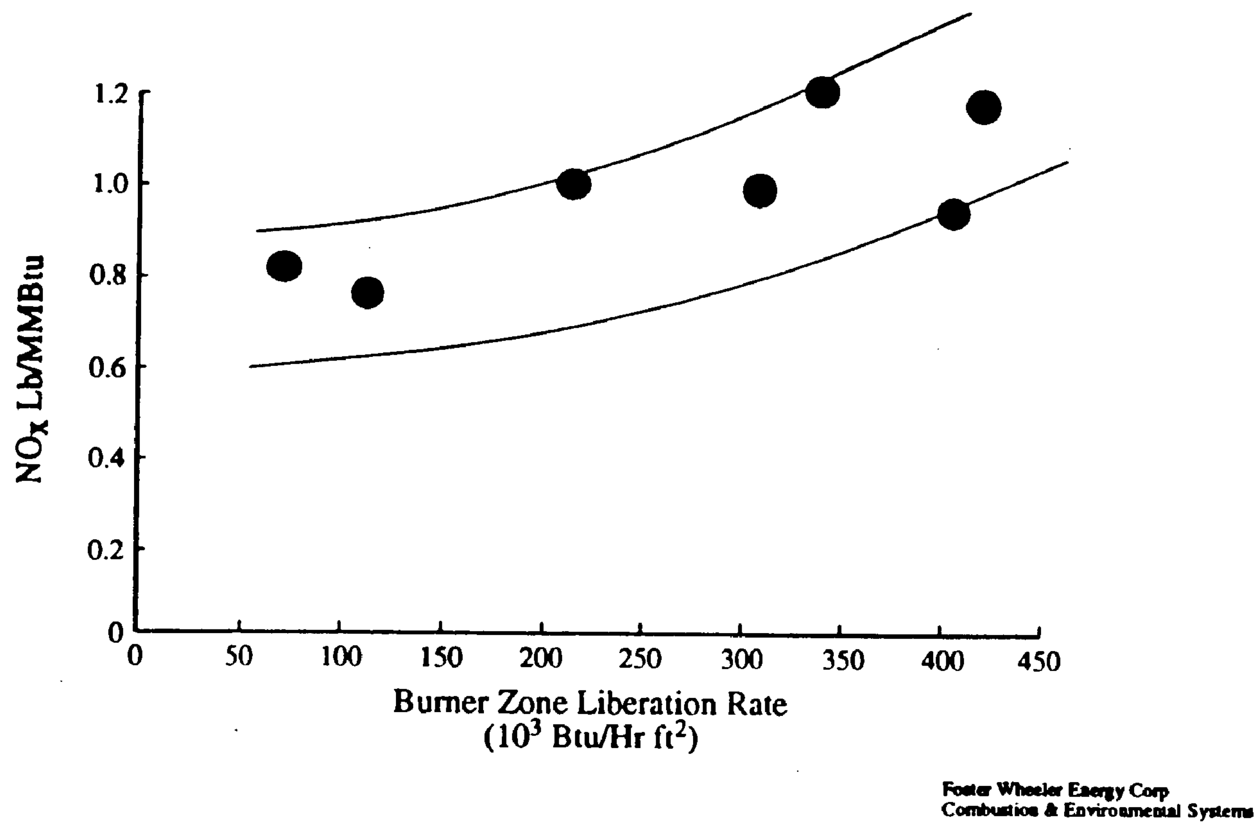


Figure 6-2. Foster Wheeler boiler NO_x correlation.

LESSON PLAN

CHAPTER 7. NATURAL GAS–FIRED BOILERS

Goal: To familiarize the participant with supply systems and firing equipment for natural gas fired boilers and typical environmental concerns of these units.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the key components of the fuel supply system.
2. Identify combustion conditions that produce blue and yellow flames.
3. Describe the design characteristics of the 3 major types of gas fired burners.
4. Describe the common locations or configurations of natural gas burners in boilers.
5. Understand that the burner zone heat release is a design consideration for controlling NO_X emissions.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

What is the cleanest burning fossil fuel? Why?

Presentation Outline:

7.1 Introduction

7.2 Fuel Supply System

7.3 Burner Arrangements

7.4 Boiler Designs Parameters

7.5 Emissions

References for Presentation Slides

Slide 7-4 *North American Combustion Handbook*, Second Edition, North American Manufacturing Company, 1978.

Slide 7-10 Singer, J.G., *Combustion: Fossil Power Systems,* 3rd Edition, Combustion Engineering, Inc., 1981.

Slide 7-11 Price, Joyce V., et al., "Low NO_x Oil/Gas Burner Retrofits and Their Effects on Overall Emissions and Boiler Performance," May, 1993 EPA/EPRI Joint Symposium on Stationary Combustion NO_X Control.

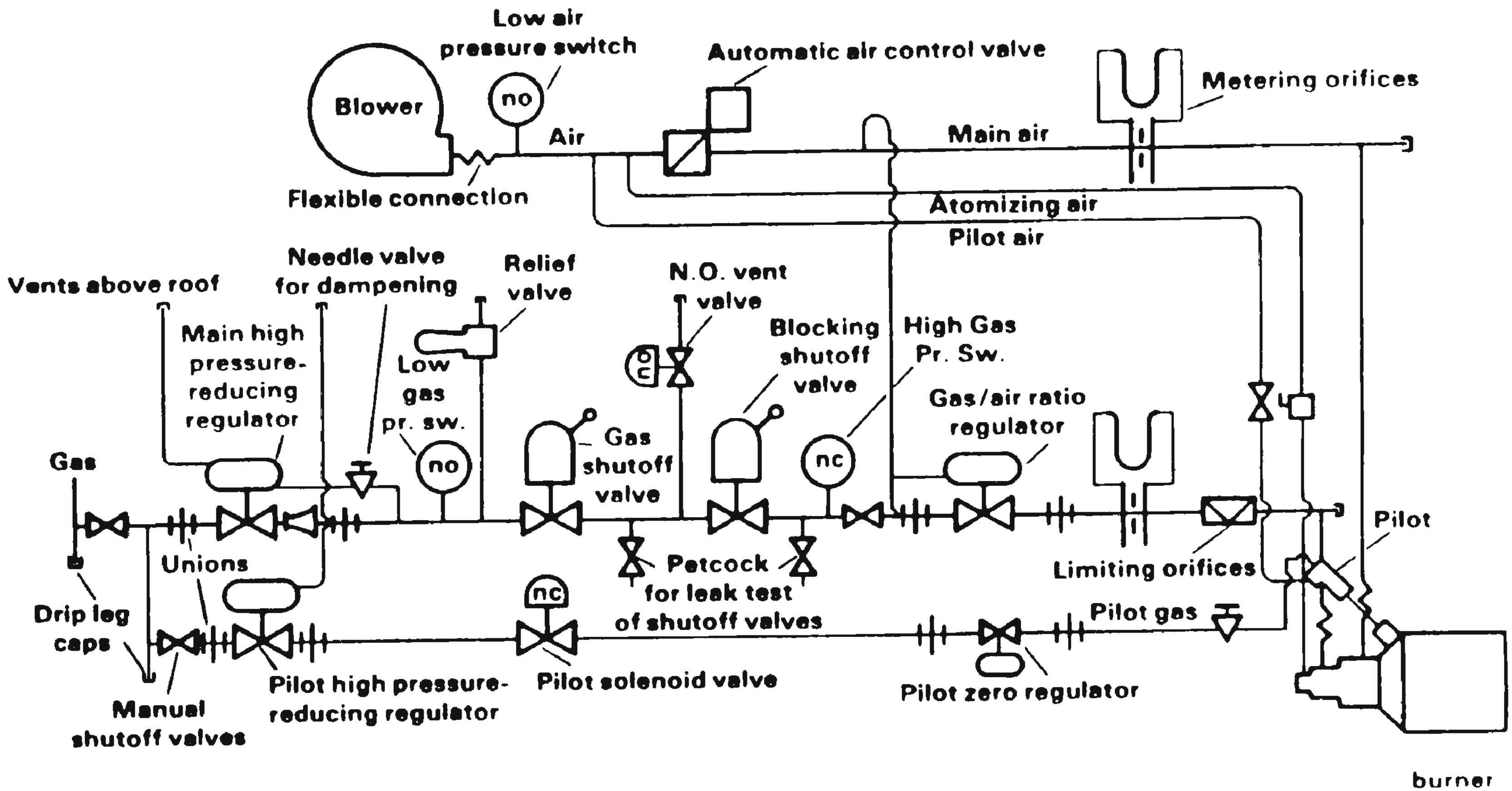
Slide 7-12 "Alternative Control Techniques Document -- NO_X Emissions from Industrial Commercial/Institutional (ICI) Boilers," U.S. EPA, EPA-453 / R-94-022, March, 1994.

CHAPTER 7. NATURAL GAS FIRED BOILERS

NATURAL GAS FUEL SYSTEM

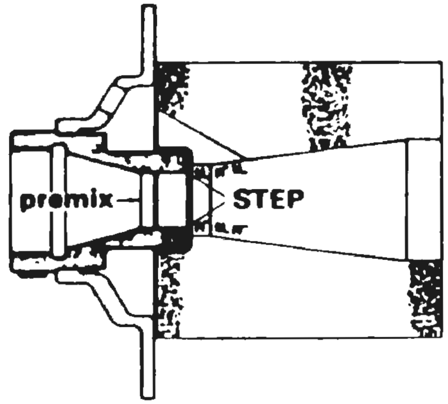
Pressure regulator
Low gas-pressure switch
High gas-pressure switch
Manual plug shutoff valve
Solenoid Valve
Automatic main gas shut-off valve
Flow control valves

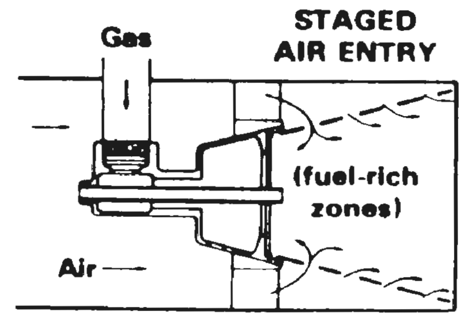
NATURAL GAS TRAIN CONFIGURATION

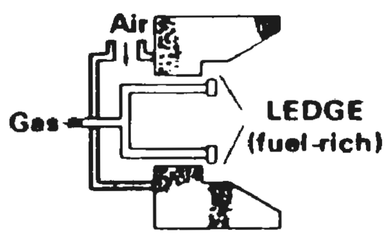


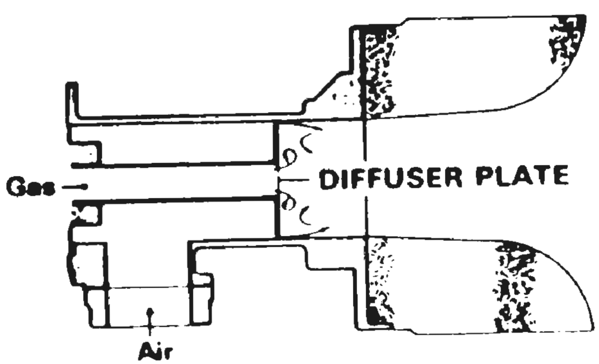
Slide 7 - 3

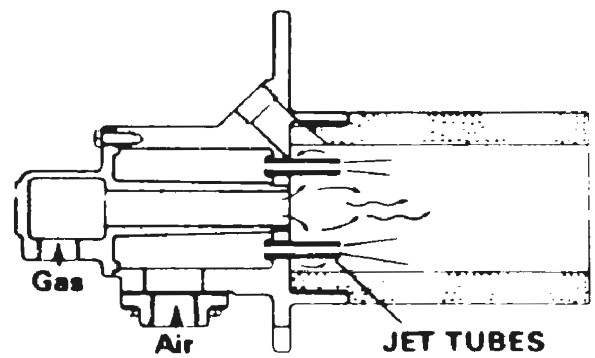
BURNER DESIGNS FOR FLAME STABILITY



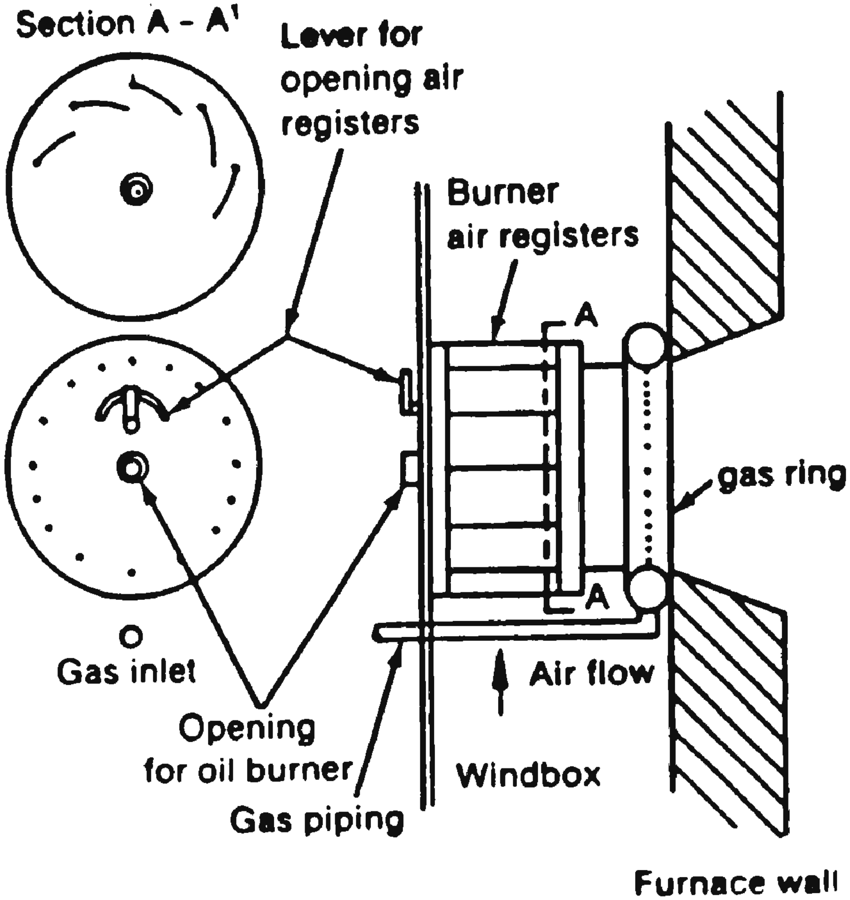






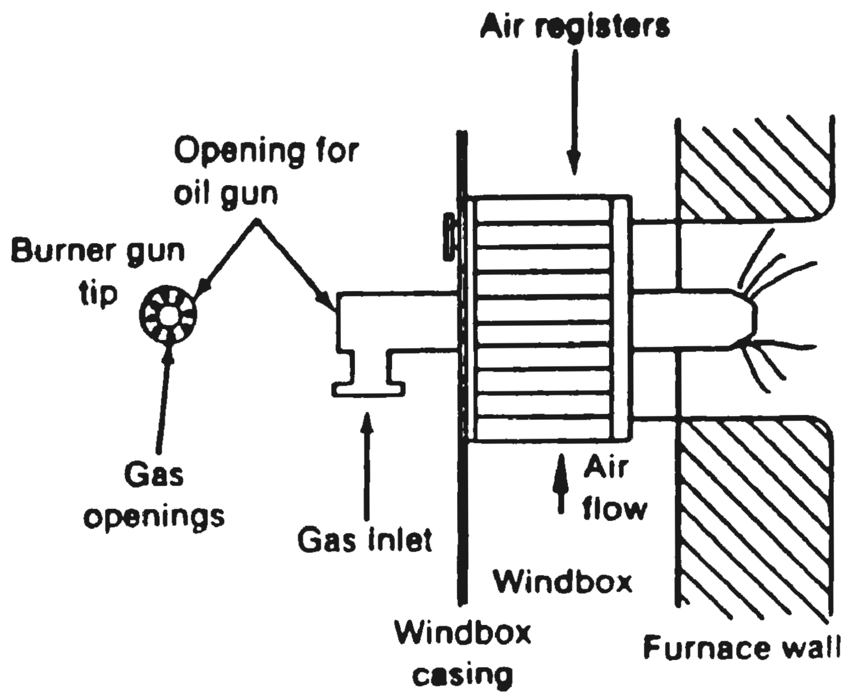


RING–TYPE GAS BURNER



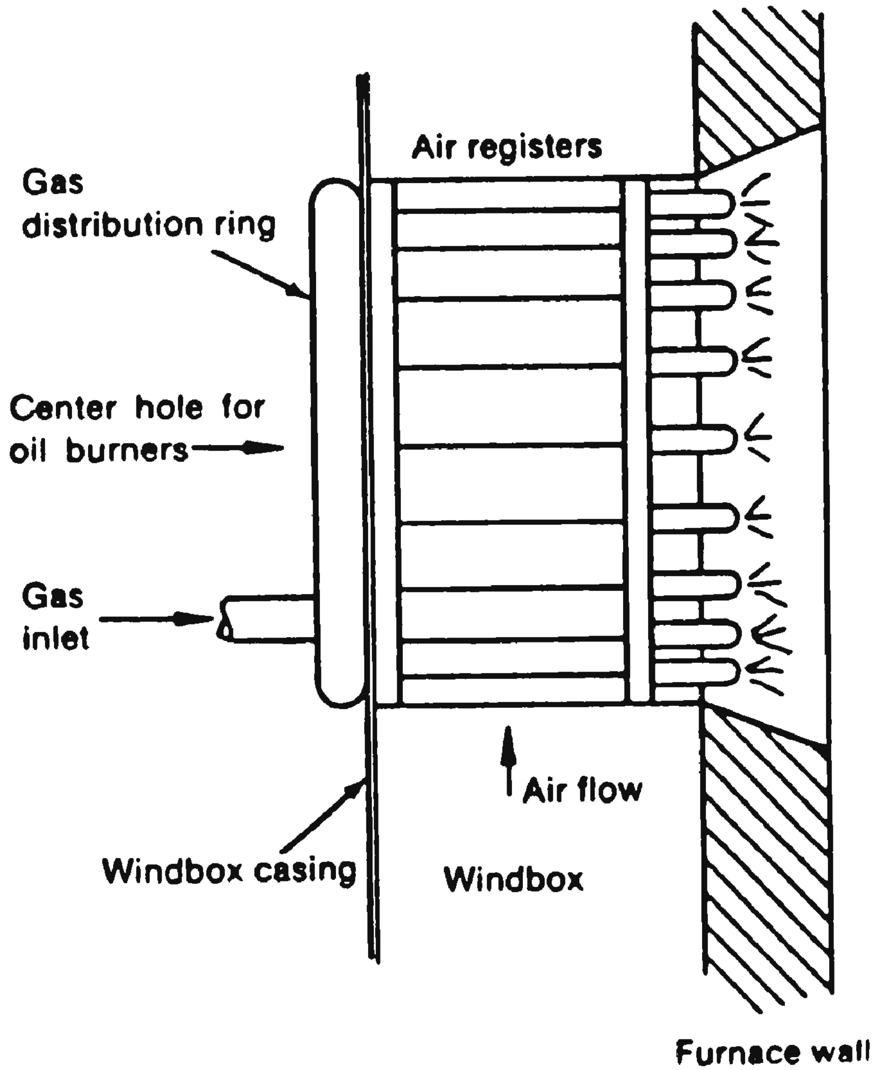
Slide 7 - 5

GUN–TYPE GAS BURNER



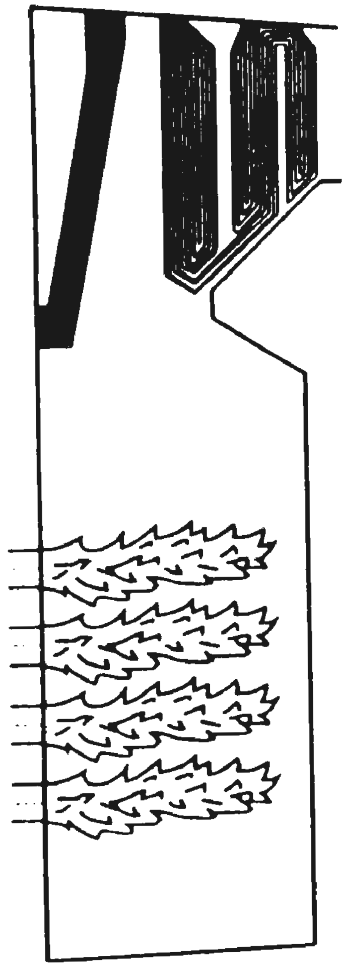
Slide 7 - 6

SPUD–TYPE GAS BURNER

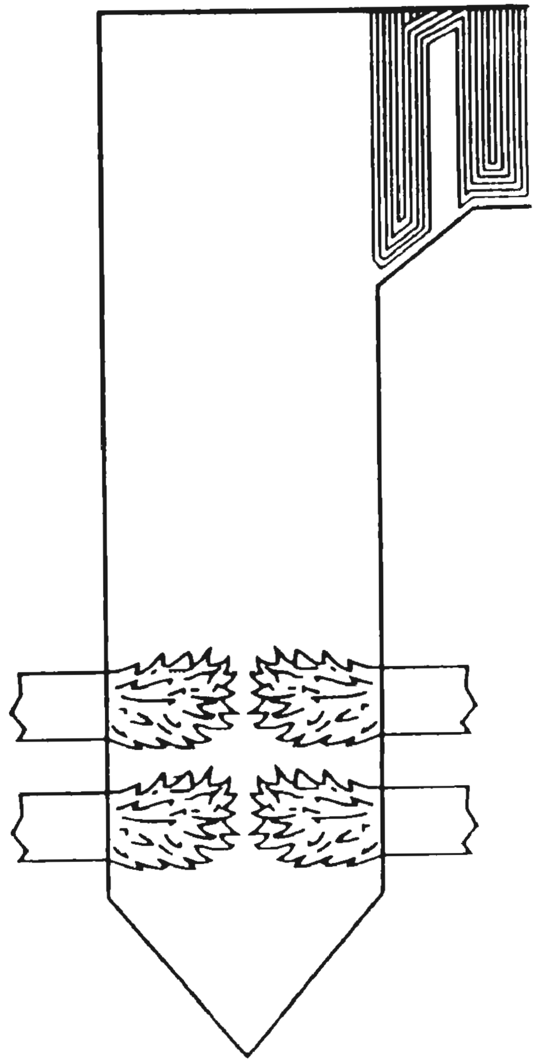


WALL MOUNTED BURNER CONFIGURATIONS

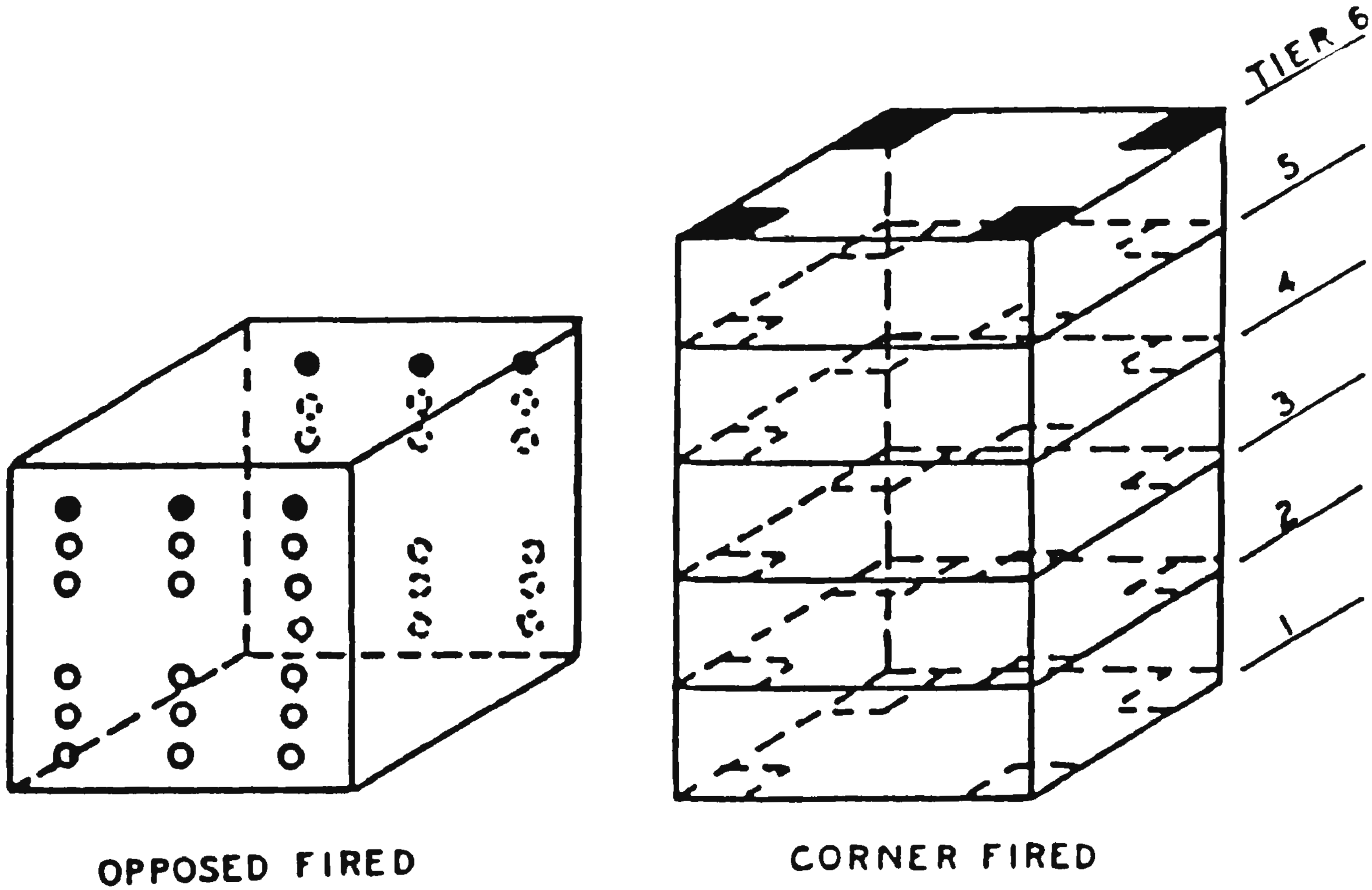
Front Wall Firing



Opposed Wall Firing

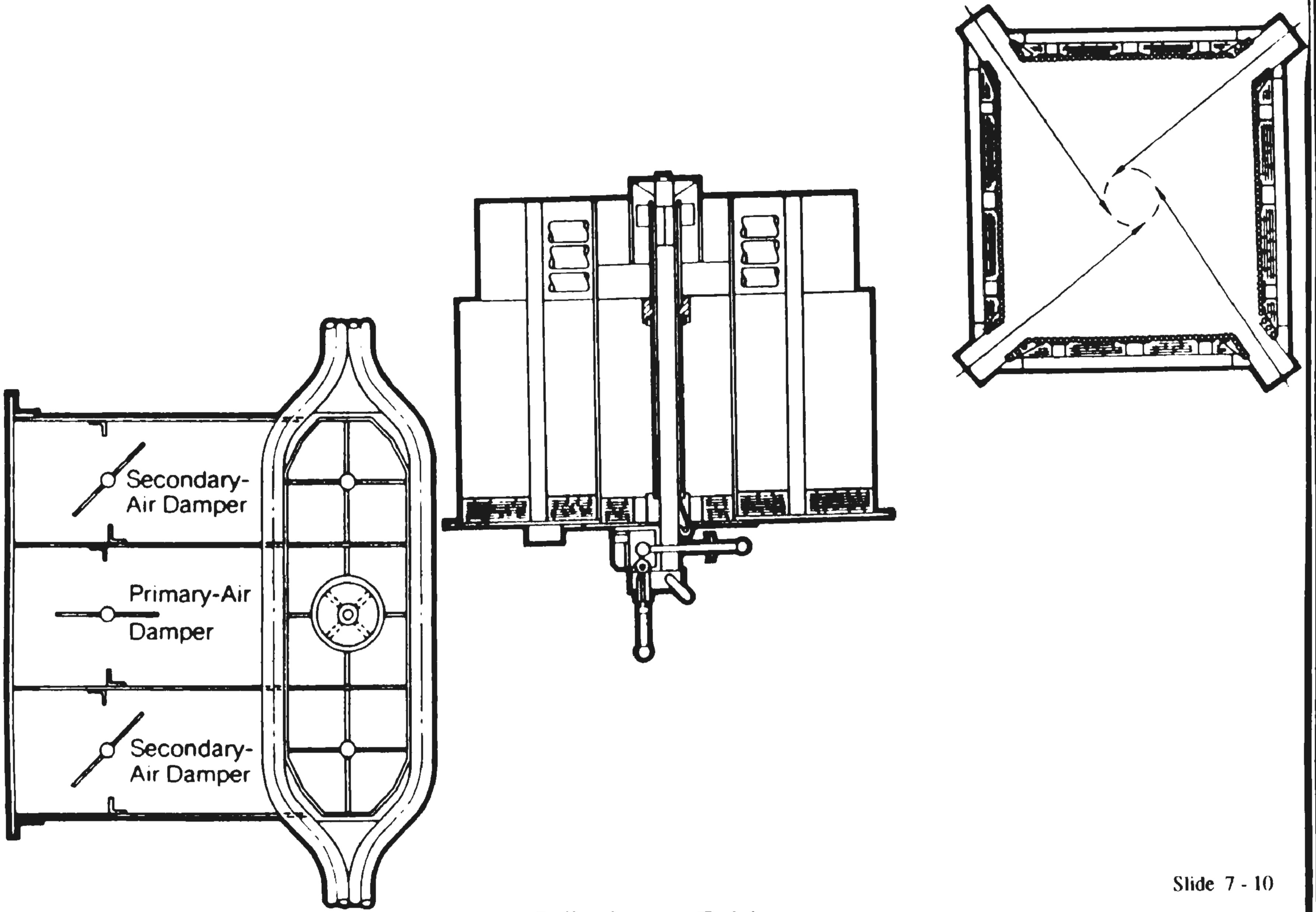


MULTIPLE BURNER PATTERNS

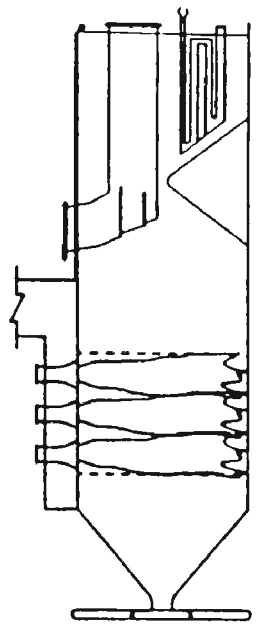
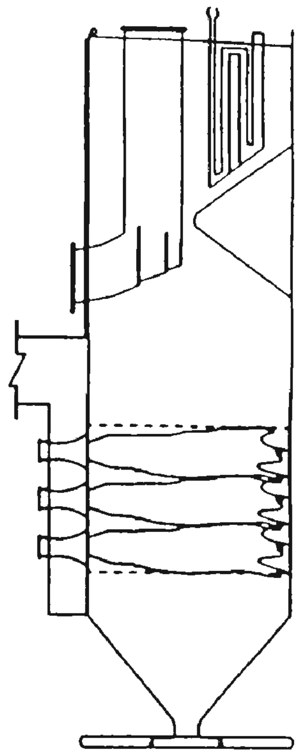


Slide 7 - 9

TANGENTIAL FIRING BURNER LOCATIONS[4]



FURNACE VOLUME EFFECTS[3]

PARAMETER \ UNIT DESIGN	HIGH HEAT RELEASE RATE	LOW/MEDIUM HEAT RELEASE RATE
FURNACE ELEVATION (SAME MW SIZE UNIT)		
BURNER ZONE VOLUME	(3 X Burner Spacing) X Width X Depth	1.66 X (High HRR Volume)
BURNER ZONE HEAT RELEASE RATE	88,000 BTU/Hr/Ft3	53,000 BTU/Hr/Ft3
NOx @ MCR GAS FIRING*		
LOW EXCESS AIR BURNER	0.55 Lb/Million BTU	0.22 Lb/Million BTU

UNCONTROLLED EMISSION DATA FROM NATURAL GAS-FIRED BOILERS[5]

Boiler Type and Capacity	NO_x, lb/MMBtu[a]	CO, lb/MMBtu[a]	THC, lb/MMBtu[a]
≤ 100 MMBtu/hr	0.03 to 0.31	0.0 to 1.45	0.0 to 0.02
> 100 MMBtu/hr	0.04 to 0.45	0.0 to 0.23	0.0 to 0.05

[a]To convert to ppm @ 3% O_2, multiply by the following: NO_x, 835; CO, 1,370; THC, 2,400

LESSON PLAN

CHAPTER 8. OIL FIRED BOILERS

Goal: To present the participant with the basic operating systems of oil fired boilers and familiarize them with specific designs and operating parameters.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the functions of fuel oil delivery system.
2. Discuss the various attributes of oil gun designs.
3. Understand what components in oil contribute to pollutant emissions.
4. Describe how CO can be reduced if CO emissions are too high.
5. Understand that the color of smoke emitted from the combustion process gives an indication of what problems may exist in the combustion process.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What are the advantages and disadvantages to burning oil?

Presentation Outline:

8.1 Introduction

8.2 Fuel Supply System

8.3 Burner Arrangements

8.4 Boiler Designs Parameters

8.5 Emissions

References for Presentation Slides

Slide 8-3 Wilson, R. Dean, *Boiler Operator's Workbook,* American Technical Publishers, Inc., 1991.

Slide 8-4 *North American Combustion Handbook*, Second Edition, North American Manufacturing Company, 1978.

Slide 8-5 Wilson, R. Dean.

Slide 8-6 Ibid.

Slide 8-7 Ibid.

Slide 8-8 Ibid.

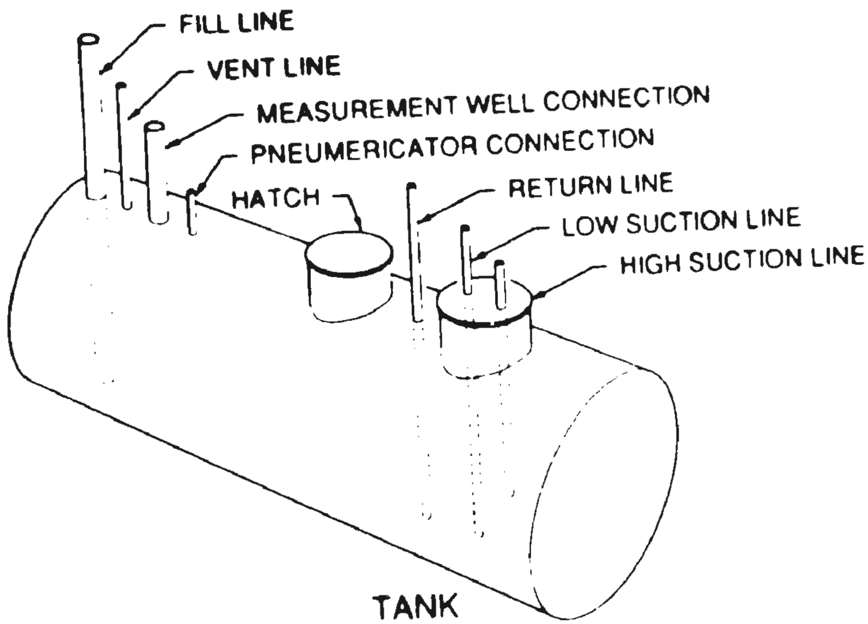
Slide 8-10 "Alternative Control Techniques Document -- NO_X Emissions from Industrial Commercial/Institutional (ICI) Boilers," Draft, U.S. EPA, July, 1993.

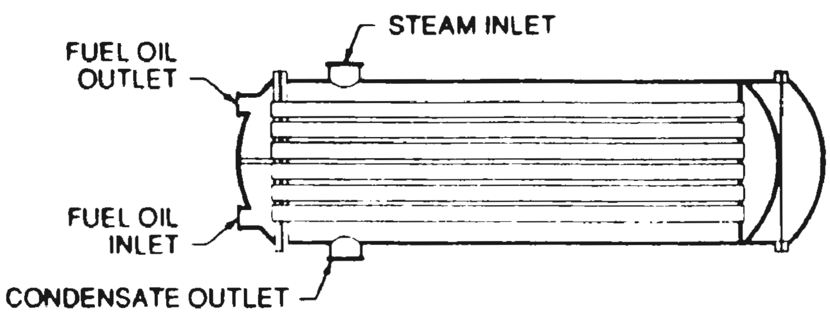
CHAPTER 8. OIL FIRED BOILERS

FUEL OIL SUPPLY SYSTEM COMPONENTS

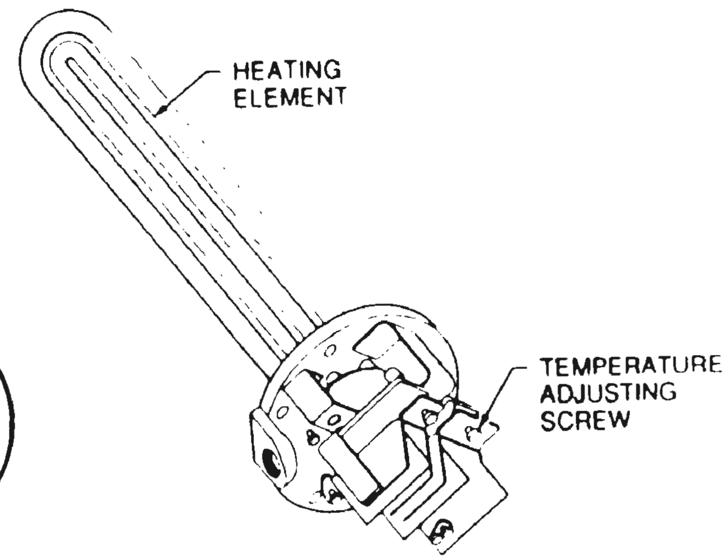
Fuel Oil Tank
Oil Pressure Regulator with bypass
Oil Heater
Oil Heater Relief Valve
Fuel Oil Strainers
Pump
Pump Discharge Relief Valve
Atomizing Gun

FUEL OIL TANK AND TANK HEATERS[1]





SHELL-AND-TUBE

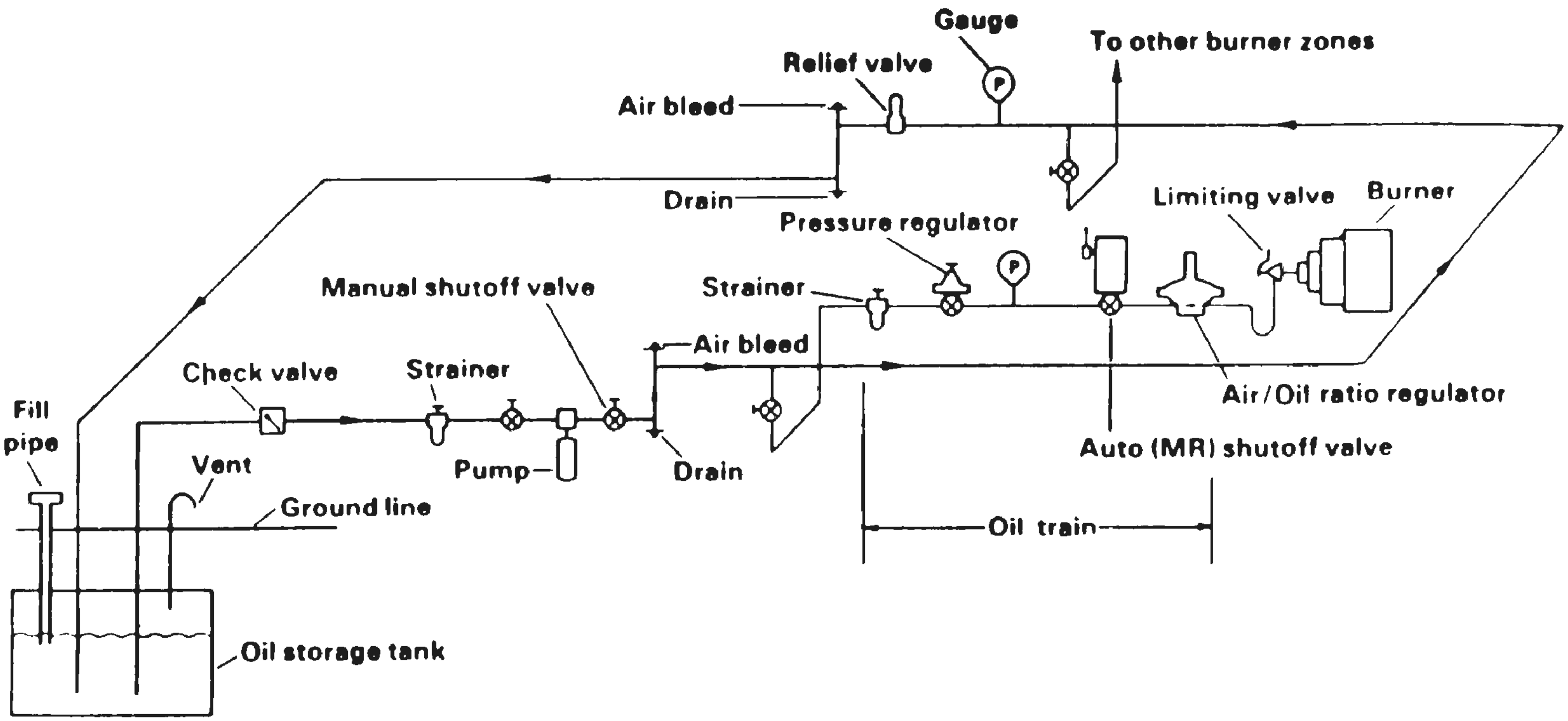


ELECTRIC

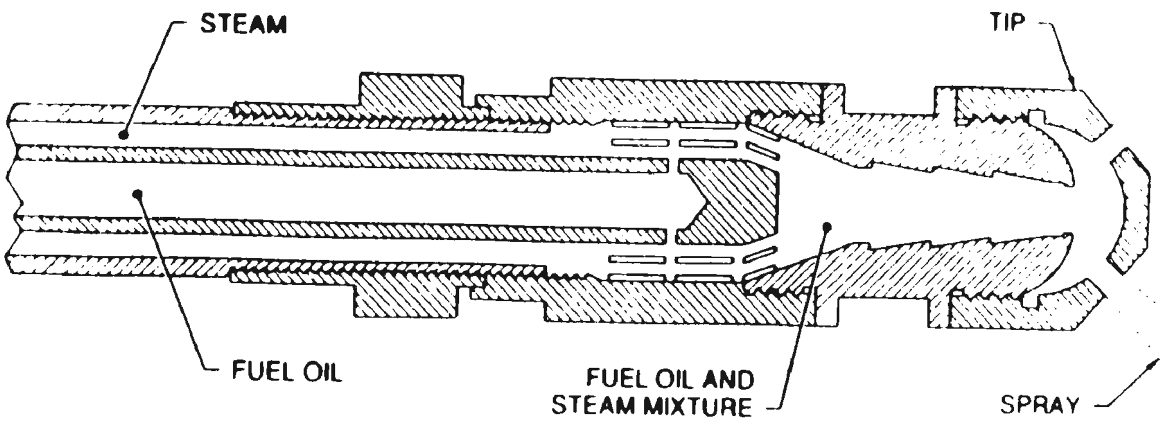
HEATERS

Slide 8 - 3

FUEL OIL SYSTEMS PIPING[2]

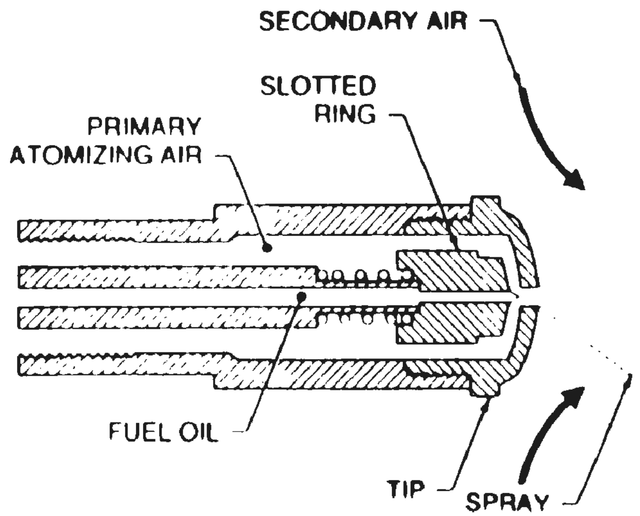


T–JET STEAM ATOMIZER[1]



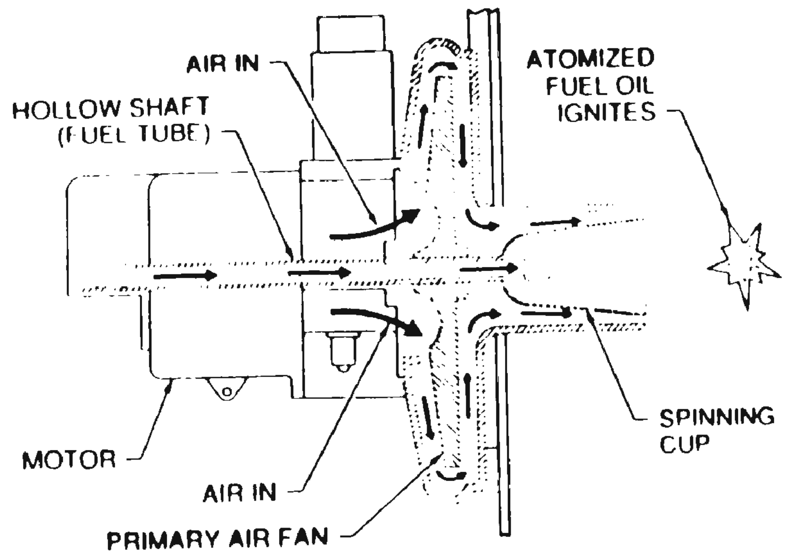
Slide 8 - 5

Y-JET STEAM/AIR ATOMIZER[1]

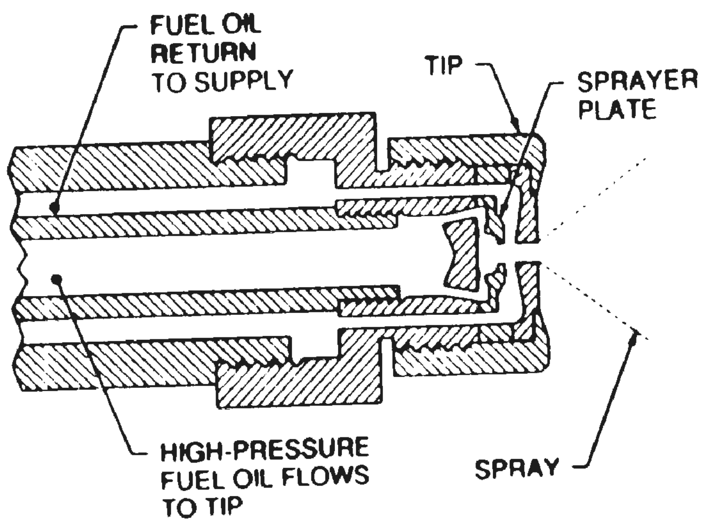


Slide 8 - 6

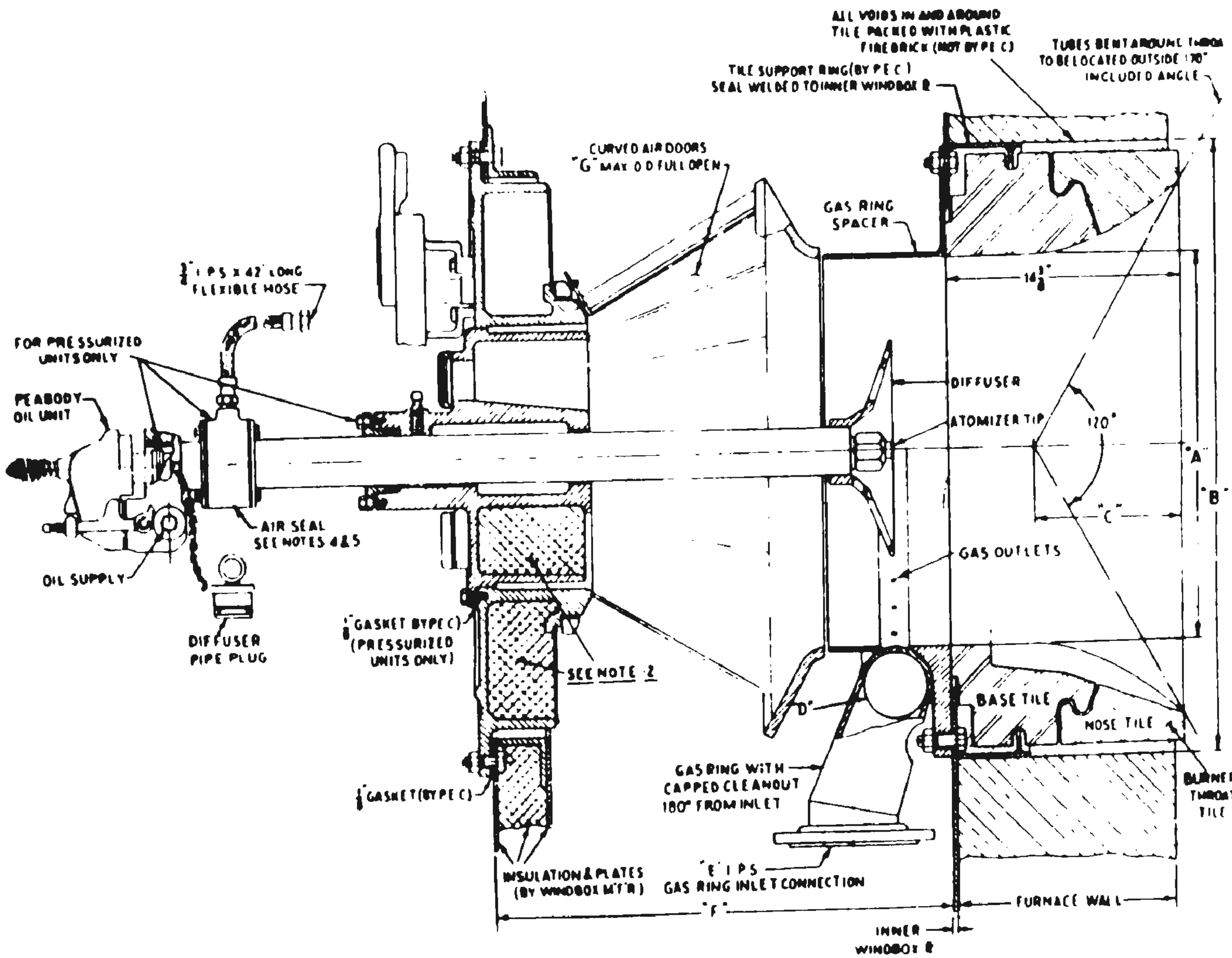
ROTARY CUP ATOMIZER[1]



MECHANICAL ATOMIZER[1]



DUAL FUEL BURNER CROSS SECTION



Slide 8 - 9

UNCONTROLLED EMISSIONS DATA FOR OIL-FIRED BOILERS[5]

Oil Type and Boiler Capacity	NO_x lb/MMBtu[a]	CO lb/MMBtu[a]	THC lb/MMBtu[a]
Residual Oil:			
Watertube Units:			
10 to 100 MMBtu/hr	0.20 to 0.79	0.0 to 0.11	0.0 to 0.03
> 100 MMBtu/hr	0.31 to C.60	0.0 to 0.02	0.002 to 0.02
Distillate Oil:			
Watertube Units:			
10 to 100 MMBtu/hr	0.08 to 0.16	0.0 to 1.18	0.0 to 0.003
>100 MMBtu/hr	0.18 to 0.23	0.0 to 0.84	0.001 to 0.009

[a]To convert to ppm @ 3% O_2, multiply by the following: NO_x, 790; CO, 1,300; THC, 2,270

Slide 8 - 10

LESSON PLAN

CHAPTER 9. PULVERIZED COAL BOILERS.

Goal: To present the participant with the basic operating systems and functional components of pulverized coal boilers and to familiarize them with typical emissions characteristics.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the coal characteristics relevant to pulverization.
2. Understand that moisture can cause soft coal to be more difficult to grind than a hard coal.
3. Describe a basic coal transport system from bunker to burner.
4. Understand the basic differences between various pulverizer air systems utilized in coal fired boilers.
5. Understand the basic operation of different pulverizer designs.
6. Describe the main attributes of various coal fired furnace firing configurations.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

Why is coal ground to a fine powder?

Presentation Outline:

9.1 Introduction

9.2 Pulverizing Properties of Coal
- A. Grindability
- B. Moisture
- C. Wear Properties

9.3 Coal Preparation
- A. Coal Crushers
- B. Coal Feeders

Presentation Outline (Continued):

9.4 Methods of Pulverizing and Conveying Coal
- A. Storage System
- B. Direct–Fired System
- C. Semi-direct System
- D. Source of Heated Air

9.5 Pulverizing Air Systems
- A. Indirect Coal–Storage Pulverizing Systems
- B. Direct Firing Arrangements

9.6 Types of Pulverizers
- A. Ball–Tube Mills
- B. Impact Mills
- C. Attrition Mills
- D. Ring–Roll and Ball–Race Mills
- E. Types of Pulverizers for Various Materials

9.7 Pulverized Coal Boilers
- A. Wall Fired Boilers
- B. Tangentially Fired Boilers
- C. Vertically Fired Boilers
- D. Cyclone Fired Boilers

9.8 Emissions

References for Presentation Slides

Slide 9-4 Singer, J.G., *Combustion: Fossil Power Systems*, 3rd Edition, Combustion Engineering, Inc., 1981.

Slide 9-5 Ibid.

Slide 9-7 Ibid.

Slide 9-8 Ibid.

Slide 9-11 Ibid.

Slide 9-14 Ibid.

Slide 9-16 Ibid.

Slide 9-17 Elliott, C.T., *Standard handbook of Powerplant Engineering*, McGraw–Hill Publishing Company, New York, 1989.

Slide 9-18 Ibid.

References for Presentation Slides (Continued)

Slide 9-19	Ibid.
Slide 9-20	Singer, J.G.
Slide 9-22	Elliot, C.T.
Slide 9-23	Ibid.
Slide 9-24	Ibid.
Slide 9-25	Ibid.
Slide 9-28	*Steam, Its Generation and Use,* 40th Edition, Babcock and Wilcox Company, 1992.
Slide 9-29	Ibid.
Slide 9-30	Ibid.

CHAPTER 9. PULVERIZED COAL BOILERS

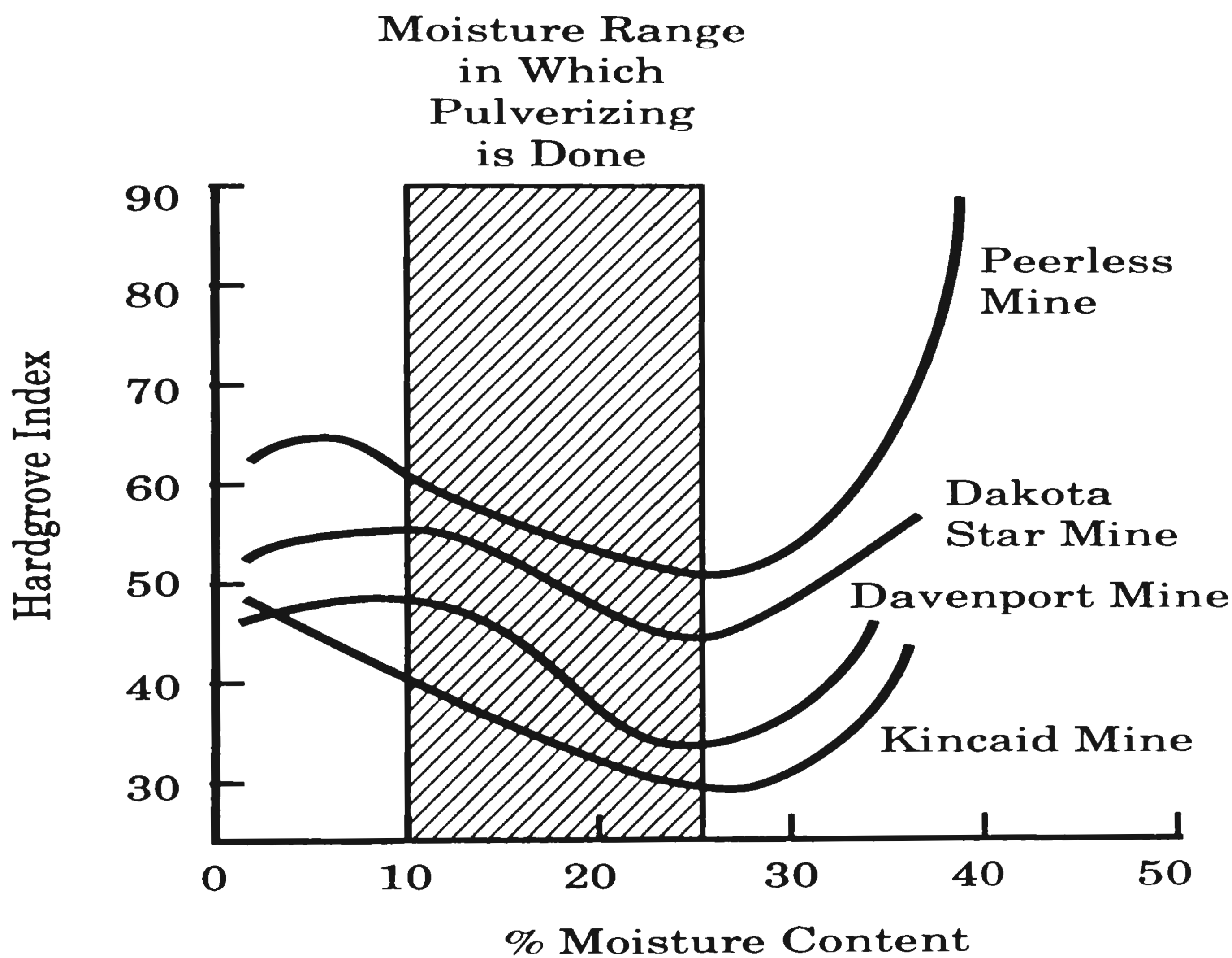
PULVERIZED COAL SYSTEMS

Pulverizing Properties of Coal
Coal Preparation
Methods of Pulverizing and Conveying Coal
Pulverizing Air Systems
Types of Pulverizers
Pulverized Coal Boilers

PULVERIZING PROPERTIES OF COAL

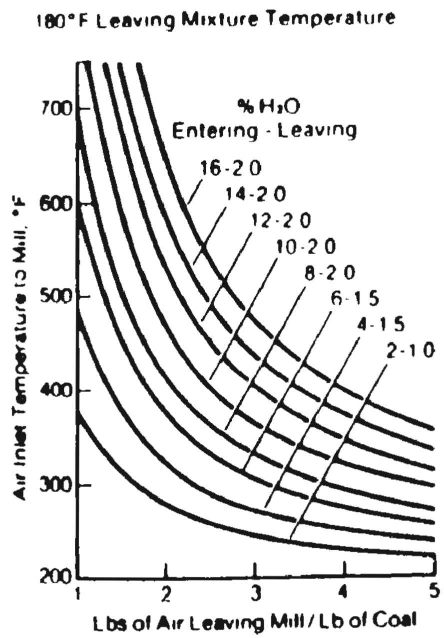
Grindability
Moisture
Wear Properties

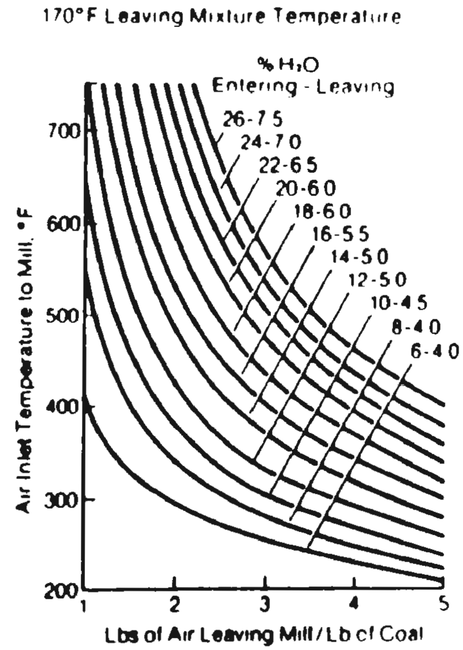
NORTH DAKOTA LIGNITES[1]



Slide 9-4

TEMPERATURE OF AIR TO MILL[1]





Slide 9 - 5

COAL PREPARATION

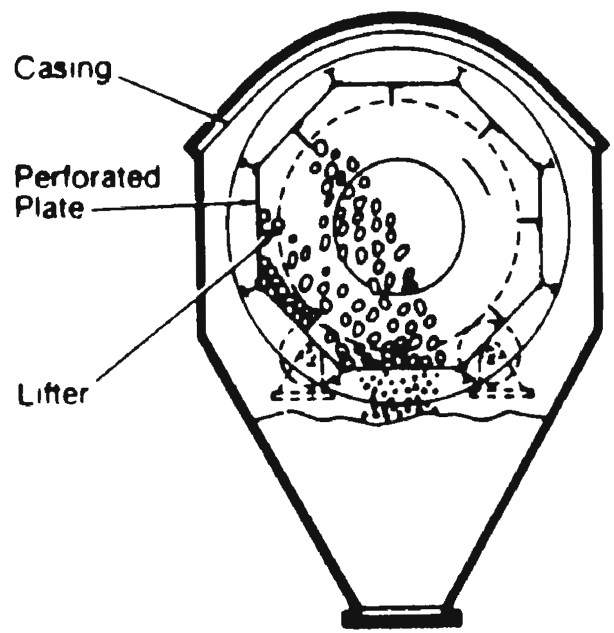
Coal Crushers

- Swing-Hammer Crushers
- Roll Crushers

Coal Feeders

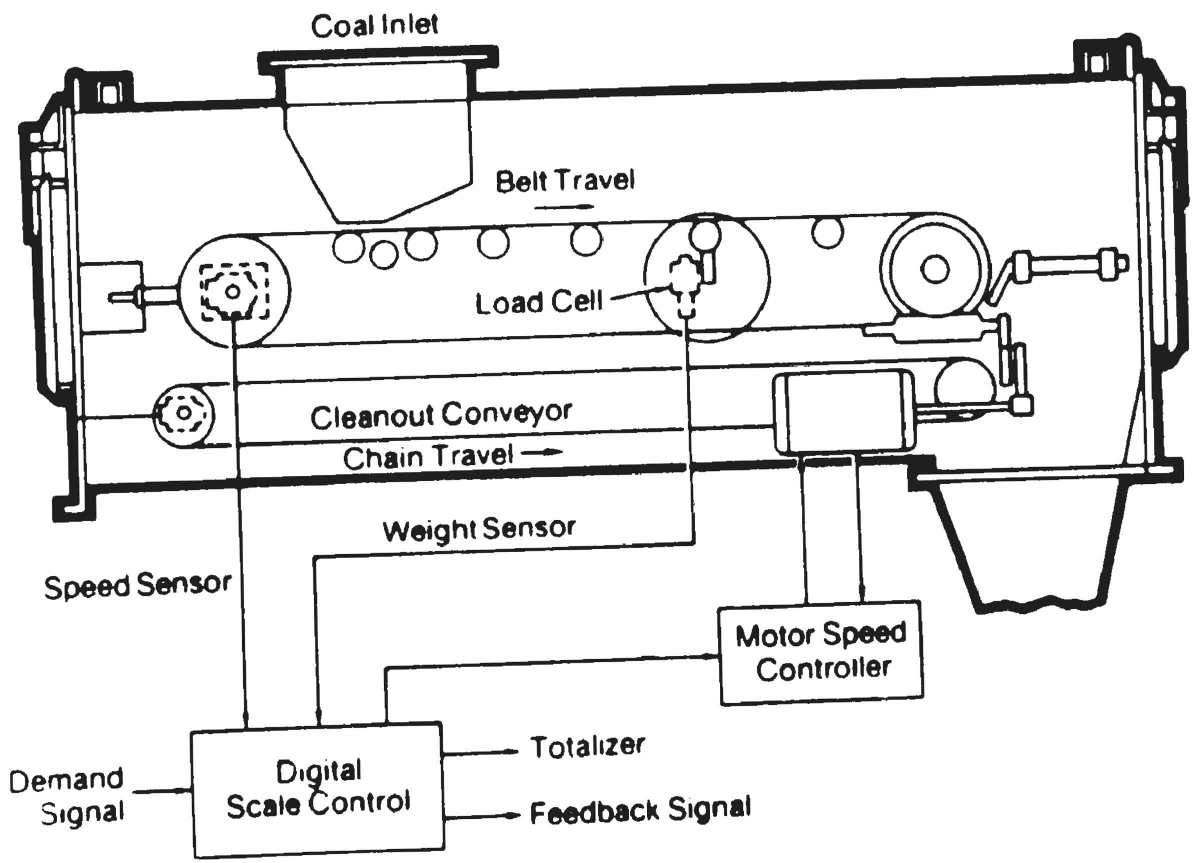
- Belt Feeders
- Overshot Feeders

BRADFORD BREAKER[1]



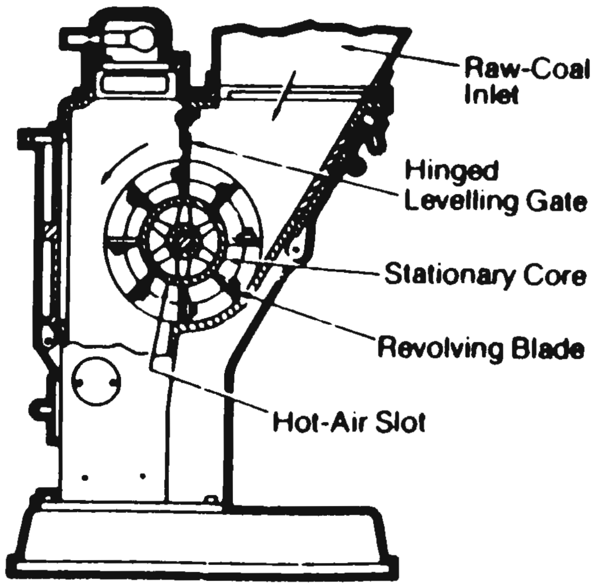
Slide 9 - 7

SCHEMATIC OF BELT–TYPE GRAVIMETRIC COAL FEEDER[1]



Slide 9 - 8

OVERSHOT ROLL FEEDER[1]



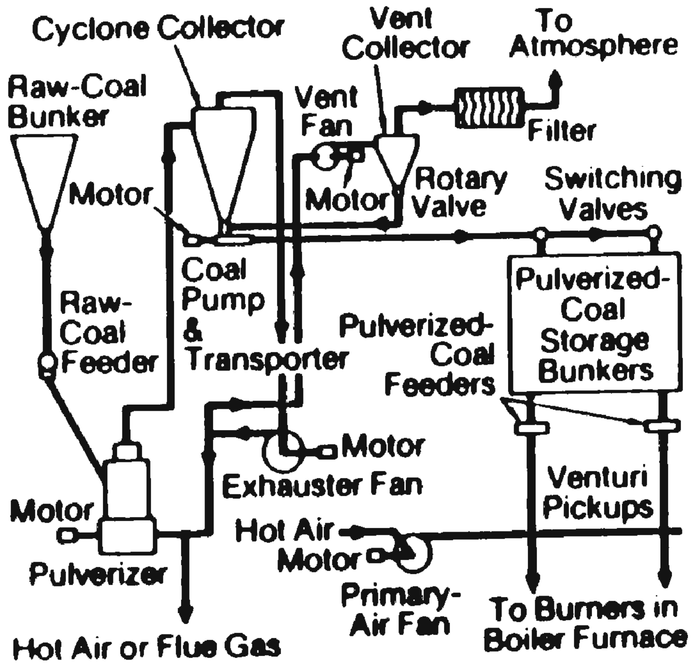
Slide 9 - 9

METHODS OF PULVERIZING AND CONVEYING COAL

Storage System
Direct–Fired System
Semidirect System

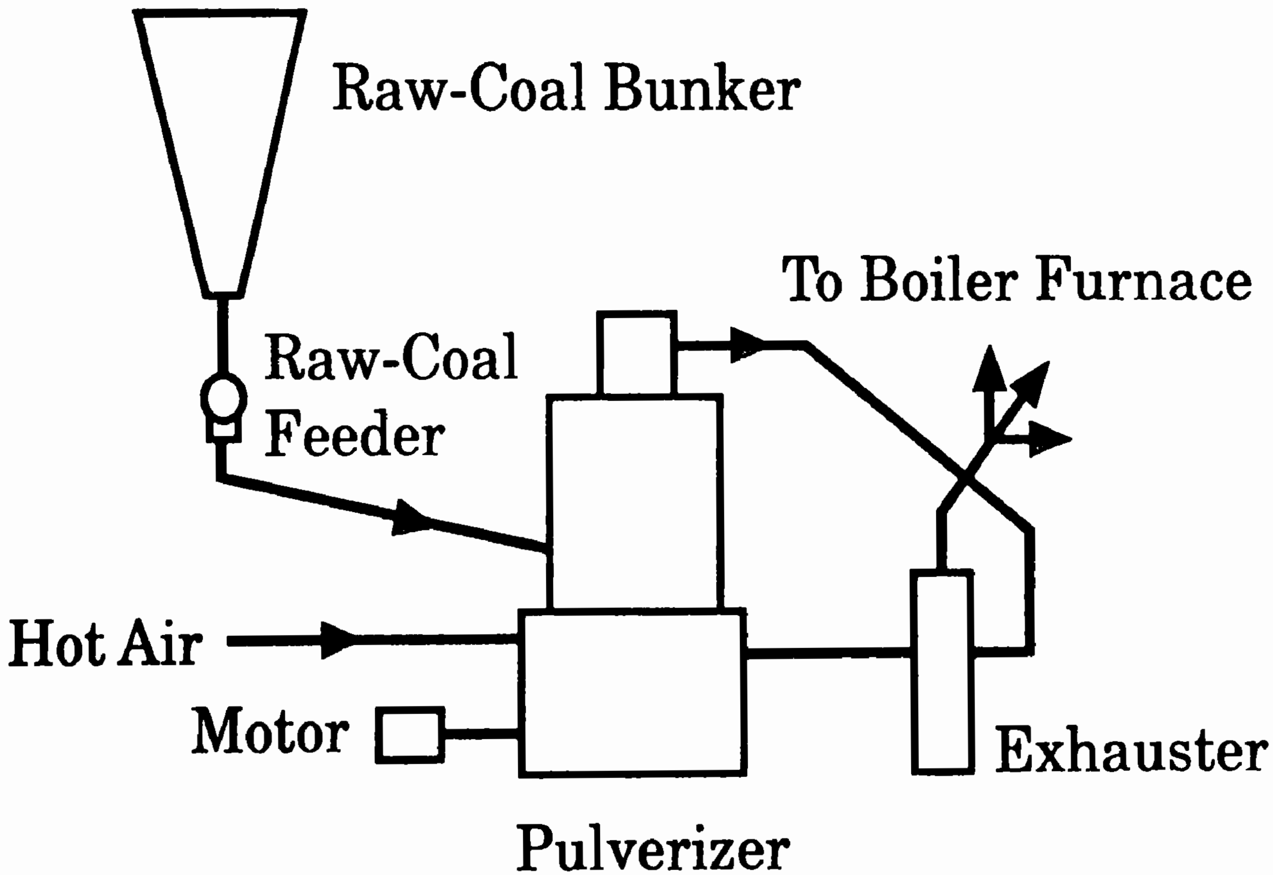
Slide 9 - 10

STORAGE SYSTEM[1]



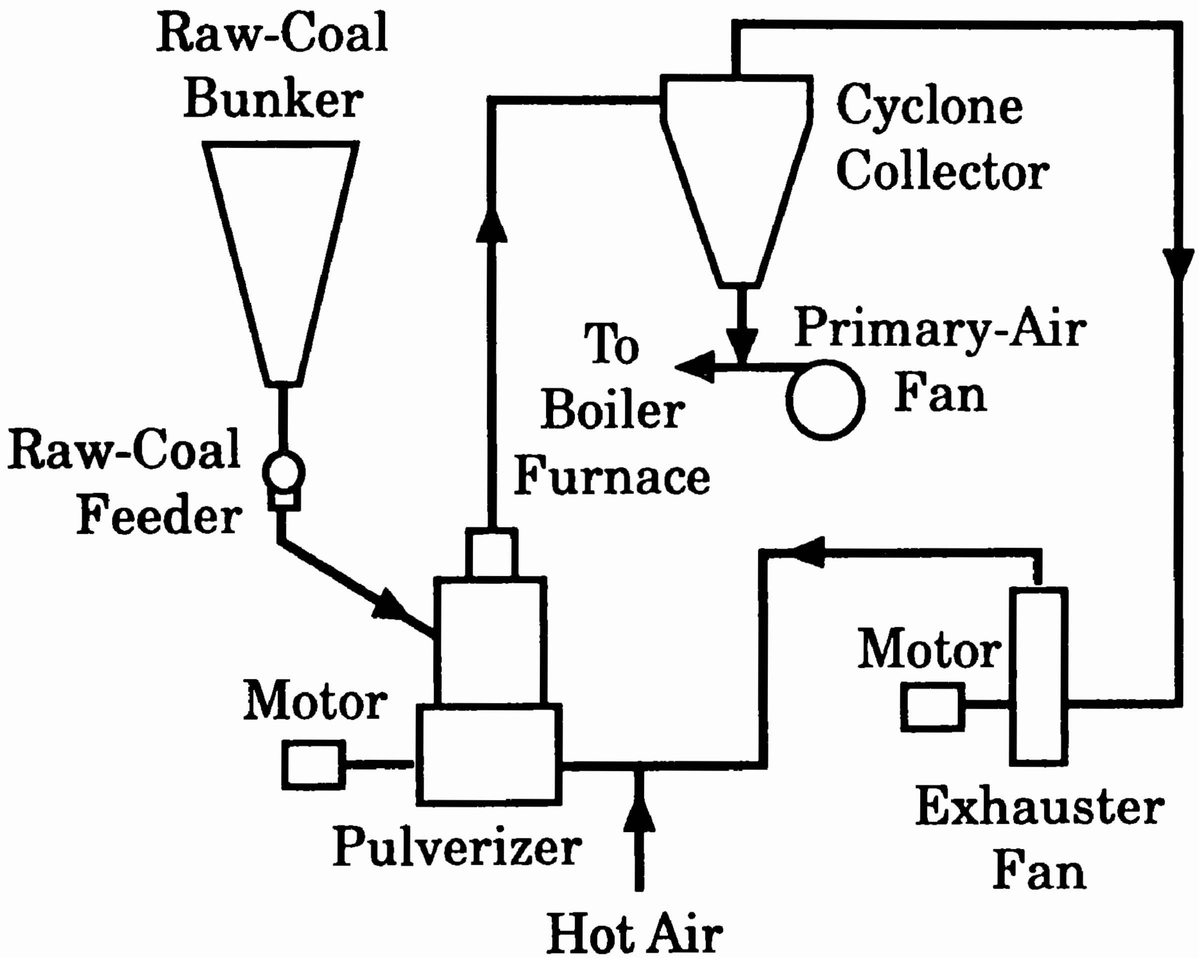
Slide 9 - 11

DIRECT-FIRED SYSTEM



Slide 9 - 12

SEMIDIRECT SYSTEM



Slide 9 - 13

ALLOWABLE MILL OUTLET TEMPERATURES, °F[1]

System	Storage	Direct	Semidirect
High-rank, high volatile bituminous	130 *	170	170
Low-rank, high volatile bituminous	130 *	160	160
High-rank, low-volatile bituminous	135 *	180	180
Lignite	110	110–140	120–140
Anthracite	200	...	...
Petroleum coke (delayed)	135	180–200	180–200
Petroleum coke (fluid)	200	200	200

* 160°F permissible with inert atmosphere blanketing of storage bin and low oxygen concentration conveying medium.

PULVERIZING AIR SYSTEMS

Indirect Coal-Storage Pulverizing Systems

- Primary Air
- Vented Air

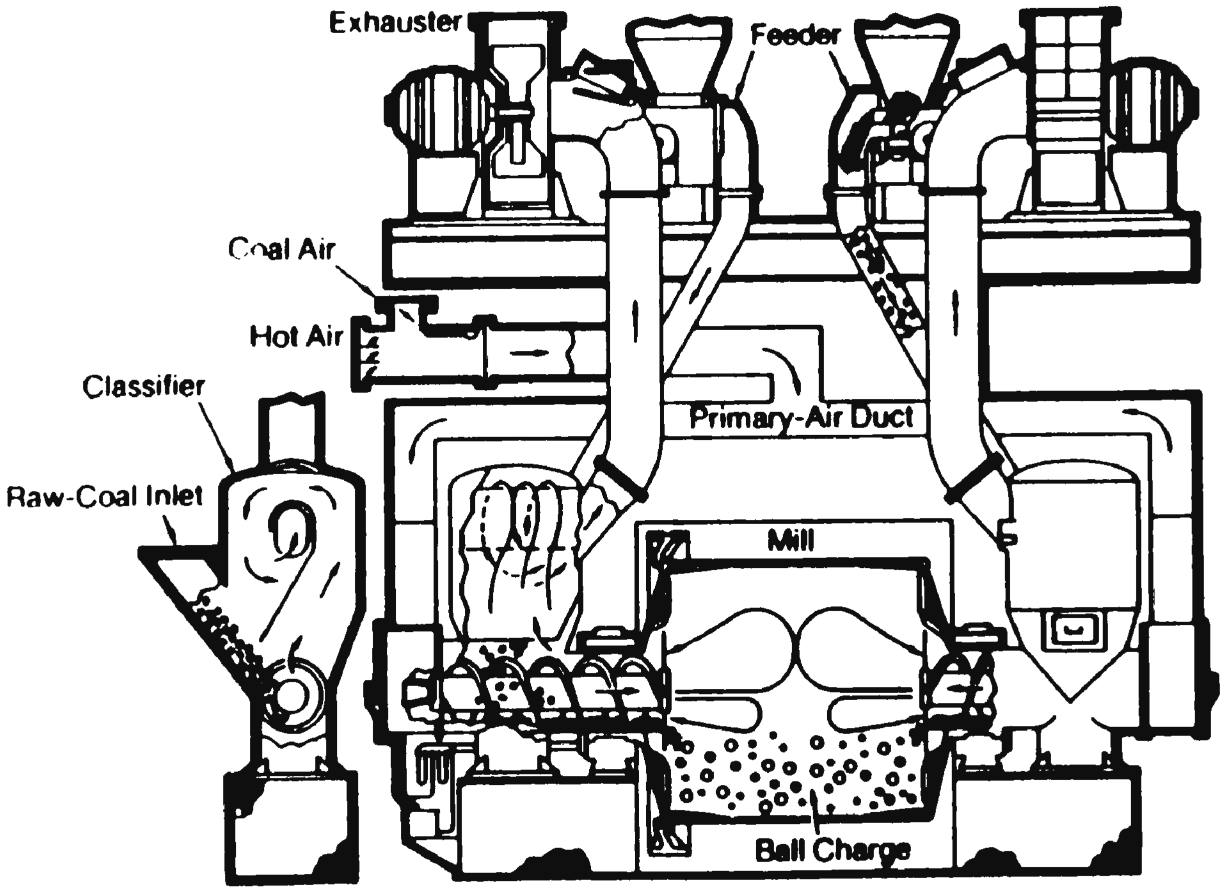
Direct-Firing Arrangements

- Suction System
- Pressure Exhauster System
- Cold Primary Air System

PULVERIZER TYPES[1]

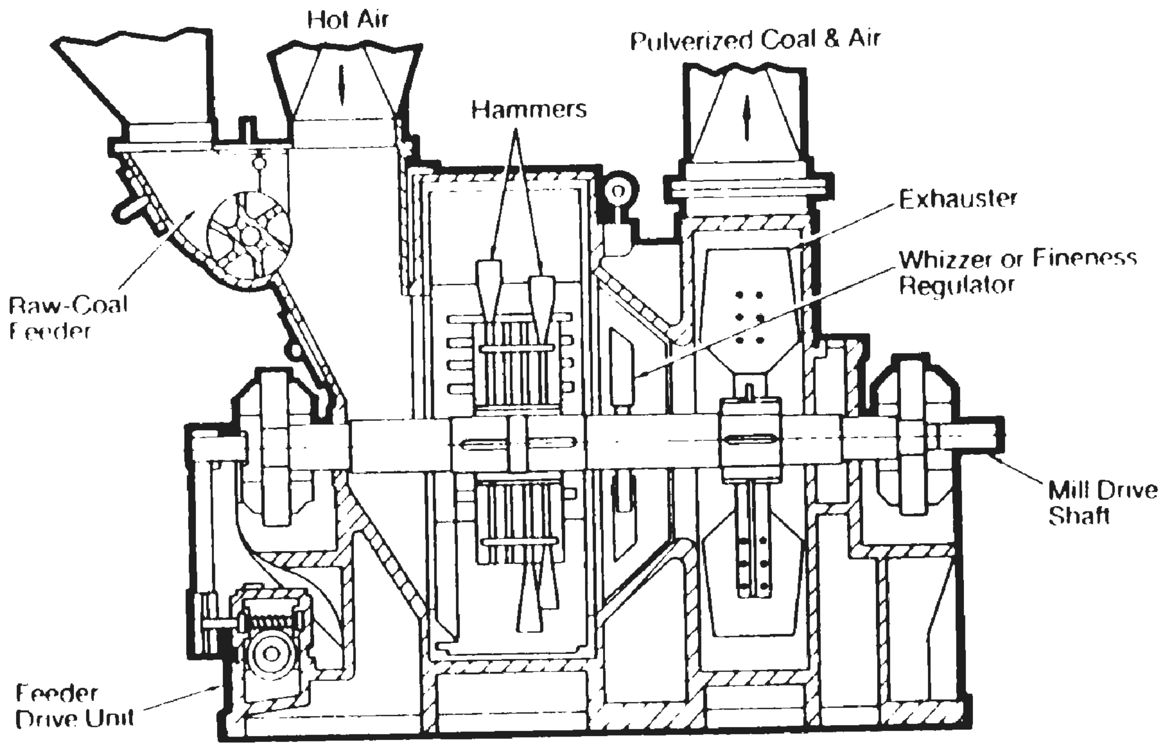
Speed	Low	Medium	High
Type	Ball-Tube Mill	Ring Roll or Ball-Race Mill	Impact or Hammer Mill Attrition Mill

ARRANGEMENT OF BALL-TUBE MILL[3]



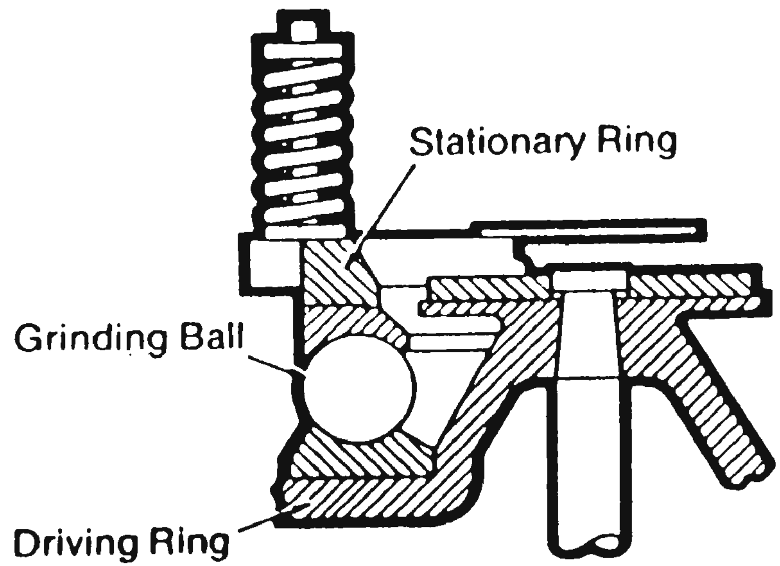
Slide 9 - 17

DIAGRAM OF AN IMPACT MILL[1]



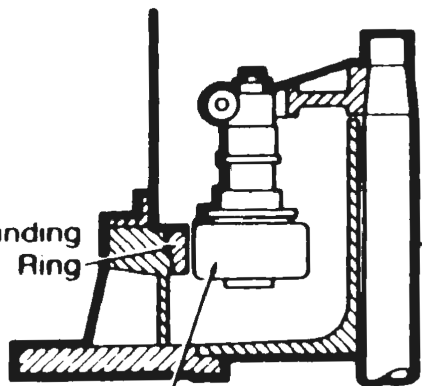
Slide 9 - 18

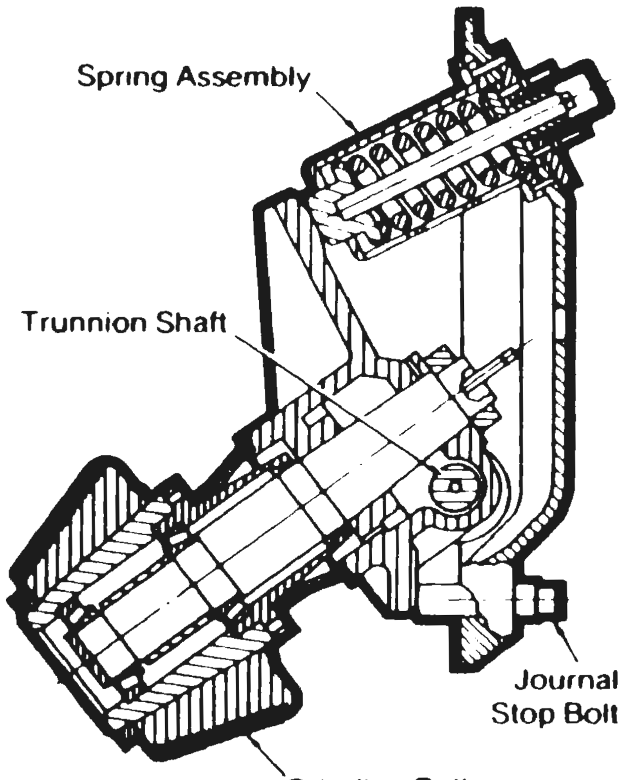
DIAGRAM OF BALL–RACE MILL[3]



Slide 9 - 19

DIAGRAM OF RING-ROLL MILL JOURNAL ASSEMBLY[3]





Slide 9 - 20

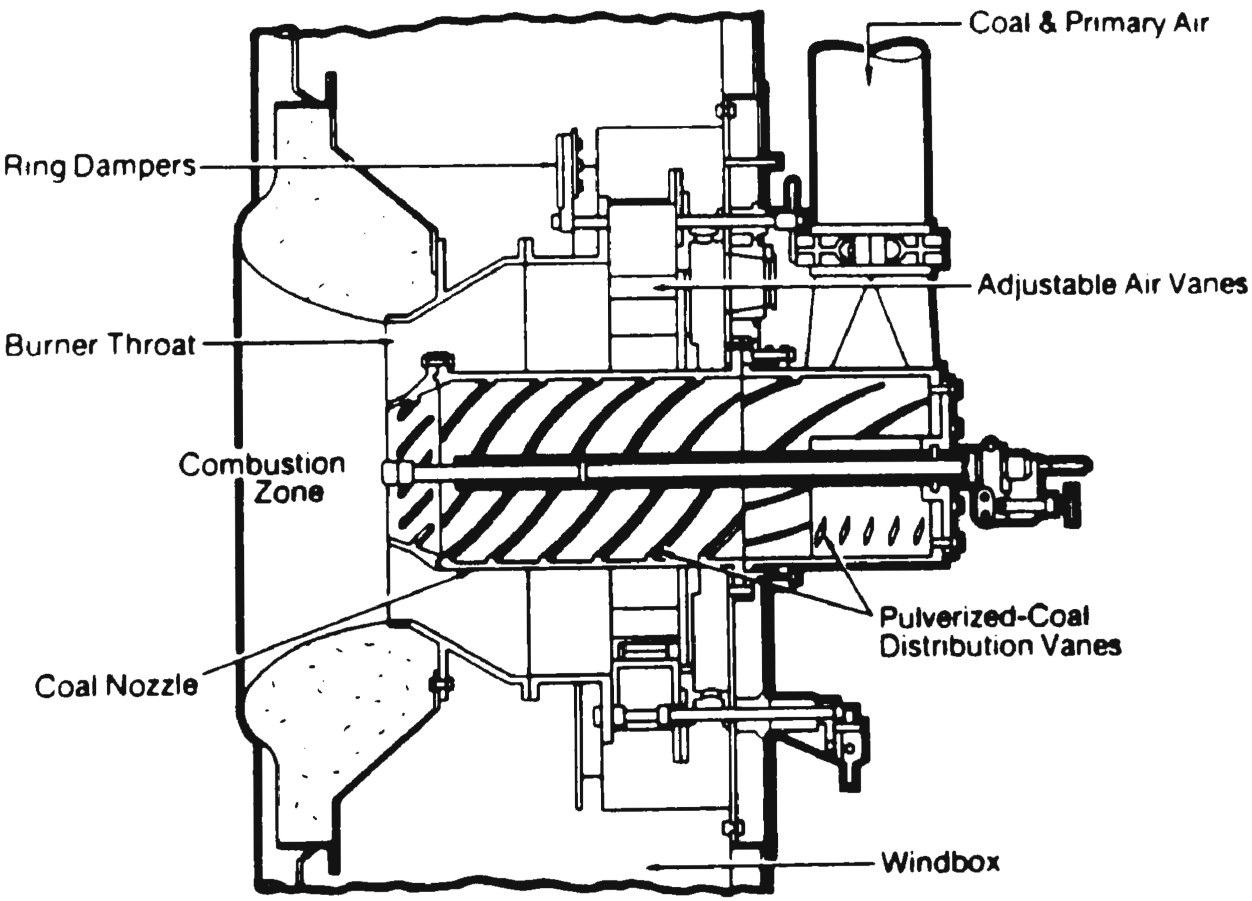
TYPES OF PULVERIZERS FOR VARIOUS MATERIALS[1]

Type of Material	Ball-Tube	Impact and Attrition	Ball Race	Ring Roll
Low-volatile anthracite	x	...	...	...
High-volatile anthracite	x	...	x	x
Coke breeze	x	...	...	...
Petroleum coke (fluid)	x	...	x	x
Petroleum coke (delayed)	x	x	x	x
Low-volatile bituminous coal	x	x	x	x
Med-volatile bituminous coal	x	x	x	x
High-volatile A bituminous coal	x	x	x	x
High-volatile B bituminous coal	x	x	x	x
High-volatile C bituminous coal	x	...	x	x
Subbituminous A coal	x	...	x	x
Subbituminous B coal	x	...	x	x
Subbituminous C coal	...	...	x	x
Lignite	...	...	x	x
Lignite and coal char	...	...	x	x
Brown coal	...	x	...	...

PULVERIZED-COAL BOILERS

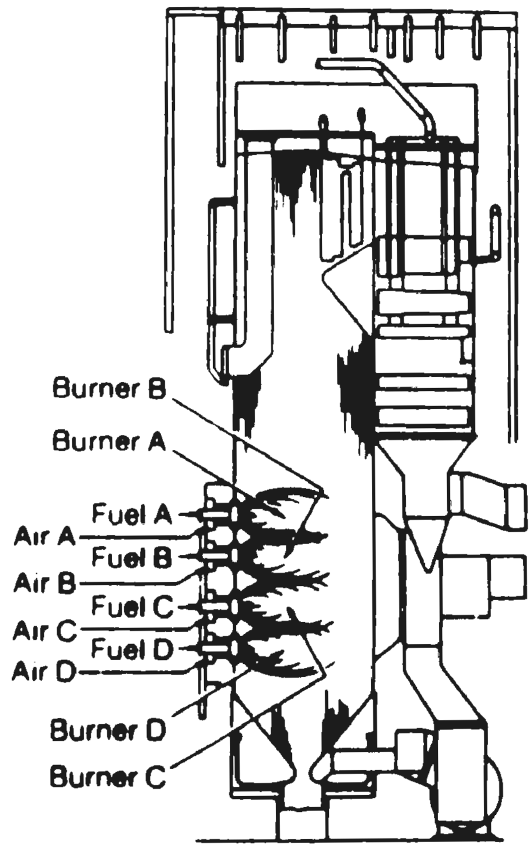
Wall-Fired Boilers
Tangentially-Fired Boilers
Vertically-Fired Boilers
Cyclone-Fired Boilers

BURNER FOR HORIZONTAL FIRING OF COAL[3]



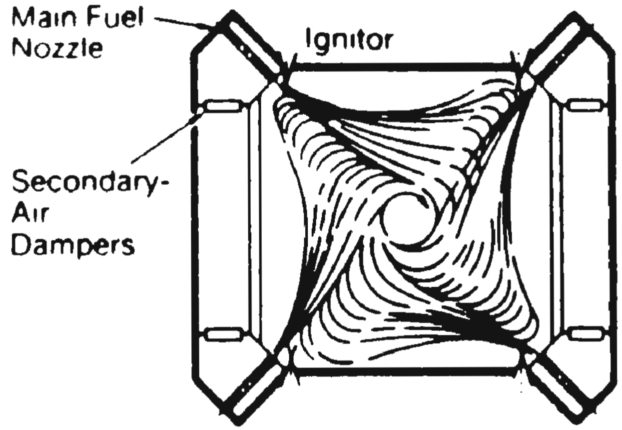
Slide 9 - 23

FLOW PATTERN OF HORIZONTAL (WALL) FIRING[3]



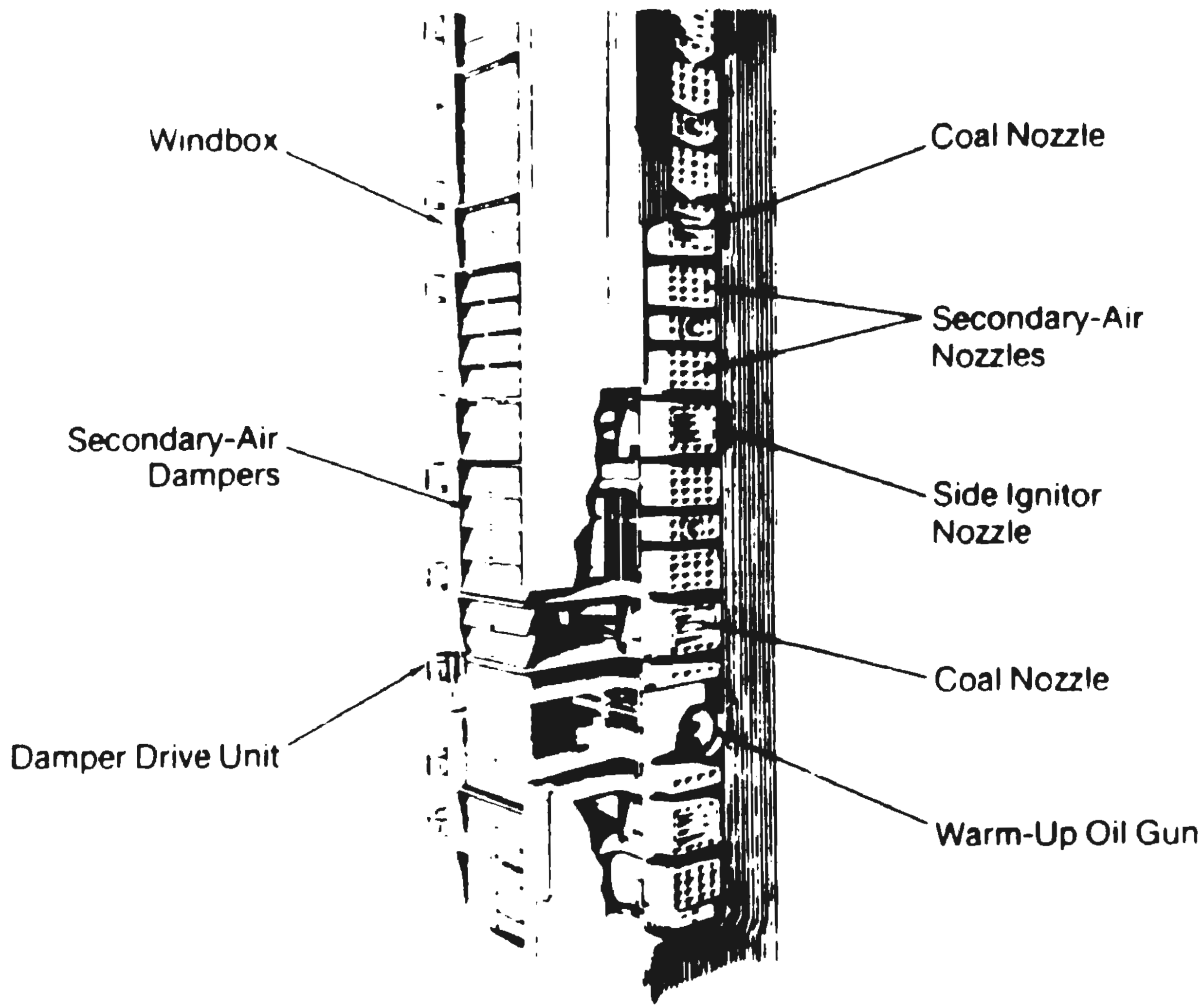
Slide 9 - 24

TANGENTIAL FIRING PATTERN[3]



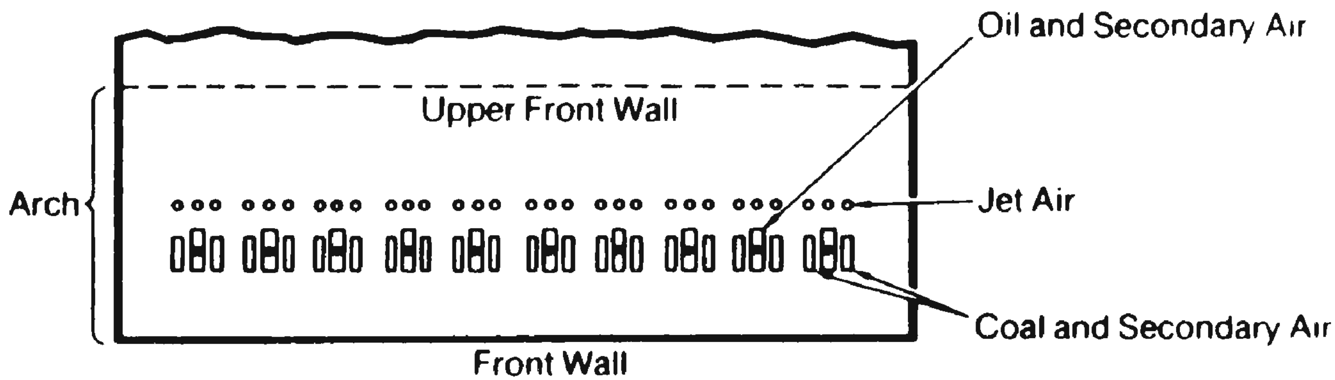
Slide 9 - 25

ARRANGEMENT OF CORNER WINDBOX FOR TANGENTIAL FIRING OF COAL[3]



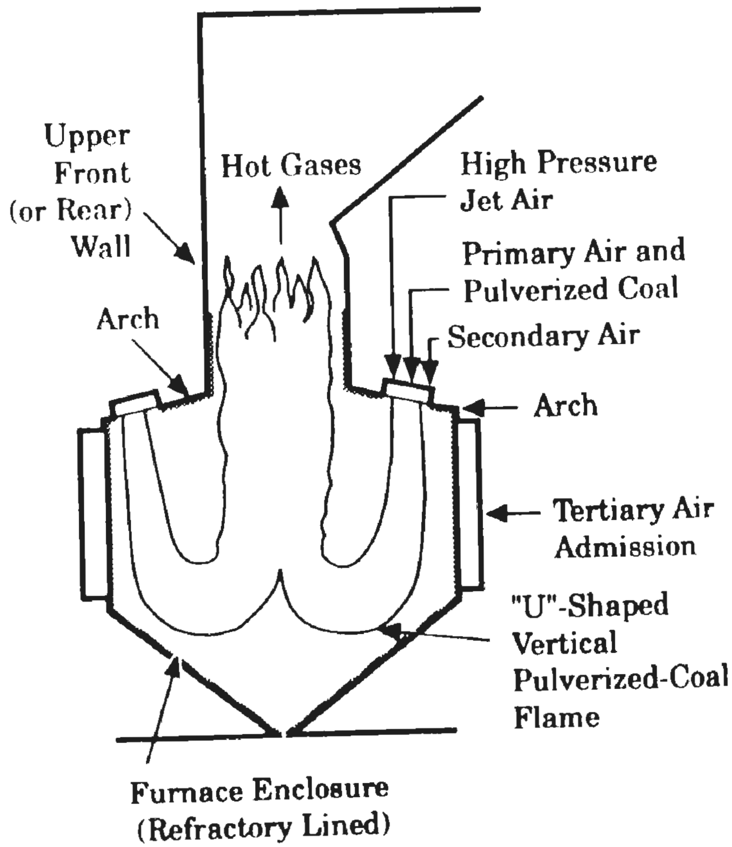
Slide 9 - 26

BURNER ARRANGEMENT OF VERTICALLY FIRED BOILERS



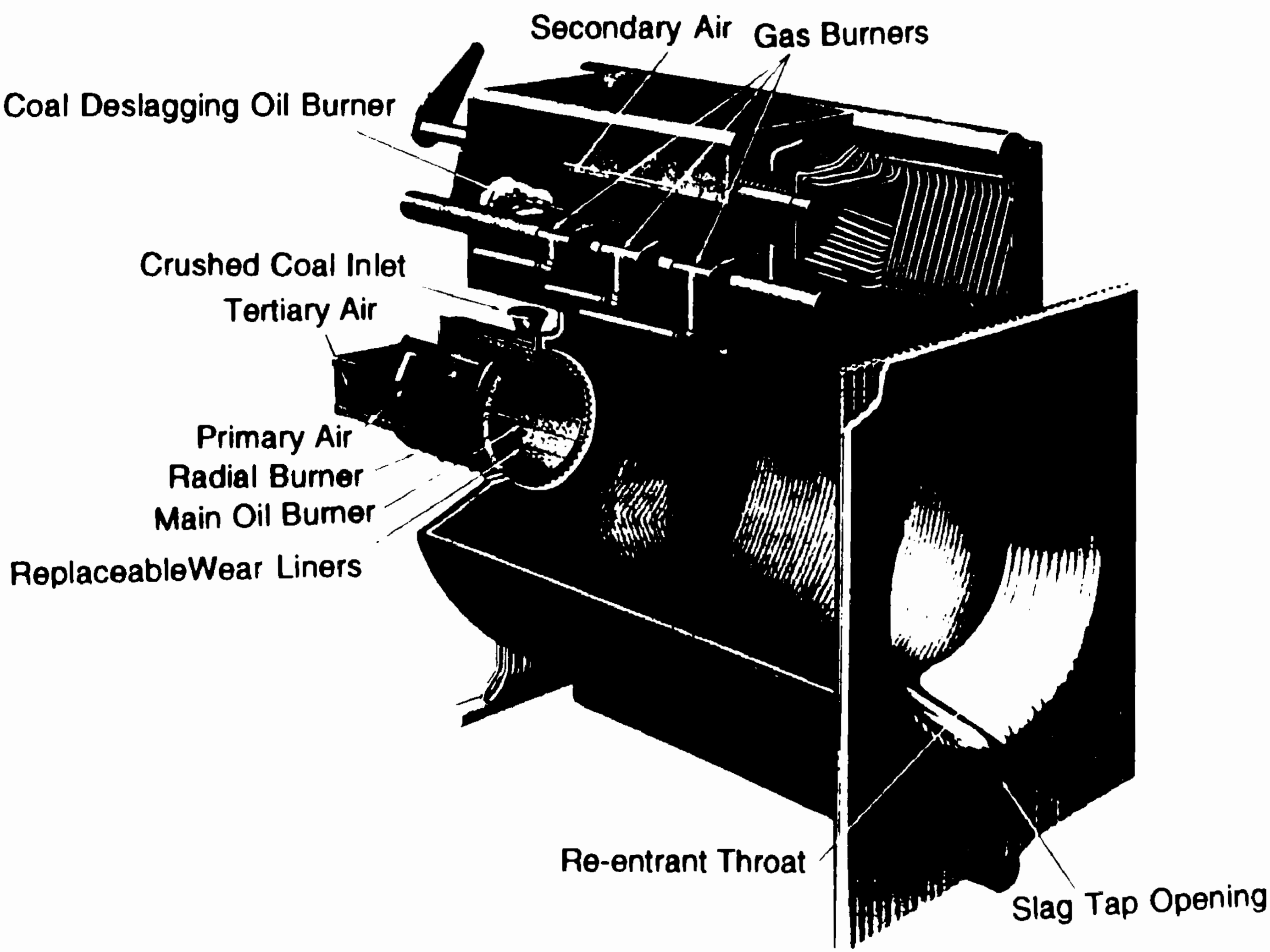
Slide 9 - 27

FLOW PATTERN OF VERTICAL FIRING



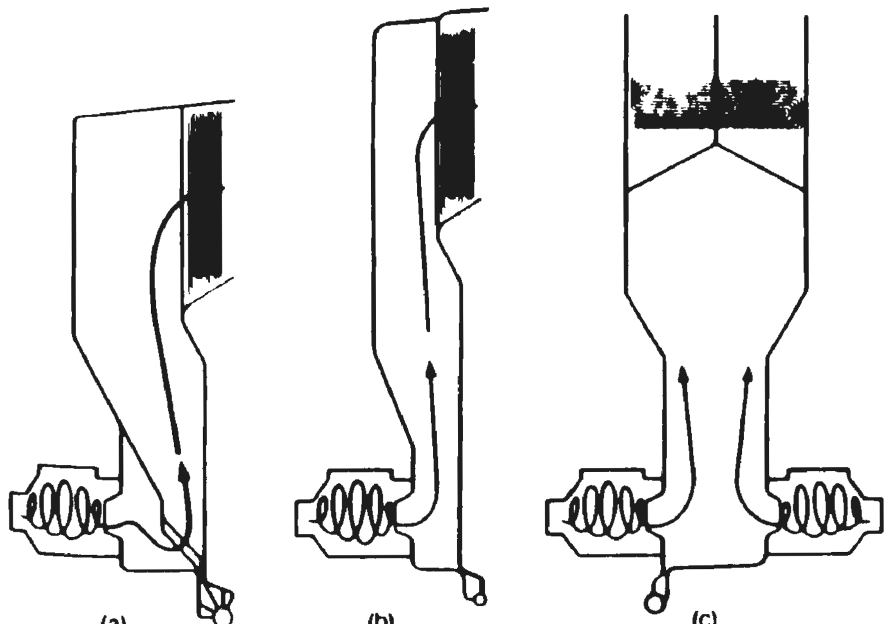
Slide 9 - 28

CYCLONE FURNACE[2]



Slide 9 - 29

FINAL ARRANGEMENTS USED FOR CYCLONE FURNACES[2]



(a)
Screened Furnace
Arrangement
Single Wall

(b)
Open Furnace
Arrangement
Single Wall

(c)
Open Furnace
Arrangement
Double Wall

Slide 9 - 30

COAL FIRED BOILER EMISSIONS
(500 MW Boiler, 2.5 % sulfur, 16% ash)[2]

Emissions	Discharge Rate (t/h) Uncontrolled	Controlled	Control Equipment
SO_x as SO_2	9.3	0.9	Wet Limestone Scrubber
NO_x as NO_2	2.9	0.7	Low-NO_x Burners
CO_2	485	485	Not Applicable
Flyash to Air*	22.9	0.05	ESP or Baghouse
Ash to Landfill*	9.1	32	Controlled Landfill
Scrubber Sludge (Gypsum plus Water)	0	25	Controlled Landfill or Wallboard Quality Gypsum

* As flyash emissions to the air decline, ash shipped to landfills increases.

LESSON PLAN

CHAPTER 10. STOKERS

Goal: To familiarize the participant with the specific design, operating systems and characteristics unique to stoker boilers.

Objectives:

Upon completion of this unit an operator should be able to:

1. Point out the unique attributes of a stoker boiler.
2. Describe the different types of stoker designs.
3. Understand the basic differences between different grate designs used in stoker boilers.
4. Discuss fuel characteristics required by stokers and be familiar with the basic designs employed in stokers.
5. Describe the function of overfire air in stoker combustion.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

Does anyone know what a tuyére is?

How are the fuel particle sizes different in stoker boilers than in pulverized coal boilers?

Presentation Outline:

10.1 Introduction

10.2 Types of Stoker

10.3 Underfeed Stokers
- A. Side ash Discharge Type
- B. Rear Ash Discharge Type
- C. Coal Specifications
- D. Boiler Furnaces
- E. Overfire Air and Combustion Air

Presentation Outline (Continued):

10.4 Mass Feed Stokers
- A. Chain Grate
- B. Traveling Grate
- C. Water-Cooled Vibrating Grate
- D. Fuel Specifications
- E. Furnace Design
- F. Overfire Air

10.5 Spreader Stokers
- A. Fuel
- B. Fuel Burning
- C. Fuel Feeders
- D. Types of Grates
- E. Overfire Air
- F. Fly Carbon Reinjection

10.6 Emissions

References for Presentation Slides

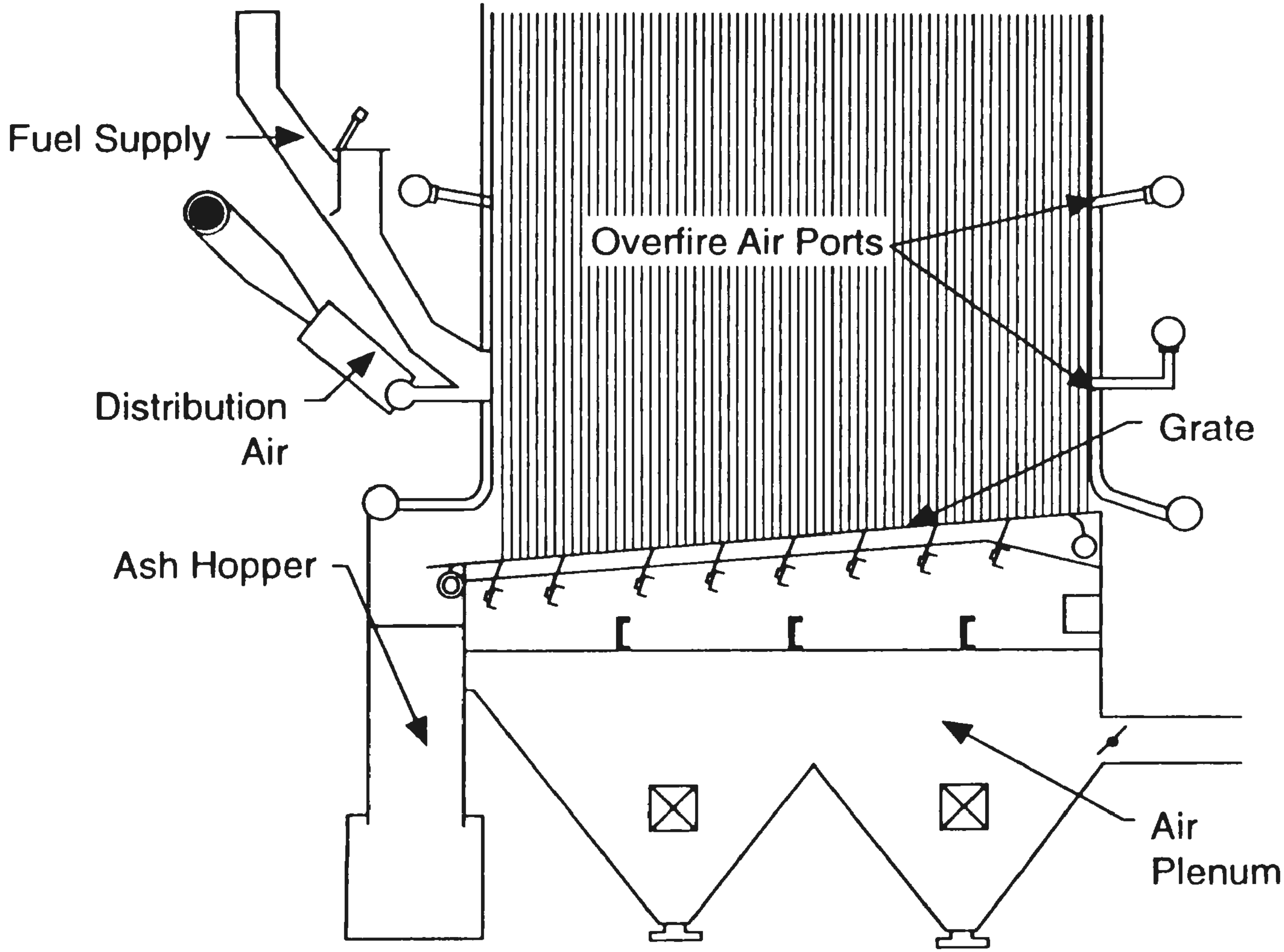
Slide 10-8	*Steam, Its Generation and Use,* 40th Edition, Babcock and Wilcox Company, 1992.
Slide 10-13	Ibid.
Slide 10-16	Elliot, C.T., *Standard handbook of Powerplant Engineering*, McGraw–Hill Publishing Company, New York, 1989.
Slide 10-17	Ibid.
Slide 10-24	*Steam, Its Generation and Use*

CHAPTER 10. STOKERS

COMPONENTS OF A STOKER

Fuel Supply System
Burning Grate
Overfire Air System
Ash Discharge System

VIBRATING GRATE STOKER



Slide 10 - 3

TYPES OF STOKER

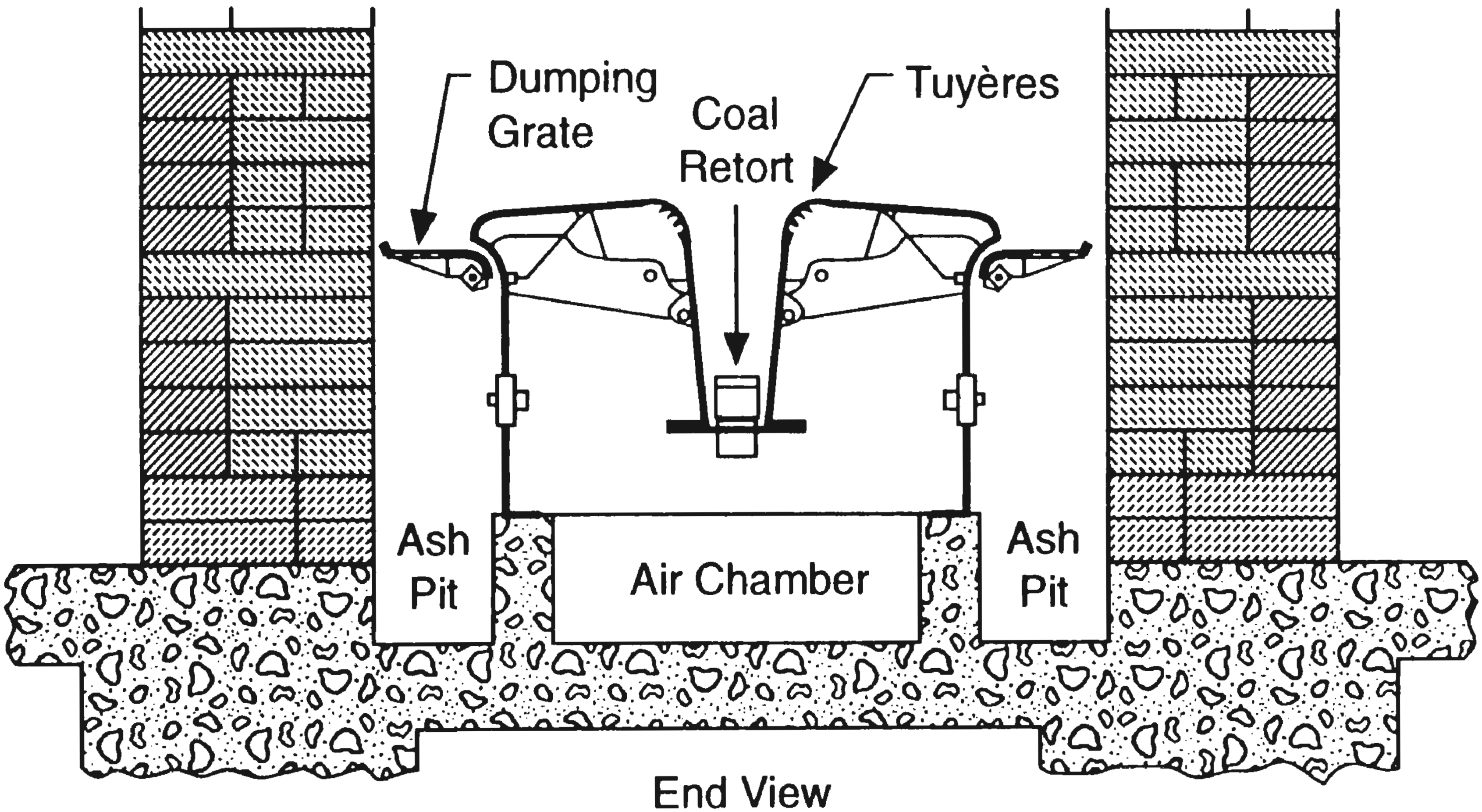
Underfeed System
Overfeed System
- Mass Feed System
- Spreader System

Slide 10 - 4

UNDERFEED STOKERS

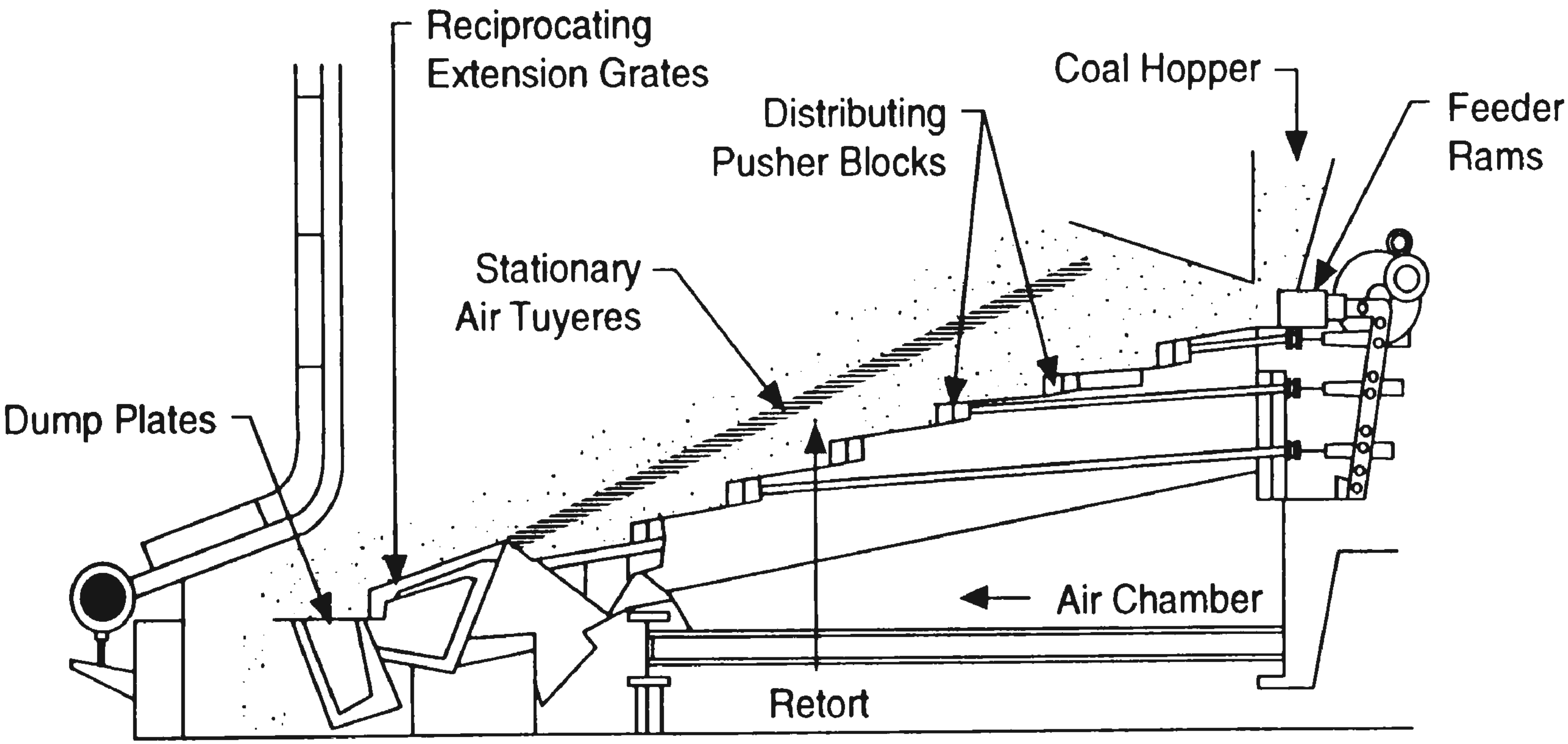
Side Ash Discharge Type
Rear Ash Discharge Type
Coal Specifications
Boiler Furnaces
Overfire Air and Combustion Air

SINGLE RETORT UNDERFIRE STOKER WITH HORIZONTAL FEED, SIDE ASH DISCHARGE



Slide 10 - 6

UNDERFEED STOKER WITH REAR ASH DISCHARGE



Slide 10 - 7

TYPICAL UNDERFEED STOKER COAL CHARACTERISTICS [2]

		Stationary Grate	Moving Grate
Moisture	% vol.	0 to 10	0 to 10
Volatile Matter	% vol.	10 to 40	30 to 40
Fixed Carbon	% vol.	40 to 50	40 to 50
Ash	% vol.	5 to 10	5 to 10
Higher Heating Value	Btu/lb	12,500	12,500
Free Swelling Index		5 max	7 max
Ash Softening Temp.*	°F	2,500**	2,500**
Coal Size	in	1 x 0.25 max 20% through 0.25 with round screen.	Equal portions: 0.25, 0.25 to 0.5, 0.5 to 1.0.

* The ash softening temperature is the temperature at which the height of a molten globule is equal to half its width under reducing atmosphere conditions.

** Below 2500°F the moving grate is derated linearly to 70% of its rated capacity at 2300°F ash fusion temperature. Stationary grates are derated linearly to 70% at 2100°F ash fusion temperature and use steam for temperatures below about 2400°F fusion temperature.

MASS FEED STOKERS

Grate Types

Chain Grate

Traveling Grate

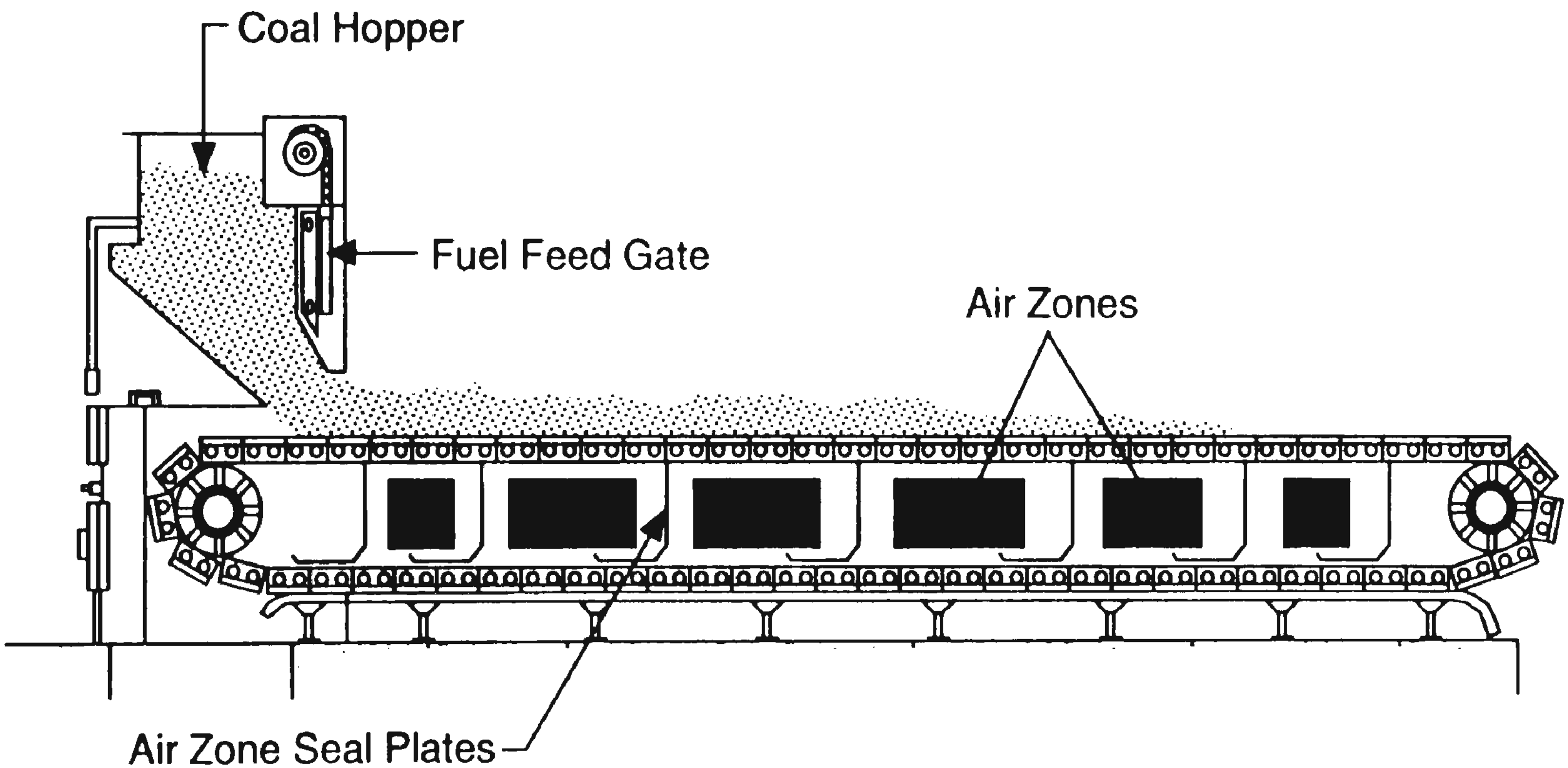
Water-Cooled Vibrating Grate

Coal Specifications

Furnace Design

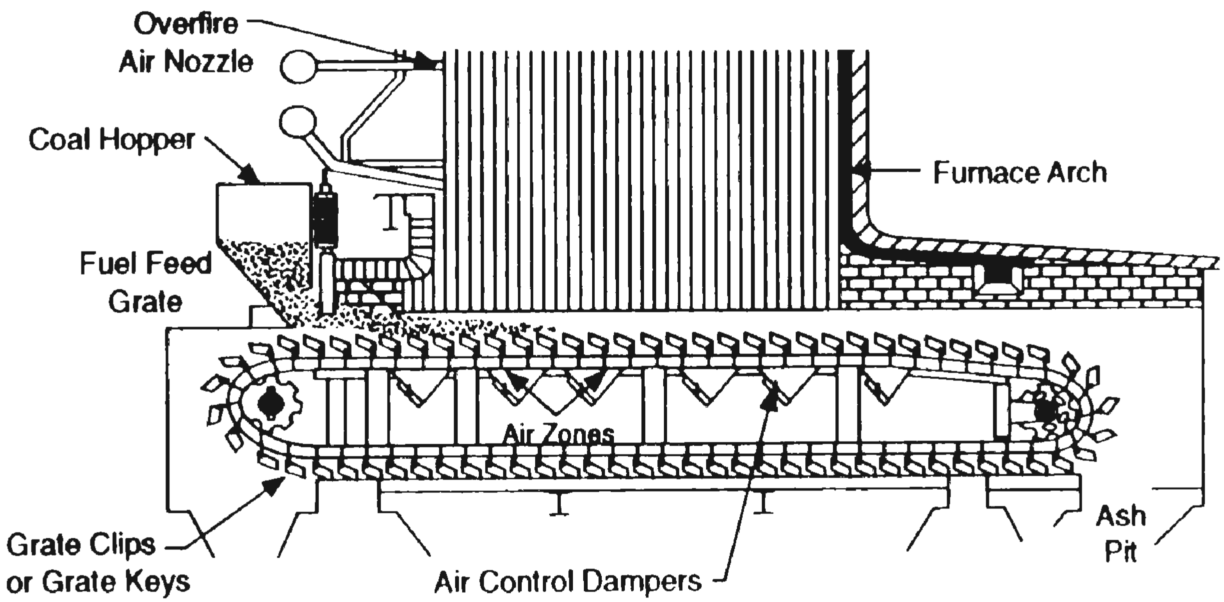
Overfire Air

CROSS SECTION OF OVERFEED MASS–BURNING CHAIN–GRATE STOKER



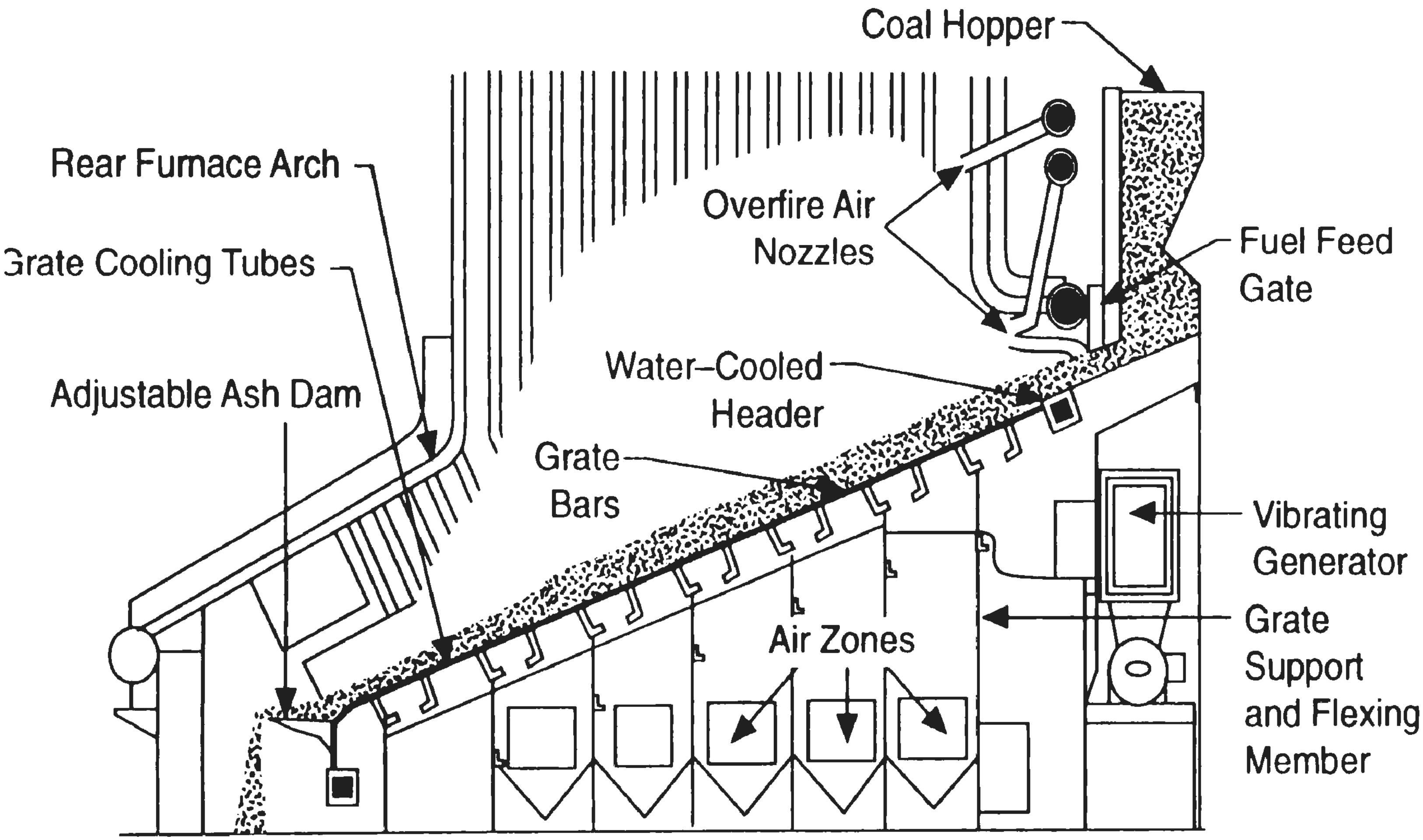
Slide 10 - 10

CROSS SECTION OF OVERFEED MASS-BURNING TRAVELING-GRATE STOKER



Slide 10 - 11

WATER–COOLED, VIBRATING–GRATE STOKER



Slide 10 - 12

TYPICAL MASS STOKER COAL CHARACTERISTICS [2]

		Chain/Traveling Grate	Water-Cooled Grate
Moisture	% vol.	0 to 10	0 to 10
Volatile Matter	% vol.	10 to 40	30 to 40
Fixed Carbon	% vol.	40 to 50	40 to 50
Ash	% vol.	5 to 10	5 to 10
Higher Heating Value	Btu/lb	12,500	12,500
Free Swelling Index		5 max	7 max
Ash Softening Temp.*	°F	2,500	2,500
Coal Size	in	1 x 0.25 max 20% through 0.25 with round screen.	Equal portions: 0.25, 0.25 to 0.5, 0.5 to 1.0.

* See Slide 10-8 for definition.

Slide 10 - 13

SPREADER STOKERS

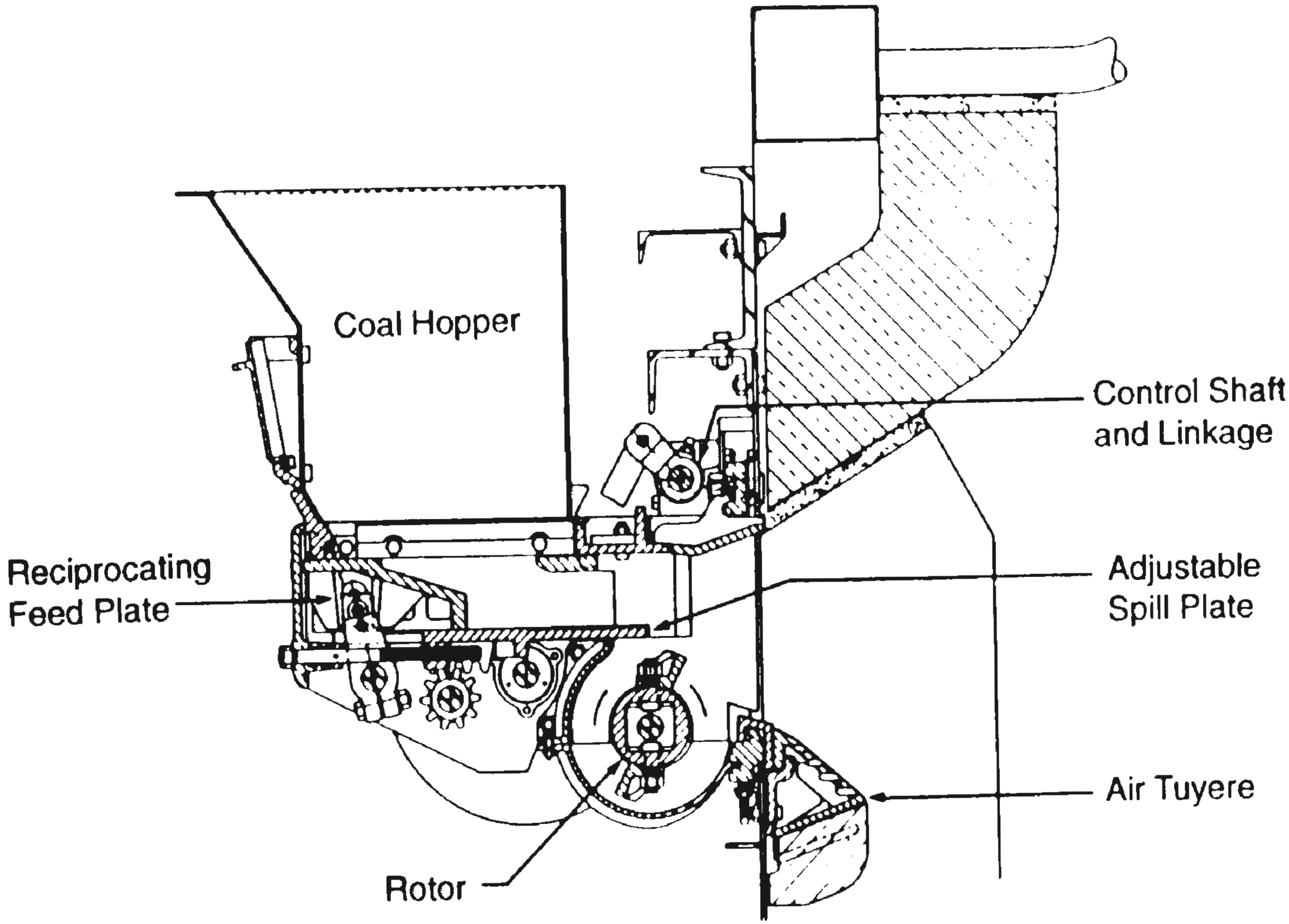
- Fuels
- Fuel Burning
- Fuel Feeders
- Types of Grates
- Overfire Air
- Fly Carbon Reinjection

Slide 10 - 14

FUEL FEEDERS

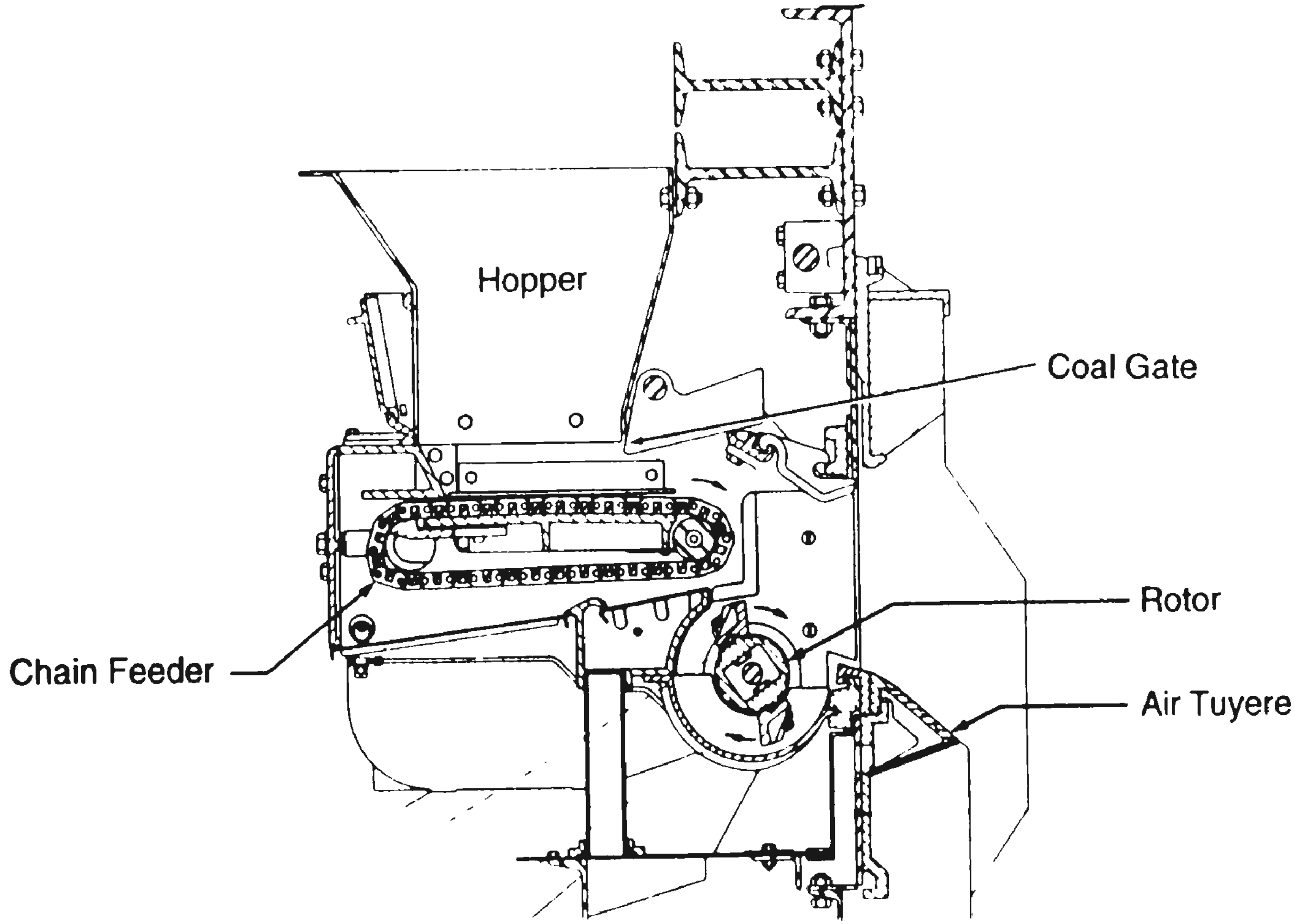
Reciprocating Feeder
Chain Feeder
Drum Feeder

RECIPROCATING COAL FEEDER[3]



Slide 10 - 16

CHAIN–TYPE COAL FEEDER[3]

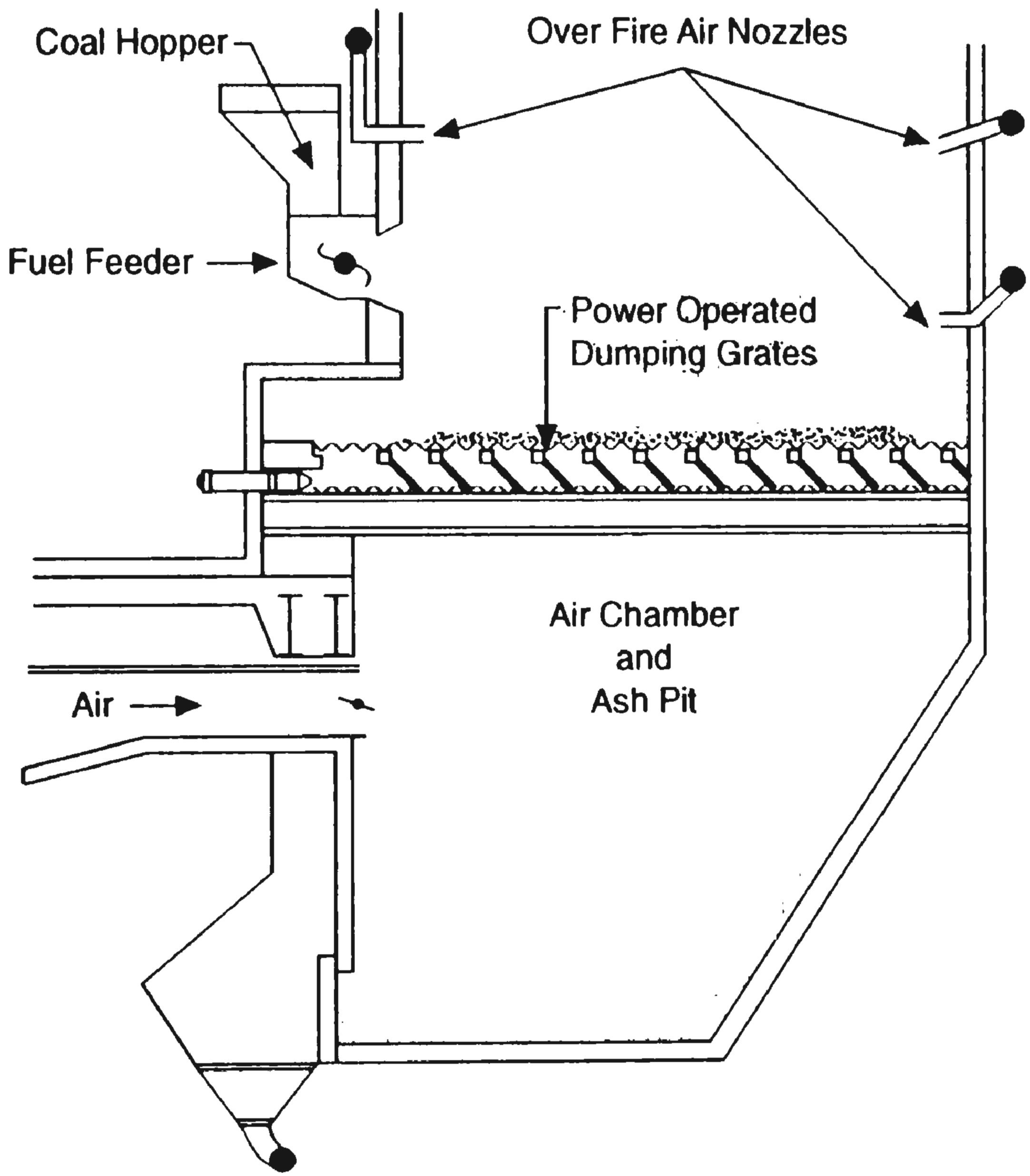


Slide 10 - 17

TYPES OF GRATES

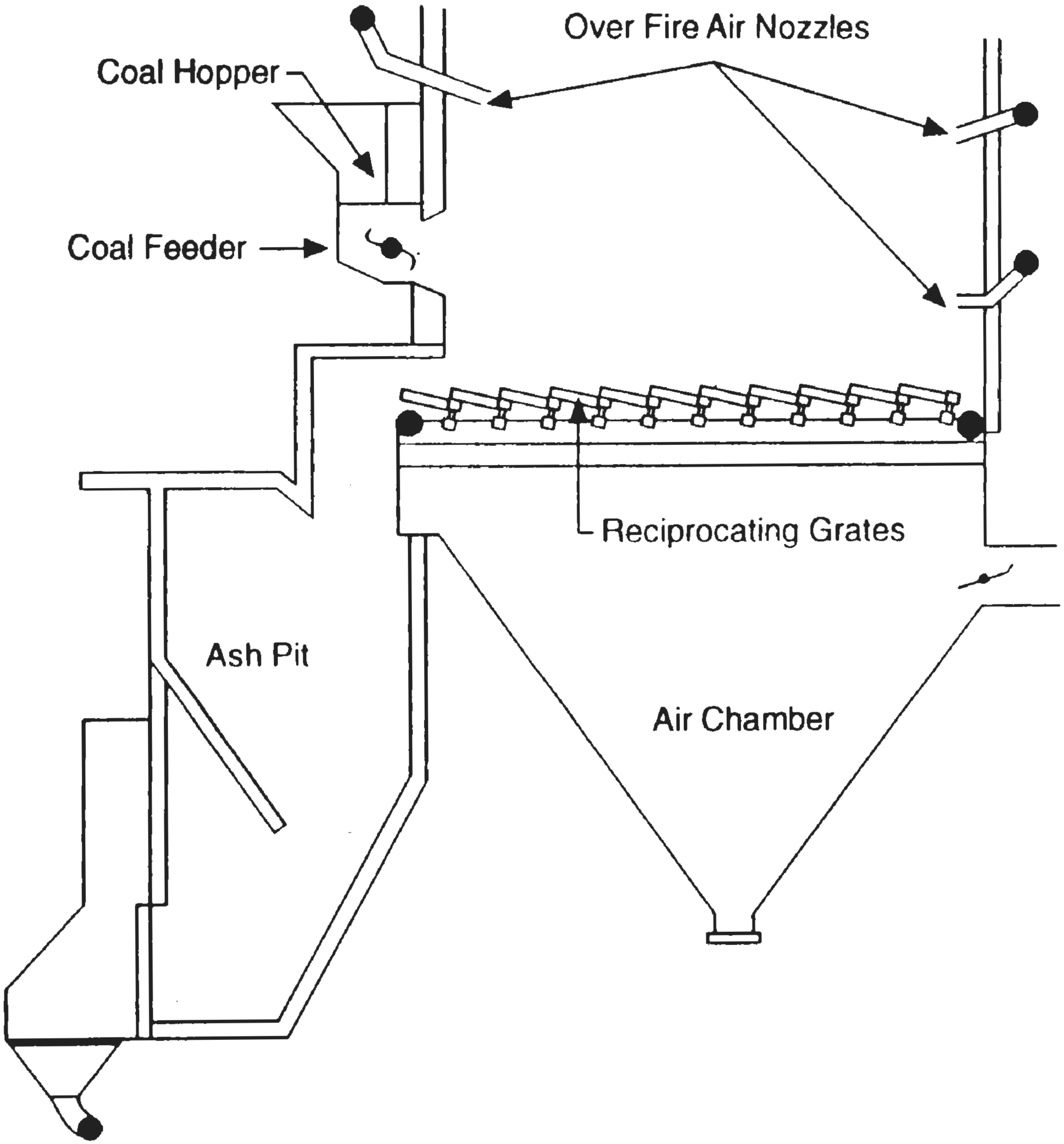
Stationary and Dumping
Reciprocating
Vibrating
Traveling
Vibrating, Water-Cooled

SPREADER STOKER WITH DUMPING GRATES



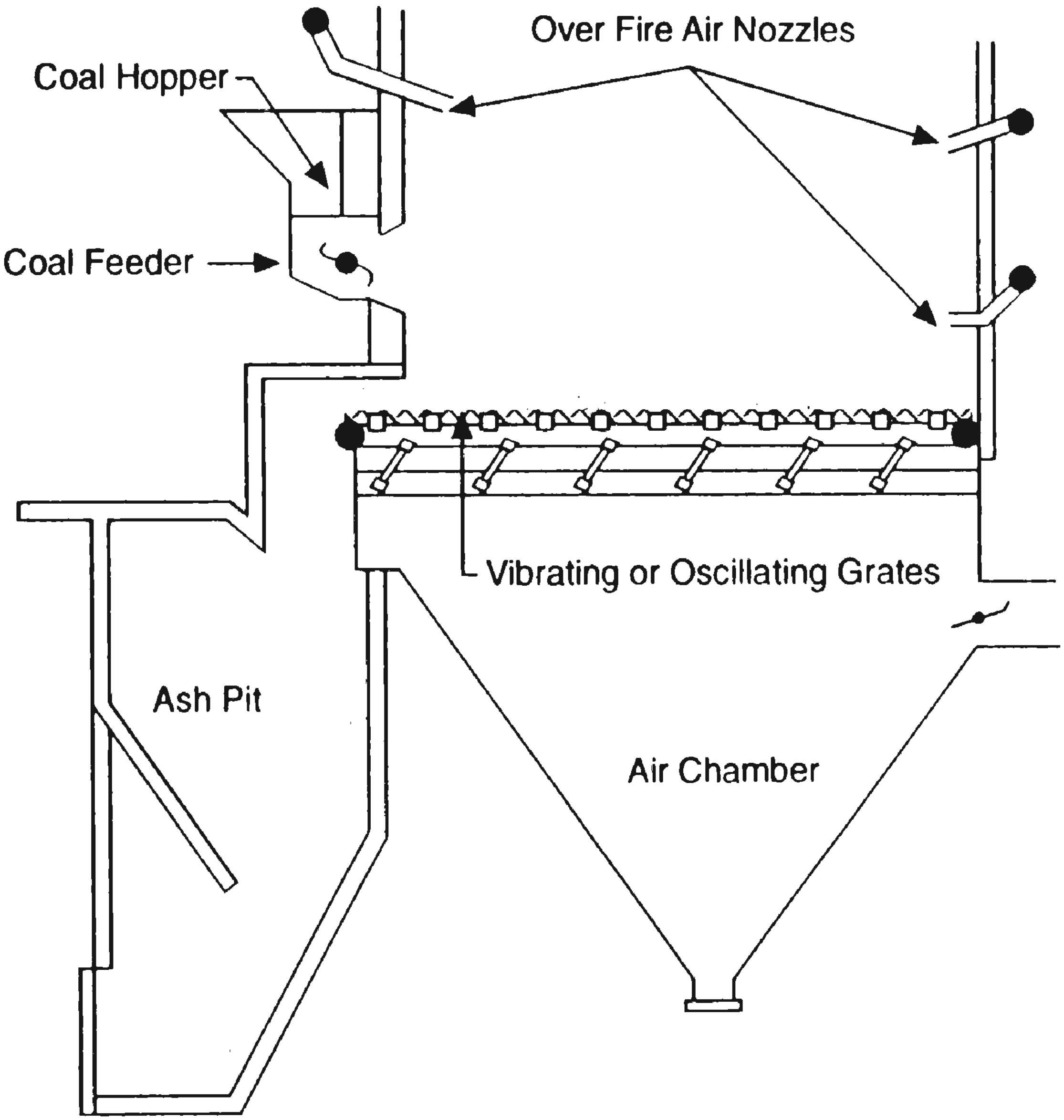
Slide 10 - 19

SPREADER STOKER WITH RECIPROCATING GRATES



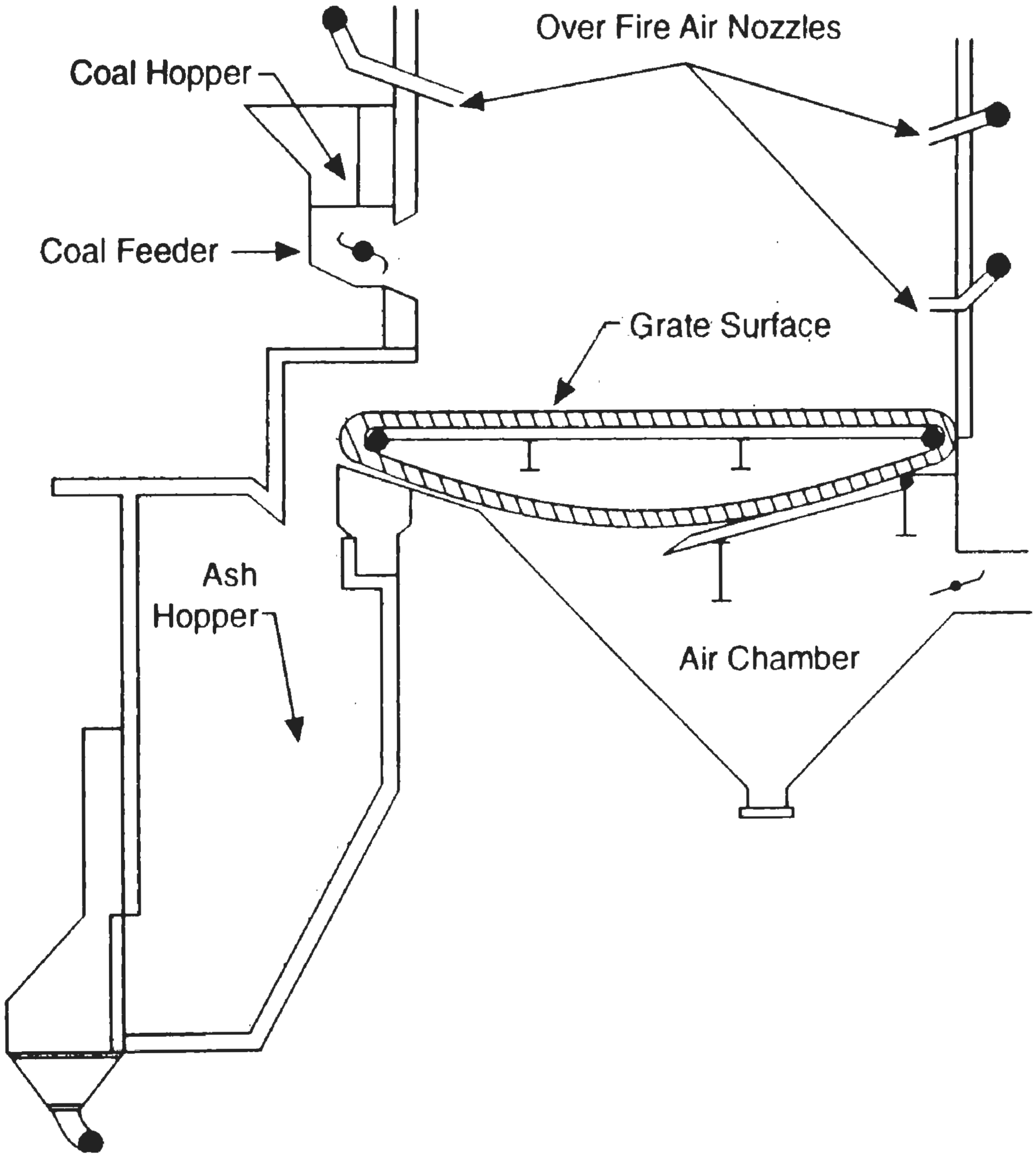
Slide 10 - 20

SPREADER STOKER WITH VIBRATING GRATES

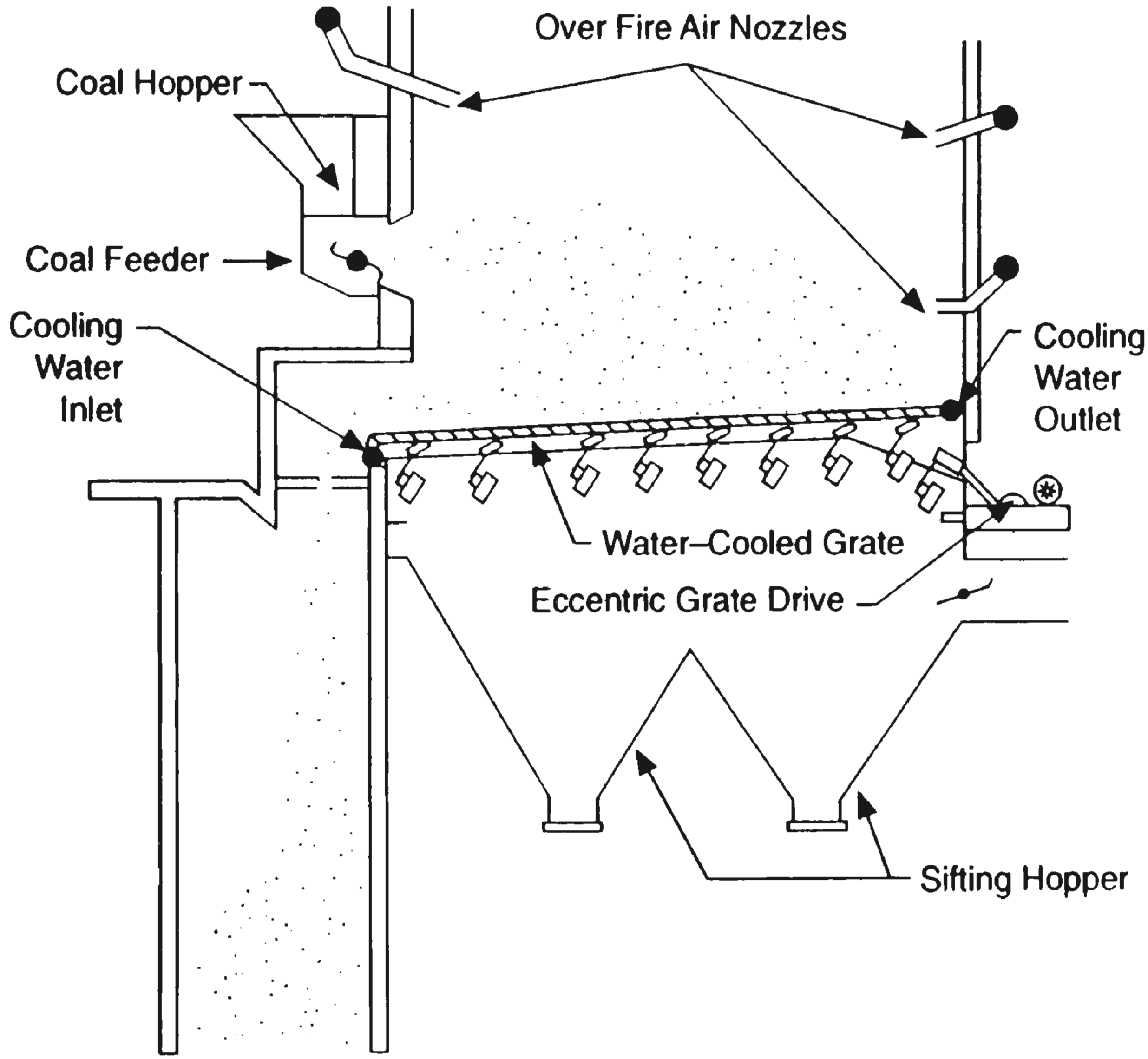


Slide 10 - 21

SPREADER STOKER WITH TRAVELING GRATES



SPREADER STOKER WITH WATER-COOLED VIBRATING GRATES



Slide 10 - 23

TYPICAL UNCONTROLLED EMISSIONS FOR SPREADER–STOKER FIRING [2]

	NO_x (as NO_2) lb/MM Btu	CO lb/MM Btu	Unburned with Reinjection	Carbon Loss* without Reinjection
Bituminous	0.35 to 0.50	0.05 to 0.30	0.5 to 2.0	3 to 6
Subbituminous	0.30 to 0.50	0.05 to 0.30	0.5 to 1.5	3 to 5
Lignite	0.30 to 0.50	0.10 to 0.30	0.5 to 1.5	3 to 5

* % of Heat Input

LESSON PLAN

CHAPTER 11. FLUIDIZED–BED BOILERS.

Goal: To present the participant with the key benefits of fluidized–bed boilers and give an overview of the design and operating characteristics.

Objectives:

Upon completion of this unit an operator should be able to:

1. Describe the 4 different conditions characterizing the interaction between the bed particles and air flow through the bed.
2. Identify the advantages of fluidized bed combustion over more conventional combustion systems.
3. Understand the control parameters for operating fluidized bed boilers.
4. Understand the concept of bed–inventory and its importance to heat release in the operation of a fluidized bed boiler.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

Can anyone explain what some of the advantages are with fluidized bed boilers?

What kind of fuels are best for a fluidized bed boiler?

Presentation Outline:

11.1 Introduction

11.2 Typical Fluidized–Bed Conditions

11.3 Fluidized–Bed Combustion Advantages
- A. Reduced Emissions
- B. Fuel Flexibility

11.4 Atmospheric Pressure Fluidized–Bed Boilers
- A Bubbling Bed
- B. Circulating Bed

Presentation Outline (Continued):

11.5 Fluidized–Bed Boiler Furnace Design
- A. Design Information
- B. Bed Material
- C. Pressure Drop
- D. Heat Transfer
- E. Heat and Material Balance

11.6 Fluidized–Bed Boiler Arrangements
- A. Boiler Subsystems
- B Auxiliary Equipment

11.7 Operation
- A. System Control
- B. Bed Temperature Control
- C. Bed Material Inventory Control
- D. Overfire Air Control

11.8 Emissions
- A. Sulfur Dioxide
- B. Nitrogen Oxides
- C. Carbon Monoxide and Hydrocarbons
- D. Particulate

References for Presentation Slides

Slide 11-3 *Steam, Its Generation and Use*, 40th Edition, Babcock and Wilcox Company, 1992.

Slide 11-5 Ibid.

Slide 11-6 Ibid.

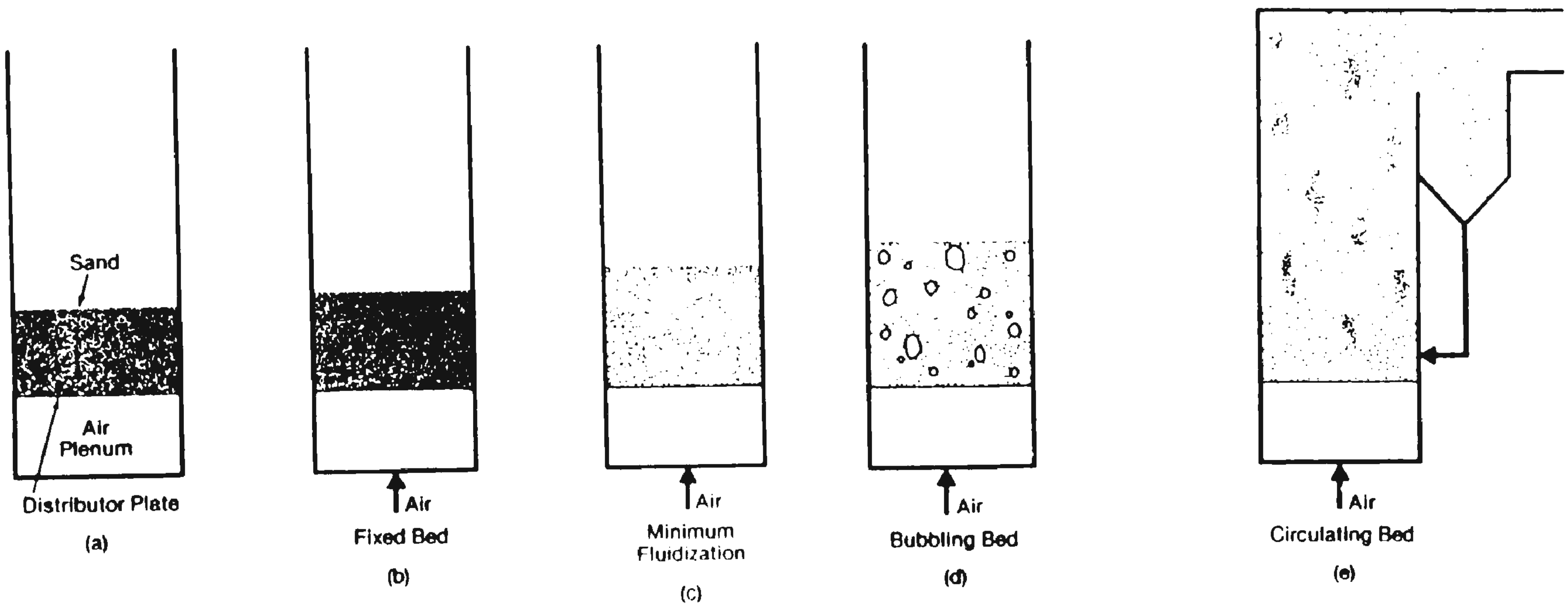
Slide 11-7 Ibid.

CHAPTER 11. FLUIDIZED–BED BOILERS

FLUIDIZED-BED BOILERS

Typical Fluidized–Bed Conditions
Fluidized–Bed Combustion Advantages
Atmospheric Pressure Fluidized–Bed Boilers
Fluidized–Bed Boiler Furnace Design
Fluidized–Bed Boiler Arrangements

TYPICAL FLUIDIZED–BED CONDITIONS[1]



Slide 11 - 3

FLUIDIZED–BED COMBUSTION ADVANTAGES

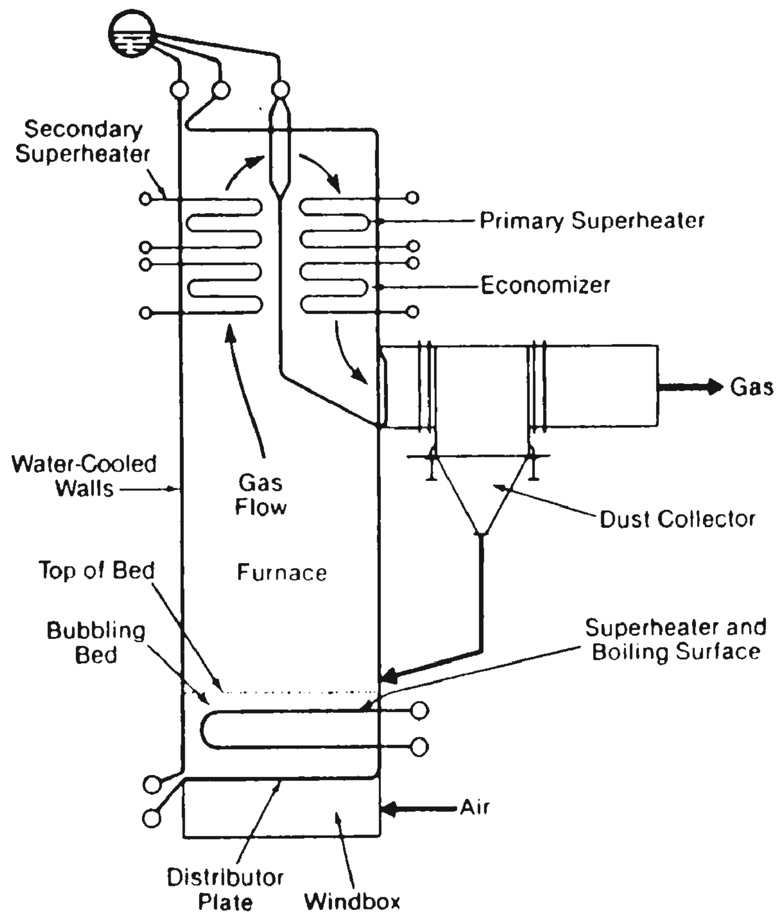
Reduced Emissions

- SO_2
- NO_x

Fuel Flexibility

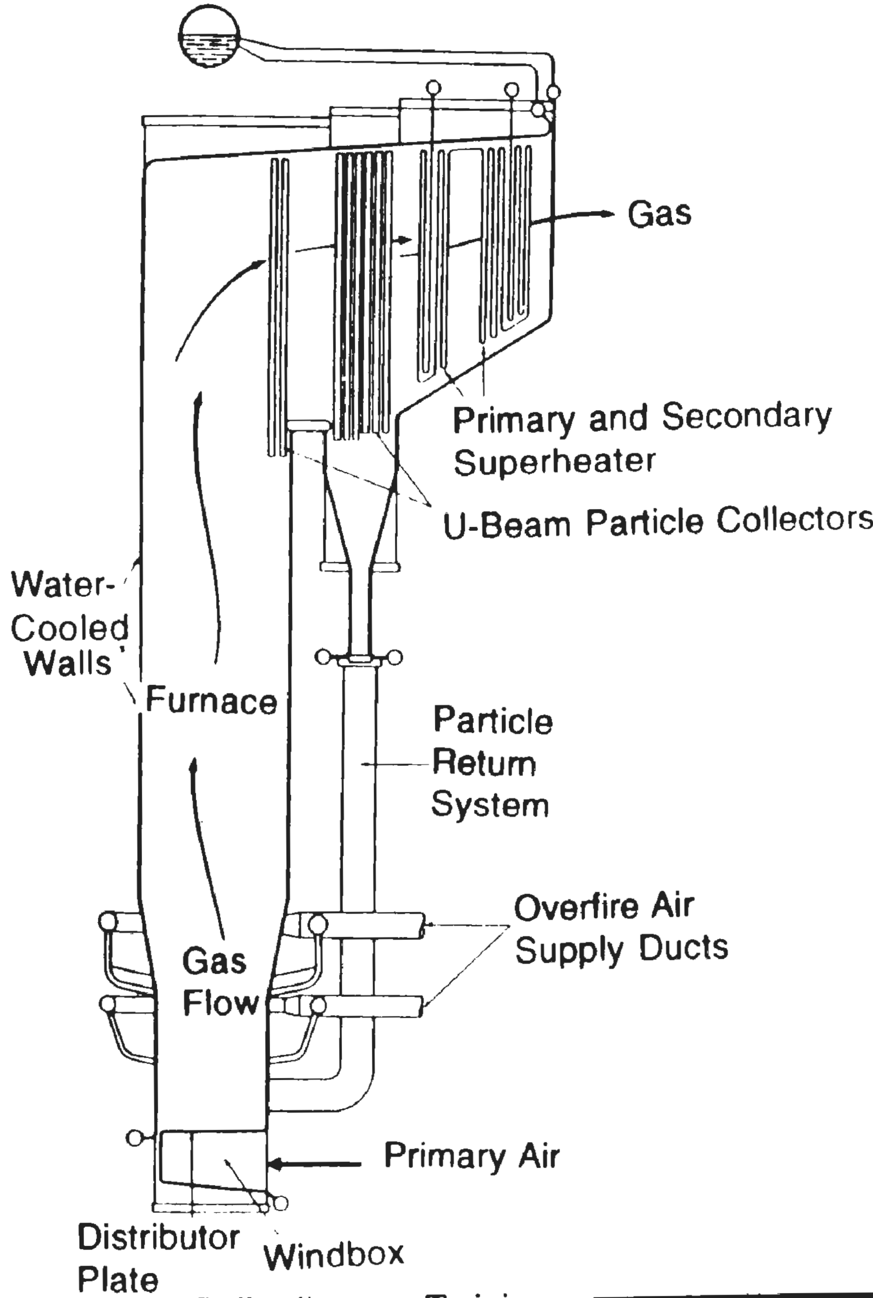
- Fuel Ash Properties
- Low Btu Fuels
- Fuel Preparation

TYPICAL BUBBLING FLUIDIZED–BED BOILER SCHEMATIC[1]



Slide 11 - 5

TYPICAL CIRCULATING–BED BOILER SCHEMATIC[1]



Slide 11 - 6

FLUIDIZED–BED BOILER FURNACE DESIGN

Design Information
Bed Material
Pressure Loss
Heat Transfer

FLUIDIZED-BED BOILER ARRANGEMENTS

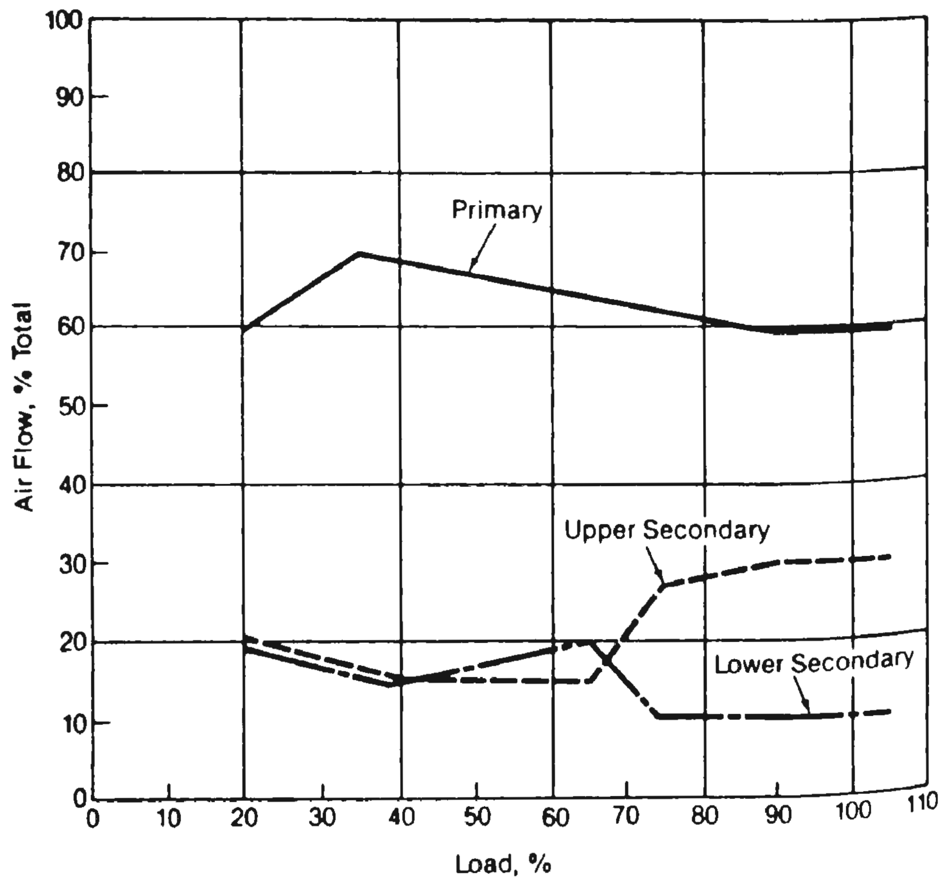
Boiler Subsystem
- Distributor Plate
- Overfire Air System
- Boiler Furnace

Auxiliary Equipment
- Fuel Feed System
- Sorbent Feed System
- Ash Removal System
- Sootblowers

OPERATION

System Control
Bed Temperature Control
Bed Material Inventory Control
Overfire Air Control

AIR FLOW DISTRIBUTION[1]



Slide 11 - 10

FLUIDIZED-BED BOILER EMISSIONS

Sulfur Dioxide
Nitrogen Oxides
Carbon Monoxide and Hydrocarbon
Particulates

LESSON PLAN

CHAPTER 12. GAS TURBINE WITH A HEAT RECOVERY STEAM GENERATOR.

Goal: To give the participant a general description of both gas turbine and the heat recovery steam generators.

Objectives:

Upon completion of this unit an operator should be able to:

1. List the three components comprising the gas turbine.
2. Describe the principle power generation process from combustion in a gas turbine.
3. Understand that turbine power is directly related to mass throughput and therefore temperature and pressure ratios of a gas turbine are major factors influencing the efficiency.
4. Identify the 3 combustor types found in gas turbines.
5. Discuss the different operating cycles used in power generation.
6. Understand the fact that NO_x formation in gas turbines is predominantly thermal NO_x and therefore combustion temperatures are the major factor in controlling NO_x emissions
7. Discuss different emission control processes available to G.T. operation.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

What is cogeneration?

What are the main components of a turbine?

Presentation Outline:

12.1 Introduction

12.2 Gas Turbine Description

Presentation Outline (Continued):

12.3 Design Classifications

12.4 Operating Cycles and Efficiency

12.5 NO_x Formation Mechanisms

12.6 Control Options

CHAPTER 12. GAS TURBINE WITH A HEAT RECOVERY STEAM GENERATOR

12.1 Introduction

12.2 Gas Turbine Description

12.3 Design Classifications

12.4 Operating Cycles and Efficiency

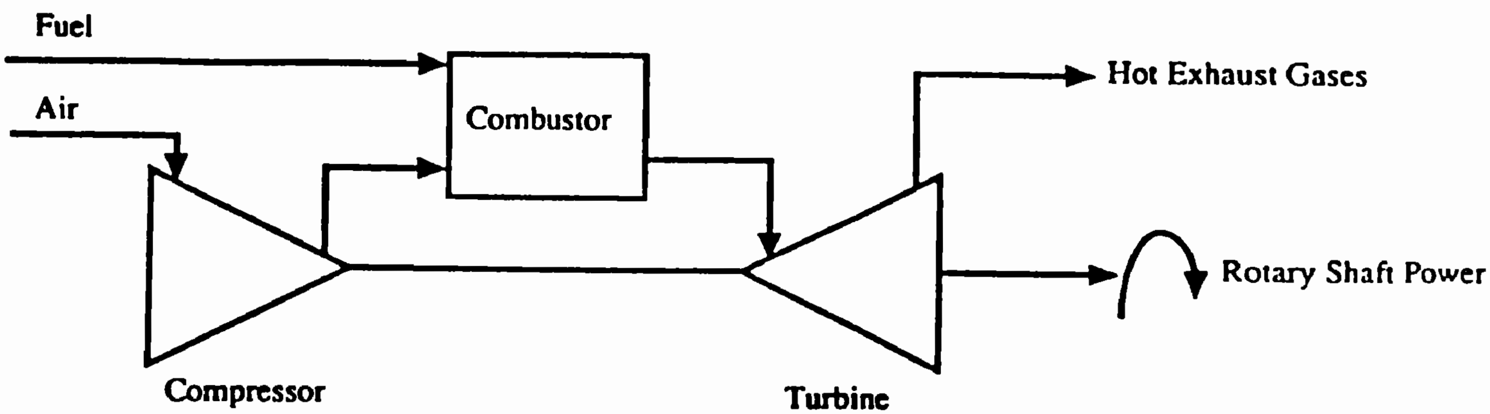
12.5 NO_x Formation Mechanisms

12.6 Control Options

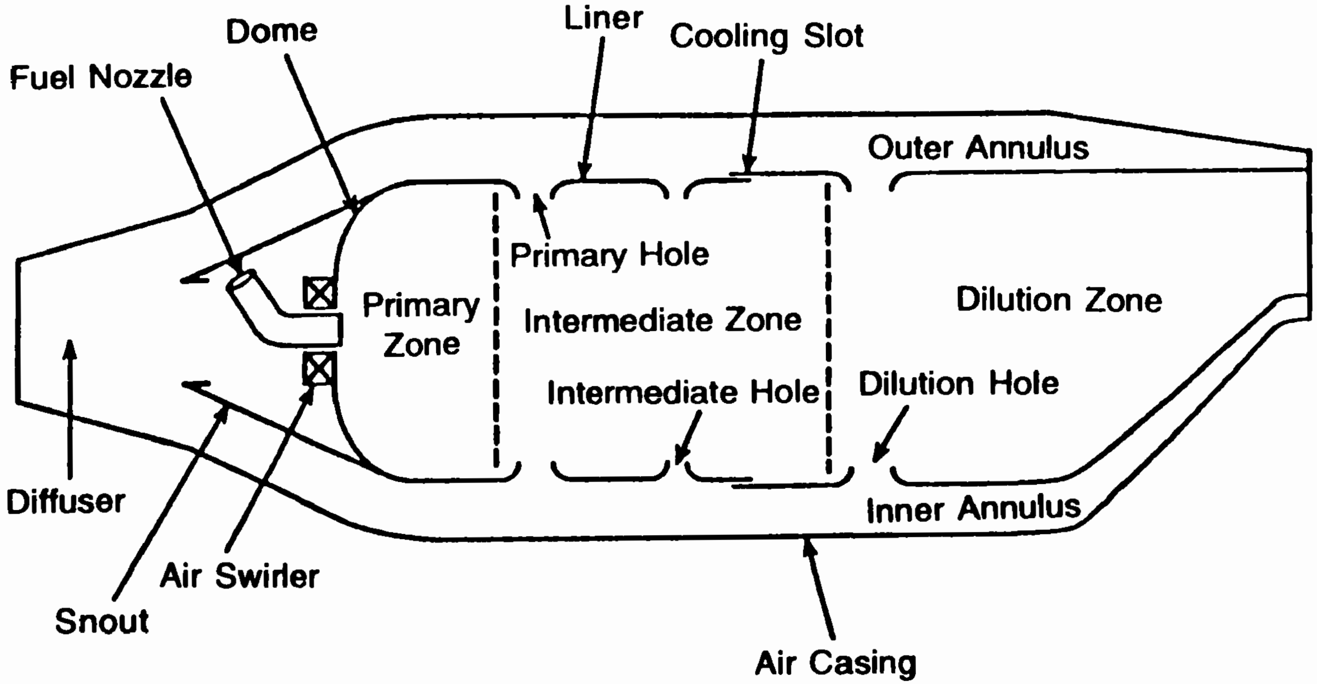
GAS TURBINE COMPONENTS

- Compressor
- Combustor
- Turbine

SIMPLIFIED GAS TURBINE SCHEMATIC



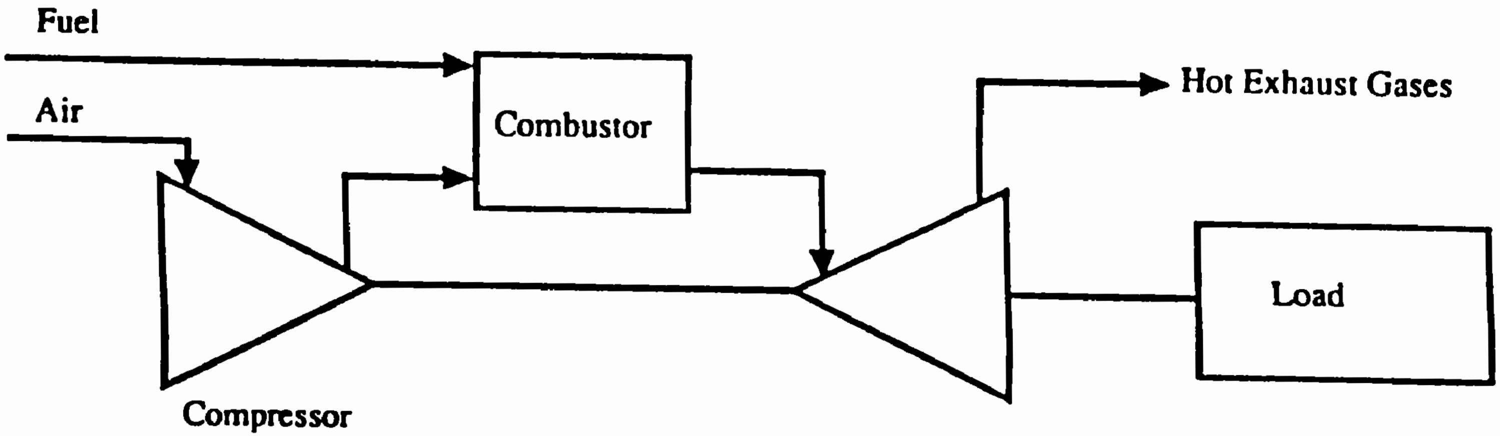
SCHEMATIC OF A TYPICAL SGT COMBUSTOR



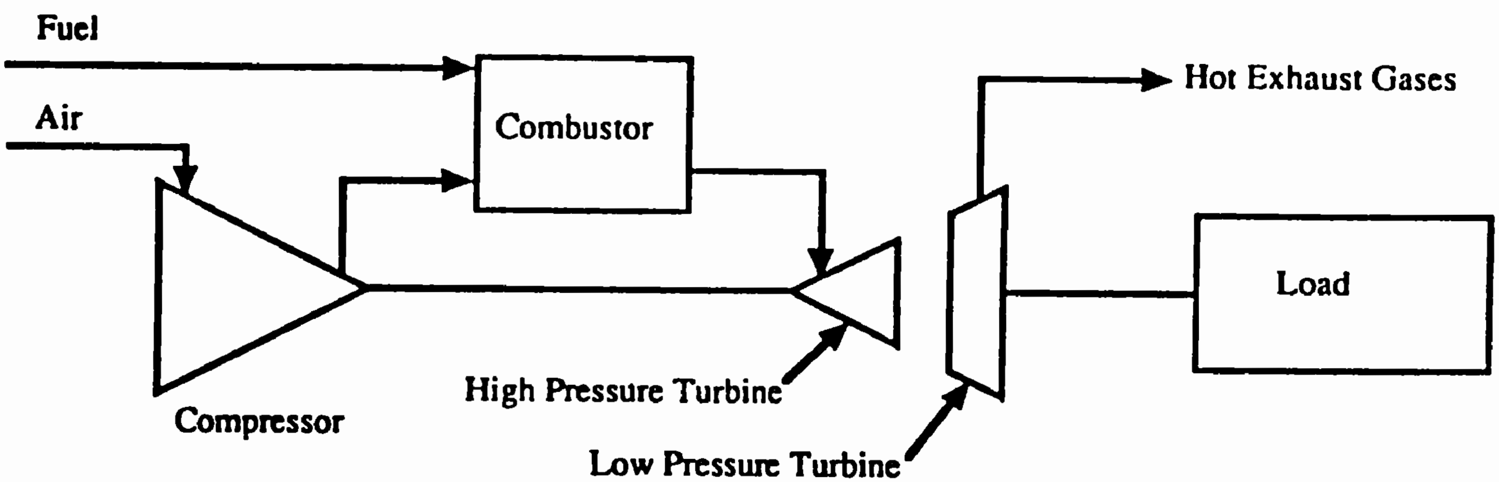
DESIGN CLASSIFICATIONS

- Single-Shaft or Dual Shaft
- Aero-Derivative or Heavy Duty
- Combustor Design

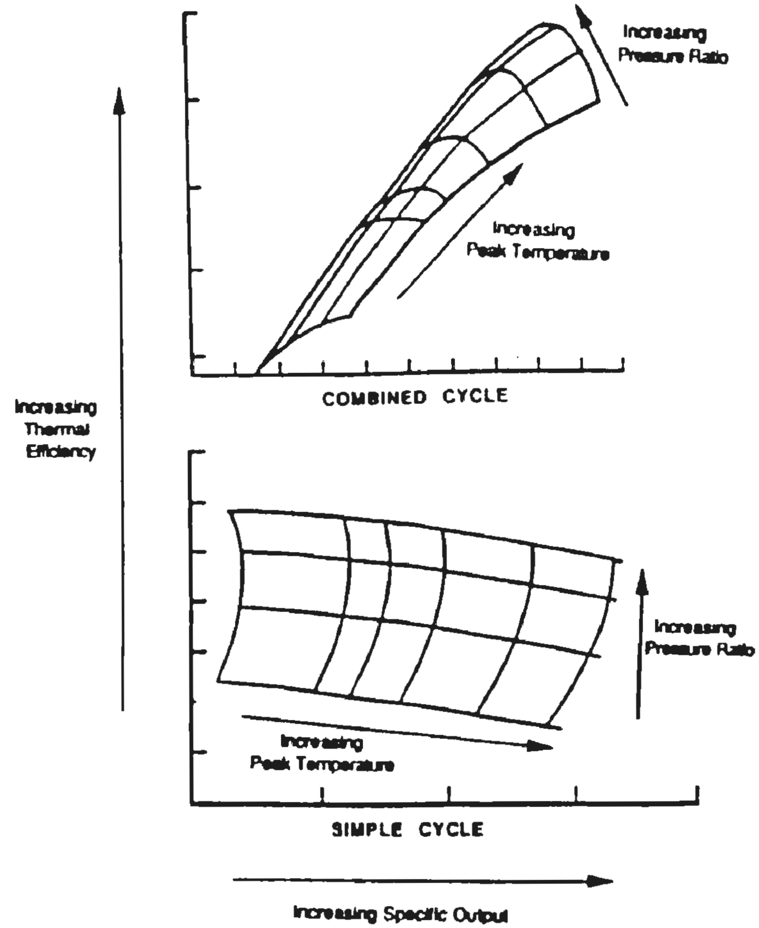
SINGLE–SHAFT GAS TURBINE



DOUBLE–SHAFT GAS TURBINE



EFFECT OF TEMPERATURE AND PRESSURE ON THERMAL EFFICIENCY

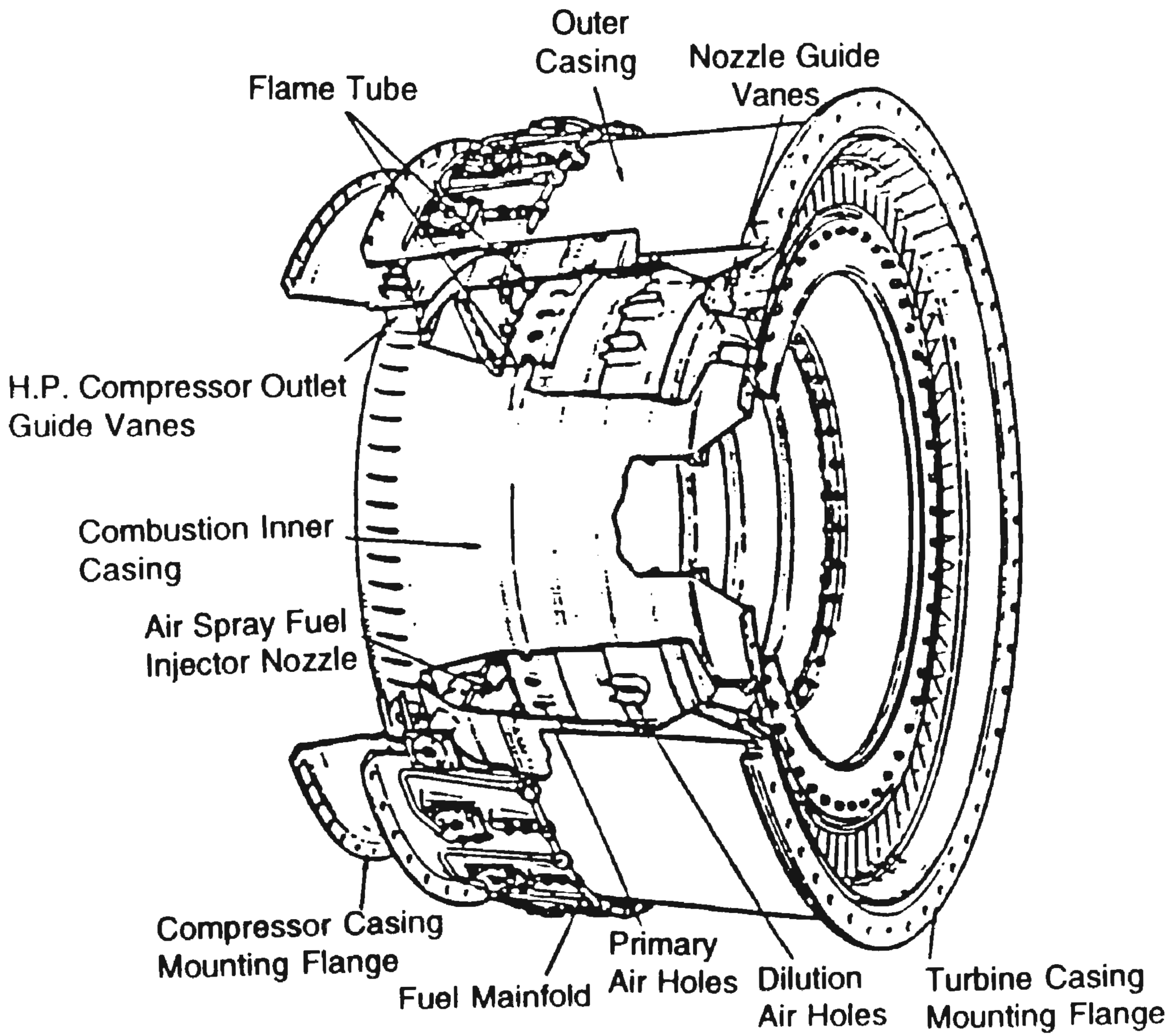


Slide 12 - 8

COMBUSTOR DESIGN

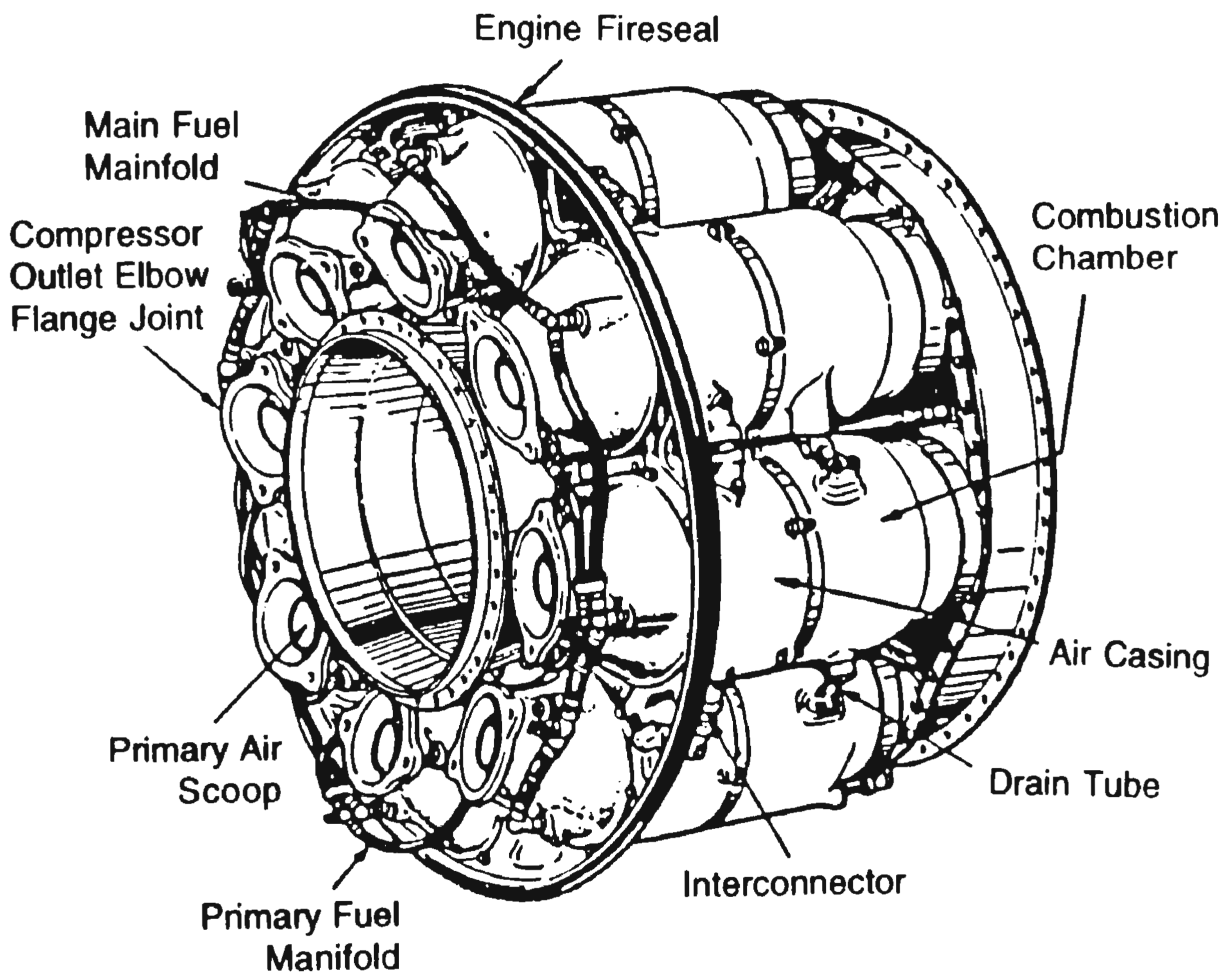
- Annular
- Can-Annular
- Silo

ANNULAR COMBUSTOR



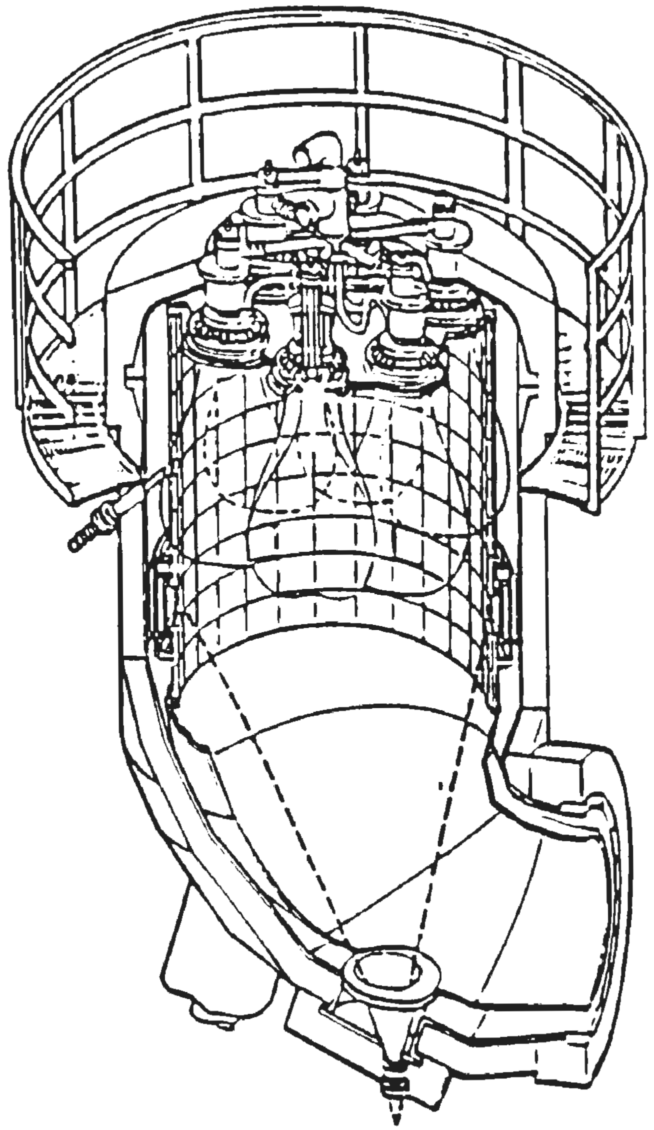
Slide 12 - 10

CAN-ANNULAR COMBUSTOR



Slide 12 - 11

SILO COMBUSTOR

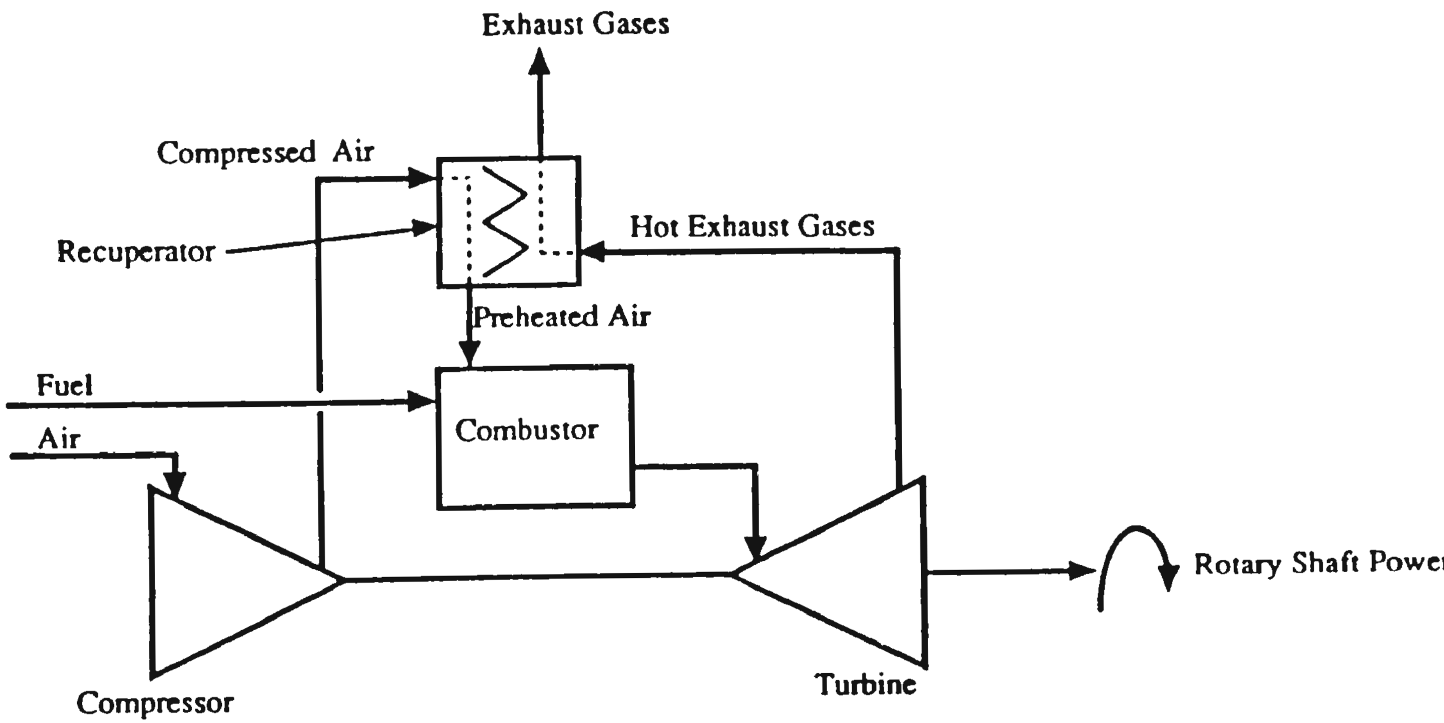


Slide 12 - 12

OPERATING CYCLE

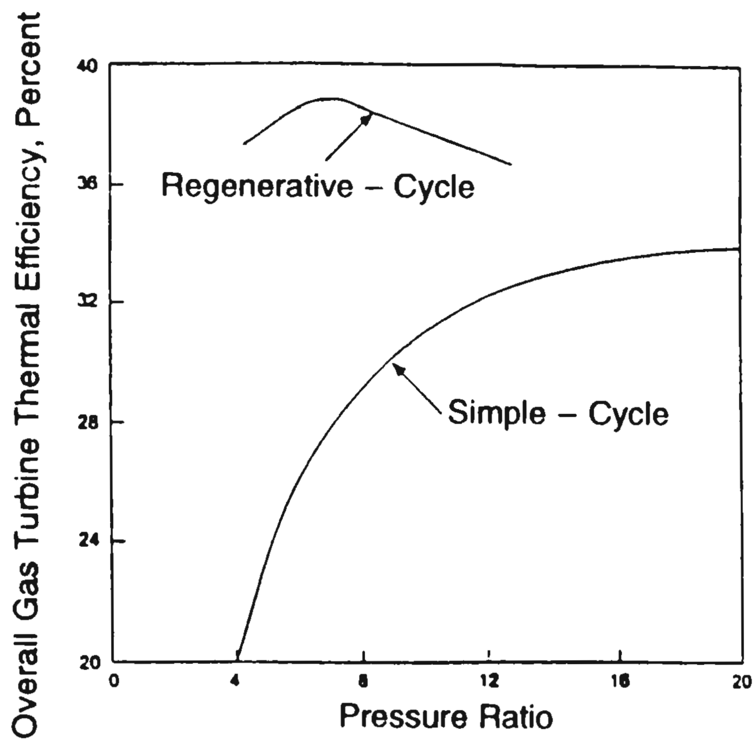
- Efficiency
- Simple Cycle
- Regeneration
- Cogeneration
- Combined Cycle

REGENERATIVE CYCLE GAS TURBINE



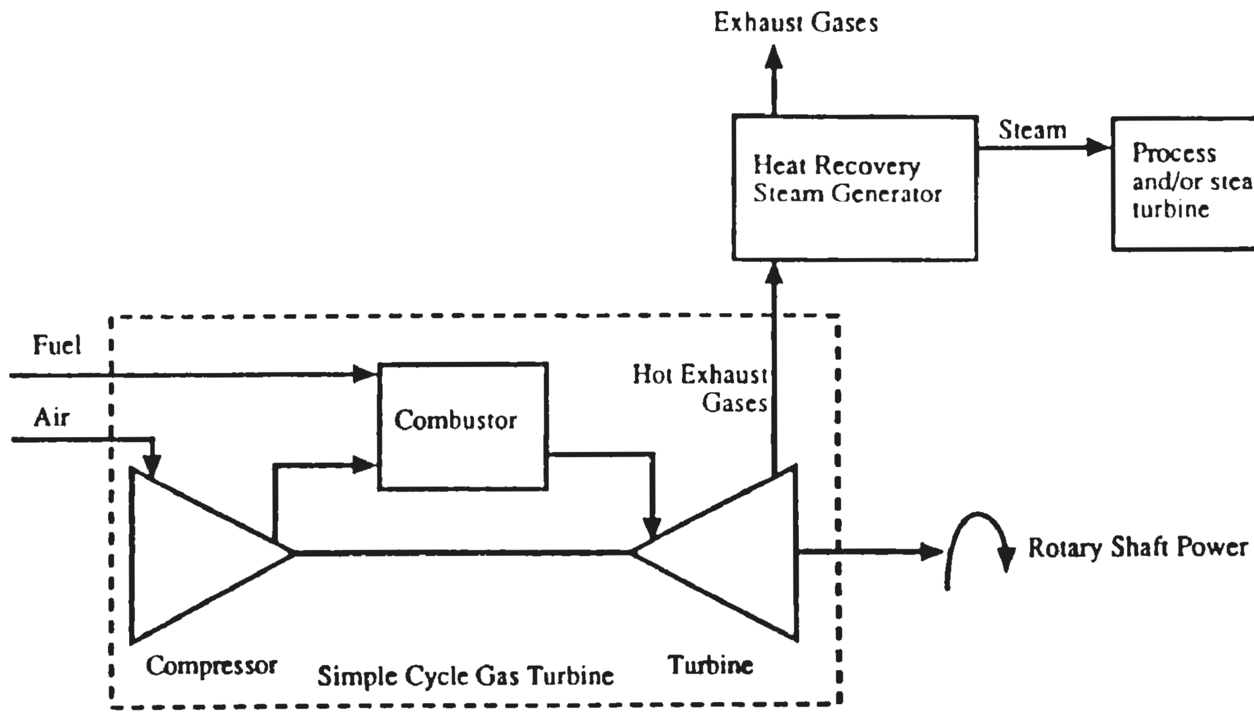
Slide 12 - 14

EFFECT OF REGENERATIVE CYCLE ON GT THERMAL EFFICIENCY



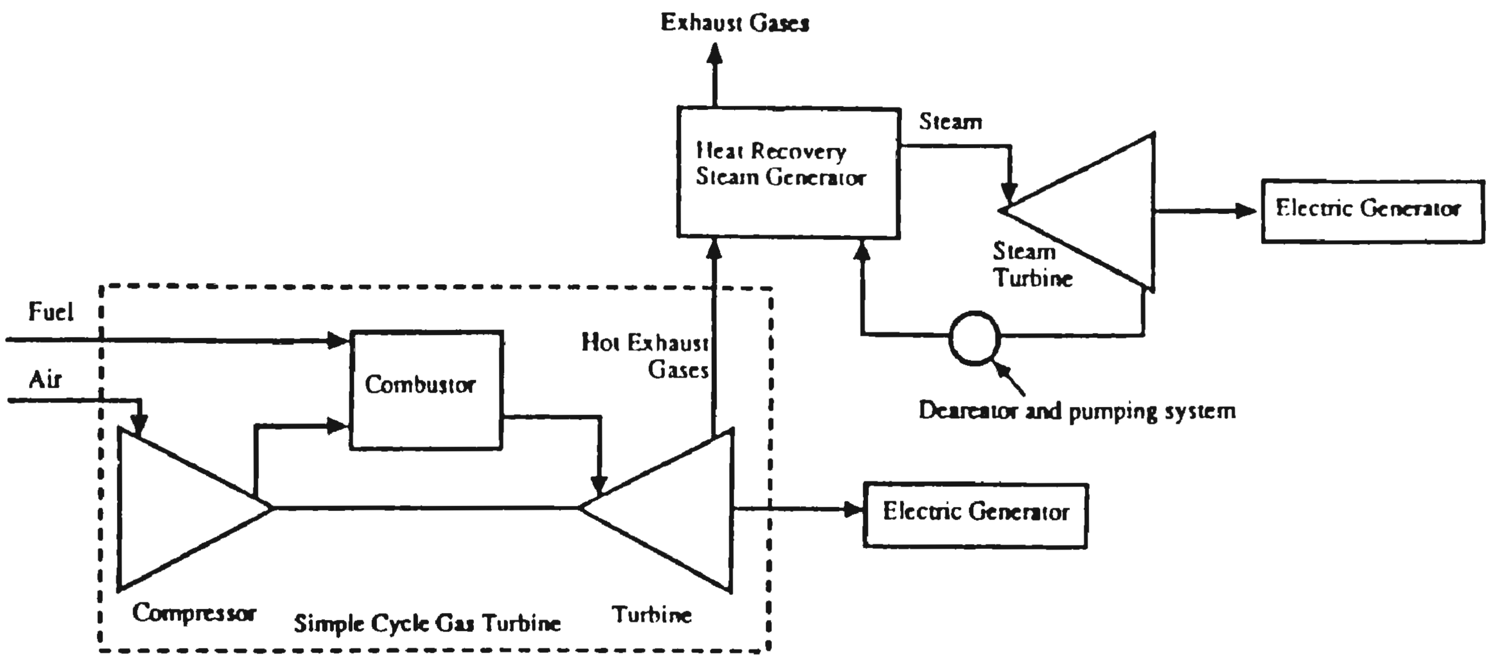
Slide 12 - 15

STATIONARY GAS TURBINE COGENERATION UNIT



Slide 12 - 16

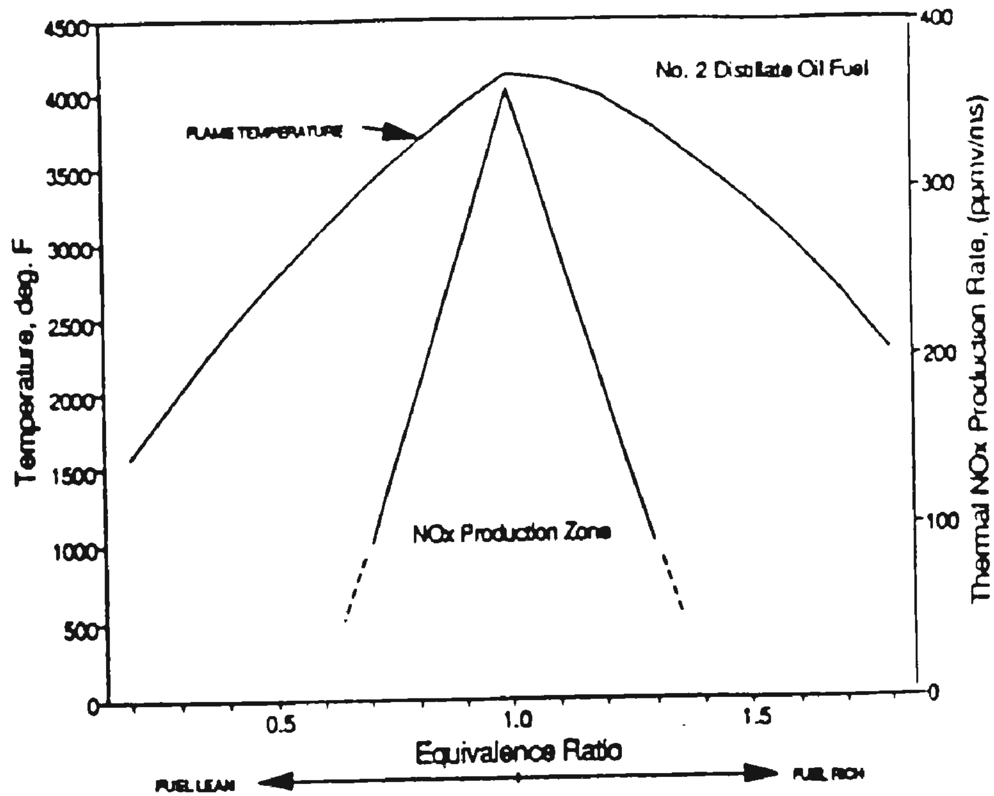
STATIONARY GAS TURBINE COMBINED CYCLE UNIT



GAS TURBINE CHARACTERISTICS THAT DETERMINE NO_x EMISSIONS

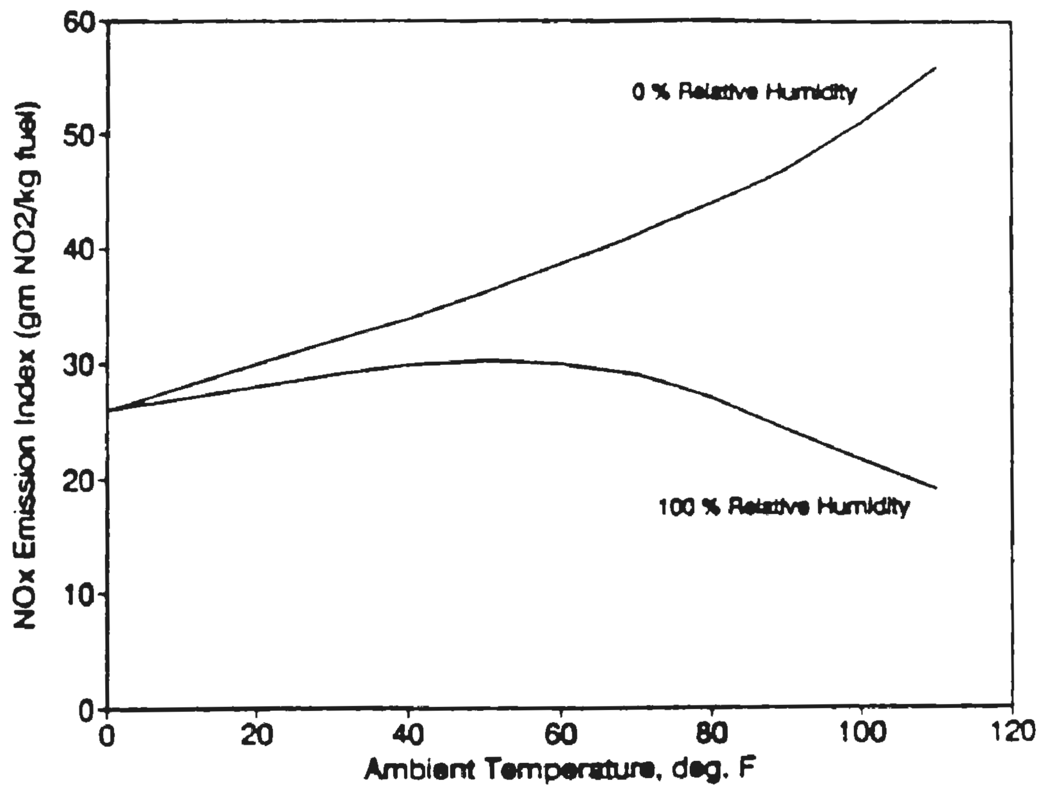
- Combustor Design
- Type of Fuel
- Ambient Conditions
- Operating Cycle
- Output Level

THERMAL NO_x PRODUCTION AS A FUNCTION OF FLAME TEMPERATURE AND EQUIVALENCE RATIO



Slide 12 - 19

EFFECT OF HUMIDITY AND TEMPERATURE ON NO_X



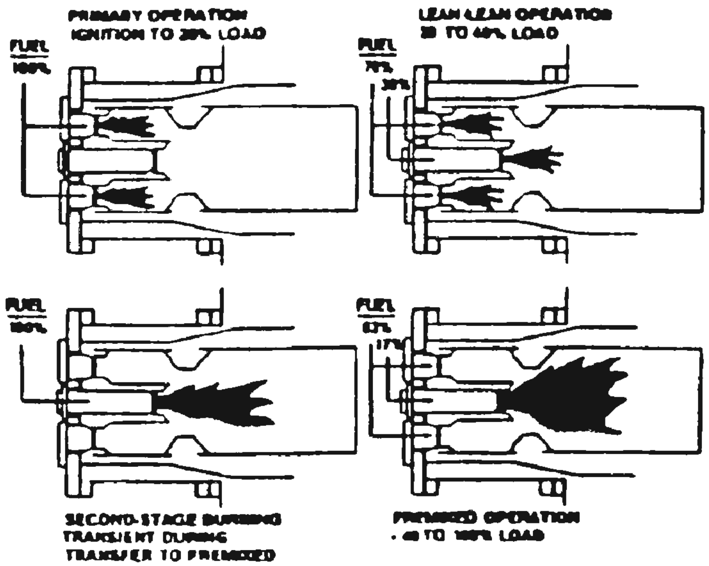
CONTROL OPTIONS

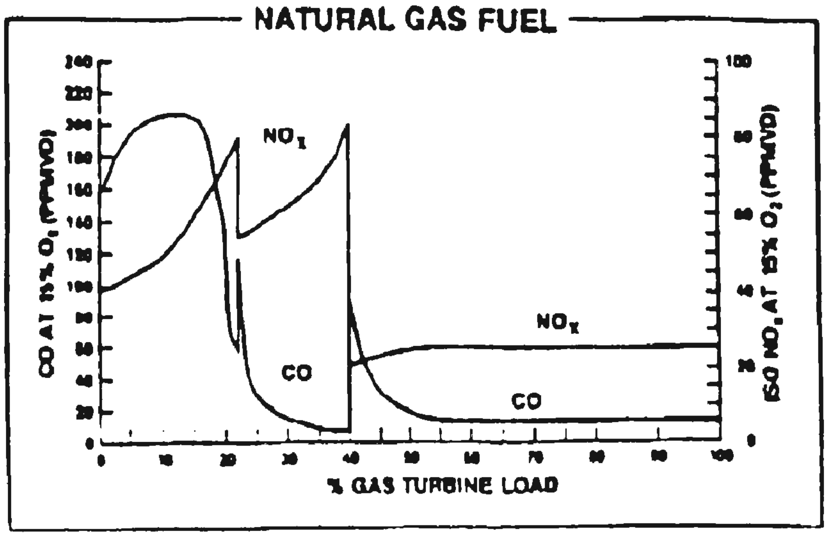
- Fuel Switching
- Water/Steam Injection
- Fuel Emulsion
- Combustion Modifications
- Selective Catalytic Reduction
- Oxidation Catalyst

COMBUSTION MODIFICATIONS TO LOWER NO_x EMISSION RATE

- **Lean Combustion and Reduced Residence Time**
- **Lean Premixed Combustion**
- **Dual-Staged Rich/Lean Combustion**

LOW NO_X STAGING AND NO_X CONCENTRATION PROFILE



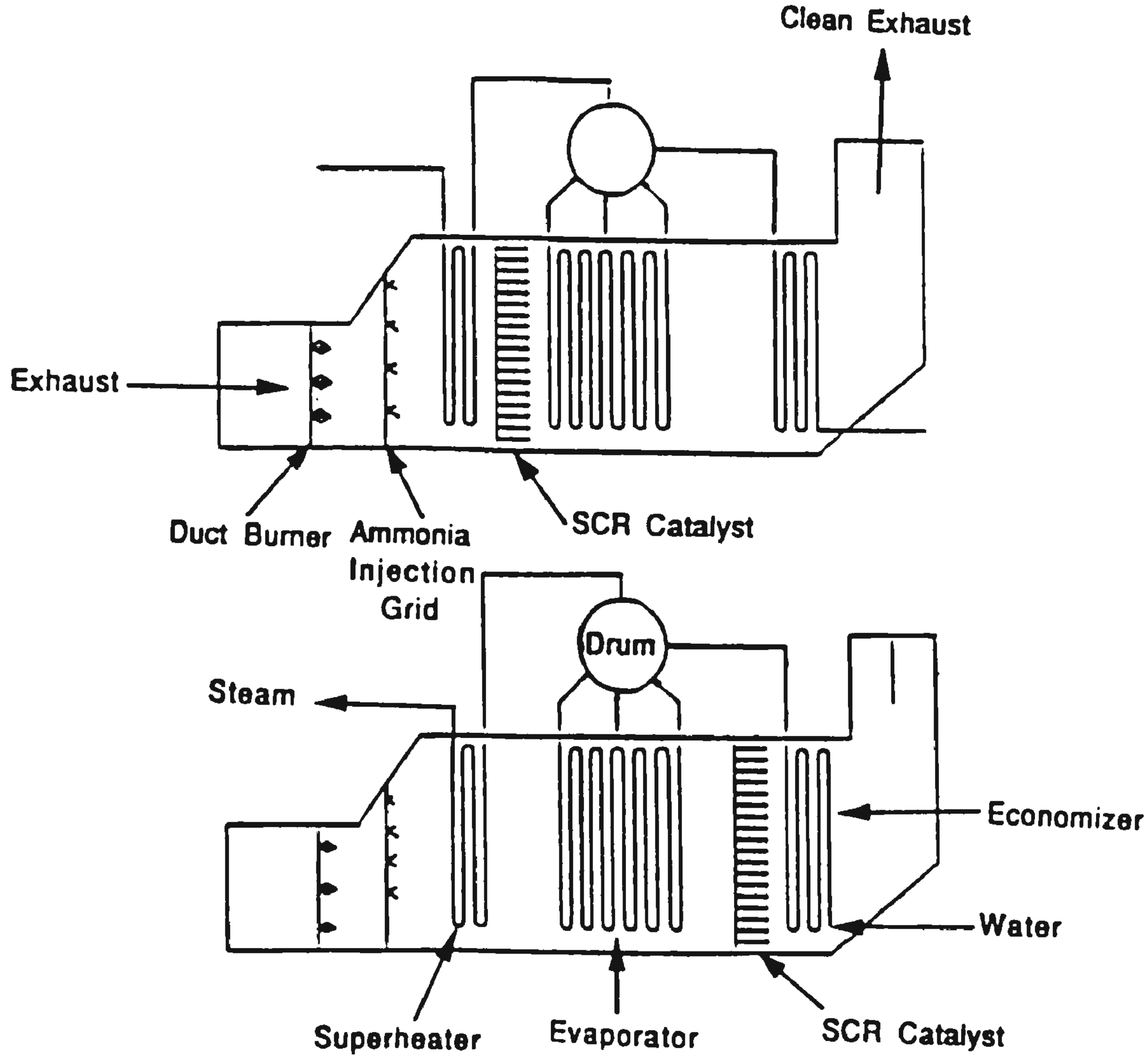


SCR REACTION

$$NO + NH_3 + 1/2\ O_2 \longrightarrow N_2 + 3/2\ H_2O$$

$$NO_2 + 2\ NH_3 + 1/2\ O_2 \longrightarrow 3/2\ N_2 + 3/2\ H_2O$$

POSSIBLE LOCATIONS FOR SCR UNIT IN HRSG



Slide 12 - 25

LESSON PLAN

CHAPTER 13. PACKAGE BOILERS

Goal: To present the participants with common package boiler designs and their characteristic pollutant emissions.

Objectives:

Upon completion of this unit an operator should be able to:

1. Describe the three types of major package boiler designs.
2. Describe the advantages/disadvantages of a firetube boiler design.
3. Describe three types of firetube boilers.
4. Describe the advantages/disadvantages of a watertube boiler design.
5. Describe three types of watertube boilers.
6. Describe the expected emissions from a package boiler.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

What is a package boiler?

What applications are best for a package boiler?

Presentation Outline:

13.1 Introduction

13.2 Package Boiler Types
- A. Firetube
  1. HRT
  2. Scotch Marine
  3. Firebox
- B. Watertube
  1. "O" Type
  2. "A" Type
  3. "D" Type
- C. Cast Iron Sectional

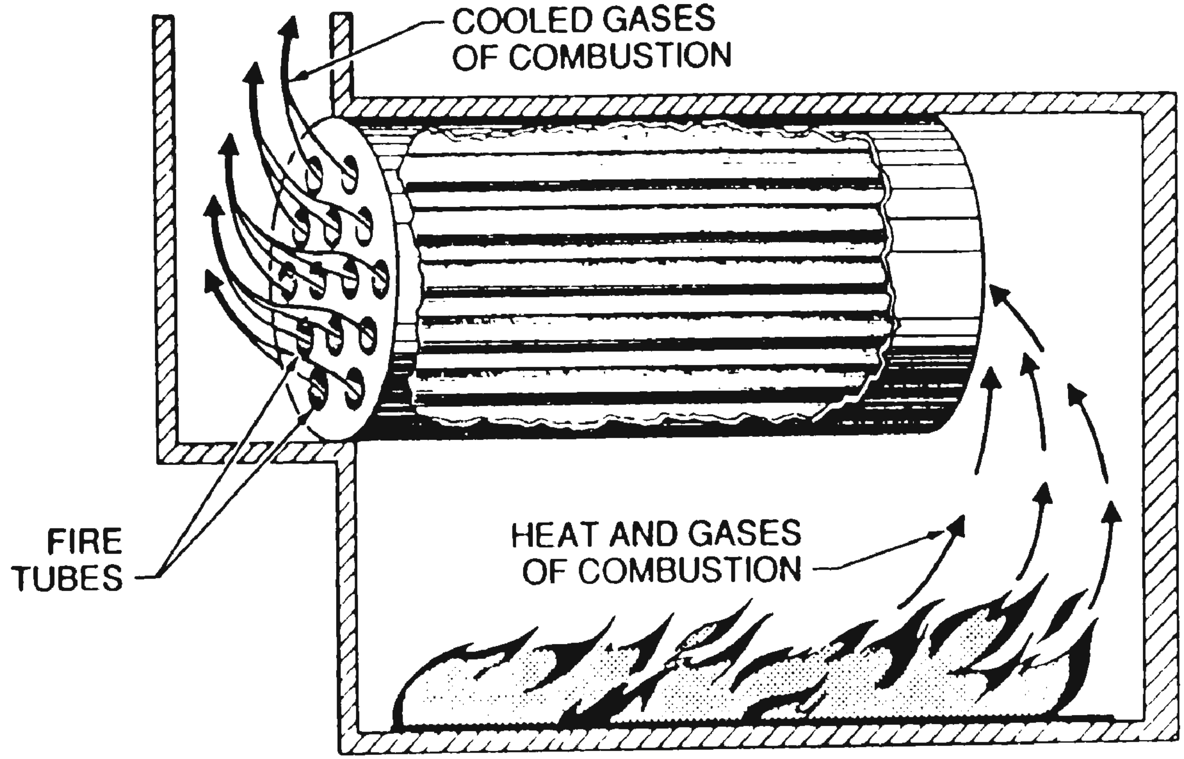
13.3 Emissions

References for Presentation Slides

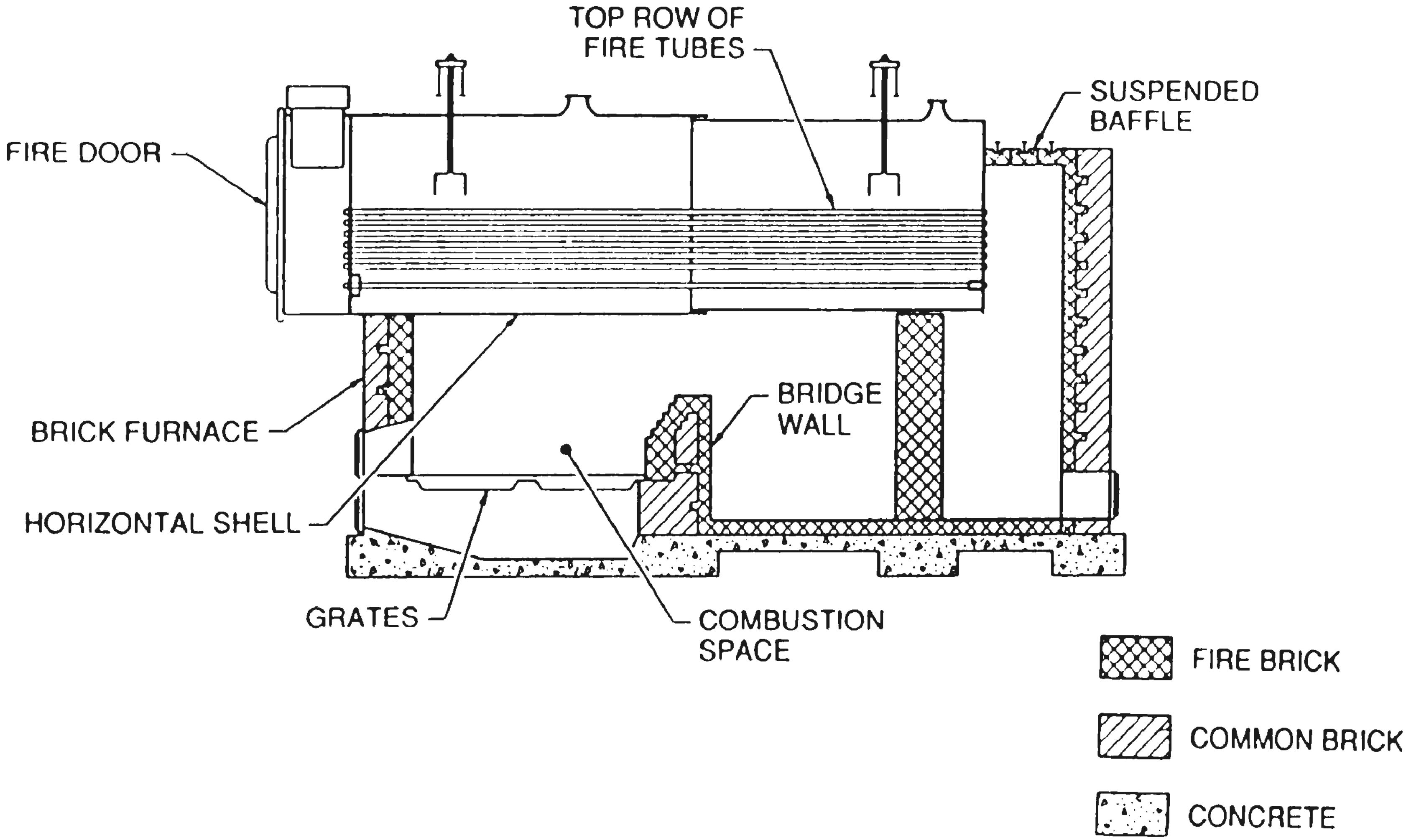
Slide 13-3	Wilson, R. Dean, *Boiler Operator's Workbook*, American Technical Publishers, Inc., 1991.
Slide 13-4	Ibid.
Slide 13-5	Ibid.
Slide 13-6	Ibid.
Slide 13-7	Ibid.
Slide 13-8	Ibid.
Slide 13-9	Ibid.
Slide 13-10	Ibid.
Slide 13-11	"Alternative Control Techniques Document -- NO_X Emissions from Industrial Commercial/Institutional (ICI) Boilers," U.S. EPA, EPA-453 / R-94-022, March, 1994.

CHAPTER 13. PACKAGE BOILERS

FIRETUBE BOILER

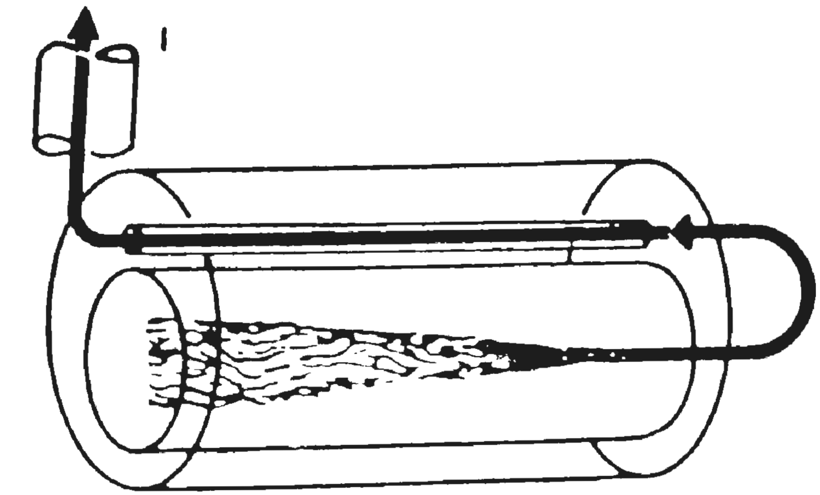


HORIZONTAL RETURN TUBULAR BOILER[1]

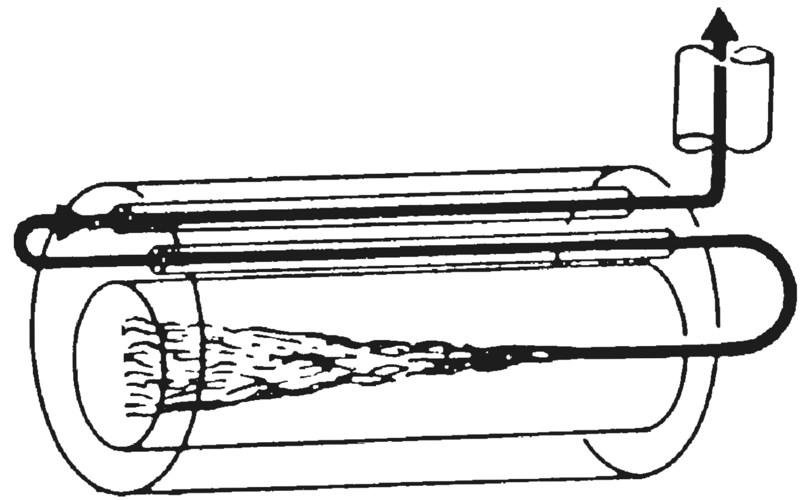


Slide 13 - 3

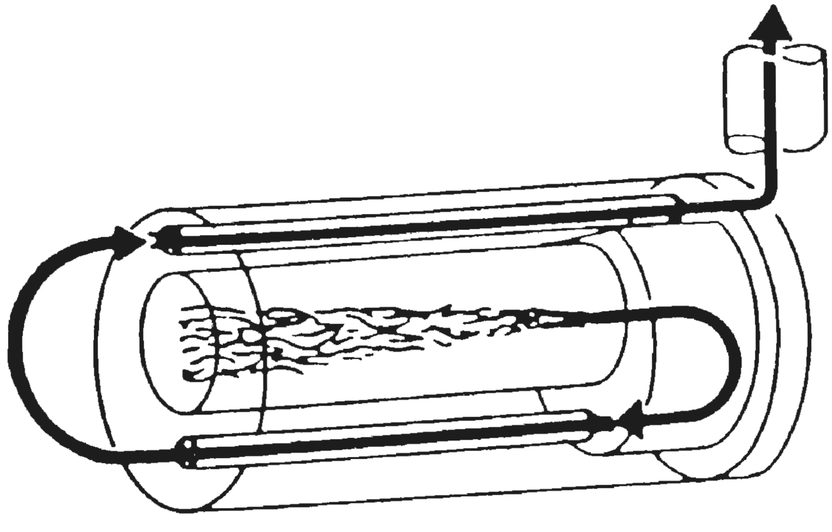
MULTIPLE PASS FIRETUBE BOILER ARRANGEMENTS[1]



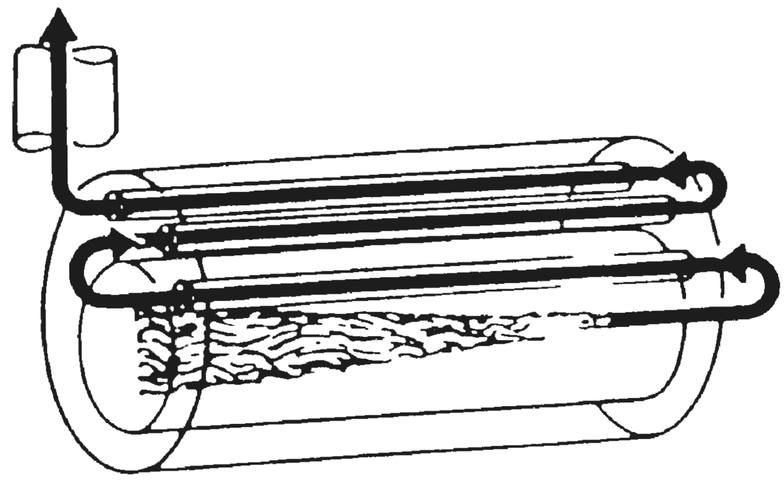
2-pass Dryback



3-pass Dryback

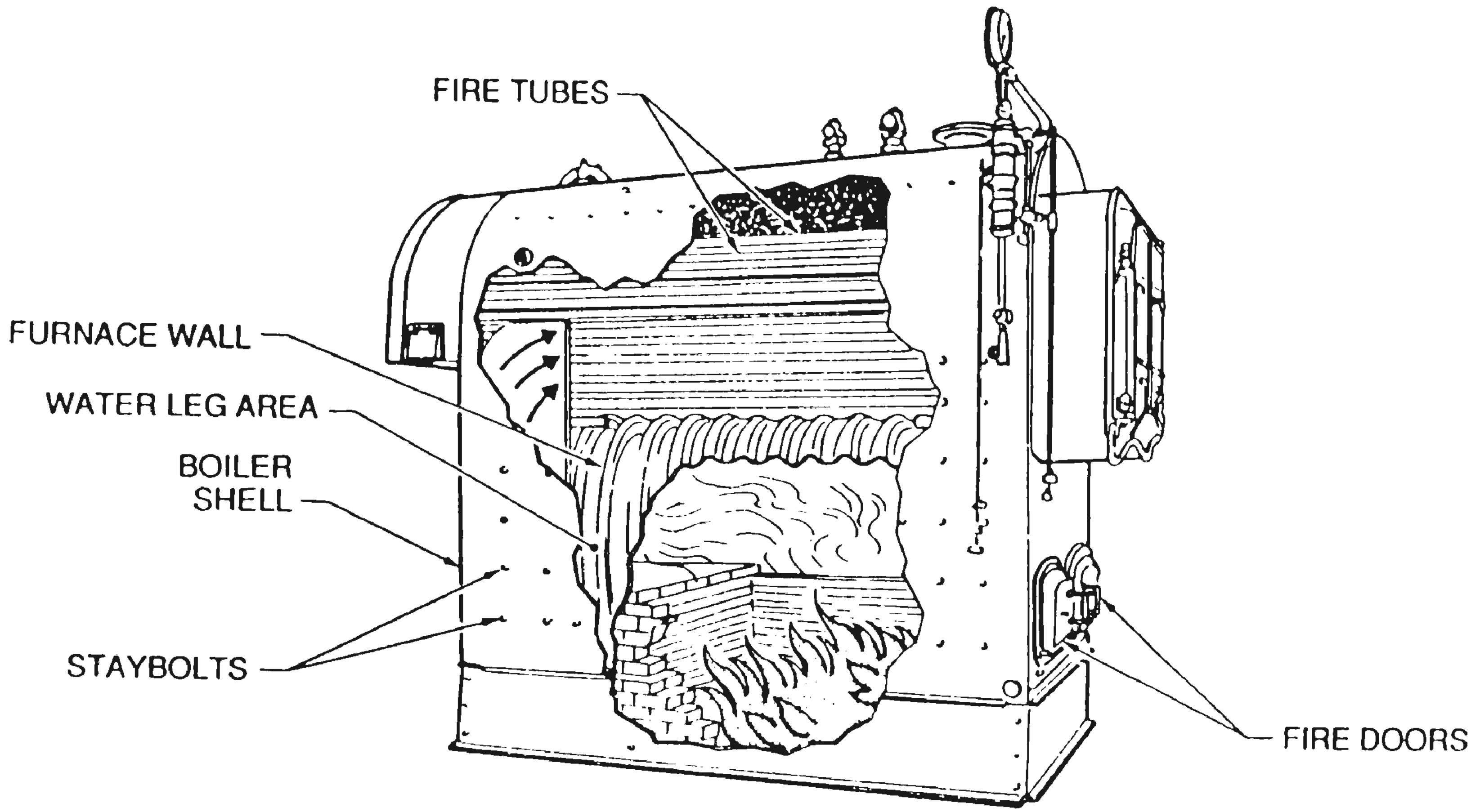


3-pass Wetback



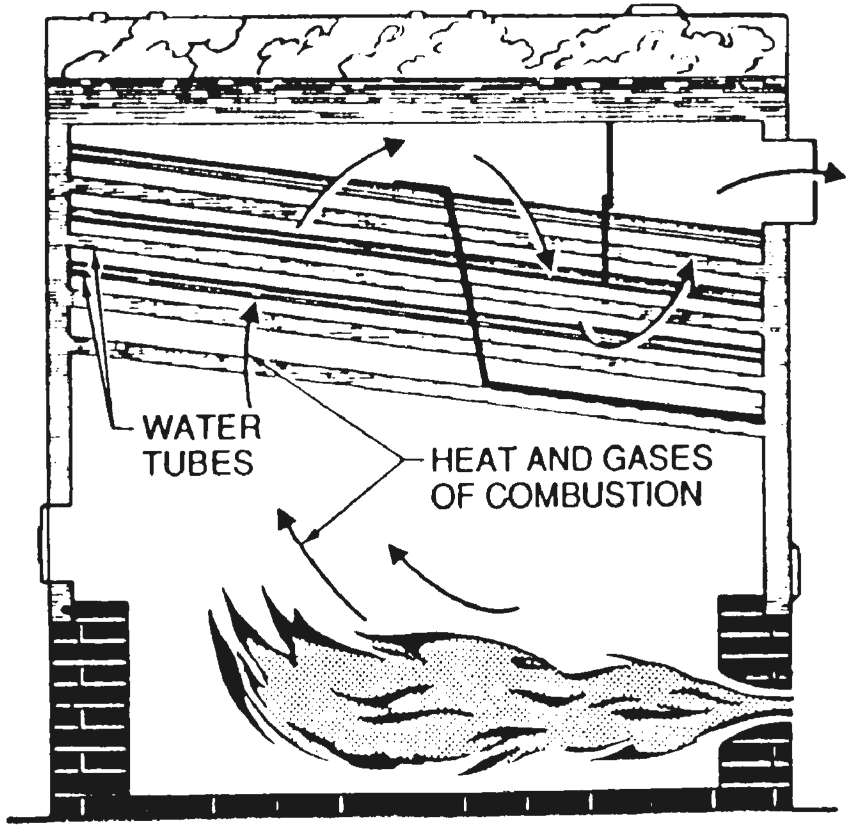
4-pass Dryback

FIREBOX BOILER[1]



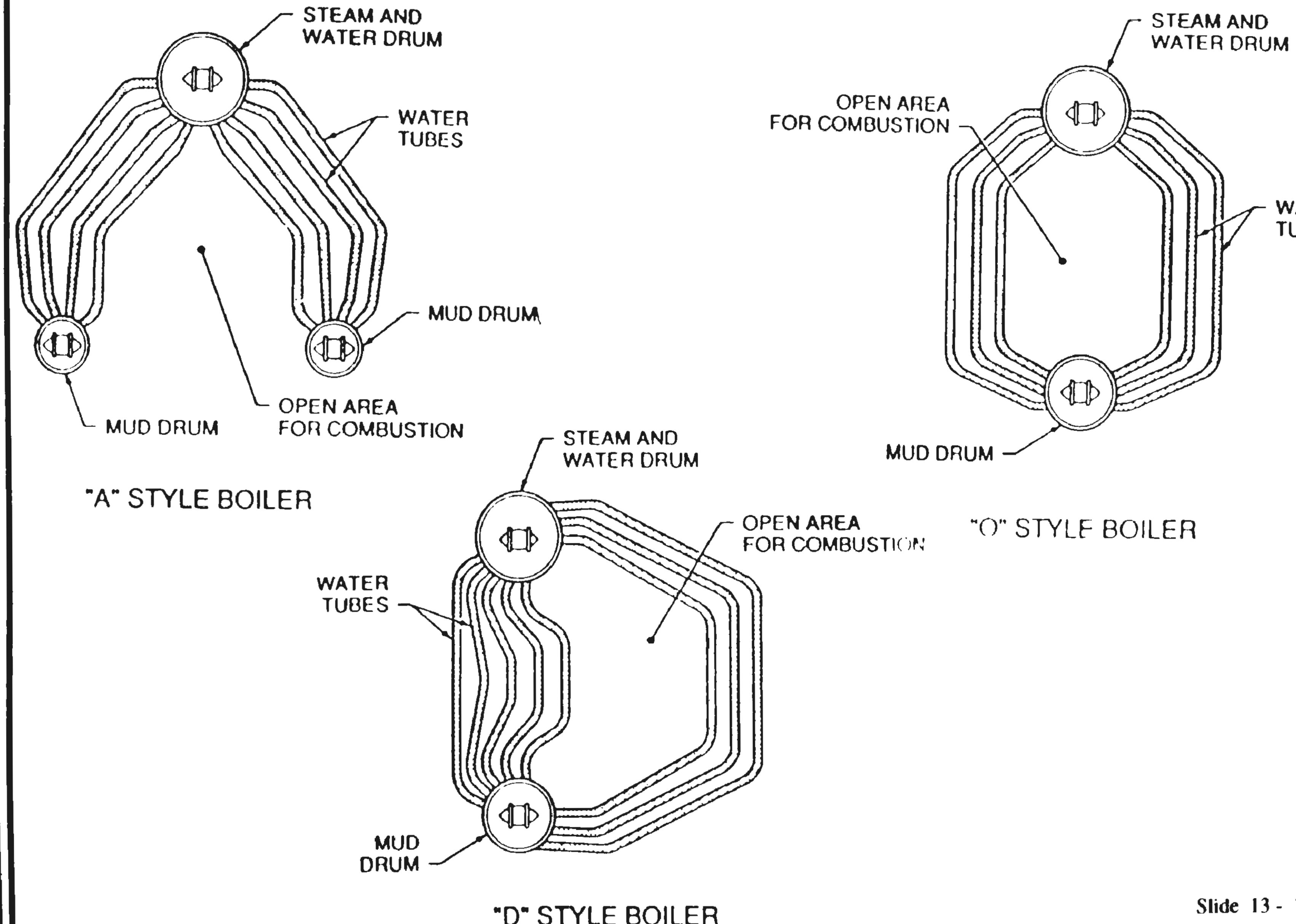
Slide 13 - 5

WATERTUBE BOILER[1]



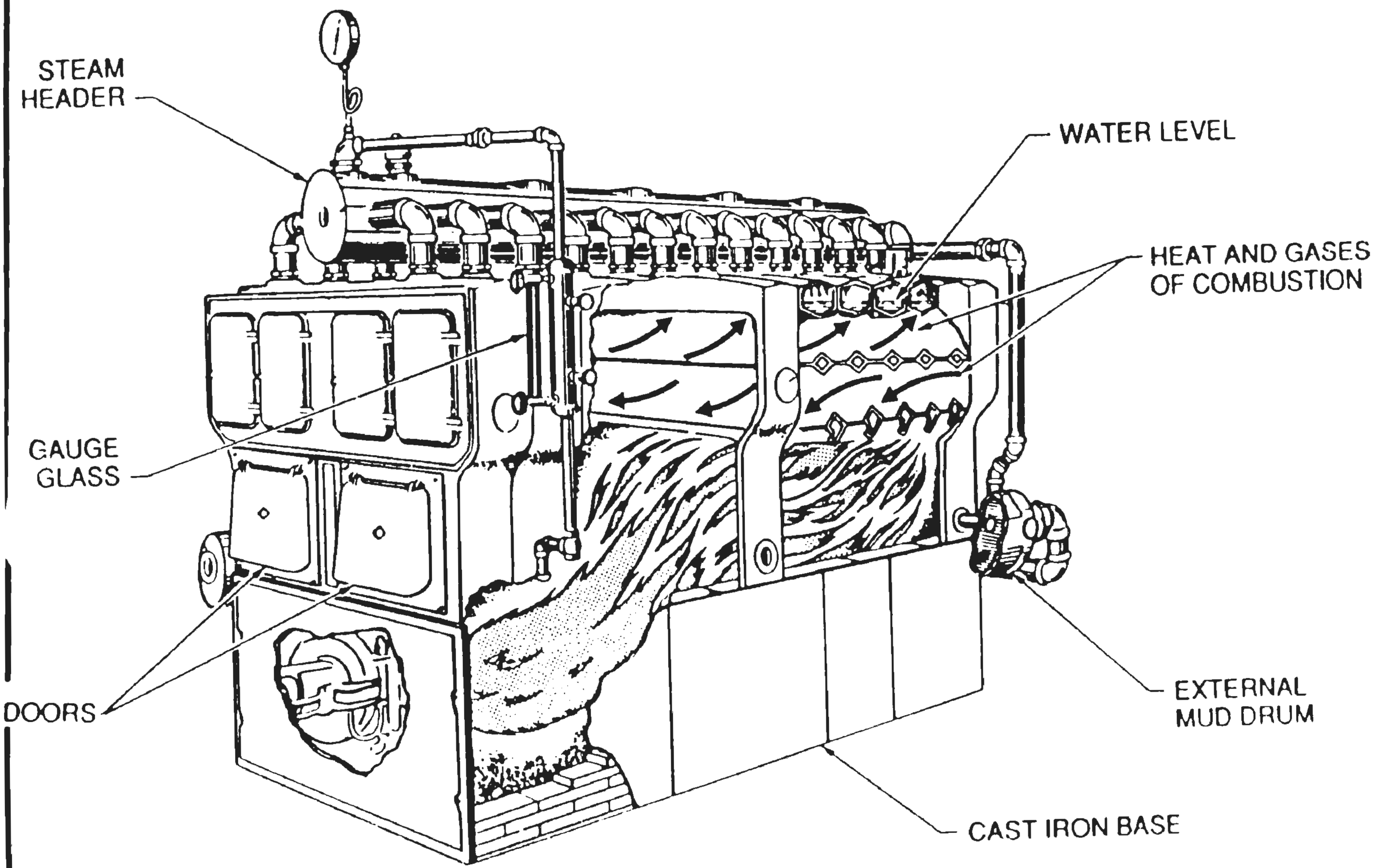
Slide 13 - 6

WATERTUBE BOILER CONFIGURATIONS[1]



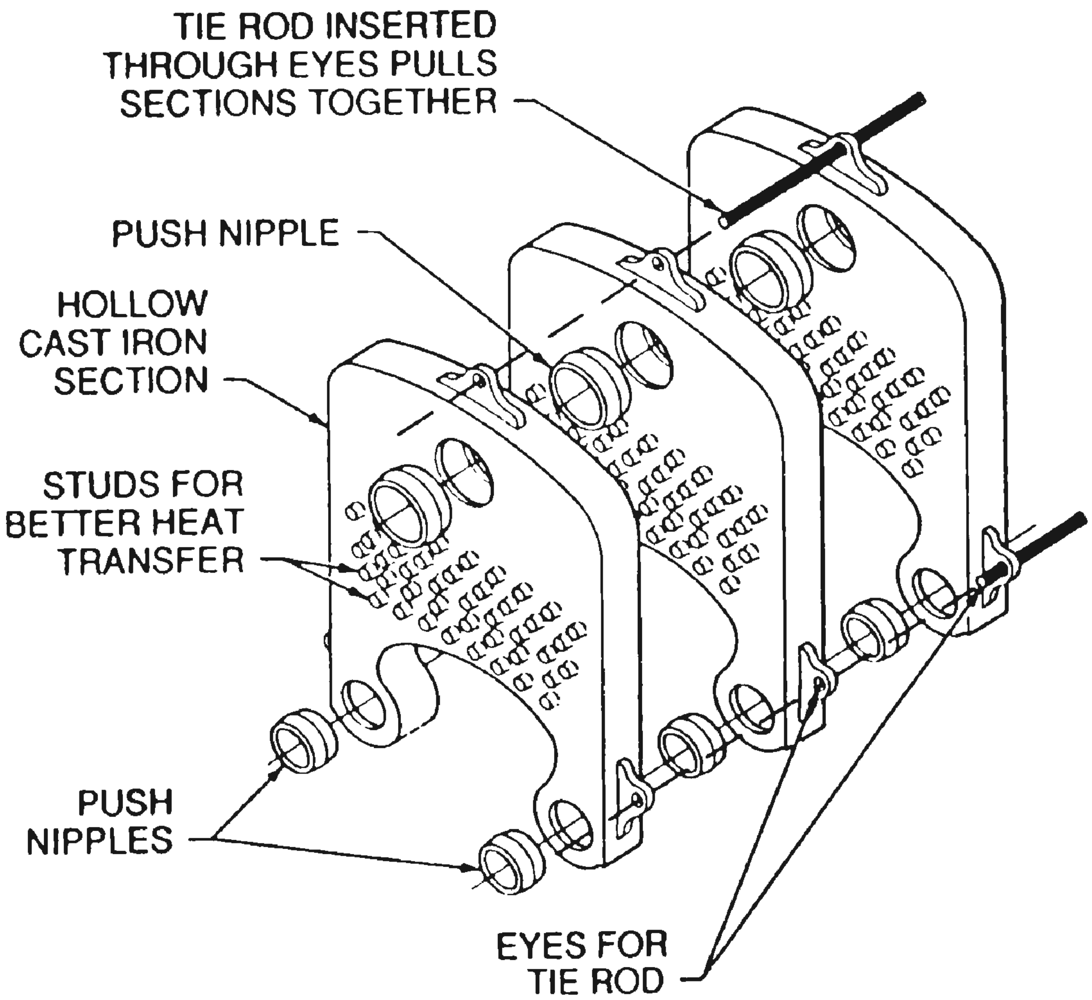
Slide 13 - 7

CAST IRON SECTIONAL BOILER[1]



Slide 13 - 8

PUSH-NIPPLE CAST IRON SECTION [1]



Slide 13 - 9

FIRETUBE BOILER EMISSIONS[5]

Fuel	NO_x (lb/MMBtu)[a]	CO (lb/MMBtu)	THC (lb/MMBtu)
Natural Gas	0.07 to 0.13	0.0 to 0.784	0.004 to 0.117
Distillate Fuel Oil	0.11 to 0.39	0.0 to 0.014	0.012[b]
Residual Fuel Oil	0.21 to 0.39	0.0 to 0.023	0.002 to 0.014

[a] To convert to ppm @ 3% O_2, multiply by the following: NO_x, 790; CO 1300; THC, 2270

[b] Single data point

LESSON PLAN

CHAPTER 14. NORMAL OPERATION

Goal: To present the participants with a general description of boiler operation and to highlight the most important operating parameters to monitor and control.

Objectives:

Upon completion of this unit an operator should be able to:

1. Describe conditions required for proper combustion.

2. Describe what fuel supply equipment requires periodic checking and how often those checks should be made.

3. List potential causes of low drafts in a natural draft furnace.

4. Understand that loss of ignition can lead to explosive conditions and it is the operators responsibility to prevent this occurrence.

5. Discuss potential problems arising from poor or improper boiler water treatment. They should also be familiar with the checks and maintenance procedures for boiler feedwater.

6. Know that if water levels fall below minimum the fuel and air supplies must be stopped immediately and that adding feed water to a dry hot boiler will damage the drum materials.

7. Describe proper procedures for correcting high water levels.

8. Understand that high levels of excess O_2 result in higher heat loss out of the stack.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

What are some of the responsibilities that a boiler operator has while operating a boiler?

What are some hazards of poor maintenance of boiler safety controls?

Presentation Outline:

14.1 Introduction
14.2 Maintaining Suitable Combustion Conditions
14.3 Monitoring Combustion
14.4 Maintaining Steam Temperature and Pressure
14.5 Maintaining Suitable Feedwater Conditions
14.6 Monitoring the Steam/Water Circuit
14.7 Controlling the Steam Temperature
14.8 Startup Procedures
14.9 Shutdown Procedures

CHAPTER 14. NORMAL OPERATION

14.1 Introduction

14.2 Maintaining Suitable Combustion Conditions

14.3 Monitoring Combustion

14.4 Maintaining Steam Temperature and Pressure

14.5 Monitoring Suitable Feedwater Conditions

14.6 Monitoring Steam/Water Circuit

14.7 Controlling the Steam Temperature

14.8 Startup Procedures

14.9 Shutdown Procedures

FUEL SUPPLY

Coal

Oil

Gas

FUEL SUPPLY CHECKLIST

FUEL	EQUIPMENT	ACTION	FREQUENCY
Coal	Coal Bunkers	Check level	Start and end of shift
	Conveying Equipment	Check for wear	Once a shift
	Coal Hopper	Check level	Once an hour
	Ash Pit	Check level and empty	Once a shift / as required
	Pulverizer Mills	Visually inspect and ensure constant supply of fuel to burners.	Once an hour
Fuel Oil	Storage/Supply Tanks	Check level	Start and end of shift
	Duplex Strainers	Switch and clean	Once a shift / as required
	Burner Tips	Clean and inspect	Once a day
Gas	Reducing Station or Booster Compressor	Ensure proper inlet and outlet pressure	Once an hour
	Burner Air Register	Inspect and check for proper operation	Once a shift
	Burner Tip	Clean and inspect	Once a day
	Boiler Casing	Inspect for air leaks	Once a shift

COMBUSTION AIR SUPPLY

- Natural Draft

- Mechanical Draft
    - Balanced
    - Pressurized Furnace

FLAME APPEARANCE

- Length
- Color
- Shape
- Stability

COMBUSTION AIR

Flow
Temperature
Pressure

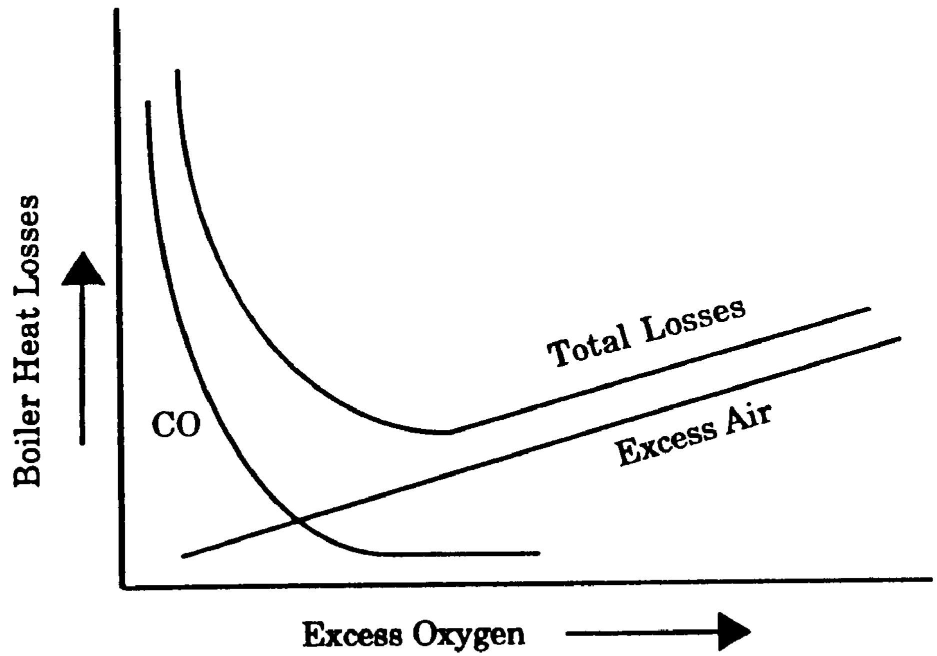
FUEL MONITORING PARAMETERS

Fuel Type	Pressure	Temperature	Flow
Solid			
Pulv. Coal			X
Stoker Coal			X
Refuse (Garbage)			X
Liquid			
Oil	X	X	X
Chem By-Product	X	X	X
Gaseous			
Nat. Gas	X	X	X
Gaseous By-Product	X	X	X

FLUE GAS ANALYSIS

O_2
CO_2
CO
NO_X
SO_2

Boiler Efficiency Based on Flue Gas Analysis



Slide 14 - 9

PRESSURE/TEMPERATURE CONTROL

A. Monitor Steam Pressure
B. Maintain Proper Fuel-Air Ratio
C. Monitor Superheater Outlet Temperature

BOILER WATER PROBLEMS

Deposits or Scale
Waterside Corrosion
Carry-over or Priming
Caustic Embrittlement

MAINTAINING WATER LEVEL

Regular Maintenance/Operation
Low Level Problems
High Level Problems

Slide 14 - 12

SUPERHEAT STEAM TEMPERATURE CONTROL

Desuperheater
Burner Tilt
Flue Gas Recirculation
Sootblower

Slide 14 - 13

STARTUP PROCEDURES

- Pre-startup Inspection
- Establishment of Water Level
- Light-off
- Warm-up

RECOMMENDED PRE-STARTUP INSPECTION CHECKLIST

- Pressure Measurement Device Accuracy
- Blowoff Valves Closed and Functional
- Gauge Glass and shut-off valves
- Infrared Detection System
- Main Steam Valve Inspection
- Safety Valves Inspection
- Fans Operational Condition
- Pumps Operational Condition
- Water Conditioning System

LESSON PLAN

CHAPTER 15. AUTOMATIC CONTROL SYSTEMS.

Goal: To give the participant a brief overview of automatic control systems as applied to boiler operation.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the operating principles of different control technologies used in boilers in the present and past.
2. Describe the basic elements that make up an automatic control system.
3. List the key control parameters needing automatic control (both gas side and waterside) in typical boiler operations.
4. Discuss the attributes differentiating different control system configurations and describe advantages and disadvantages of each. They should also be familiar with typical applications for different types of control configurations.
5. Discuss the advantages of using microprocessor controls.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

What types of control systems are used in the facilities that you work in?

Presentation Outline:

15.1	Introduction
15.2	Types of Analog Control Systems
15.3	Types of Digital Control Systems
15.4	Automatic Control System Elements
15.5	Gas-side and Water-side Control Parameters
15.6	Single, Two, & Three Element Controllers
15.7	Microprocessor Based Control Systems
15.8	Control System Applications

CHAPTER 15. AUTOMATIC CONTROL SYSTEMS

Types of Analog Control Systems

Mechanical
Hydraulic
Pneumatic
Discrete Electronic Components

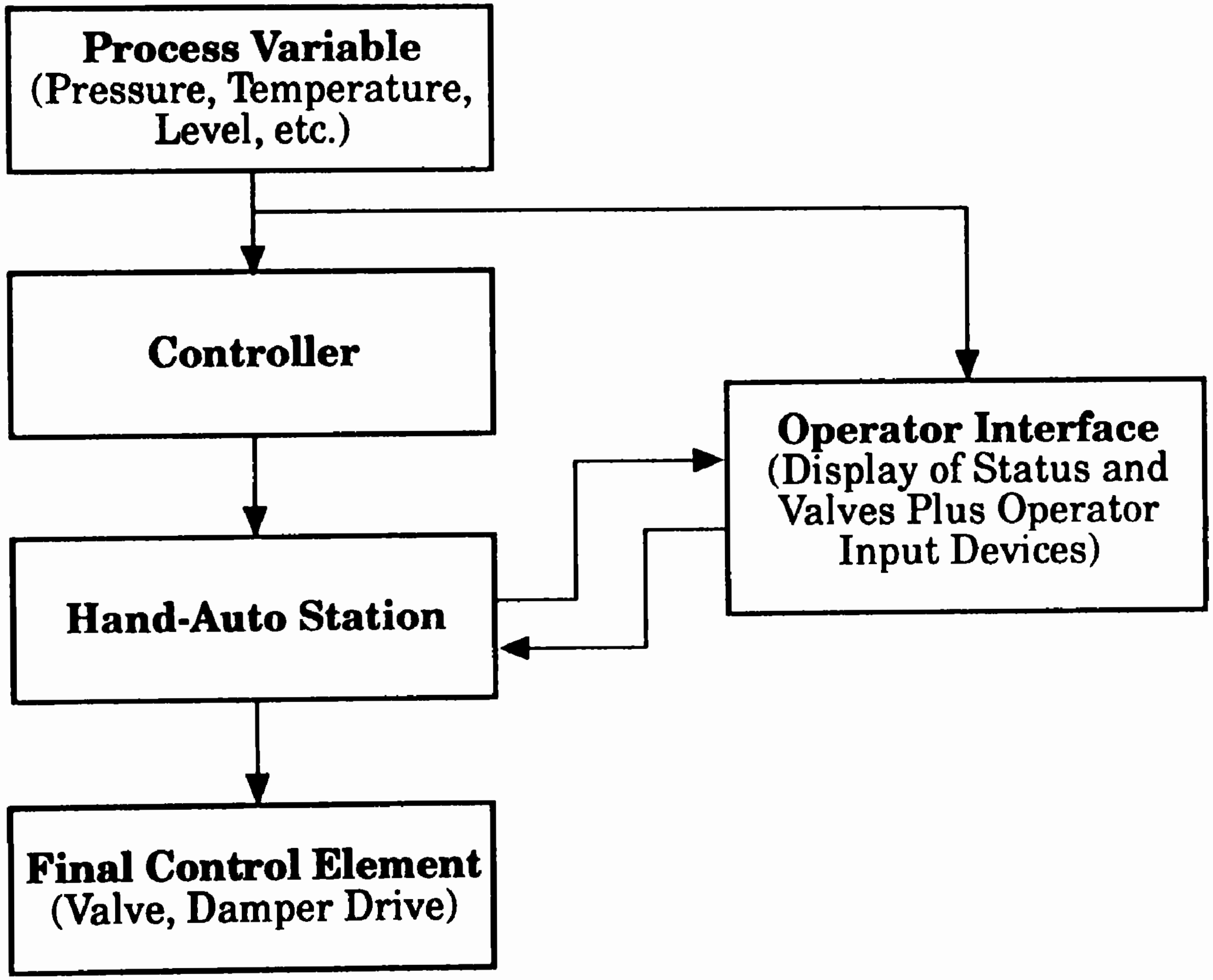
Types of Digital Control Systems

- Straight Mechanical
- Hard Wired Interlocks
- Relay Systems
- Discrete Component Electronic
- Microprocessor

Automatic Analog Control System Elements

Process or Measured Variable
Controller
Hand/Auto Station
Operator Interface
Final Control Element

Automatic Control System Elements



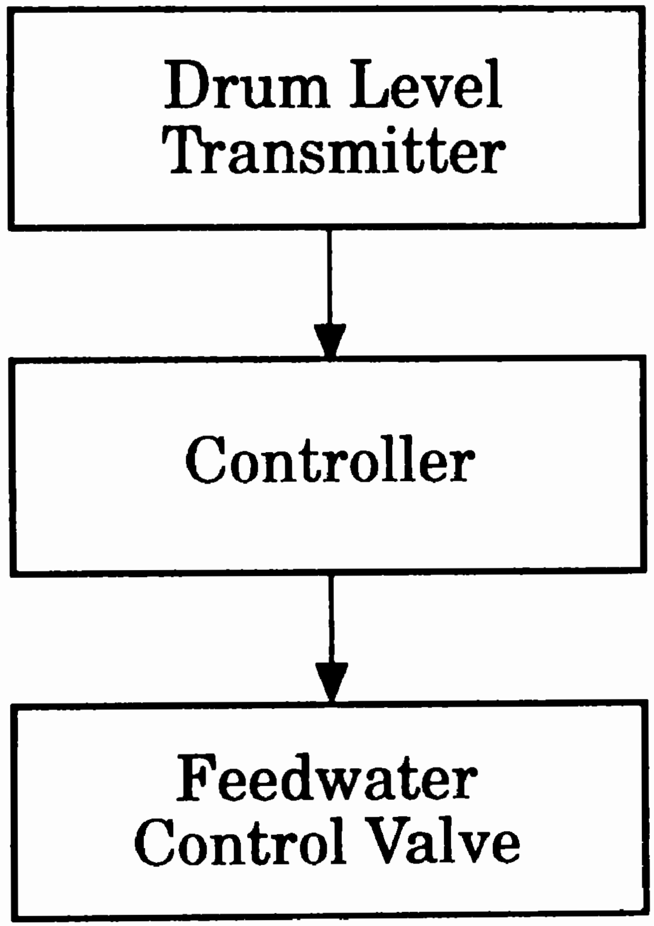
Gas-Side and Water-Side Control Parameters

Steam Pressure
Drum Level (if applicable)
Main Steam Temperature
Reheat Steam Temperature (if applicable)
Furnace Draft (if applicable)
Desired Excess Air

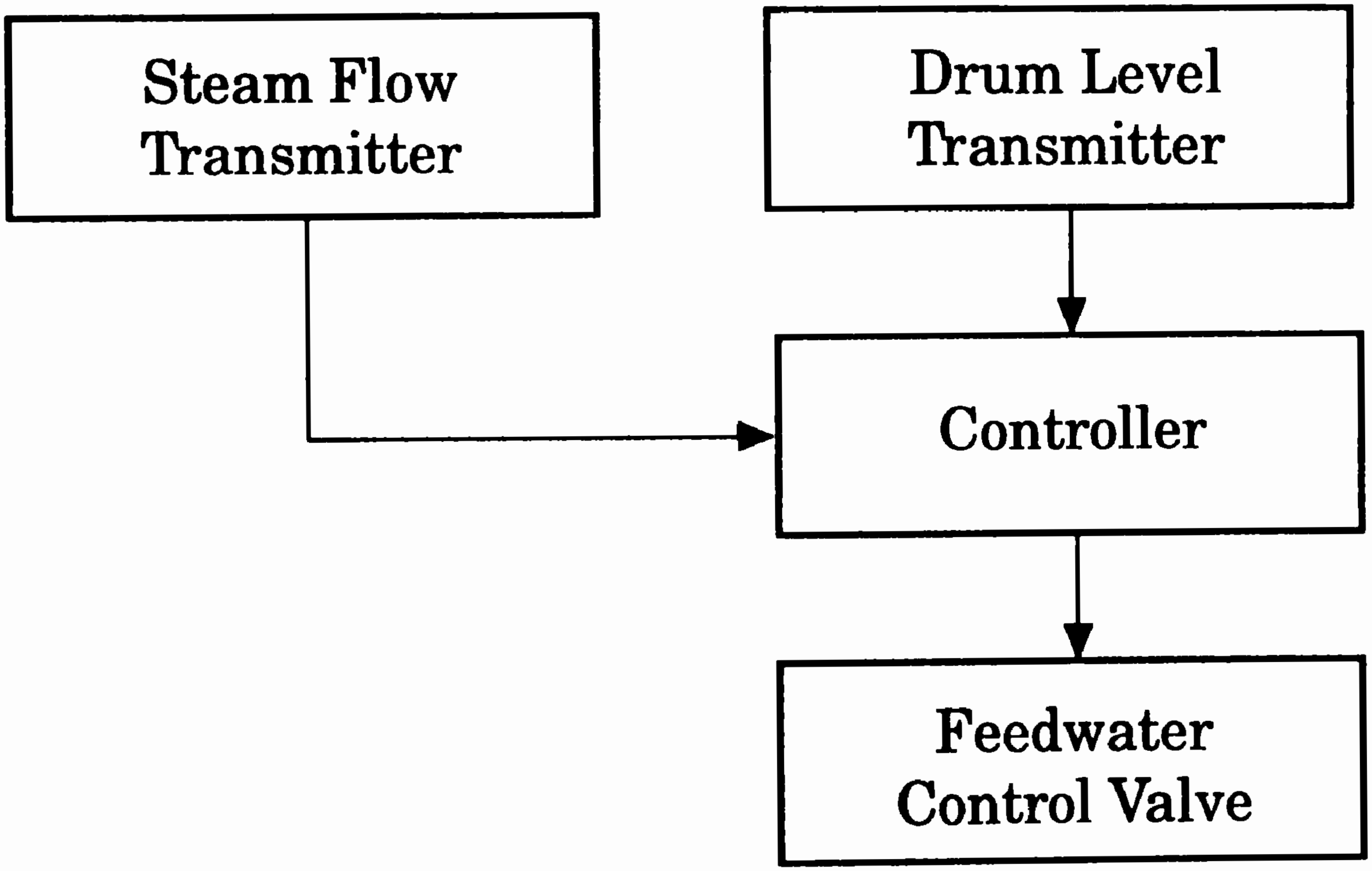
Control System Configuration

Single Element
Two Element Feed Forward
Two Element Cascade
Three Element

Single Element Feedwater Control

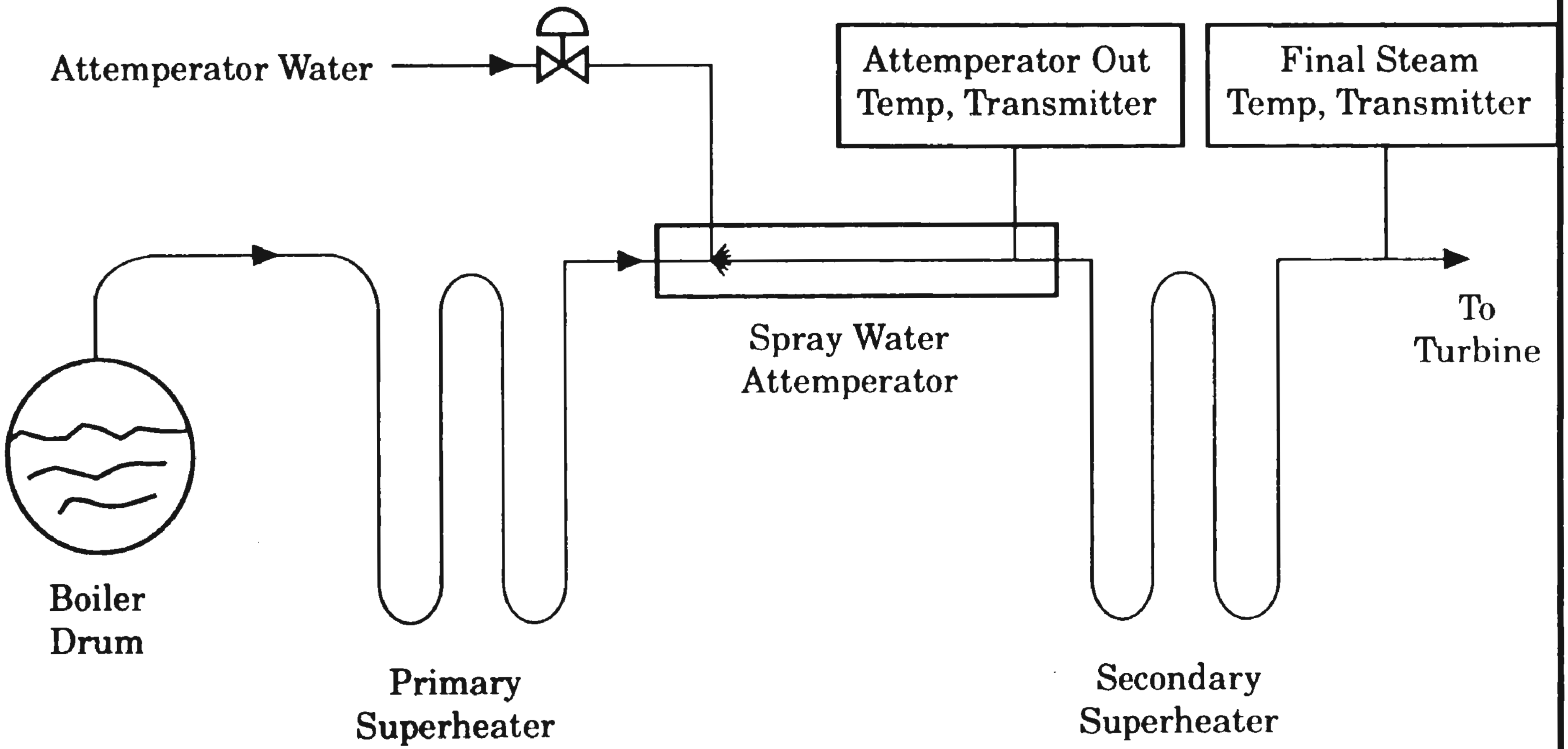


Two Element Feedwater Control (Feedforward)



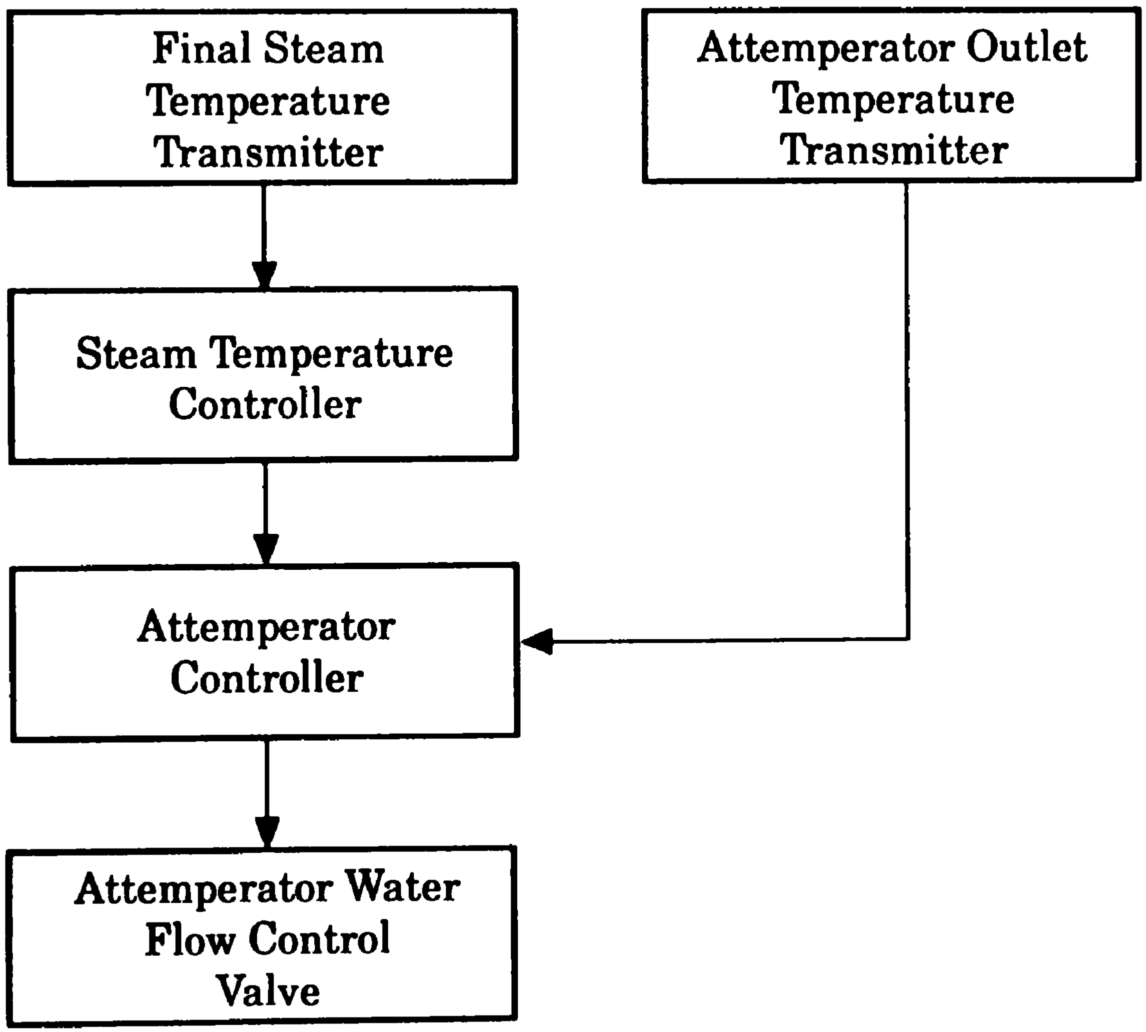
Slide 15 - 9

Spray Water Attemperator Water Schematic

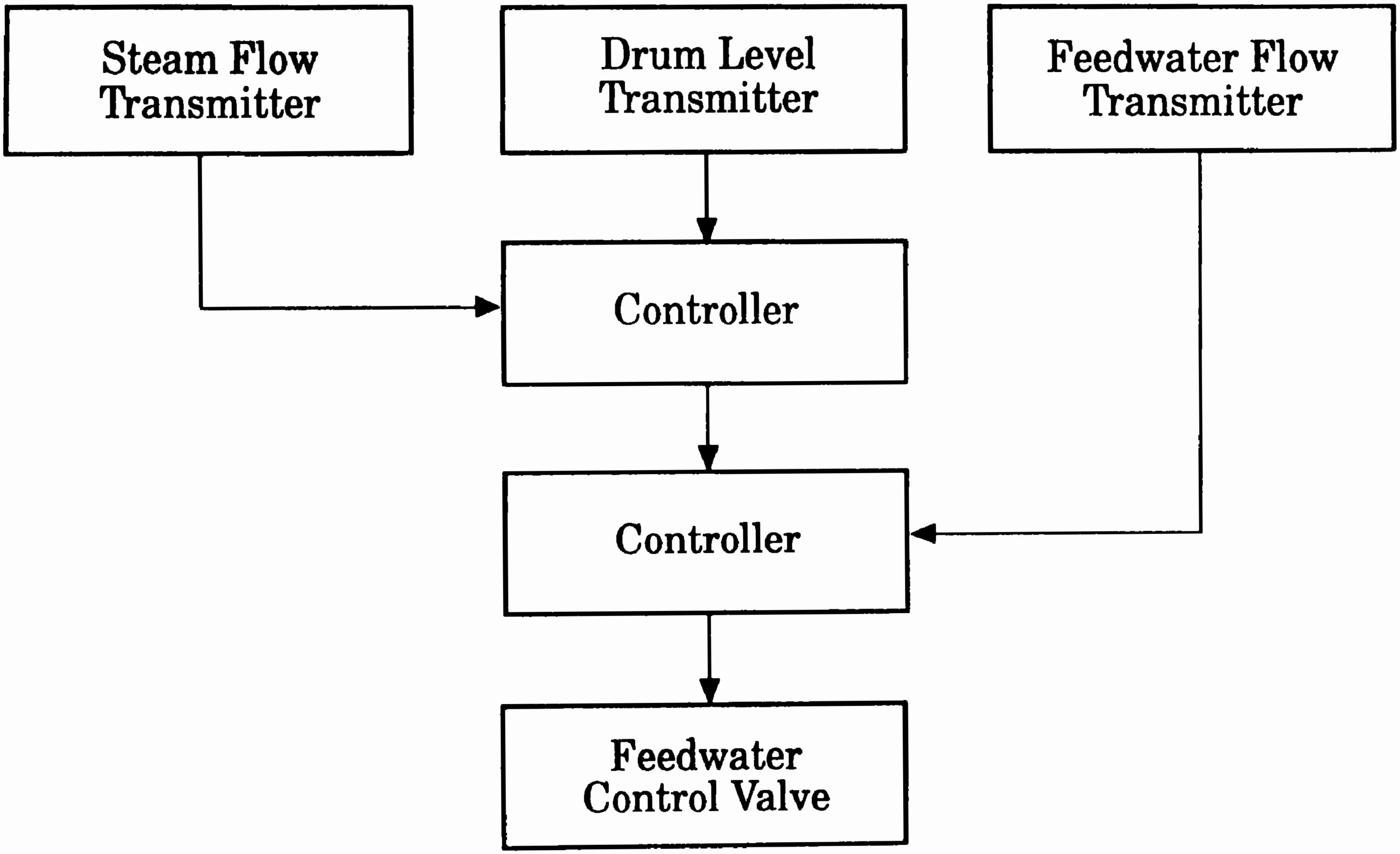


Slide 15 - 10

Two Element Steam Temperature Control (Cascade)



Three Element Feedwater Control



Slide 15 - 12

Advantages of Microprocessor Systems

Flexibility
Improved Operator Interface
Reliability
Ability to Incorporate and Integrate Numerous Systems in a Single Package

Control Systems Applications

Boiler Combustion Controls
Boiler Feedwater Controls
Boiler Steam Temperature Controls
Boiler Draft Control
Feedwater Heater Level Controls
Hotwell Level Controls
Deaerator Pressure Controls
Air Heater Cold End Temperature Controls
Numerous Other Applications

LESSON PLAN

CHAPTER 16. INSTRUMENTATION: GENERAL MEASUREMENTS

Goal: To give the participant a general overview of measurement devices, instruments and sensors available to boiler operations.

Objectives:

Upon completion of this unit an operator should be able to:

1. Describe the basic devices available for pressure temperature, level and flow measurement.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

What are the parameters that need to be measured to monitor the boiler operation?

Presentation Outline:

16.1 Introduction

16.2 Pressure Measurement

16.3 Temperature Measurement and Equivalence

16.4 Level Measurement

16.5 Flow Measurement

16.6 Weigh Scales

CHAPTER 16. INSTRUMENTATION: GENERAL MEASUREMENTS

16.1 Introduction

16.2 Pressure Measurement

16.3 Temperature Measurement and Equivalences

16.4 Level Measurement

16.5 Flow Measurement

16.6 Weigh Scales

Pressure Measurement

Pressure Gauges
Manometers
Pressure Transmitters
Draft Gauges

Temperature Measurement

Human Hand
Liquid Filled Bulb & Tube
Liquid Filled Bulb & Gauge
Thermocouple with Readout Device
Resistance Temperature Detector with Readout Device
Optical Pyrometer

Level Measurement

Float Type
Sight or Gauge Glass
Level Transmitter

Flow Measurement

Open Channel
Variable Area Meters
Pitot Tube
Differential Pressure
Turbine Meters

LESSON PLAN

CHAPTER 17. ELECTRICAL THEORY

Goal: To present the participants with the basic principles of electricity to give the knowledge required for understanding transformers, rectifiers and electric generators.

Objectives:

Upon completion of this unit an operator should be able to:

1. Understand the concept of AC and DC electrical current.
2. Describe the basic parameters of electricity such as voltage, current, resistance.
3. Use Ohm's Law and apply it to basic calculations of electrical quantities such as voltage, current and power.
4. Apply AC power relationships to simple calculations or power.
5. Describe basic fundamental operations of electrical equipment such as motors, transformers, generators.
6. List commonly used instruments for measuring electrical parameters.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

Who can explain the difference between AC and DC electrical current?

What is voltage?

Presentation Outline:

17.1 Introduction

17.2 Fundamental Parameters
- A. Current
- B. Voltage
- C. Other Parameters
- D. Ohm's Law
- E. DC Wattage or Power
- F. AC Wattage or Power

Presentation Outline (Continued):

17.3 Electrical Power Equipment
- A. Motors
- B. Generators
- C. Transformers
- D. Other Equipment

17.4 Instruments and Meters

CHAPTER 17. ELECTRICAL THEORY

17.1 Introduction

17.2 Fundamental Parameters

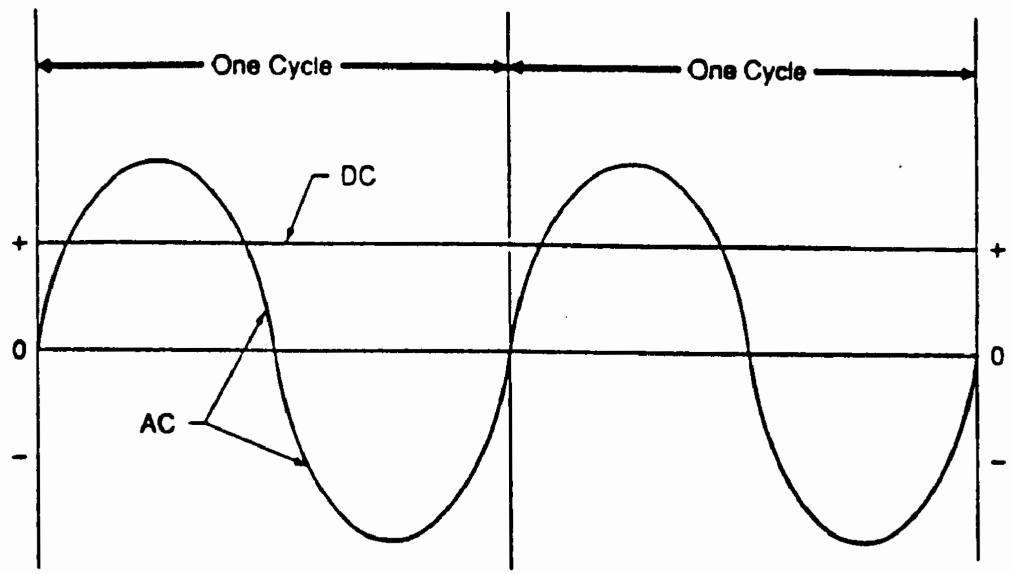
17.3 Electrical Power Equipment

17.4 Instruments and Meters

BASIC ELECTRICITY

DC vs. AC Current
Ohms Law
Power
Electrical Phases
Motors and Generators
Transformers
Rectifiers

STEADY DC AND OSCILLATING AC ELECTRON FLOW

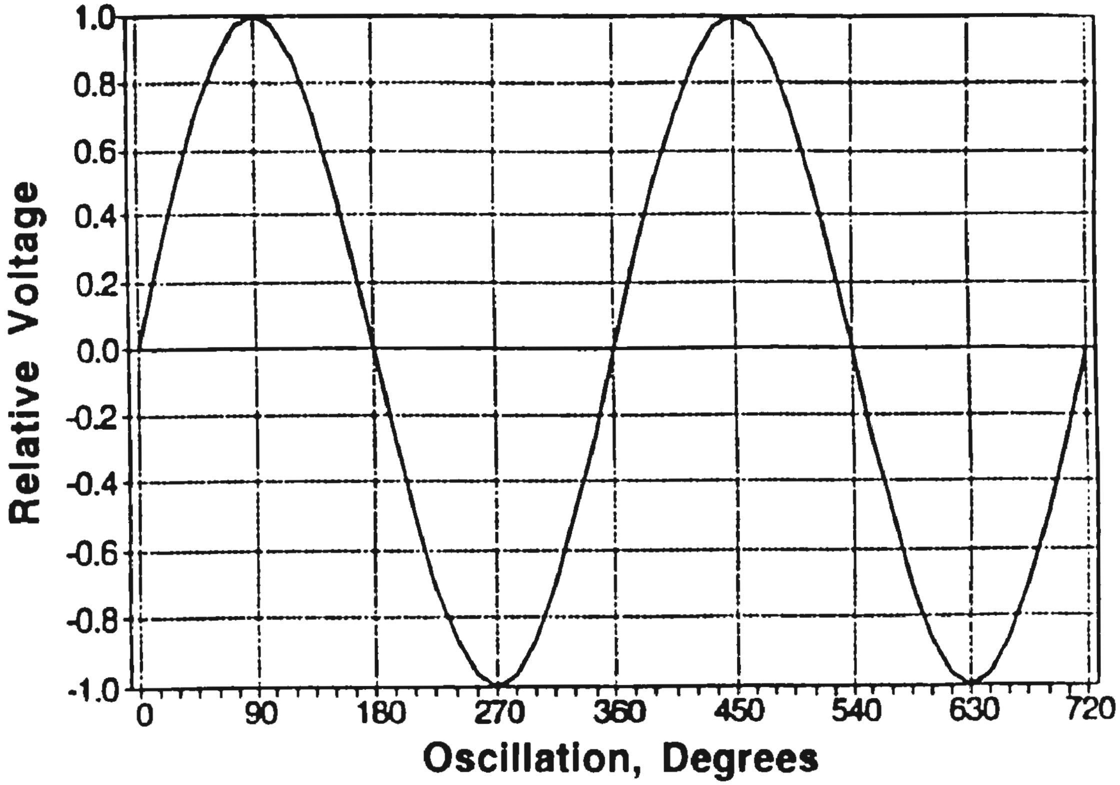


Slide 17 - 3

ELECTRICITY – FLUID FLOW ANALOGY

Parameter	*Electricity*	*Fluids*
Flow Rate	**Electron Flow/Current (amps)**	**Fluid Flow (gpm)**
Driving Force	**Electrical Potential Difference or Voltage (volts)**	**Pressure Difference (psi)**

VOLTAGE OSCILLATIONS OF ALTERNATING CURRENT



OTHER BASIC ELECTRICAL PARAMETERS

Conductor	Material Which Permits Electrons to Flow
Resistance	Measures Opposition to Flow
Ohm	Unit of Electrical Resistance
Insulator	Material with High Resistance
Circuit	The Path of Electrical Current from a Source through Various Conductors and Devices

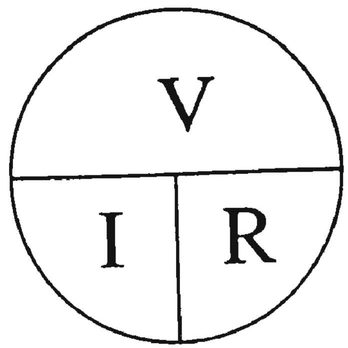
OHM's LAW
VOLTAGE–CURRENT RELATIONSHIP

Voltage = Current x Resistance

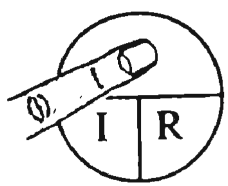
V = I x R

I = V / R

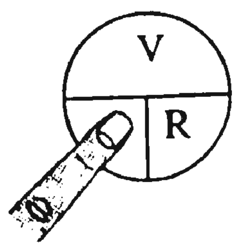
GRAPHICAL RELATIONSHIP OF VOLTAGE AND CURRENT BY OHM'S LAW



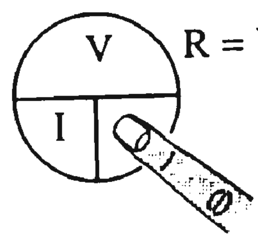
V = Voltage (volts)
I = Amperage (amps)
R = Resistance (ohms)



V = I x R



I = V / R



R = V / I

DC POWER RELATIONSHIPS

Power = Voltage x Current

$$P = V \times I$$

$$P = (I \times R) \times I$$

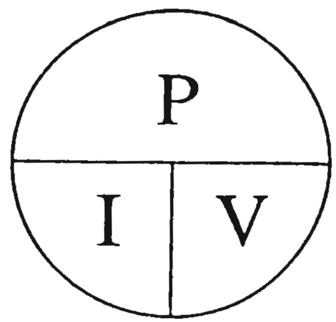
$$P = (I)^2 \times R$$

or

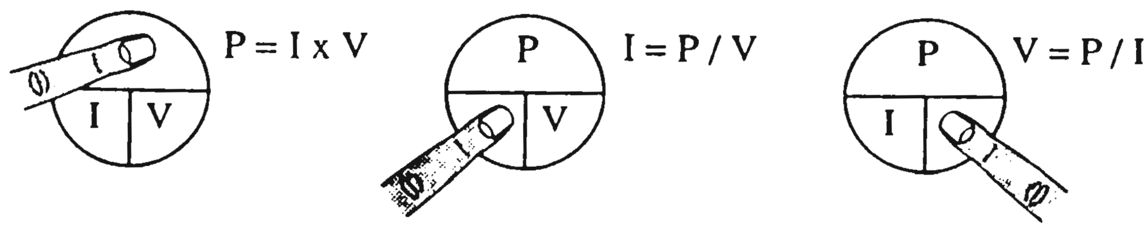
$$P = (V / R)^2 \times R$$

$$P = (V)^2 / R$$

GRAPHICAL RELATIONSHIP OF POWER



P = Power (watts)
I = Amperage (amps)
V = Voltage (volts)



AC POWER RELATIONSHIPS

Power = Voltage x Current x Power Factor

$$P = V \times I \times \cos Ø$$

$$P = (I \times R) \times I \times \cos Ø$$

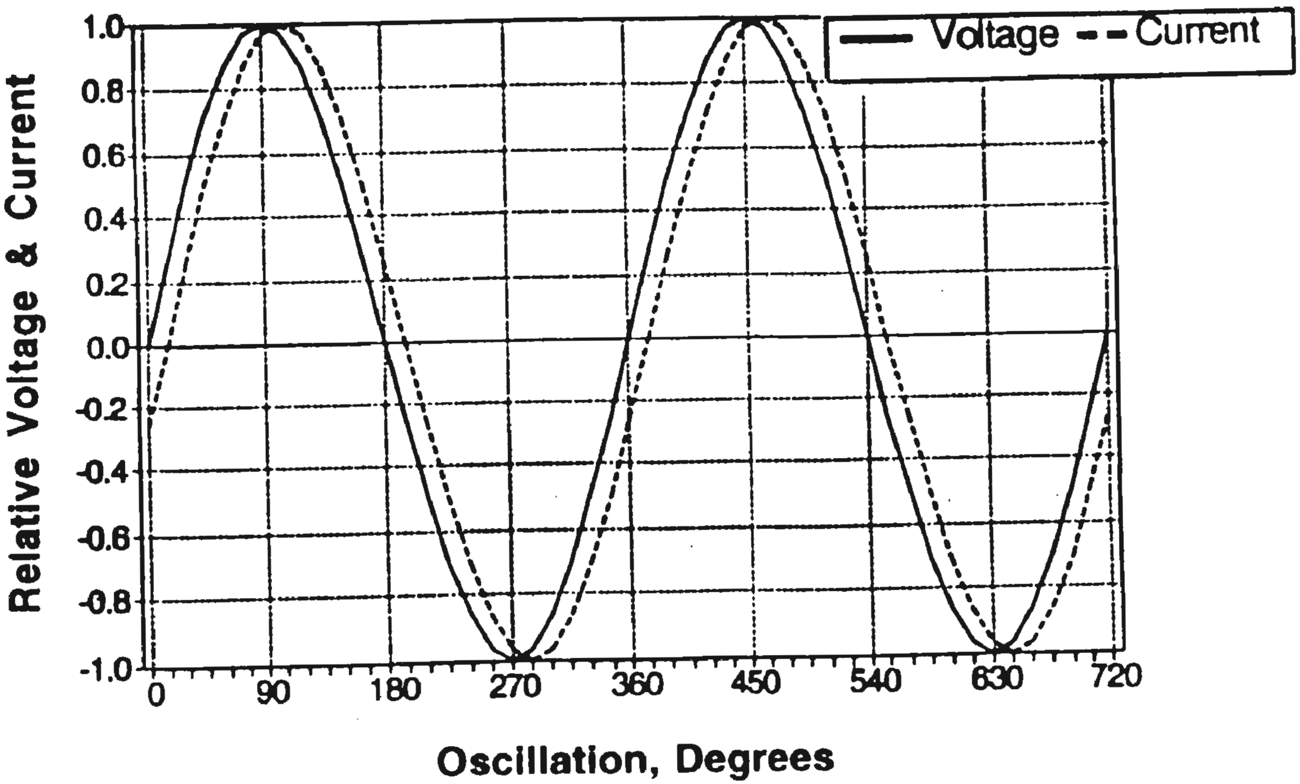
$$P = (I)^2 \times R \times \cos Ø$$

or

$$P = V \times (V / R) \times \cos Ø$$

$$P = (V)^2 / R \times \cos Ø$$

AC VOLTAGE AND CURRENT RELATIONSHIPS (EXAMPLE OF CURRENT LAGGING)



Slide 17 - 12

AC ELECTRICAL POWER

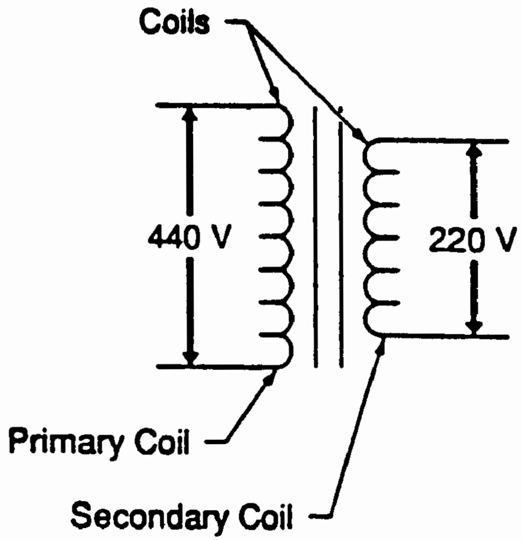
Apparent Power is Current times Voltage

$$P_{apparent} = I \times V, [KVA]$$

Power Factor

$$\text{Power Factor} = \cos \text{Ø} = P/P_{apparent}$$

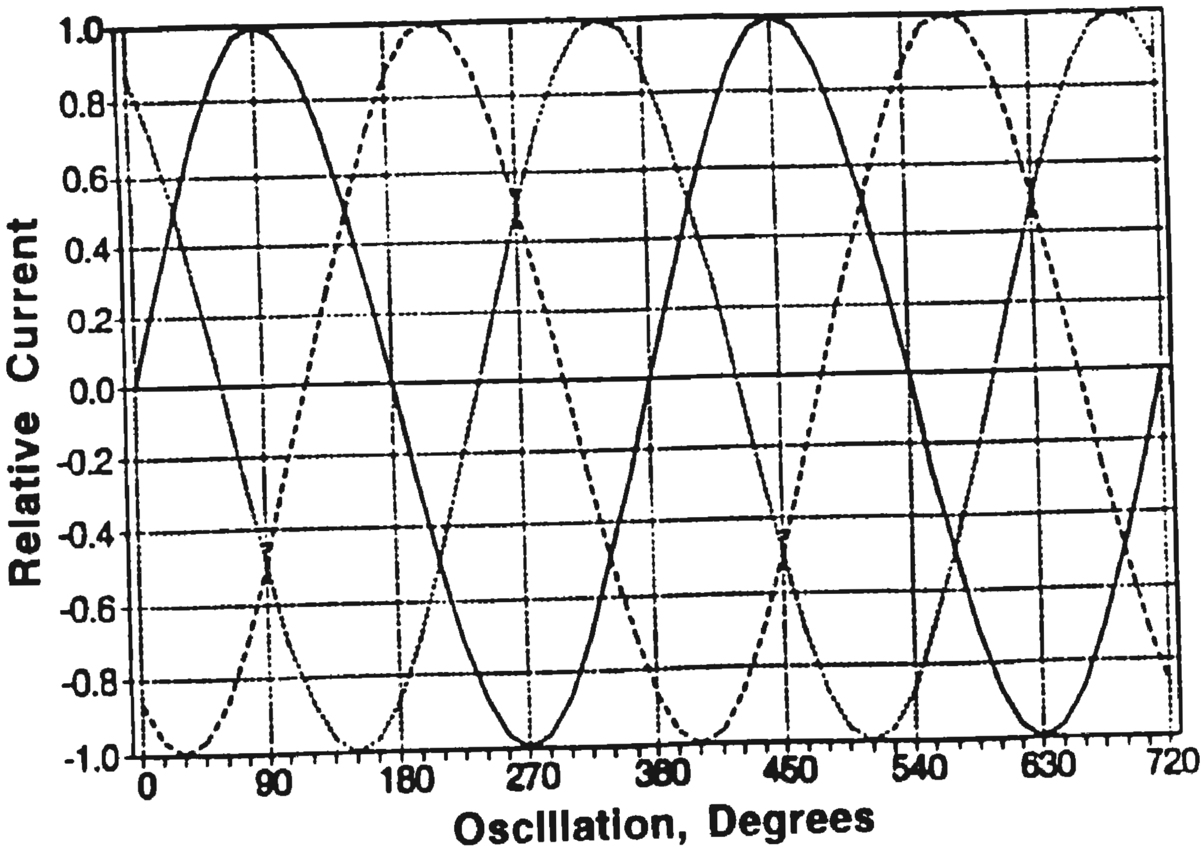
TRANSFORMER WINDING SCHEMATIC



Step-down Transformer

Slide 17 - 14

SCHEMATIC OF 3-PHASE ELECTRIC CURRENT



Slide 17 - 15

ELECTRICAL POWER EQUIPMENT

COMPONENT	FUNCTION
Voltage Regulator	Maintains Constant Voltage from AC Source
Circuit Breaker	Controls the Flow of Electricity
Rectifier	Converts AC Electricity to DC
Inverter	Converts DC Electricity to AC

INSTRUMENTS AND METERS

Voltmeters
Ammeters
Ohmmeters
Synchroscopes
Frequency Meters

LESSON PLAN

CHAPTER 18. TURBINE GENERATOR

Goal: To give the participant a general overview of turbine generator designs and operation.

Objectives:

Upon completion of this unit an operator should be able to:

1. Identify key components of an AC generator.
2. Describe the components required in a turbine generator and boiler set.
3. Understand the design differences between impulse steam turbines and reaction steam turbines.
4. Understand the importance at following cold start and shut–down procedures because of thermal and mechanical stresses on the unit.
5. Describe the use of synchroscope.
6. Discuss potential off–normal operating conditions and the respective consequences.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

Does anyone know the cold start and shutdown procedures for turbines?

How quickly can you heat up a turbine?

Presentation Outline:

18.1. Introduction

18.2. Steam Turbine Generator Description

18.3. Steam Turbine Designs

18.4. Steam Turbine Generator Operation

18.5. Generator Synchronization With Utility Grid

18.6. Turbine Generator Off-Nominal Conditions

References for Presentation Slides

Slide 18-2	Wark, Kenneth, Jr., *Thermodynamics*, Fifth Edition, McGraw Hill Book Company, New York, 1988, p. 739.
Slide 18-4	Steingrass, Fredrick M. and Frost, Harold J., *Stationary Engineering*, American Technical Publishers, Inc., Homewood, IL, 1991, pp. 227 - 275.
Slide 18-5	Ibid.
Slide 18-7	Ibid.
Slide 18-8	Ibid.

CHAPTER 18. TURBINE GENERATOR

18.1 Introduction

18.2 Steam Turbine Generator Description

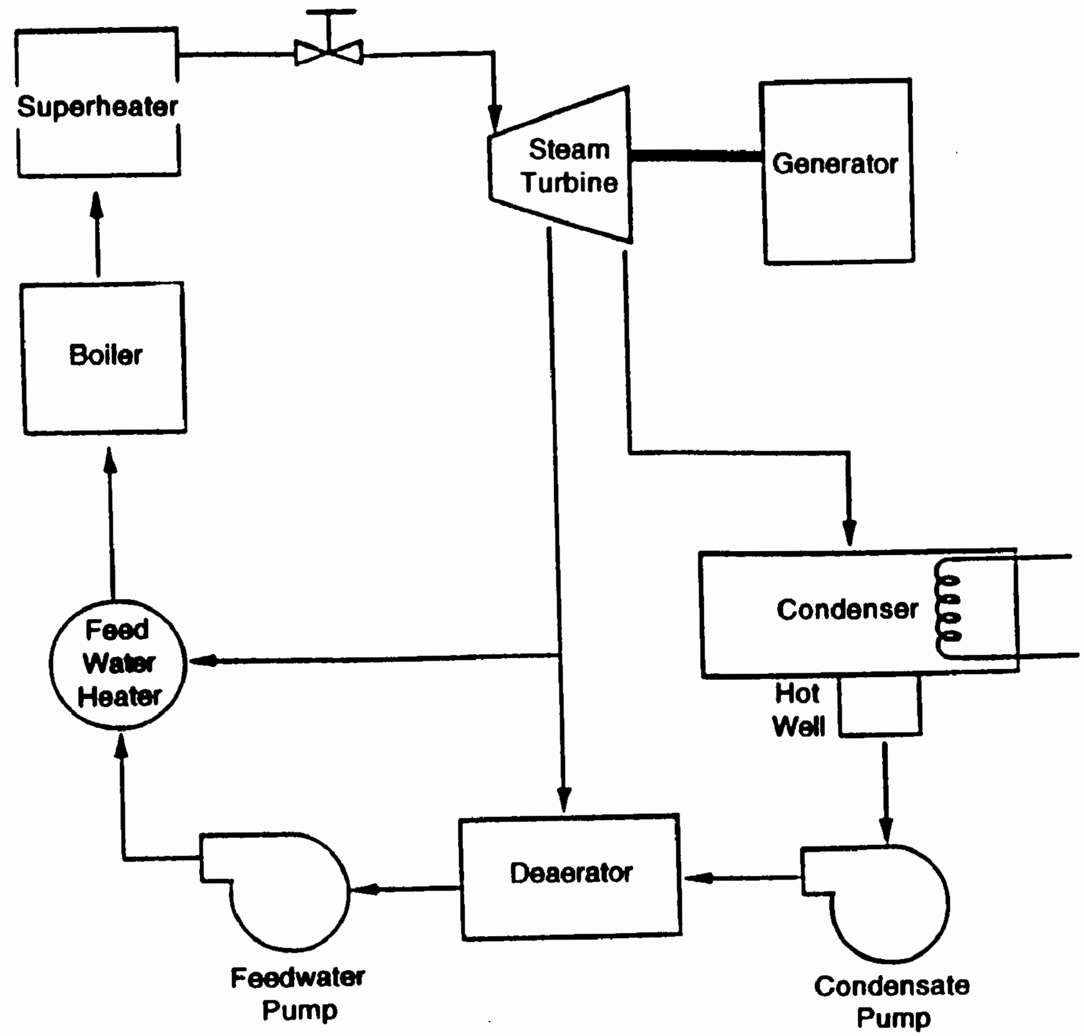
18.3 Steam Turbine Designs

18.4 Steam Turbine Generator Operation

18.5 Generator Synchronization with Utility Grid

18.6 Turbine Generator Off-Nominal Conditions

STEAM GENERATOR EQUIPMENT & FLOW SCHEMATIC[2]

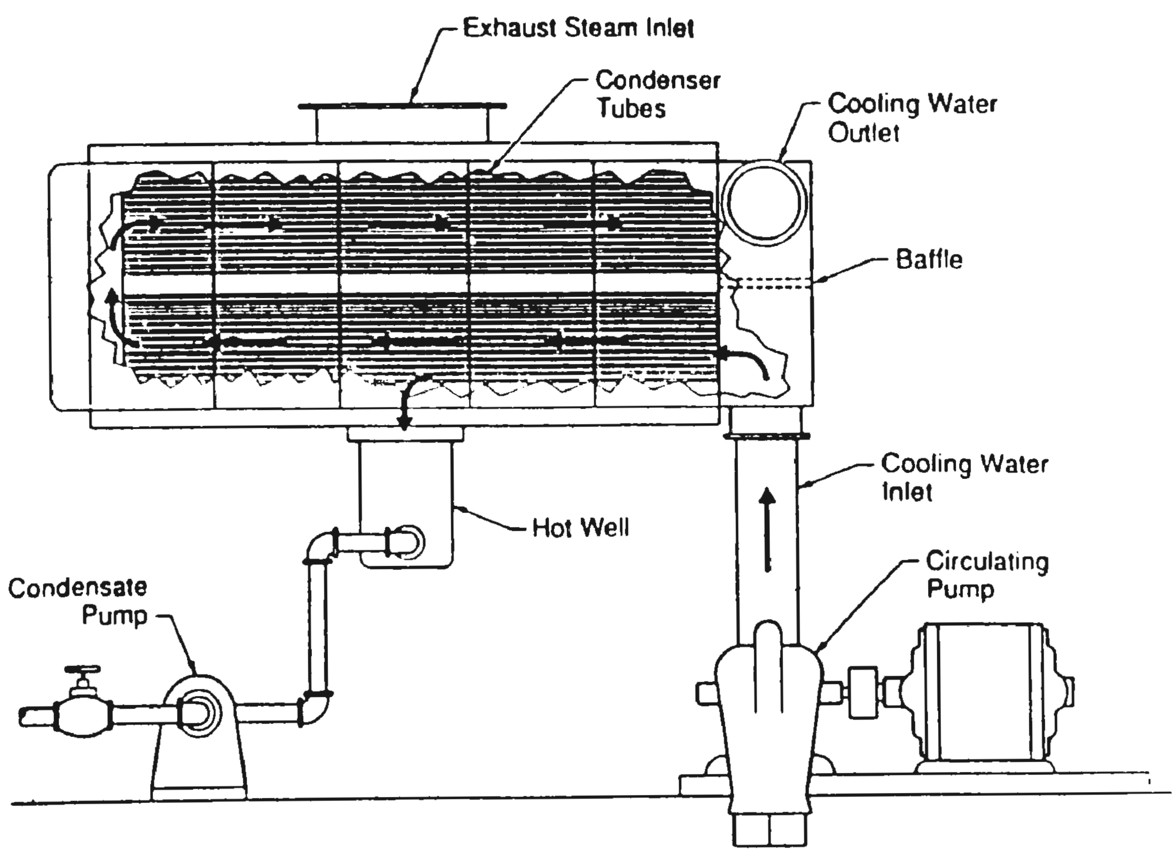


Slide 18 - 2

TURBINE GENERATOR SYSTEM COMPONENTS

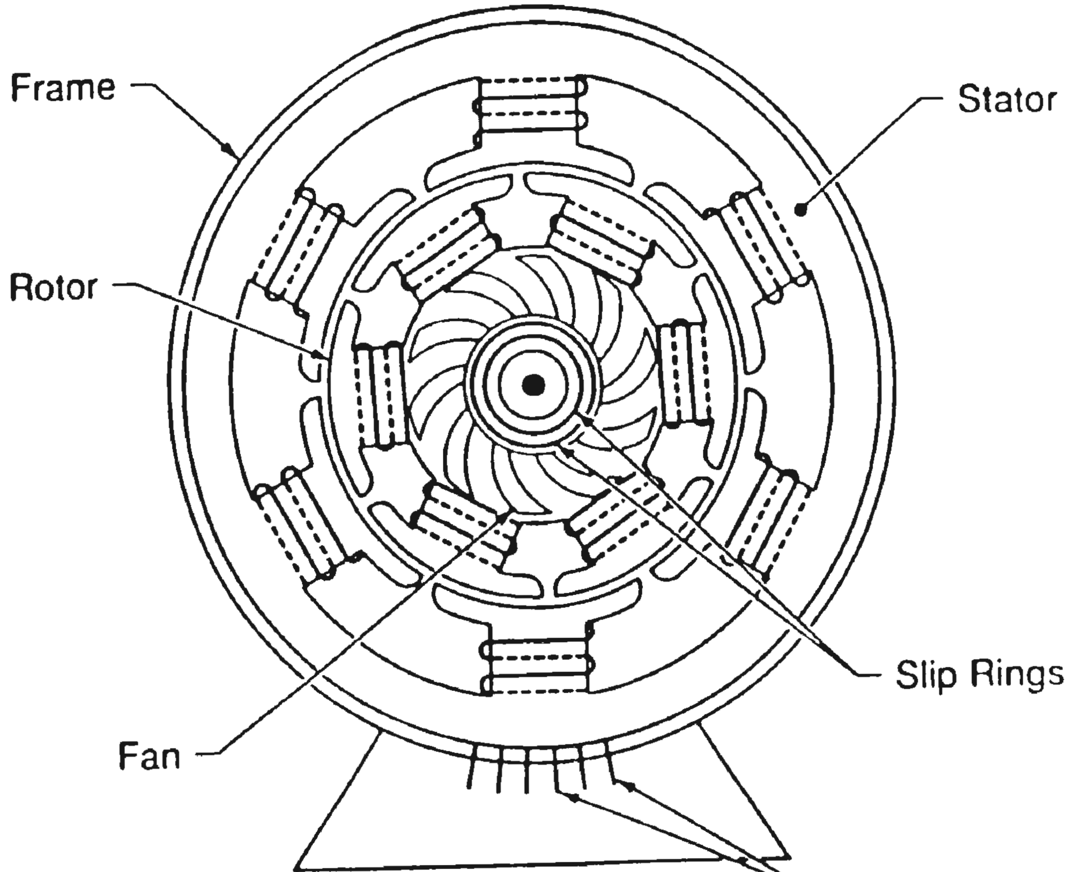
Steam Turbine
Condenser, Hotwell & Air Ejector
Condensate Pump & Heater
Deaerator
Feedwater Pumps & Heaters
Electrical Generator

STEAM CONDENSER SCHEMATIC[1]



Slide 18 - 4

AC GENERATOR[1]



STEAM TURBINE TYPES & FEATURES

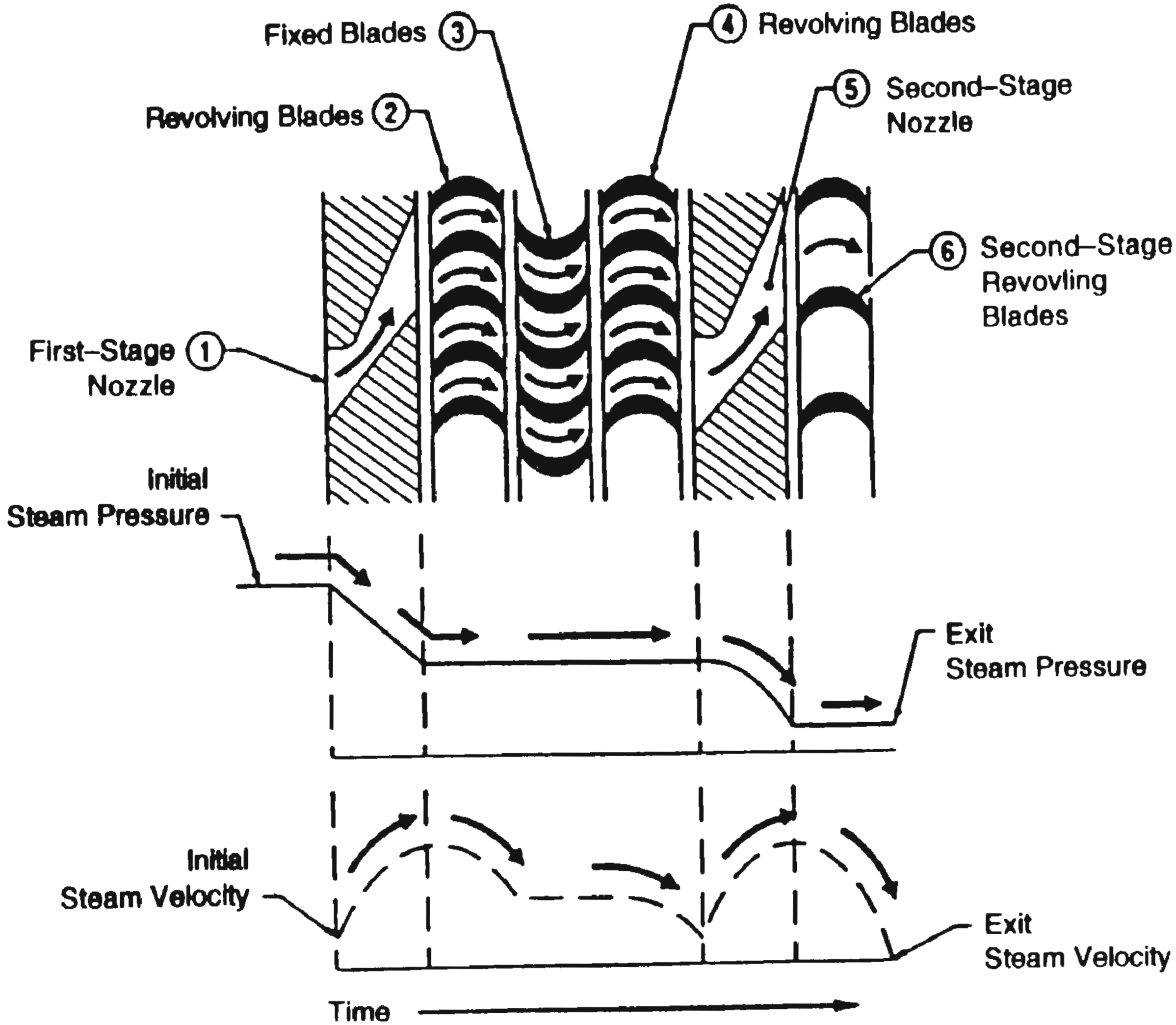
TYPES

Impluse Steam Turbine
Reaction Steam Turbine
Impulse–Reaction Steam Turbine

FEATURES

Multiple Stages
Conversion of Thermal Energy
Production of Mechnical Energy

IMPULSE TURBINE BLADE CONFIGURATION & FLOW PARAMETERS[1]



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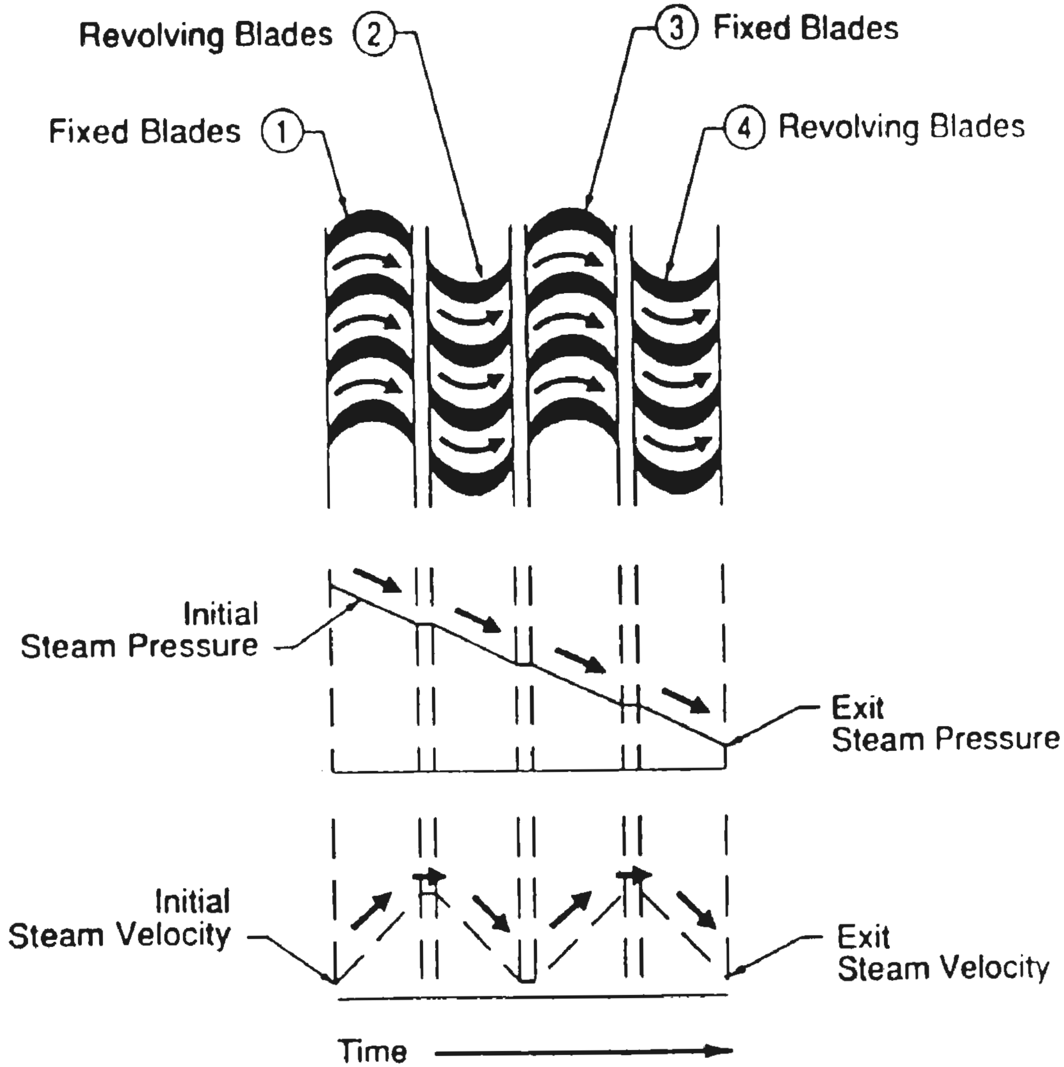
REACTION TURBINE CONFIGURATION & FLOW PARAMETERS[1]



TURBINE GENERATOR OPERATION

Cold Start
Synchronization
Shut–Down

TURBINE GENERATOR SYNCHRONIZATION

Synchroscope: Phase Angle Meter
Clockwise Rotation
Counterclockwise Rotation
Indicator Pointing Upward

TURBINE GENERATOR OFF–NORMAL CONDITIONS

Water Induction
Excessive Vibration
High Bearing Temperatures
High–Back Pressure
Speed Control

LESSON PLAN

CHAPTER 19. PREVENTATIVE MAINTENANCE

Goal: To give the participant an overview of the general aspects of preventative maintenance.

Objectives:

Upon completion of this unit an operator should be able to:

1. Understand that the operator is responsible for safety, protection of system operations, preventative maintenance, corrective maintenance, keeping good records and communication.
2. Describe the some potential economic losses that can occur at a boiler.
3. Describe the five features of a maintenance program.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What are some of the goals of preventative maintenance?

Who loses when preventative maintenance is not performed?

Can anyone describe your maintenance programs at your facility?

Presentation Outline:

19.1 Potential Economic Losses

19.2 Features of Preventative Maintenance

19.3 Periodic Inspections

19.4 In-Service Maintenance

19.5 Outage Maintenance Planning

CHAPTER 19. PREVENTATIVE MAINTENANCE

POTENTIAL ECONOMIC LOSSES

1. Cost of Preventive Maintenance
2. Personal Injury
3. Equipment Repair/Replacement
4. Lost Revenue – Equipment Downtime
5. Fines – Regulatory Violations

OPERATOR RESPONSIBILITIES

1. Safety
2. Production (System Operations)
3. Preventive Maintanance
4. Corrective Maintenance
5. Record Keeping & Communications

GOALS OF PREVENTIVE MAINTENANCE

1. Maximize Unit Reliability
2. Minimize Total Operating Costs
3. Enhance Equipment Life
4. Restore Unit Performance

FEATURES OF A MAINTENANCE PROGRAM

1. Review Vendor Recommendations
2. Identification of Problems
3. Evaluation of Options
4. Communication & Planning
5. Implementation

IN–SERVICE MAINTENANCE

1. **Follow Recommended Procedures**
2. **Know Special Design Features**
3. **Know Operational Relationships**

OUTAGE MAINTENANCE

1. Make & Update an Outage Plan
2. Arrange for Materials/Services
3. Make Detailed Inspections
4. Revise Plans as Necessary
5. Follow Proper Procedures
6. Inspect Upon Conclusion

LESSON PLAN

CHAPTER 20. SAFETY

Goal: To give the participant a general description of safety hazards, standard safety procedures, personnel protection equipment, and consequences of exposure associated with a steam generating system.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the possible causes and methods of prevention of waterside explosions on a steam generating system.
2. Discuss the possible causes and method of prevention of gas side explosions in steam generating systems.
3. Describe the kind of information that can be found on an MSDS sheet.
4. Describe standard industrial safety considerations associated with working in an industrial environment.
5. List personal protection equipment that may be required to give workers additional safety.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What kinds of safety procedures do you follow on the job?

Has anyone been close to or personally involved in an accident that could have been prevented by following simple safety guidelines?

Presentation Outline:

20.1 System Safety Hazards

20.2 Consequences of Exposure to Hazards

20.3 Standard Safety Considerations

20.4 Personnel Protection Equipment

CHAPTER 20. SAFETY

20.1 System Safety Hazards

20.2 Consequences of Exposure to Hazards

20.3 Standard Safety Considerations

20.4 Personnel Protection Equipment

SAFETY PROCEDURE ELEMENTS

1. Recognition of Hazards
2. Consequences of Exposures
3. Standard Safety Procedures
4. Personal Protection Equipment

MAJOR HAZARDS OF STEAM GENERATING SYSTEMS

- Water Side Explosions Due to Overheating and Over Pressure

- Gas Side Explosions Due to Explosive Mixtures

OTHER BOILER SYSTEM SAFETY HAZARDS

1. Combustion Gases
2. Noise
3. Observation Hatches
4. Operations in Confined Spaces
5. Boiler Auxiliary Systems

SYMPTOMS OF ILLNESS

1. Headaches
2. Lightheadedness
3. Dizziness
4. Nausea
5. Loss of Coordination
6. Difficulty in Breathing
7. Chest Pains
8. Exhaustion

STANDARD SAFETY CONSIDERATIONS

Exposure to High Pressure Steam
Exposure to Hot Water
Electrical Shock
Exposure to Chemicals
Chemical Mixing
Asbestos Exposure
Noise & Vibration
Exposure to Rotary Equipment
Awkward Access
Movement of Heavy Objects
Fire Hazards

PERSONAL PROTECTION EQUIPMENT

1. Ear Protection
2. Heavy Gloves
3. Hard Hat
4. Respirator
5. Goggles and Safety Glasses
6. Safety Shoes
7. Proper Clothing
8. Back Support
9. Gaseous Concentration Monitors

LESSON PLAN

CHAPTER 21. AIR POLLUTANTS OF CONCERN

Goal: To give the participant an overview of the types and potential health risk effects of air pollutants.

Objectives:

Upon completion of this unit an operator should be able to:

1. Identify the basic classifications of air pollutants.
2. List the five primary pollutants.
3. Describe the typical form, critical factors, and the health and welfare effects of the primary pollutants.
4. Understand that the NAAQS represents the maximum levels of pollutants permitted to exist in the air.
5. Describe the two most common types of secondary pollutants.
6. Describe the formation of secondary pollutants from primary pollutants.

Lesson Time: Approximately 75 minutes.

Suggested Introductory Questions:

Does anyone know what pollutants cause the brown color of smog?

Presentation Outline:

21.1 Introduction

21.2 Air Quality Overview

21.3 National Ambient Air Quality Standards

21.4 Primary Pollutants
- A. Particulate
- B. Sulfur Dioxide
- C. Nitrogen Dioxide
- D. Volatile Organics (VOCs)
- E. Carbon Monoxide

Presentation Outline (Continued):

21.5 Secondary Pollutants
- A. Photochemical Oxidant
- B. Acid Deposition

21.6 Hazardous Pollutants
- A. Metals
- B. Organics

CHAPTER 21. AIR POLLUTANTS OF CONCERN

AIR POLLUTANTS OF CONCERN

Primary Pollutants

Particulate Matter
Sulfur Oxides (SO_2, SO_3)
Nitrogen Oxides (NO_x, NO_2)
Hydrocarbons
Carbon Monoxide

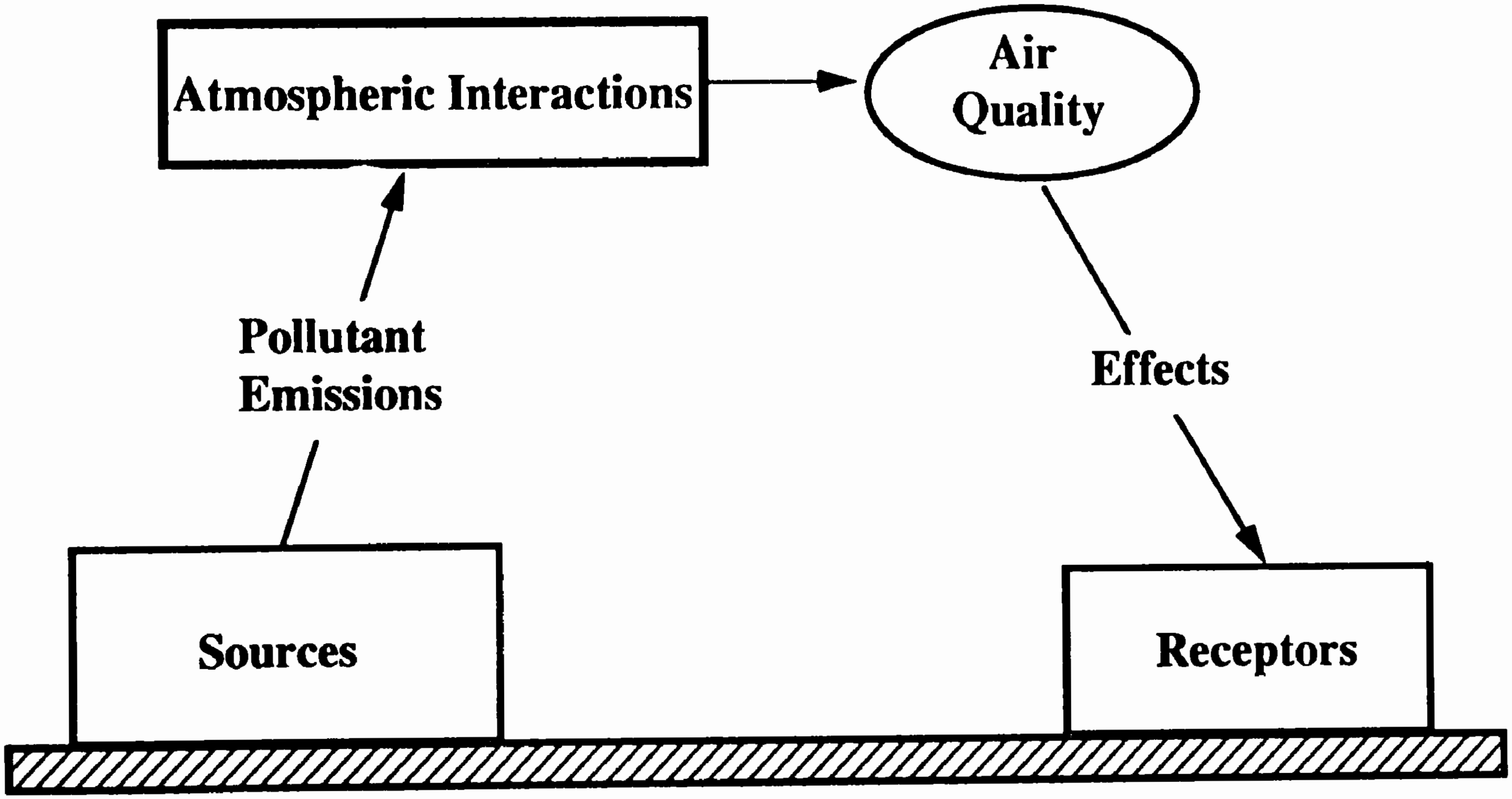
Secondary Pollutants

Photochemical Oxidant (ozone, etc...)
Sulfates

Hazardous Pollutants

Metals (Lead, Mercury, etc...)
Organics (Benzene, Vinyl Chlorides, etc...)

AIR QUALITY OVERVIEW



Slide 21 - 3

NATIONAL AMBIENT AIR QUALITY STANDARDS

POLLUTANT	AVERAGING TIME	PRIMARY STANDARD	SECONDARY STANDARD
Particulate Matter (< 10µm)	annual mean 24 hour	50 µg/m^3 150 µg/m^3	50 µg/m^3 50 µg/m^3
Sulfur Oxides	annual average 24 hour 3 hour	80 µg/m^3 365 µg/m^3	1300 µg/m^3
Nitrogen Dioxide	annual average	100 µg/m^3	Same
Hydrocarbons (corrected for methane)	3 hour	160 µg/m^3	160 µg/m^3
Carbon Monoxide	8 hour 1 hour	10 mg/m^3 40 mg/m^3	Same Same
Ozone	1 hour	235 µg/m^3	Same
Lead	3 month average	1.5 µg/m^3	Same

NAAQS OBJECTIVES

Pollutant	Objective of the Standard
Particulate	To prevent health effects due to long term exposure
Sulfur Dioxide	To prevent pulmonary irritation (primary) and to prevent odor (secondary)
Nitrogen Dioxide	To prevent possible risk to public health and atmospheric discoloration
Hydrocarbons	To reduce photochemical oxidant formation
Carbon Monoxide	To prevent interference with the capacity to transport oxygen to the blood
Ozone	To prevent eye irritation and respiratory problems and to prevent damage to vegetation
Lead	To prevent lead poisoning

PARTICULATE MATTER

Typical Form: Solid, Liquid, Aerosol

Critical Factors: Particle Size
Particle Type
Aerosol Concentration

Health Effects: Deposits in Respiratory Passages
Increases Exposure to Toxic Substances

Welfare Effect: Reduces Visibility

SULFUR OXIDES

Typical Form:	**Sulfur Dioxide – Gaseous** **Sulfates (SO_3, H_2SO_4) – Liquid**
Critical Factor:	**Conversion of SO_2 to Sulfates in the Atmosphere**
Health Effect:	**Causes Broncho constriction, Especially in Asthmatics**
Welfare Effect:	**Results in Acid Deposition**

NITROGEN OXIDES

Typical Form:	**Nitric Oxide (NO) – Gaseous** **Nitrogen Dioxide (NO_2) – Gaseous** **Nitric Acid (HNO_3) – Liquid**
Critical Factor:	**Conversion of NO to NO_2 and to Nitrates in the Atmosphere**
Health Effects:	**Damages Respiratory Tissues, Causes Respiratory Symptoms**
Welfare Effect:	**Results in Atmospheric Discoloration, Promotes Formation of Photochemical Oxidant, and Results in Acid Deposition**

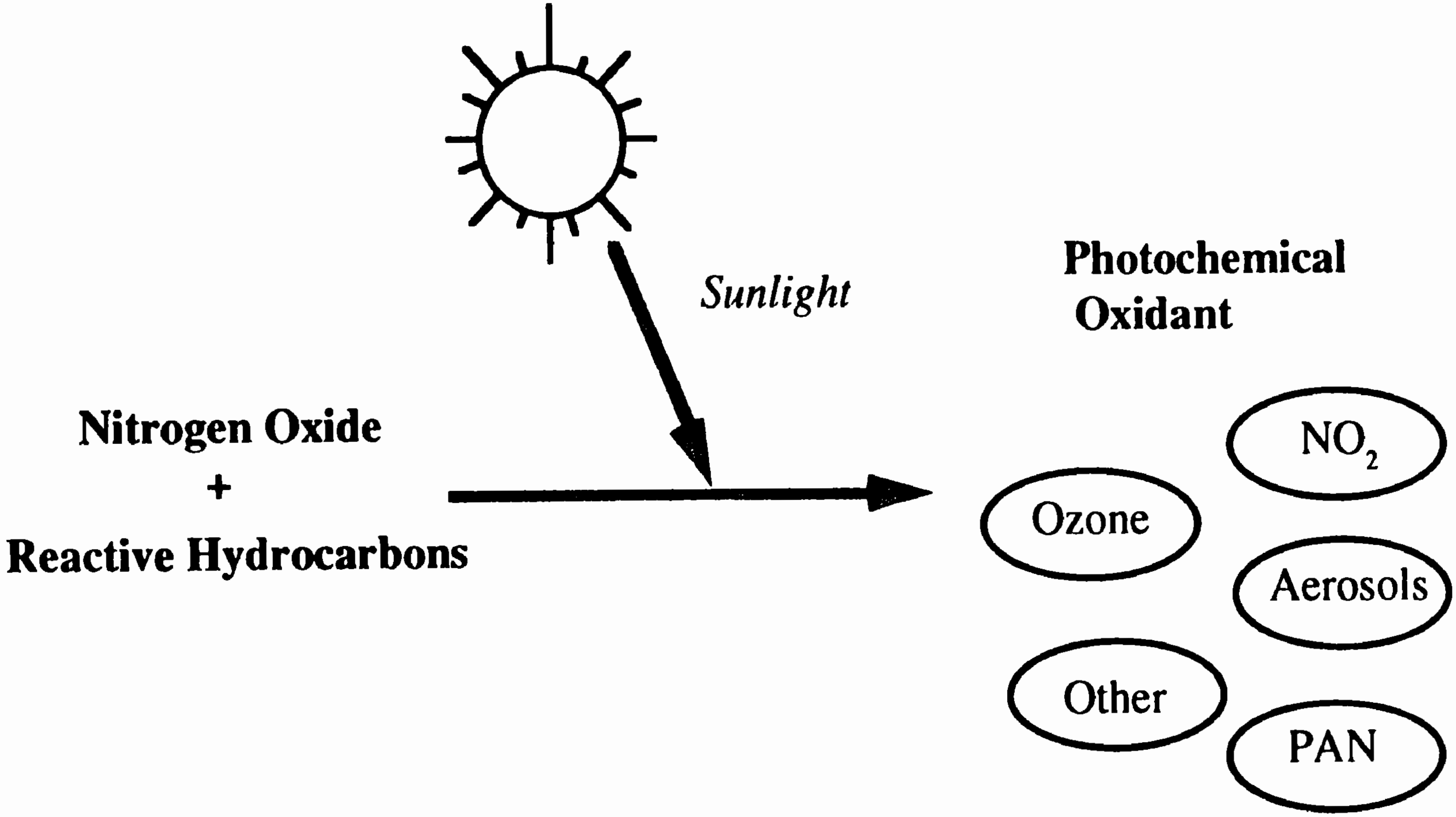
HYDROCARBONS

Typical Form:	**A Wide Range of Organic Molecules are Possible**
Critical Factor:	**Molecule Type**
Health Effects:	**Not Critical at Typical Concentrations**
Welfare Effect:	**Contributes to Photochemical Oxidant and Ozone**

CARBON MONOXIDE

Typical Form:	**Gas**
Critical Factor:	**Concentration**
Health Effects:	**Impairs Oxygen Transport in Blood** **Impacts Central Nervous System**
Welfare Effect:	**None**

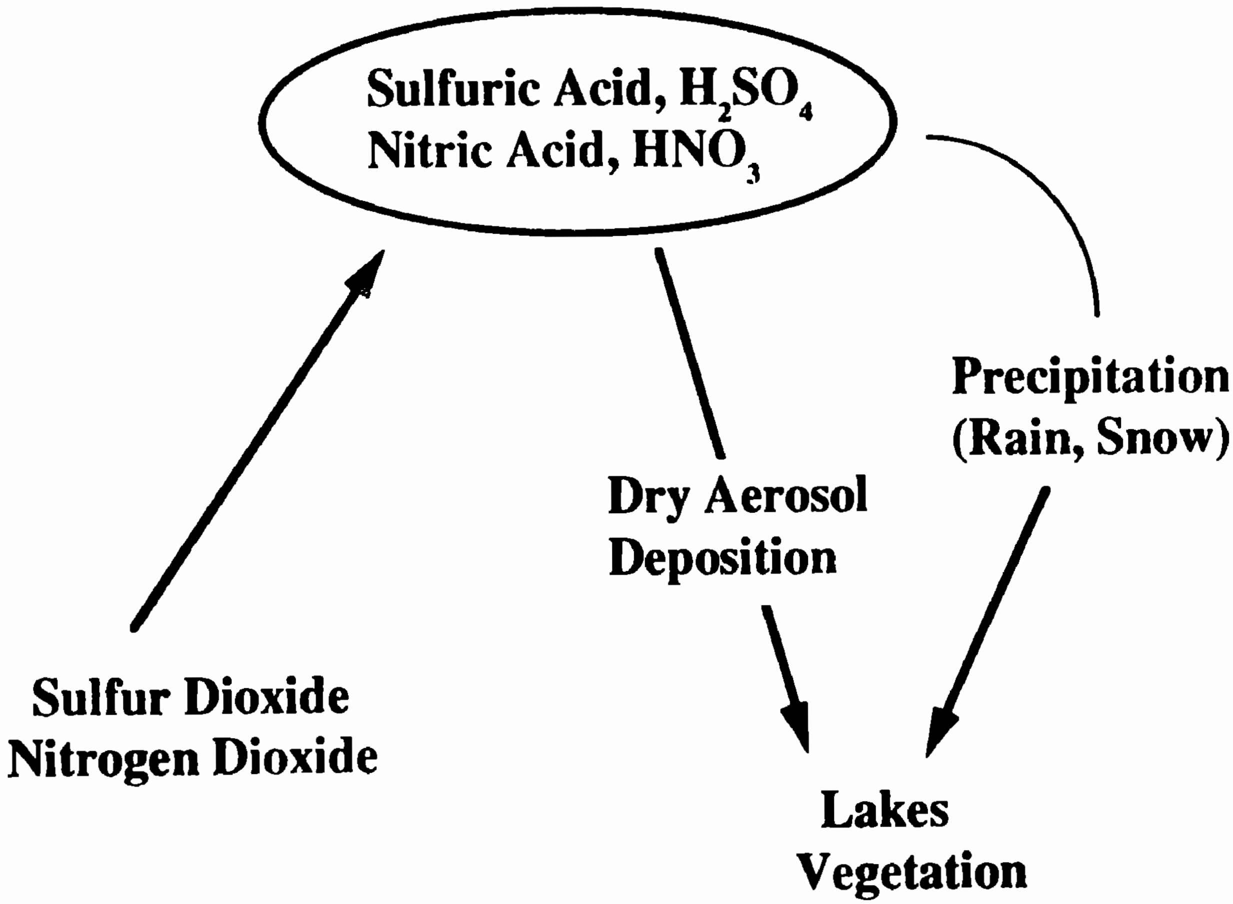
FORMATION OF PHOTOCHEMICAL OXIDANT



OZONE

Typical Form:	**Gas**
Critical Factor:	**Concentration**
Health Effects:	**Irritates Eyes and Mucous Membranes. Causes Respiratory Symptoms and Lung Damage**
Welfare Effect:	**Damages Plants and Materials**

ACID DEPOSITION



HAZARDOUS METALS

Beryllium
Copper
Mercury
Zinc Oxide
Cadmium
Inorg. Arsenic
Nickel
Lead
Chromium
Manganese
Zinc

HAZARDOUS ORGANICS

Acrolein	Benzene	Benzo(a)pyrene
Carbon Tetrachloride	Chloroform	Ethylene Dibromide
Ethylene Dichloride	HCHO	Methyl Bromide
Methylene Chloride	Peroxyacyl Nitrate (PAN)	Perchloroethylene
Toluene	Trichloroethane	1,1,1-Trichloroethane
Vinyl Chloride	Xylenes	

LESSON PLAN

CHAPTER 22. ENVIRONMENTAL REGULATIONS

Goal: To give the participant an in-depth view of environmental regulations applicable to steam generating systems.

Objectives:

Upon completion of this unit an operator should be able to:

1. Give a brief description of air pollution regulatory legislation enacted in recent history.
2. Describe the meaning of the Clean Air Act acronyms, particularly NAAQS, NSPS, SIP, PSD, and NESHAP.
3. Discuss the Clean Air Act provisions applicable to boiler operations.
4. Discuss the implications of NSPS on boiler operations and understand that NSPS regulations vary depending on fuel type.
5. Discuss the requirements related to continuous emissions monitors as applied to steam generating units.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

How have operations at your facilities been affected recently by environmental regulations?

Does anyone know what emissions criteria your steam generating units must meet?

Presentation Outline:

22.1 Regulatory Overview
- A. Clean Air Act History
- B. Clean Air Terminology
- C. Clean Air Act Provisions

22.2 Provisions of the Clean Air Act Relative to Boiler Operations

Presentation Outline (Continued):

22.3 New Source Performance Standards
- A. Performance Standards for Steam Generators (>250 MMBtu/hr)
- B. Performance Standards for Electric Utility Steam Generators (>250 MMBtu/hr)
- C. Performance Standards for Steam Generators (>100 MMBtu/hr)
- D. Performance Standards for Small Steam Generators (10–100 MMBtu/hr)

22.4 Additional Standards
- A. Acid Rain Program
- B. State Implementation Plans
- C. National Emission Standards for Hazardous Air Pollutants

22.5 Permits
- A. Title V Overview
- B. Permit Program Elements
- C. Information Requirements

CHAPTER 22. ENVIRONMENTAL REGULATIONS

22.1 Regulatory Overview

22.2 Provisions of the Clean Air Act Relative to Boiler Operations

22.3 New Source Performance Standards

22.4 Additional Standards

22.5 Permits

HISTORY OF THE CLEAN AIR ACT

1881	Smoke control ordinances passed in Chicago and Cincinnati
1955	Federal Air Pollution Control Act enacted to evaluate and assist with air pollution control
1963	Federal Clean Air Act passed to increase federal government role in protecting public health and welfare
1965	Motor Vehicle Air Pollution Control Act passed to set emissions standards for new vehicles
1967	Federal Air Quality Act Enacted to increase air pollution control efforts
1970	Clean Air Act Amendments passed to improve efforts for improving air quality
1977	Additional Amendments to the Clean Air Act passed to extend deadline for achieving air quality standards
1990	Clean Air Act Amendments passed to control acid rain, auto emissions, hazardous pollutants, and to meet the ozone standard nationwide

CLEAN AIR ACT TERMINOLOGY

NAAQS	National Ambient Air Quality Standards
PSD	Prevention of Significant Deterioration
NSPS	New Source Performance Standards
SIP	State Implementation Plans
NESHAP	National Emission Standards for Hazardous Air Pollutants

CLEAN AIR ACT CONTROL STANDARDS

Criteria Pollutants

LAER	**Lowest Achievable Emissions Rate**
BACT	**Best Available Control Technology**
RACT	**Reasonably Available Control Technology**

Hazardous Air Pollutants

MACT	**Maximum Available Control Technology**
GACT	**Generally Available Control Technology**

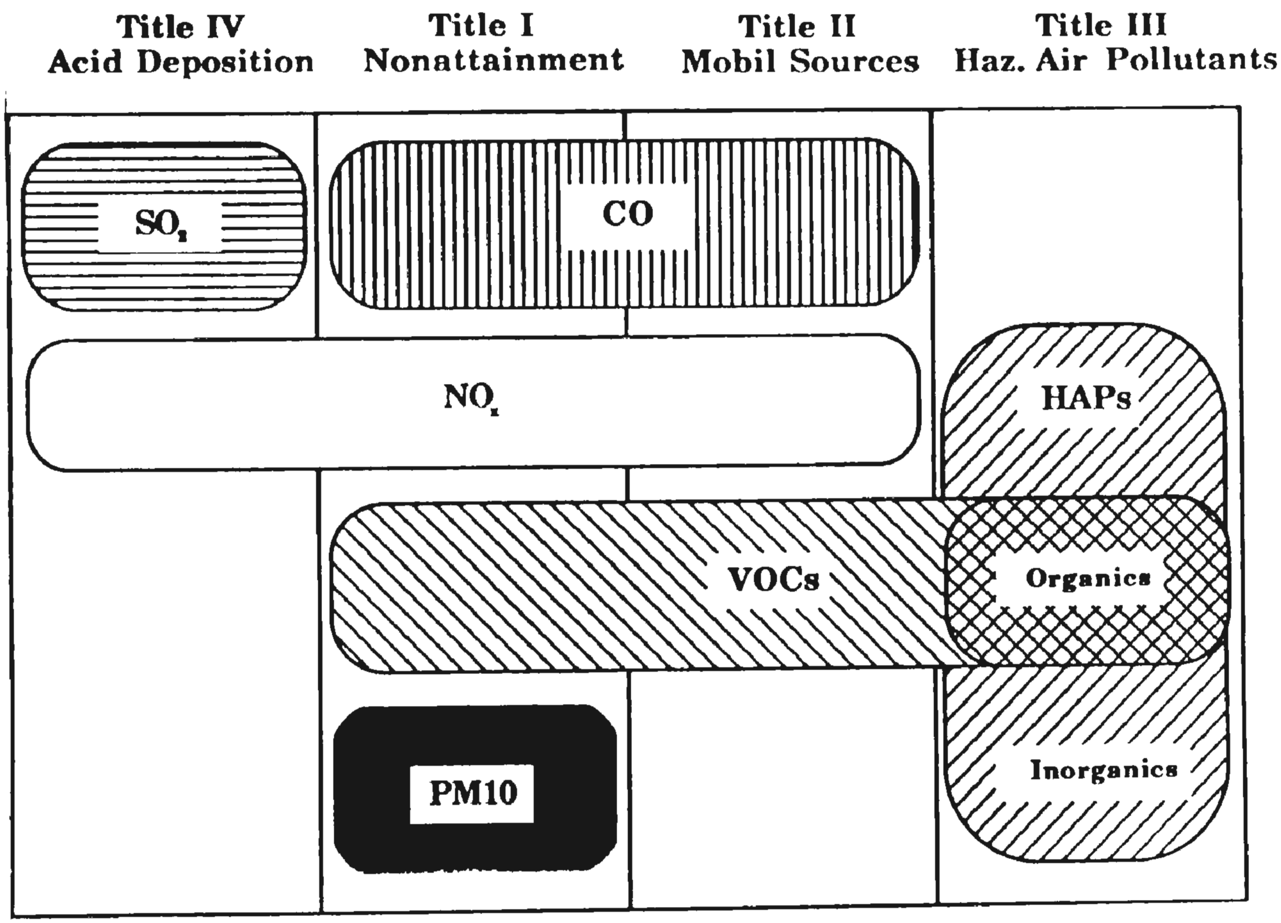
1990 CLEAN AIR ACT TITLES

I. Air Pollution Prevention and Control
II. Emissions Standards for Moving Vehicles
III. Hazardous Air Pollutants
IV. Acid Deposition Control
V. Permits
VI. Stratospheric Ozone Protection
VII. Enforcement
VIII. Miscellaneous Provisions
IX. Clean Air Research
X. Disadvantaged Business Concerns
XI. Clean Air Employment Transition Assistance

CLEAN AIR ACT PROVISIONS RELATIVE TO BOILER OPERATIONS

Title I:	**Air Pollution Prevention and Control**
Title III:	**Hazardous Air Pollutants**
Title IV:	**Acid Deposition Control**
Title V:	**Permits**

AIR POLLUTANTS COVERED BY CAAA



Slide 22 - 7

NEW SOURCE PERFORMANCE STANDARDS

Apply to New Units or Significantly Modified Units

Regulations Established for Different Groupings of Pollutants Emission Sources

- Utility Boilers
- Industrial Boilers
- Gas Turbines

Establish Stack Emission Limits for Criteria Pollutants

Limits Must be Based on Demonstrated Performance of Control Technologies

Establish Monitoring, Recordkeeping, and Reporting Requirements

NEW SOURCE PERFORMANCE STANDARDS

Steam Generators with Heat Input > 250 MMBtu/hr

Apply to Units Constructed After 8/17/71
or Significantly Modified Units

Fuel	Pollutant	Allowable Emissions Rate (lb/10^6 Btu)
Coal	SO_2	1.2
	NO_X	0.7
	Particulate	0.1
Oil	SO_2	0.8
	NO_X	0.3
	Particulate	0.1
Gas	NO_X	0.2
	Particulate	0.1

CONTINUOUS EMISSIONS MONITORS

Each boiler operator is required to install continuous emissions monitors for SO_2, NO_x, and either O_2 or CO_2 with the following exceptions:

1) Boilers burning gas do not need an SO_2 monitor.

2) Boilers burning coal and oil can opt to monitor SO_2 by fuel sampling and analysis, if they do not have a desulfurization unit.

3) Boilers with NO_X emissions which are less than 70 percent of the standards do not need to install a NO_X monitor.

4) Boilers not needing SO_2 or NO_X monitors do not need to install an O_2 or CO_2 monitor.

BOILER OPERATION LOG DATA FOR NSPS REPORTING

Calendar date

Emission rates (hourly) and/or opacity
- **Reasons for noncompliance with the emission standards**
- **Description of corrective actions taken.**

Operating days for which emission data have not been obtained by an approved method
- **Justification for not obtaining sufficient data**
- **Description of corrective actions taken.**

Type of fuel(s) combusted and reference to composition
(i.e. fuel supplier certification)

If a CEMS is used,
- **Identification of any times when the pollutant concentration exceeded the full span of the CEMS.**
- **Description of any modification to the CEMS that could affect the ability of the CEMS to comply with Performance Specifications**
- **Results of daily CEMS drift tests**

Slide 22 - 11

NSPS – SULFUR DIOXIDE & PARTICULATE

Electric Utility Steam Generators
with Heat Input > 250 MMBtu/hr

Apply to Units Constructed After 9/18/78
or Significantly Modified Units

Fuel	Pollutant	Allowable Emissions Rate (lb/10^6 Btu)	Emissions Reduction
Coal	SO_2	1.2	90%
		0.6	70%
	Particulate	0.03	99%
Oil	SO_2	0.8	90%
		0.2	0%
	Particulate	0.03	70%
Gas	SO_2	0.8	90%
		0.2	0%
	Particulate	0.03	–

NSPS – NITROGEN OXIDES Electric Utility Steam Generators with Heat Input > 250 MMBtu/hr

Apply to Units Constructed After 9/18/78 or Significantly Modified Units

Fuel	Allowable Emissions Rate (lb/10^6 Btu)	Emissions Reduction
Gaseous Fuel:		
Coal–Derived	0.5	25%
All Other	0.2	25%
Liquid Fuels:		
Coal–Derived	0.5	30%
Shale Oil	0.5	30%
All Other	0.3	30%
Solid Fuels		
Coal–Derived	0.5	65%
Fuel (25% Coal Refuse)	(1)	(1)
Fuel (25% Lignite/Slag)	0.8	65%
Fuel (25% Lignite/other)	(2)	(2)
Subbituminous	0.5	65%
Bituminous	0.6	65%
Anthracite	0.6	65%
All Other	0.6	65%

(1) exempt from the NO_x standards and monitoring requirements

(2) fuels in this category are not prorated

POTENTIAL COMBUSTION CONCENTRATIONS

Pollutant	Fuel Type	Concentration (lb/MMBtu)
Particulate	Solid	7.00
	Liquid	0.17
SO_2	All	Based Upon Fuel Content
NO_x	Solid	2.30
	Liquids	0.72
	Gaseous	0.67

CONTINUOUS EMISSIONS MONITORS

Requirements:

- Install
- Calibrate
- Maintain
- Certify
- Record Output

Monitor:

- Opacity
- Sulfur Dioxide
- Nitrogen Oxides
- Oxygen or Carbon Dioxide

SOURCE PERFORMANCE STANDARDS
Steam Generators with Heat Input > 100 MMBtu/hr
Apply to Units Constructed After 6/19/84 or Significantly Modified Units

Fuel	Pollutant	Allowable Emissions Rate (lb/10^6 Btu)	Emissions Reduction
Coal	SO_2	1.2	90%
	NO_x:		
	Spreader Stoker	0.6	–
	Mass–Feed Stoker	0.5	–
	Pulverized Coal	0.7	–
	Fluidized Bed	0.6	–
	Particulate	0.05	–
Oil			
	SO_2:		
	Residual	0.5	0%
	Others	0.8	90%
	NO_x:		
	HRR < 70,000	0.3	–
	HRR > 70,000	0.4	–
	Particulate	0.10	–
Gas			
	NO_x:		
	HRR < 70,000	0.1	–
	HRR > 70,000	0.2	–
	Particulate	0.10	–

HRR = Heat Release Rate in Btu/hr–ft^3

SOURCE PERFORMANCE STANDARDS
Steam Generators with Heat Input 10–100 MMBtu/hr

Apply to Units Constructed After 6/9/89 or Significantly Modified Units

Fuel	Pollutant	Allowable Emissions Rate (lb/10^6 Btu)	Emissions Reduction
Coal	SO_2	1.2	90%
	Particulate	0.05	–
Oil	SO_2	0.5	–
Wood	Particulate	0.10	–

Slide 22 - 17

ADDITIONAL STANDARDS REQUIRING EMISSIONS CONTROLS

- **Acid Rain Program (Title IV)**
  - SO_2
  - NO_x

- **State Implementation Plans (SIP)**
  - NO_x
  - Hydrocarbons
  - Particulate

- **National Emission Standard for Hazardous Air Pollutants (NESHAP)**
  - Hazardous Organics
  - Metals in Flyash

ACID RAIN PROGRAM

Purpose

- Reduce annual SO_2 emissions from electric utility power plants by 10 million tons by the year 2000.
- Reduce NO_x emissions from electric utility power plants by 2 million tons.

Sulfur Dioxide Control

- Phase I(1995)
  - Emissions limited to 2.5 lb/MMBtu for plants greater than 100 MW (111 affected plants).
  - SO_2 allowance/trading scheme.
- Phase II (2000)
  - Emission limited to 1.2 lb/MMBtu for nearly all power plants greater than 25 MW.
  - Nationwide cap in utility SO_2 emissions at 8.9 million tons per year.

Nitrogen Oxides Control

- Emissions limits to be established by EPA.
- Preliminary limits:
  - Tangentially fired boilers = 0.45 lb/MMBtu.
  - Wall–fired boilers = 0.50 lbs/MMBtu.
- EPA to establish limits for cyclone boilers, wet bottom boilers and boilers equipped with cell burners.
- EPA to revise NSPS.

STATE IMPLEMENTATION PLANS (SIPs)

- Plans for Implementing the Requirements of the Clean Air Act at the State Level
- SIPs Provide the Road Map for States to Meet NAAQS
- Regulations May Apply to New and Existing Sources
- Regulations May Be More Stringent than NSPS
- SIPs Must be Reviewed and Approved by Federal EPA
- As SIPs are Approved, Boiler Operators will need to Contact State Regulatory Agencies to Determine Compliance Requirements

TITLE V – PERMITS

- Comprehensive Program for Federal Operating Permits
- Applies to Significant Sources of Air Pollution:
  - Major Sources of Criteria Pollutants
  - Sources Regulated by NSPS Provisions
  - Sources Subject to NESHAP Rules
- States to Develop Operating Permit Program Based upon EPA Guidelines
- EPA to Approve Program Plan
- Annual Permit Fees ~ $25/ton of Pollutant, Except CO

STATE PERMIT PROGRAMS

- Provisions for Permit Applications and Their Completeness
- Requirements for Payment of Fees
- Authority to Issue Permits
- Provisions for Reopening and Terminating Permits
- Provisions to Ensure Operating Flexibility
- Permits to Contain Requirements for:
  - Compliance Certification
  - Monitoring Requirements
  - Reporting Requirements

PERMIT INFORMATION REQUIREMENTS

- **Location**
- **Type of Source**
- **Owner/Operator Details**
- **Source and Process Description and an Alternative Operating Scenario**
- **Emissions Inventory Information**
- **Compliance Plan (if needed)**
- **Compliance Certification**

LESSON PLAN

CHAPTER 23. CONTINUOUS EMISSION MONITORING

Goal: To give the participant descriptions of CEMS classifications, CEM components, analytical methods employed by analyzers, and operating and maintenance procedures.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the general classifications of CEM systems and describe key design differences.
2. Describe the major components of a CEMS and their respective functions.
3. List the kinds of analyzers typically used in utility and industrial boilers.
4. Discuss analytical techniques typically employed in CEM analyzers.
5. Describe the maintenance requirements needed for a CEMS.

Lesson Time: Approximately 75 minutes.

Suggested Introductory Questions:

What kind of CEM analyzers are used at your facility?

Does anyone have first hand knowledge of operating a CEMS and can you describe your system?

Presentation Outline:

23.1. Statement of Purpose

23.2. General Classifications of CEMS
  A. In-situ
  B. Extractive

Presentation Outline (Continued):

23.3. Components of CEMS
- A. Probe
- B. Sample Transport Line
- C. Conditioning System
- D. Analyzer and/or Detector
- E. Data Acquisition System (DAS)

23.4. Usage of CEMS in Utility/Industrial Boilers

23.5. Analytical Methods
- A. Spectroscopic
- B. Luminescence
- C. Electrochemical
- D. Paramagnetism

23.6. Opacity Monitors
- A. Single-Pass Transmissometer
- B. Double-Pass Transmissometer

23.7. Maintenance and Continuing Operations
- A. Calibrations
- B. Probe Blockage
- C. Condensation
- D. Leakage

CHAPTER 23. CONTINUOUS EMISSION MONITORING

23.1 Statement of Purpose

23.2 General Classifications of CEMS

23.3 Components of CEMS

23.4 Usage of CEMS in Utility/Industrial Boilers

23.5 Analytical Methods

23.6 Opacity Monitors

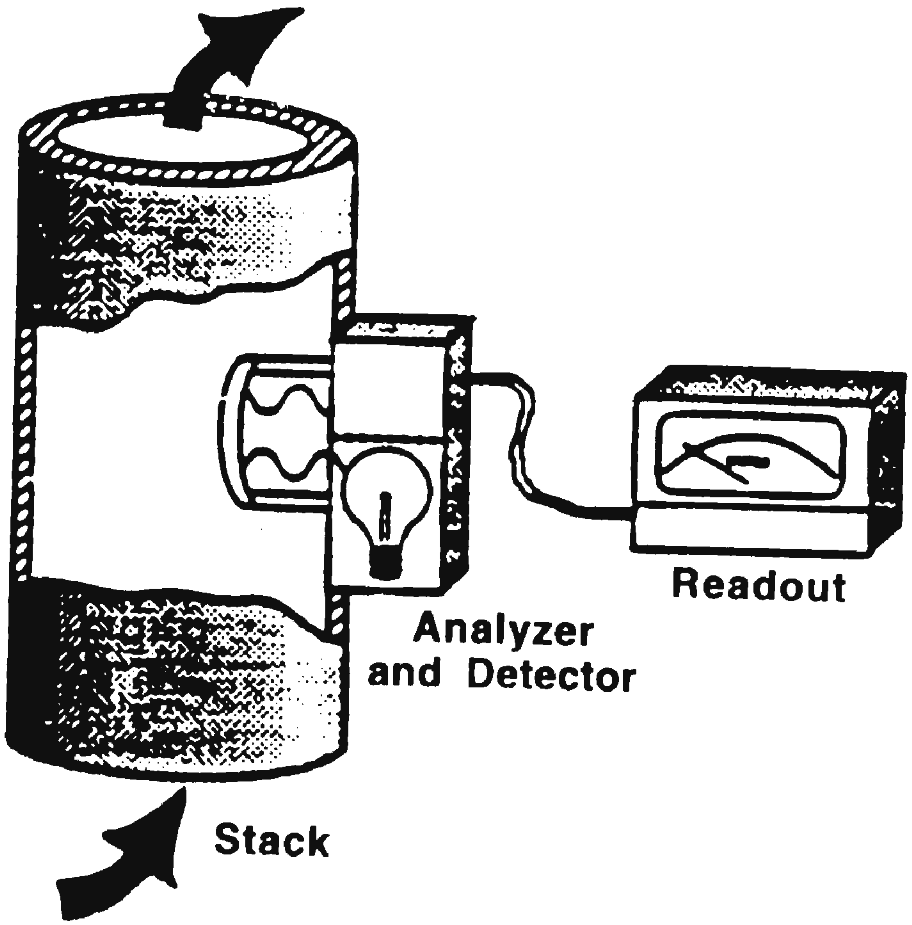
23.7 Maintenance and Continuing Operations

CLASSIFICATION OF CEMS

In–Situ

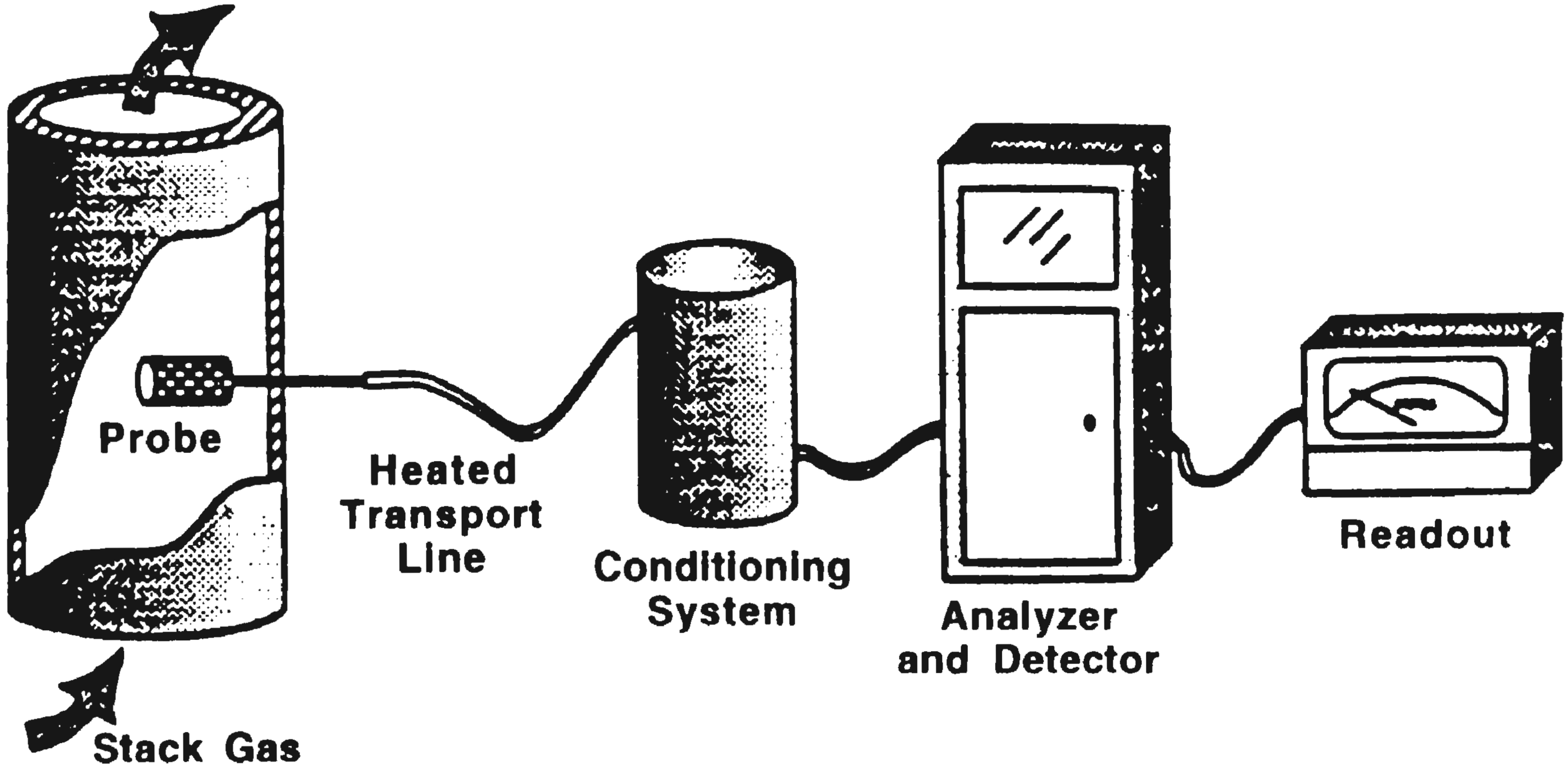
Extractive

IN–SITU CEM SYSTEMS



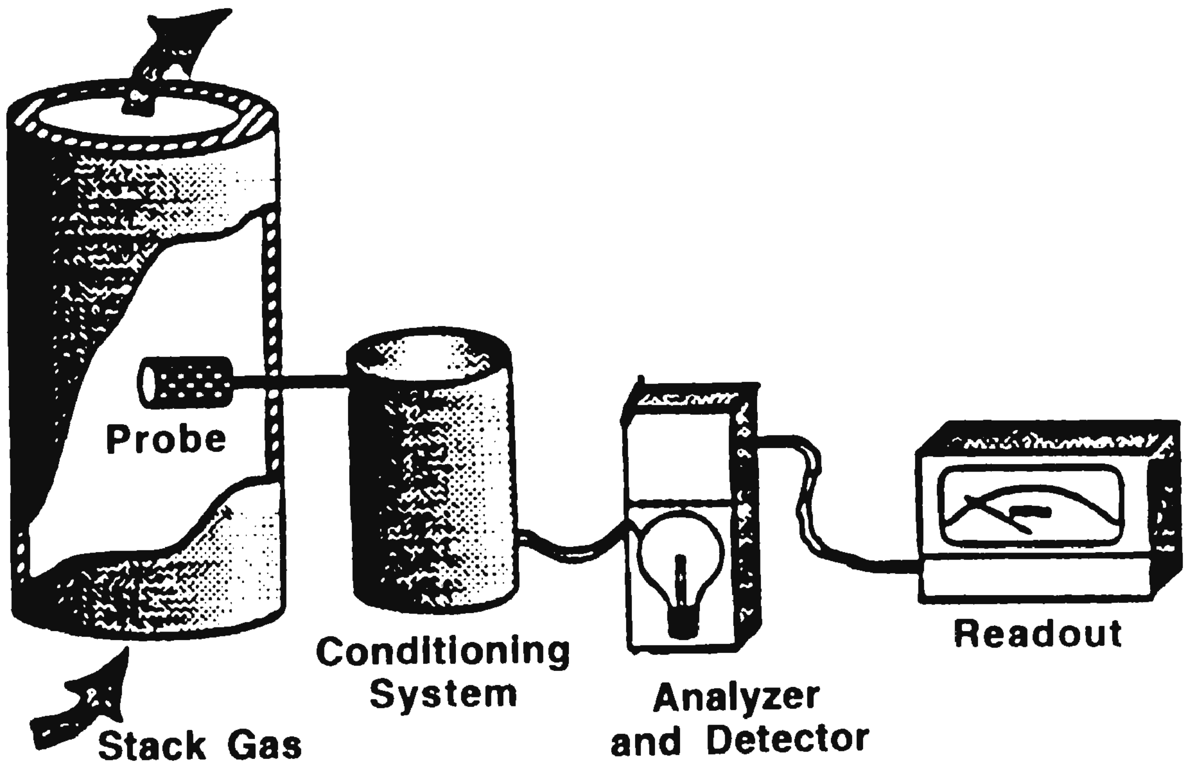
Slide 23 - 3

EXTRACTIVE CEM SYSTEMS



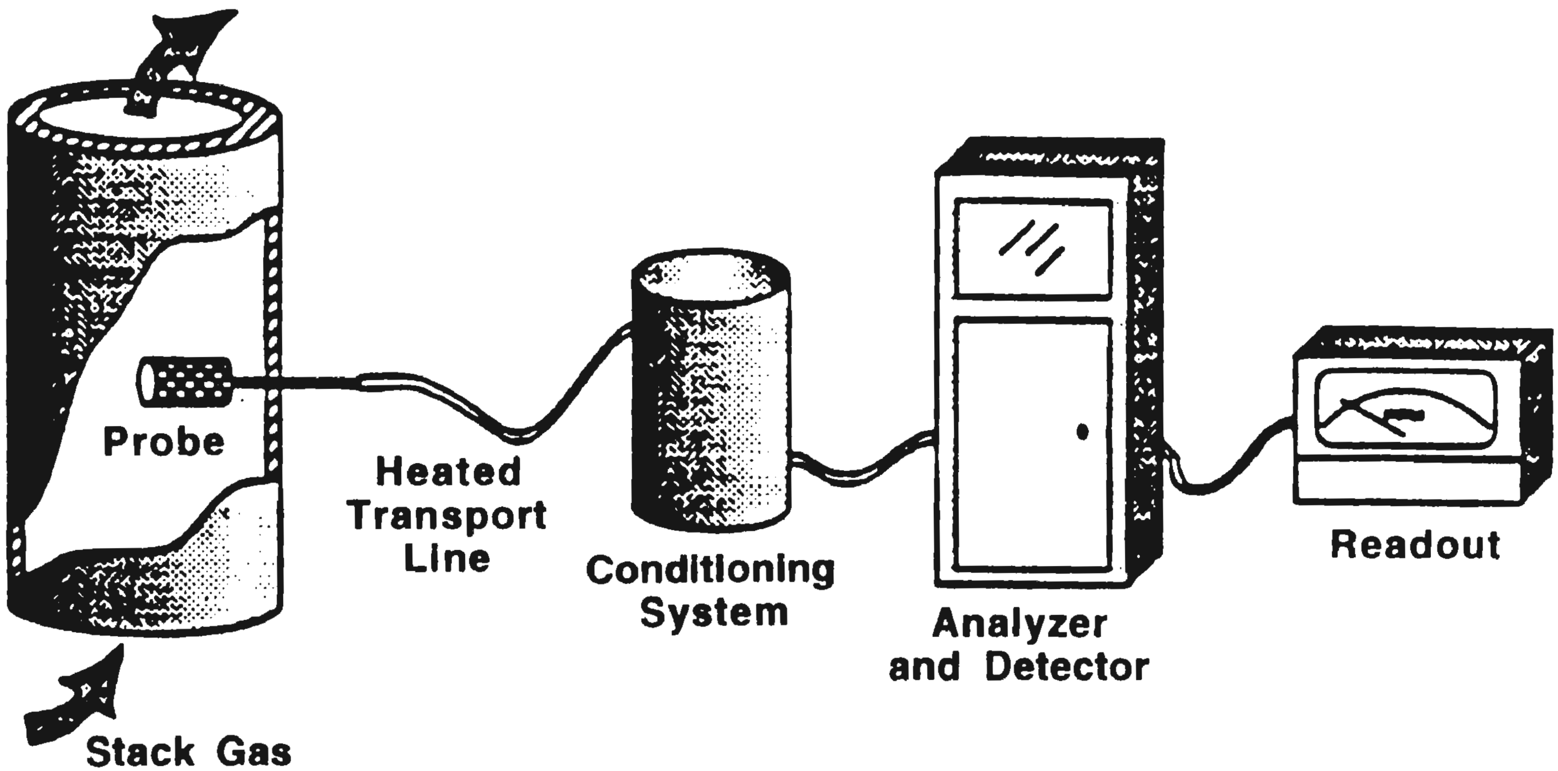
Slide 23 - 4

CLOSE–COUPLED CEM SYSTEMS



Slide 23 - 5

COMPONENTS OF CEMS



Slide 23 - 6

ANALYZERS TYPICALLY USED IN UTILITY AND INDUSTRIAL BOILERS

- Opacity
- Oxygen (O_2)
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Nitrogen oxides (NO_x)
- Sulfur Dioxide (SO_2)
- Flue-Gas Flow Rate

ANALYTICAL TECHNIQUES

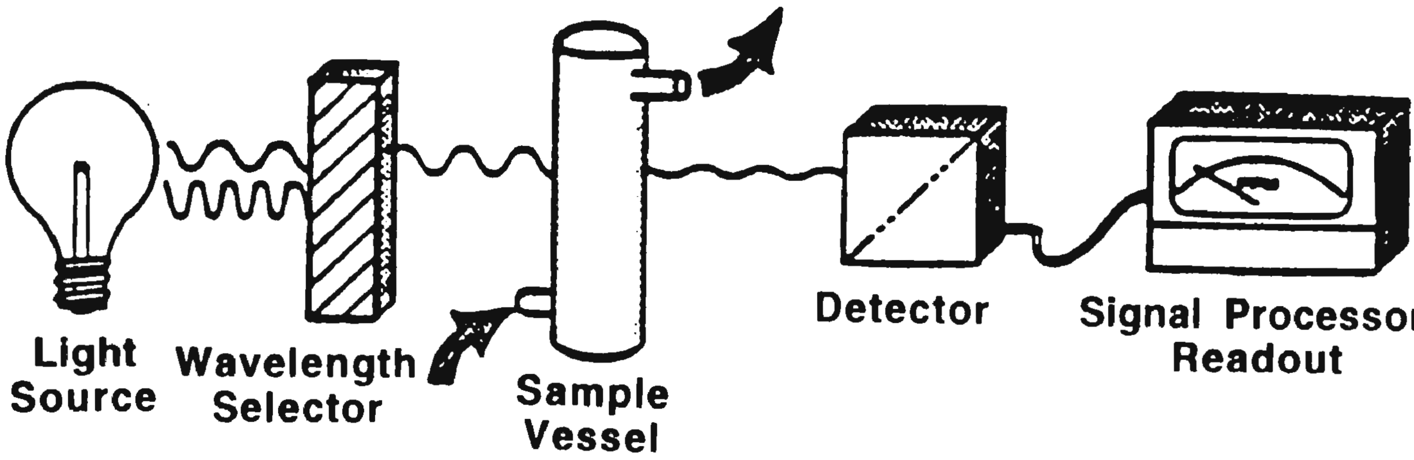
Spectroscopic

Luminescence

Electrochemical

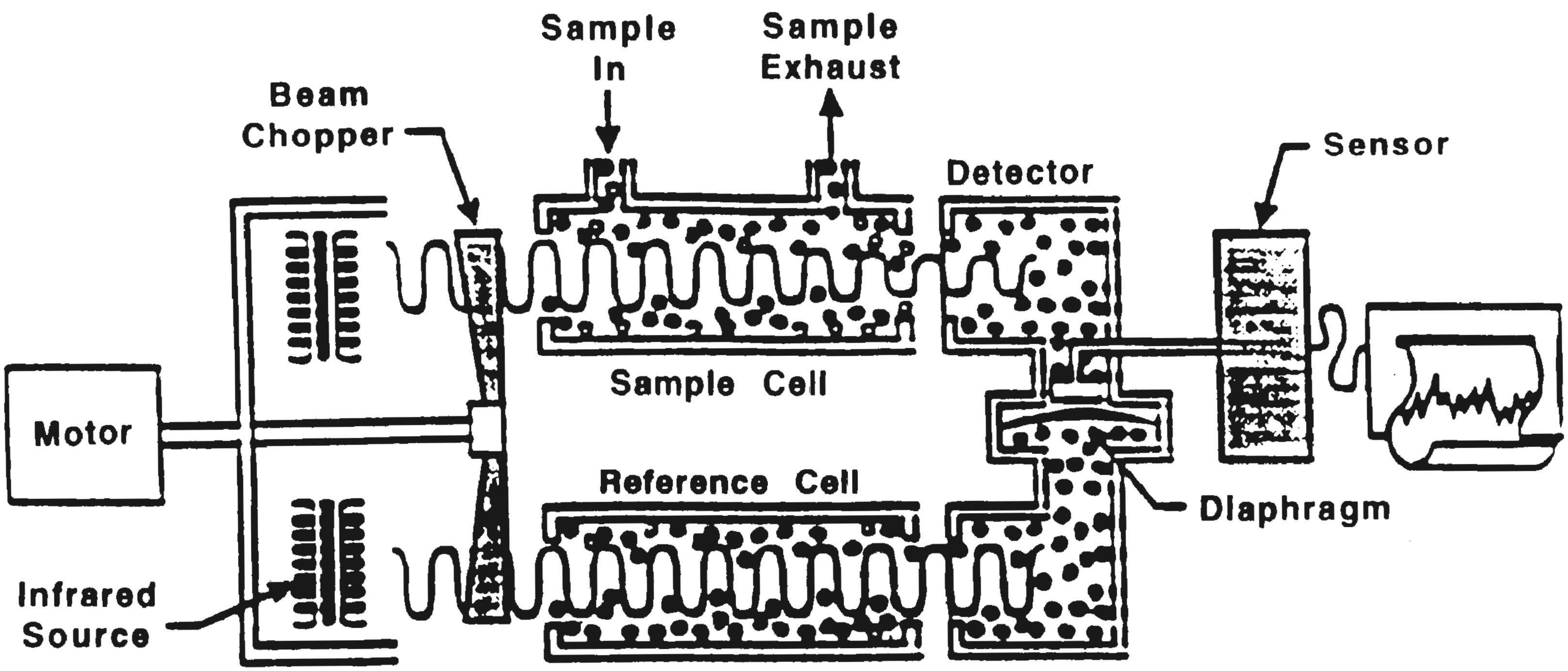
Paramagnetism

BASIC SPECTROSCOPIC INSTRUMENTATION

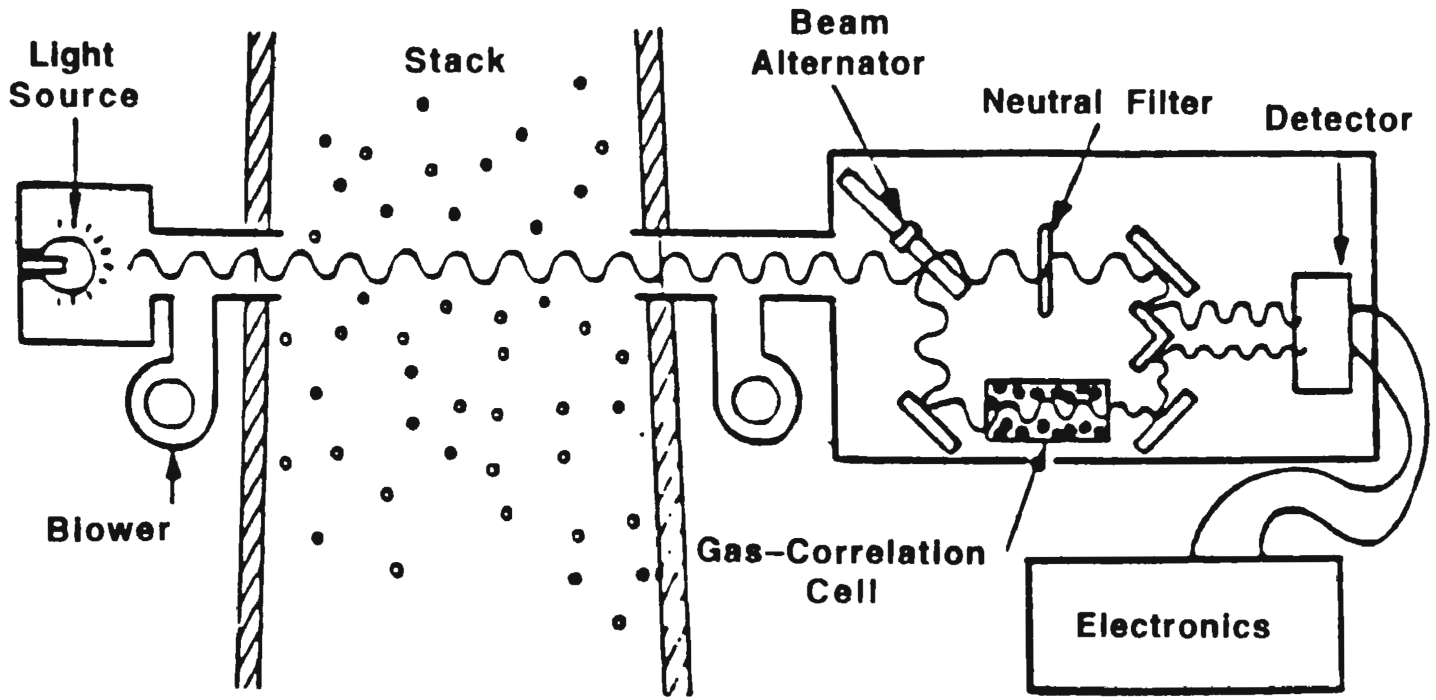


Slide 23 - 9

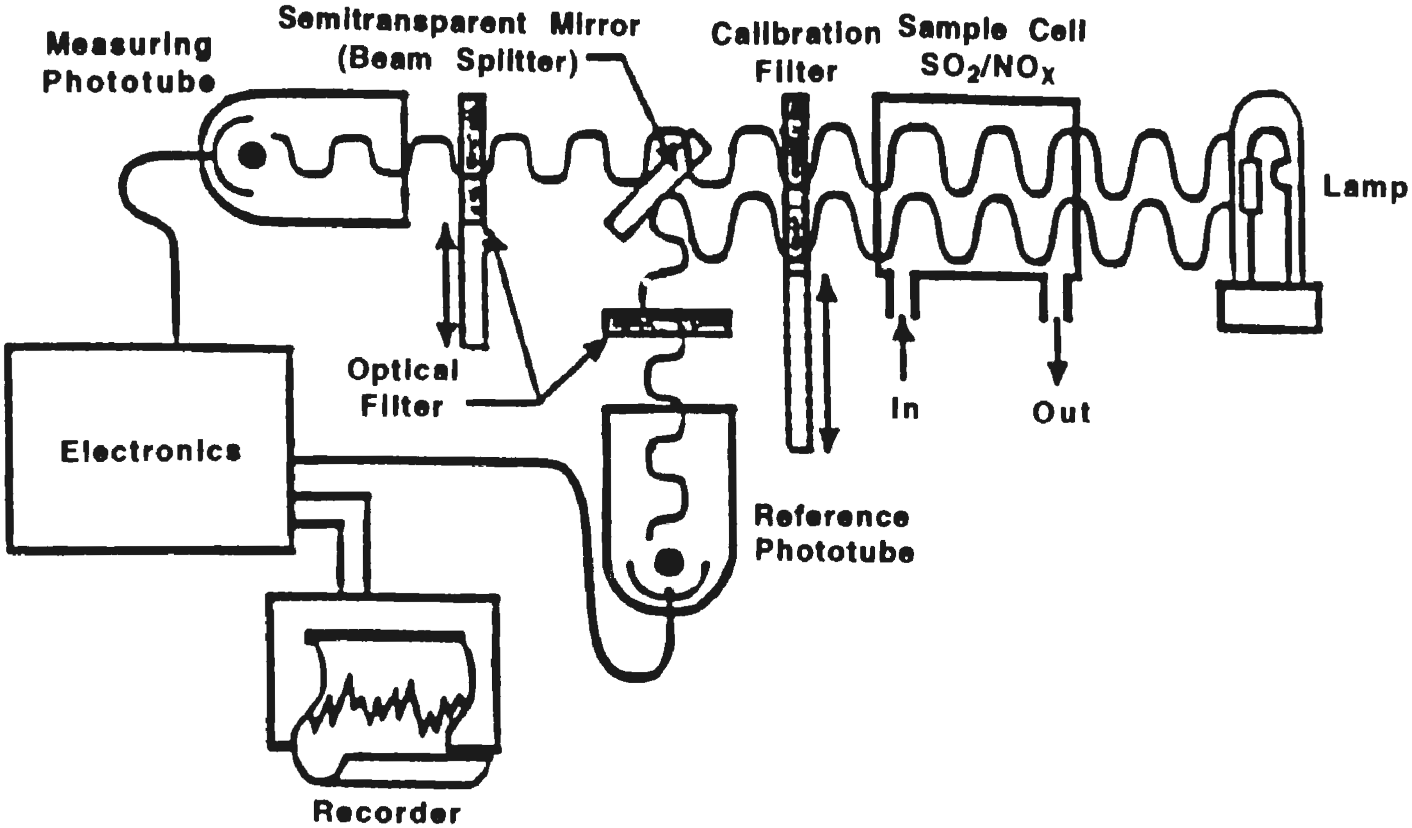
NDIR ANALYZER



GAS FILTER CORRELATION ANALYZER

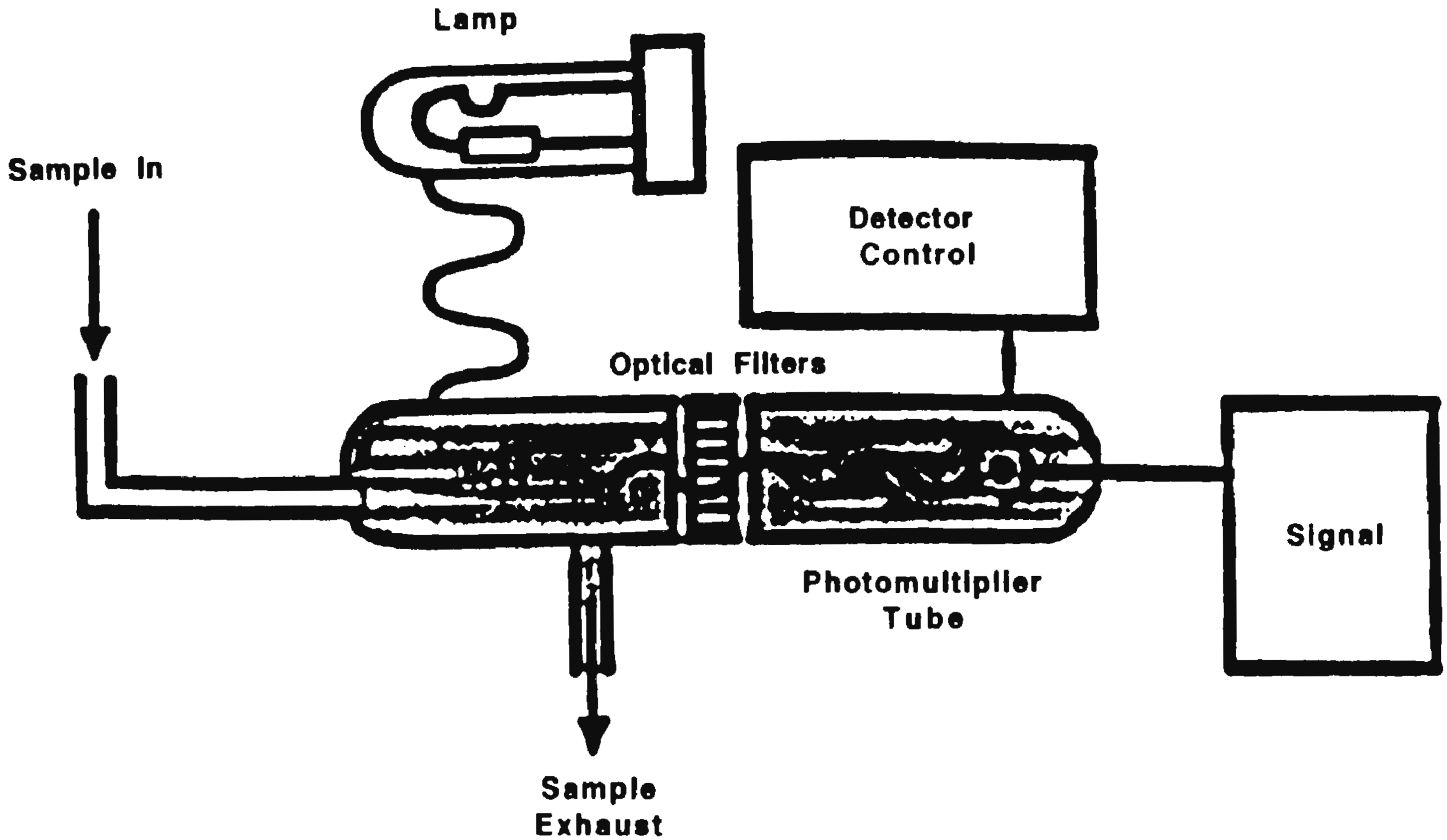


DIFFERENTIAL ABSORPTION ANALYZER



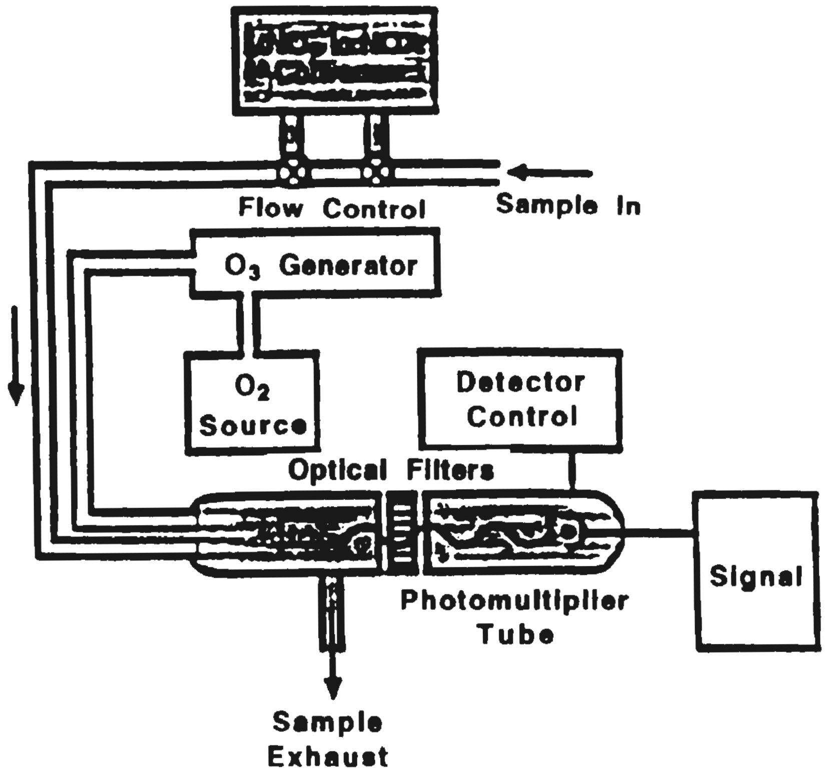
Slide 23 - 12

ULTRAVIOLET FLUORESCENCE ANALYZER



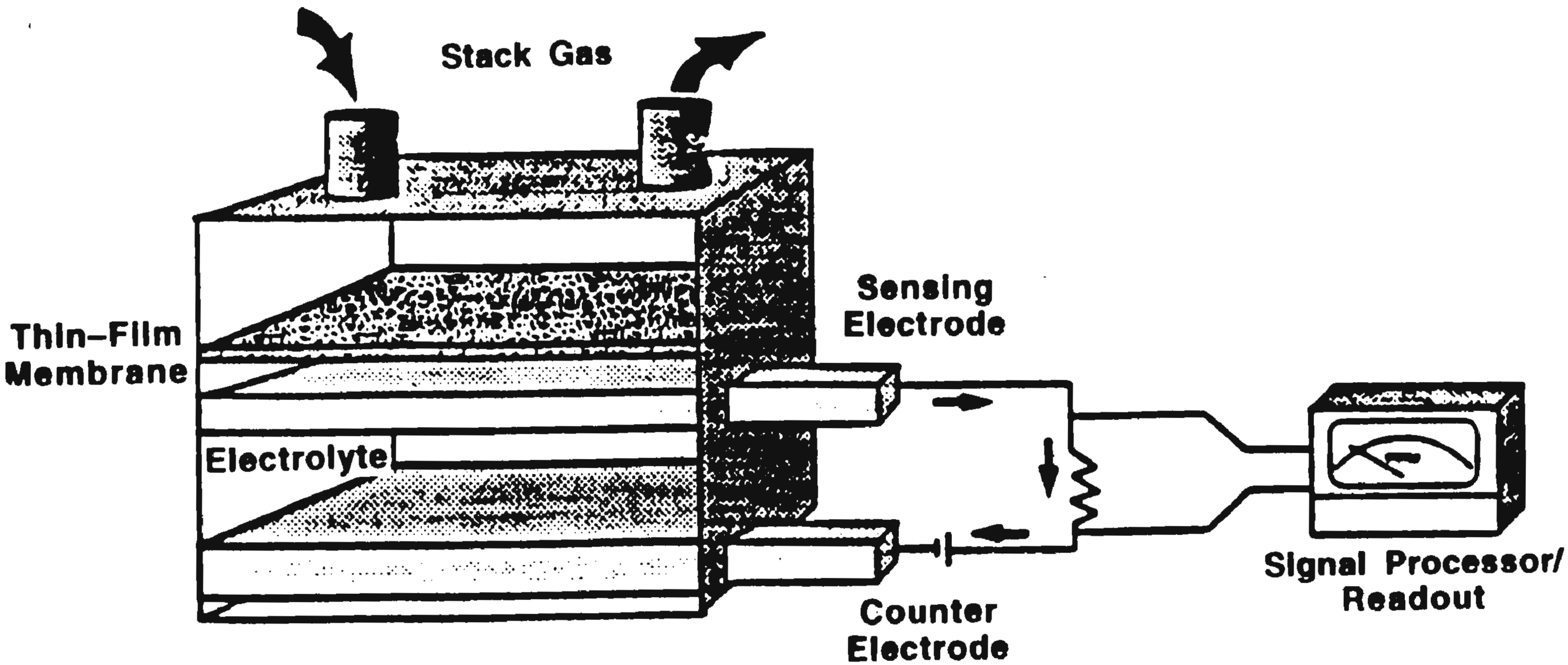
Slide 23 - 13

CHEMILUMINESCENCE ANALYZER



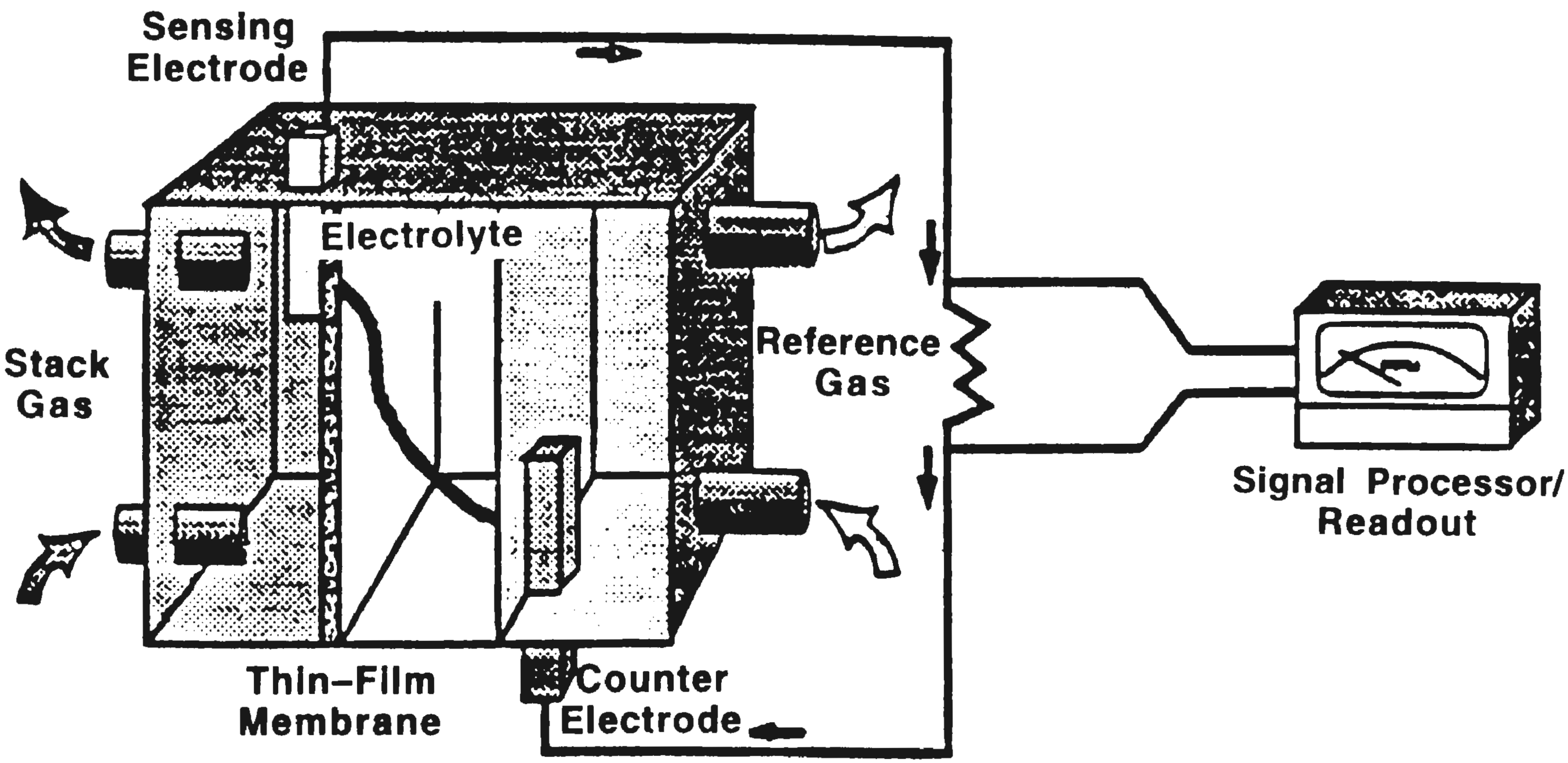
Slide 23 - 14

POLAROGRAPHIC ANALYZER



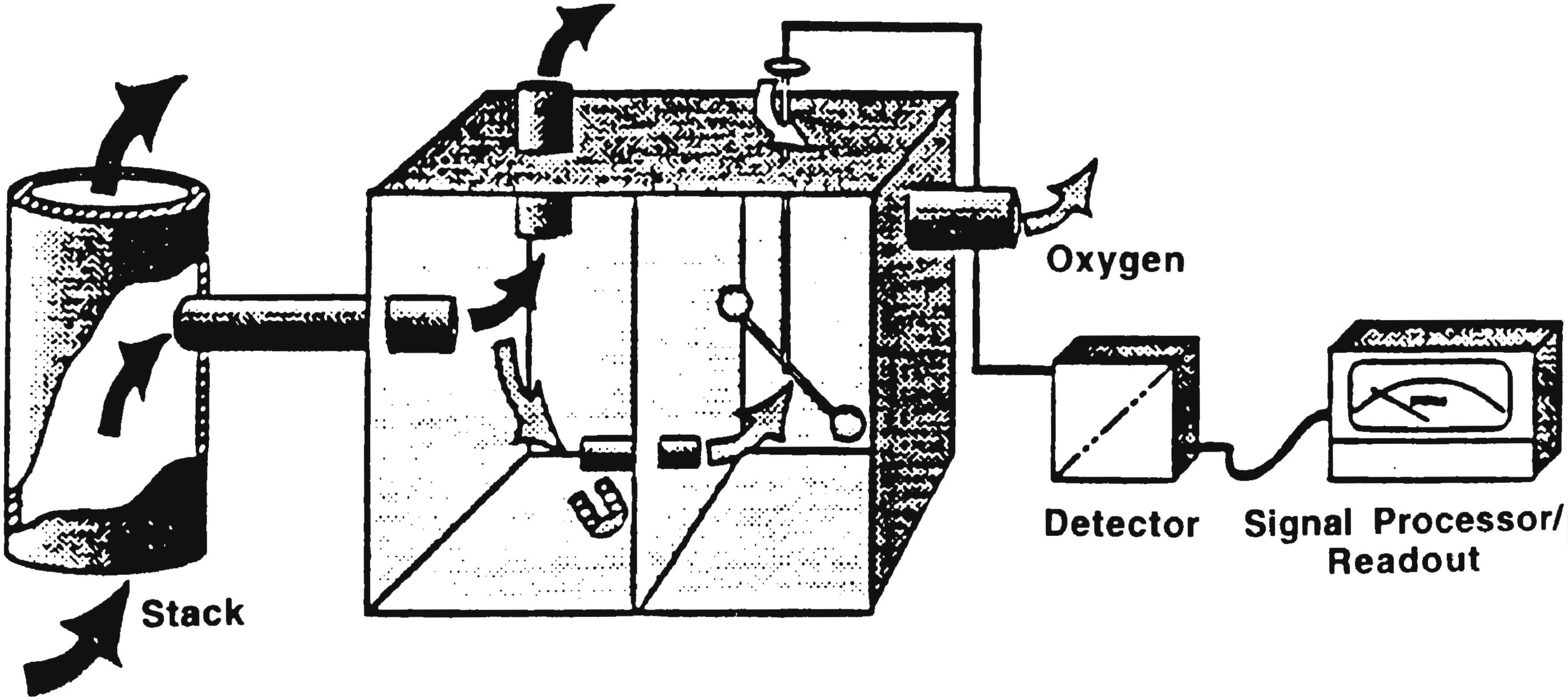
Slide 23 - 15

ELECTROCATALYTIC ANALYZER



Slide 23 - 16

PARAMAGNETIC ANALYZER



Slide 23 - 17

FLOW MONITORING TECHNIQUES

Techniques	Instrumentation or Sensor
Differential Pressure Sensing	Head Meters, Pitot Tube, Annubar Fluidic Sensor
Thermal Sensing	HeatedSensor
Acoustic Velocimetry	Ultrasonic Tranducers

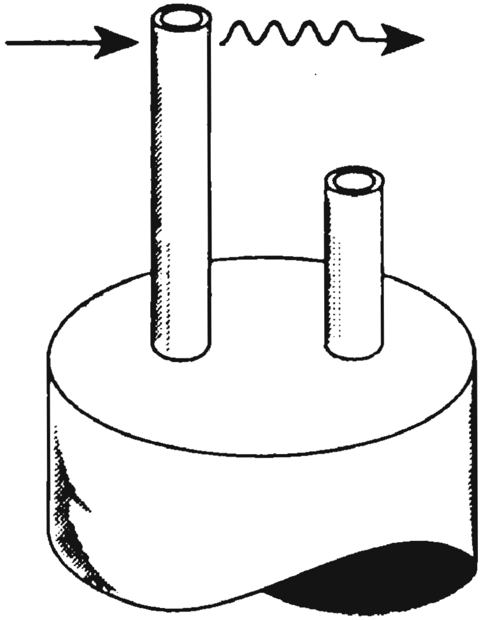
VELOCITY AND VELOCITY PRESSURE RELATIONSHIPS

$$V_s = K_p C_p \left[(T_s \Delta p)/(P_s M_s)\right]^{1/2}$$

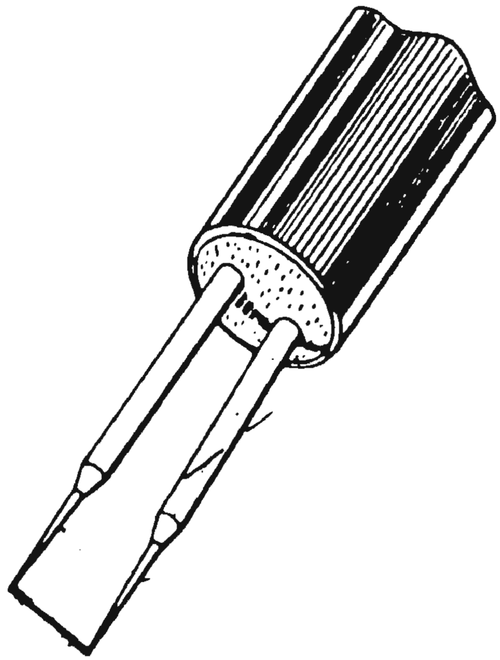
Where:

V_s = velocity of the gas
K_p = constant
C_p = pitot tube calibration coefficient
T_s = absolute temperature of the gas
P_s = absolute pressure of the gas
M_s = molecular weight of the gas

THERMAL SENSING SYSTEMS



A thermal–sensing velocity probe

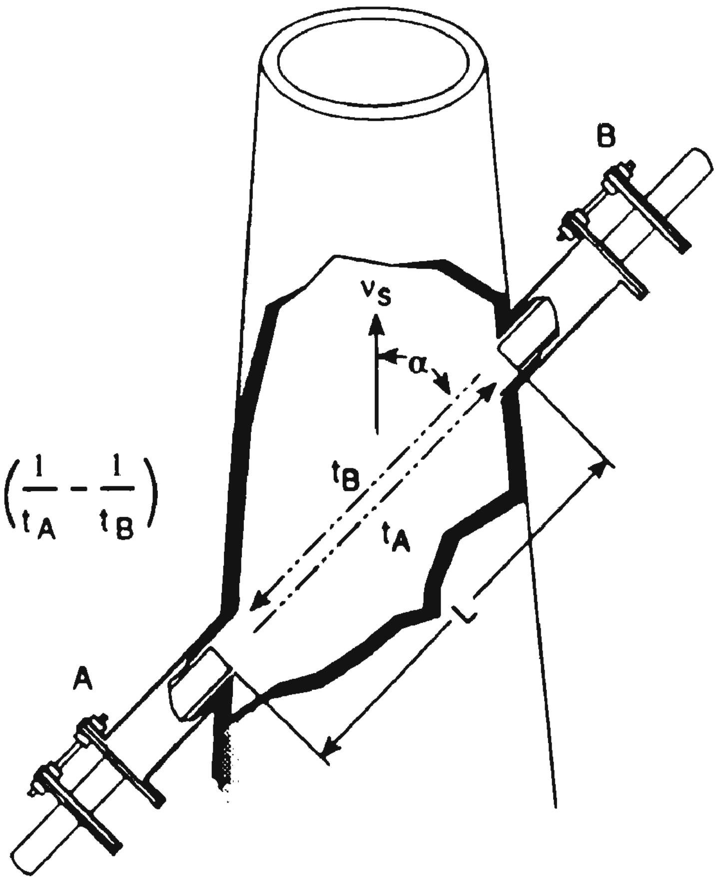


A hot–wire anemometry sensor

Slide 23 - 20

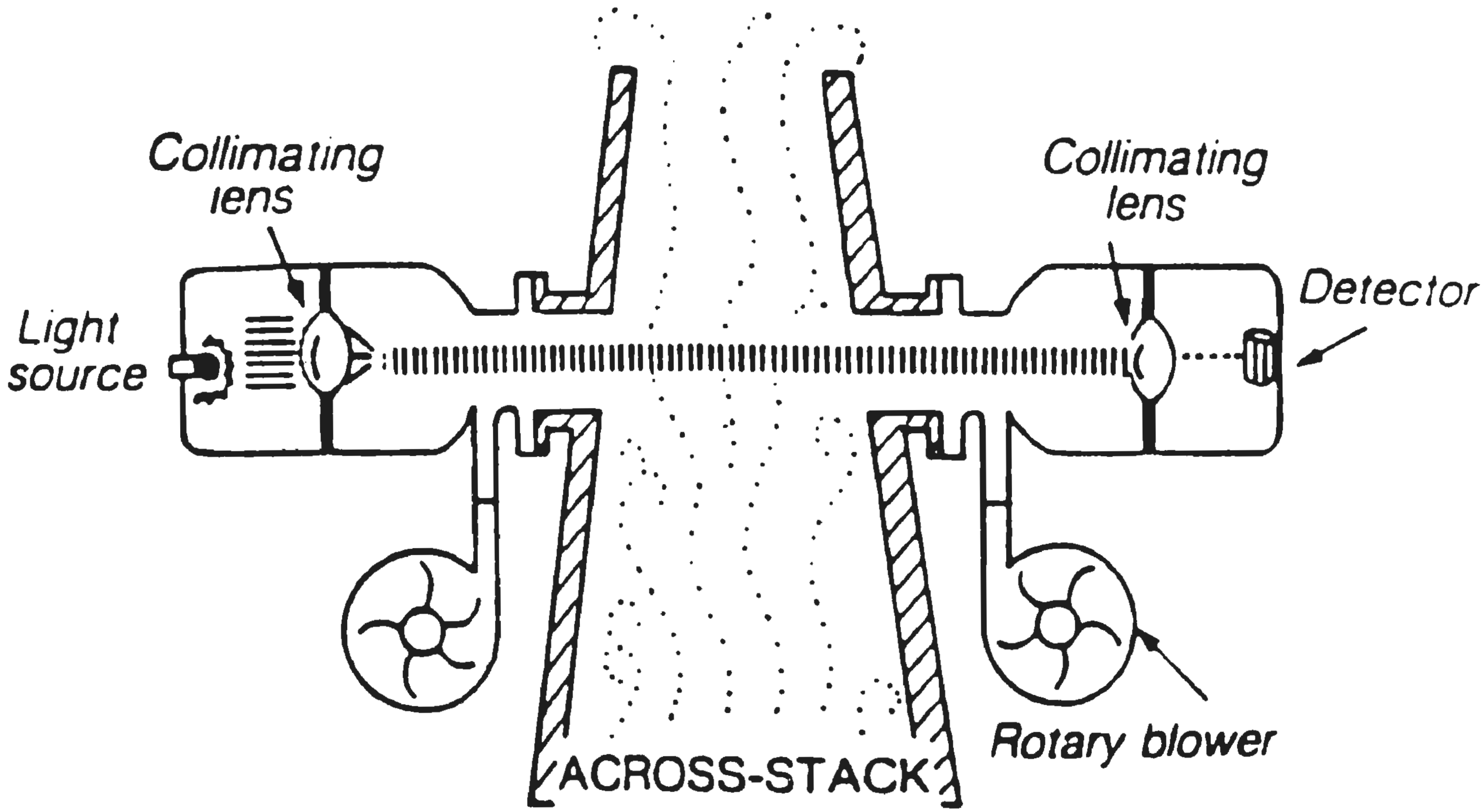
ACOUSTIC VELOCIMETRY

$$v_S = \frac{L}{2\cos\alpha}\left(\frac{1}{t_A} - \frac{1}{t_B}\right)$$



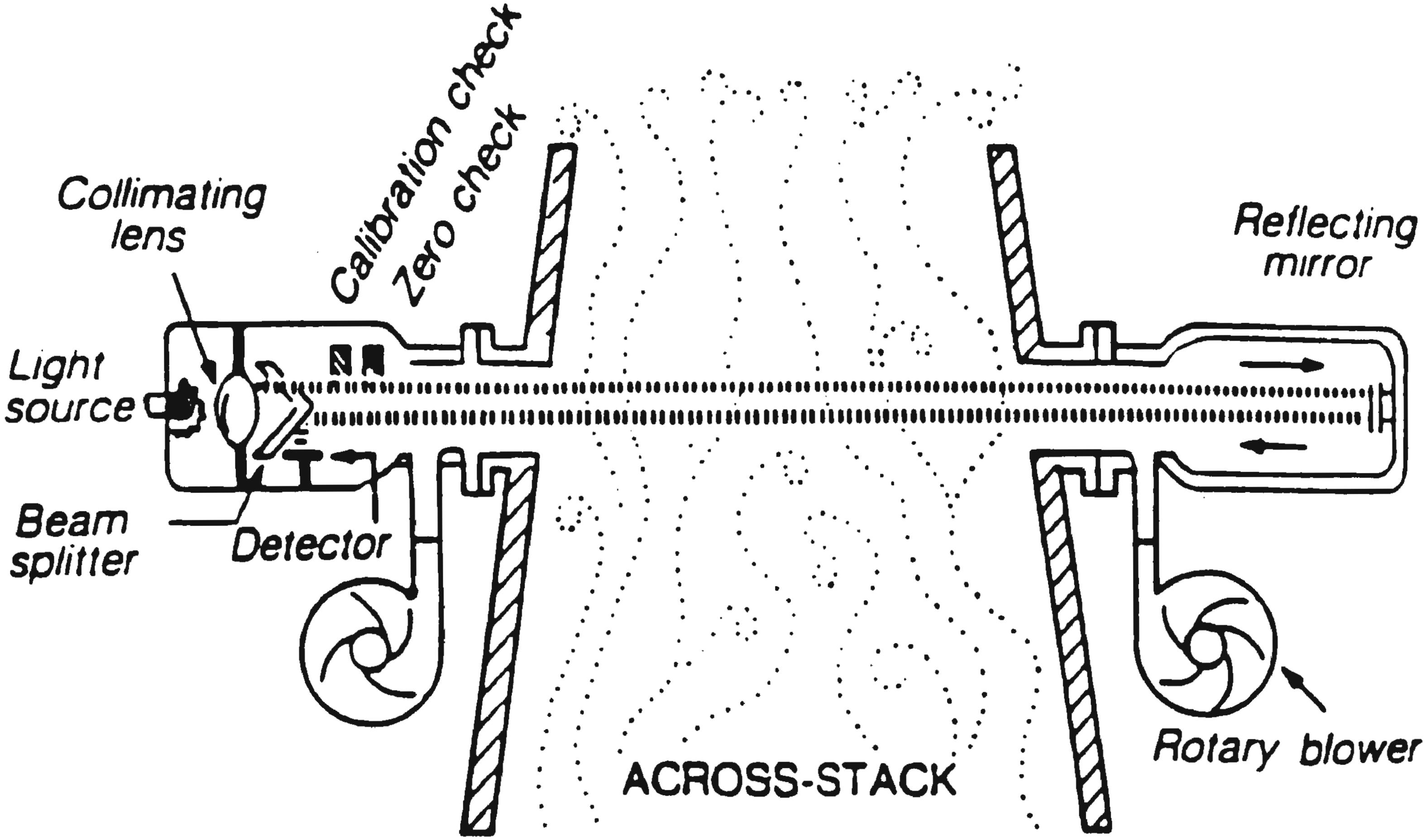
Slide 23 - 21

SINGLE PASS TRANSMISSOMETER



Slide 23 - 22

DOUBLE–PASS TRANSMISSOMETER



Slide 23 - 23

OPERATION CHECKS

Routine Calibration

Probe Blockage

Condensation

Leakage

Optical Surfaces

CEMS MAINTENANCE CHECKLIST

Filter Cleaning
Sample Line Leakage Check
Optical Surface Cleaning
Pump Maintenance
Data Recording Equipment Check

LESSON PLAN

CHAPTER 24. PARTICULATE CONTROL

Goal: To present the participants with the design, performance, and operation of some typical particulate control devices used on boilers.

Objectives:

Upon completion of this unit an operator should be able to:

1. List the control devices available for particulate removal from boiler flue gas emissions.
2. Discuss the operating principles, performance advantages and disadvantages, and operational characteristics of cyclones, ESPs, and fabric filter particulate removal systems.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What are mechanical dust collectors? (Cyclones)

What are the advantages and disadvantages of using fabric filters for particulate removal?

Presentation Outline:

24.1 Control Methods and Typical Arrangement

24.2 Cyclones
- A. Design Principles
- B. Performance
- C. Operator Duties

24.3 Electrostatic Precipitators
- A. Design Principles
- B. Performance
- C. Operator Duties

24.4 Fabric Filters
- A. Design Principles
- B. Performance
- C. Operator Duties

CHAPTER 24. PARTICULATE CONTROL

24.1 Control Methods and Typical Arrangement

24.2 Cyclones

24.3 Electrostatic Precipitators

24.4 Fabric Filters

PARTICULATE CONTROL

Particulate Pollution Sources:

Boilers, Industrial Processes, Mining, Motor Vehicles, Nature

Particulate Distribution in Boilers:

Bottom Ash, Convective Passes, Air Pollution Control Device, Stack

PARTICULATE CONTROL DEVICES

- **Cyclone**
- **Electrostatic Precipitator**
- **Fabric Filter**
- **Wet Scrubber**
- **Side Stream Separator**

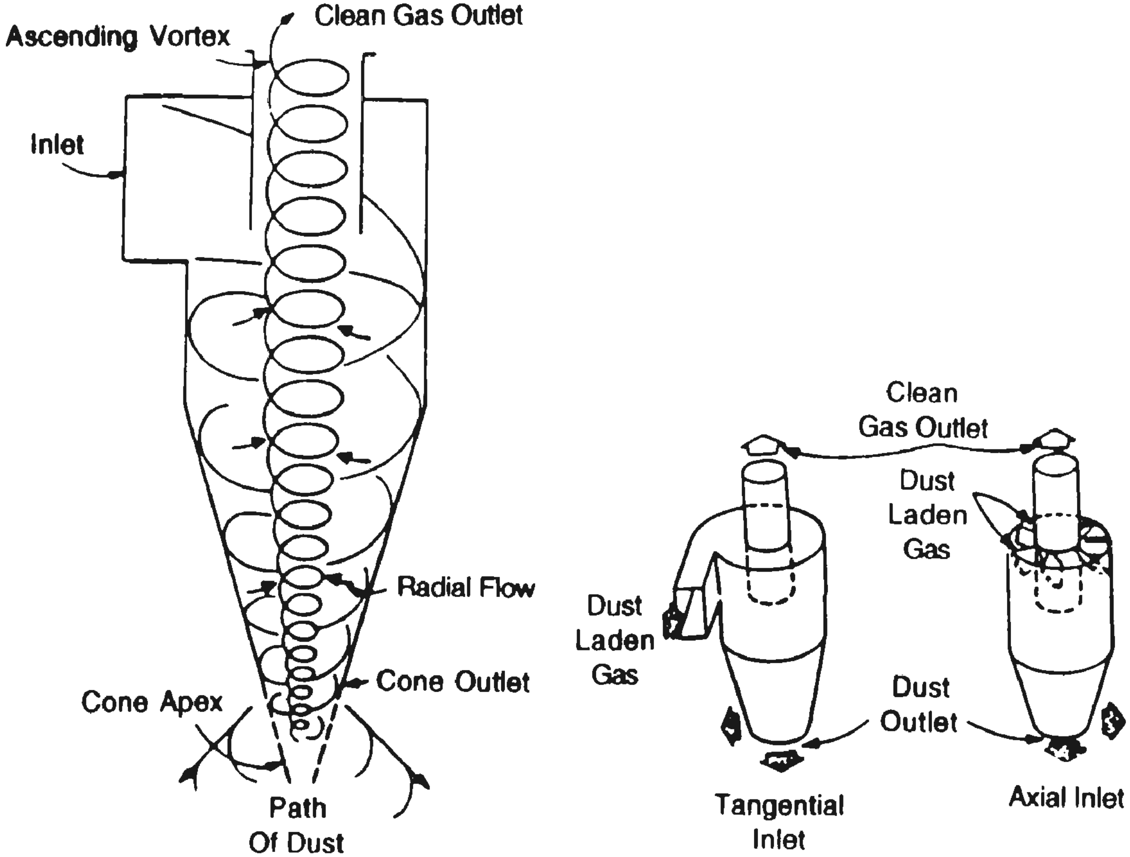
CYCLONE APPLICATION

- Low Capture Efficiency
- Poor Fine Particle Capture
- Simple Operation and Maintenance
- High Temperature Application

CYCLONE DESIGN

- Vertical Gas Chamber
- Axial or Tangential Gas Entry
- Swirling Gas Flow
- No Moving Parts

CYCLONE



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CYCLONE PERFORMANCE

Capture Efficiency is Dependent on:

- **Gas Velocity**
- **Chamber Diameter**
- **Particle Size, Density and Composition**

CYCLONE OPERATION

Pressure Drop and Inlet Gas Temperature are Routinely Monitored.

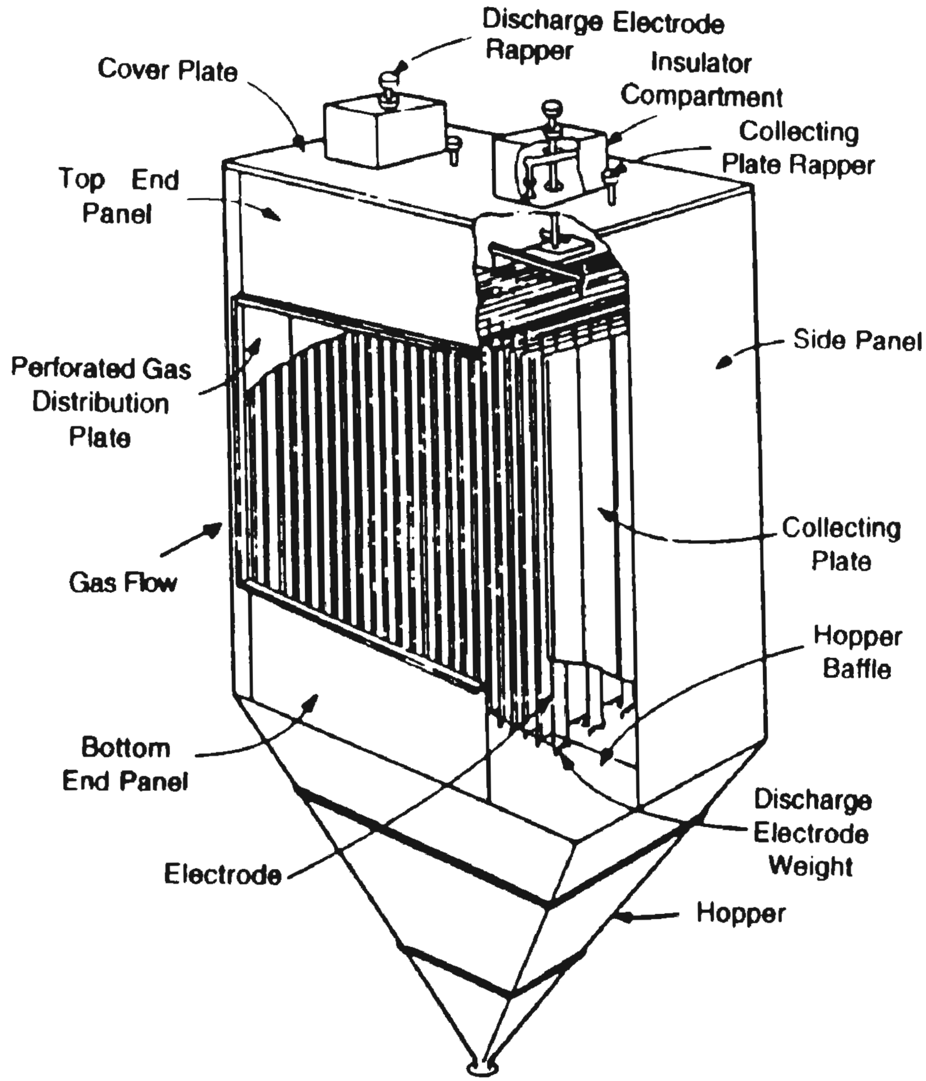
Inspection and Maintenance Requirement is Minimal.

Life Expectancy is Long.

ELECTROSTATIC PRECIPITATOR APPLICATION

- High Capture Efficiency
- Lowest Capture Occurs with 0.1 to 1 Micron Particles
- Extensive Monitoring Requirements
- Automatic Controls
- Low Routine Maintenance

ELECTROSTATIC PRECIPITATOR



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Slide 24 - 10

ESP DESIGN CHARACTERISTICS

Basic Physical Characteristics

- Number of Fields
- Number of Passages per Field
- Wire–to–Plate Spacing
- Collection Plate Surface Area
- Wire (or Rod) Diameter
- Aspect Ratio (Length to Height)

Electrical Characteristics

- Maximum Secondary Voltage
- Maximum Secondary Current
- Number of Sparks per Minute

Process Characteristics

- Gas Volume Flow Rate
- Even Flow Distribution
- Particulate Loading
- Gas Temperature
- Particle Size Distribution
- Particle Composition
- Particle Resistivity

ESP PERFORMANCE

Capture Efficiency is Dependent on:

- **Specific Collection Area (SCA)**
- **Operating Voltage**
- **Particle Characteristics**

Particle Size of 0.1 to 1 Micron is Hardest to Capture

Particle Resistivity in the Range of 2×10^{8} to 2×10^{11} ohm–cm is Best for Performance

ESP MONITORING AND MAINTENANCE

Monitoring:

- Inlet Gas Temperature
- Gas Flow Rate
- Electrical Conditions
- Rapper Intensity
- Hopper Ash Level

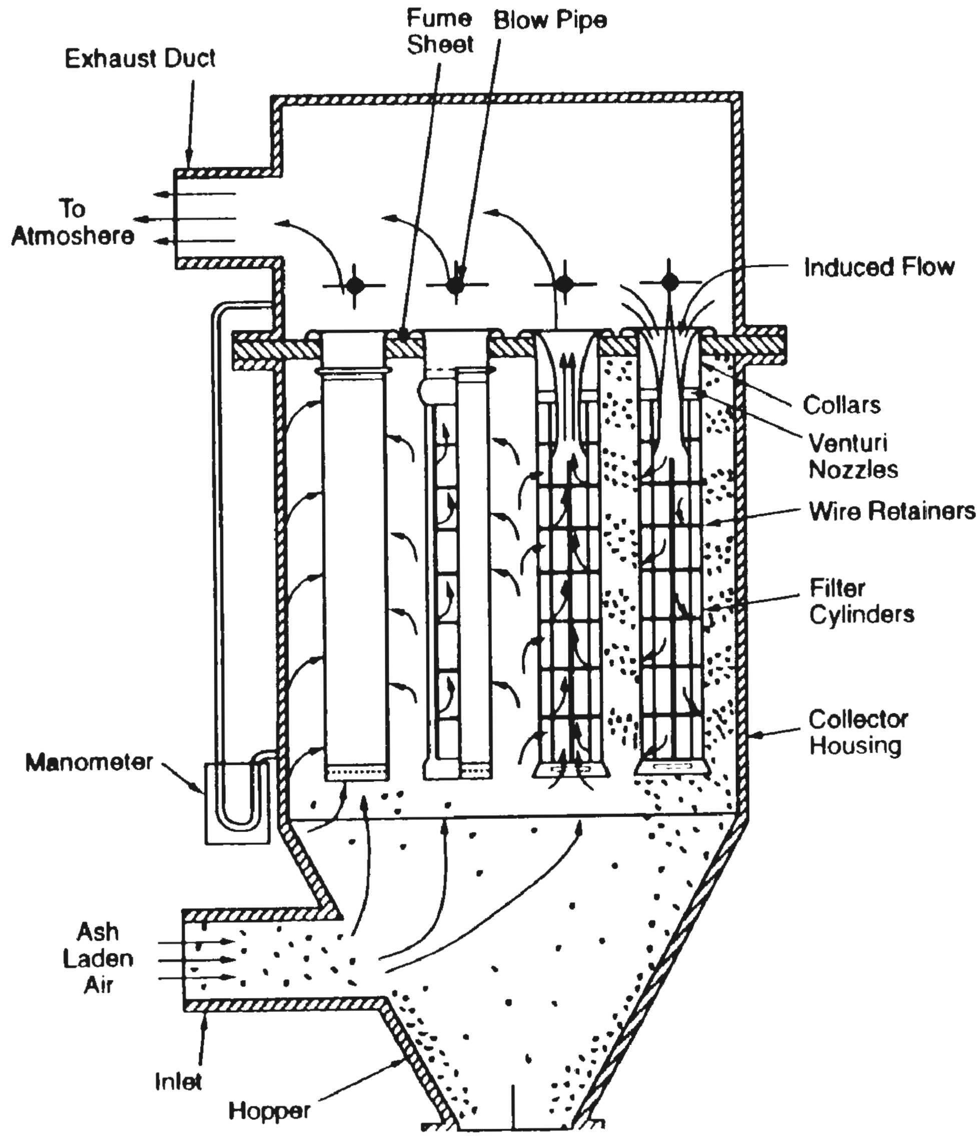
Maintenance:

- Requires Highly Trained Personnel
- Requires Low Routine Maintenance
- Inspect for Electrode Misalignment, Pitting, Ash Build–Up, Ash Hardening, Hopper Blockage, Electrode Insulation Cracks, and Rapper Performance

FABRIC FILTER APPLICATION

- High Capture Efficiency
- Capture Efficiency Independent of Particle Characteristics
- Frequent Routine Maintenance
- Monitoring, Inspection and Maintenance is Simple

FABRIC FILTER



Slide 24 - 15

PULSE JET

- High Pressure Air
- Inflates Bag to Dislodge Dust Cake
- On–Line Cleaning
- Vigorous Cleaning Limits Bag Life

REVERSE AIR

- Low Pressure Air
- Contracts Bag to Dislodge Dust Cake
- Off–Line Cleaning Requires Modular Fabric Filter System
- Low Pressure System Provides Maximum Bag Life

SHAKER

- **Mechanical Sinusoidal Bag Shaker**
- **Off–Line Cleaning Requires Modular System**
- **High Abrasion to Fabric**

SONIC

- Augments Other Cleaning Techniques
- Sonic Waves Generates Acceleration and Dislodges Dust Cake

FABRIC FILTER PROCESS MONITORING

Operation is Monitored by:

- Flue Gas Temperature
- Gas Flow Rate
- Pressure Drop
- Opacity
- CEM

High Pressure can Indicate:

- Binding or Plugging of Filters
- Excessive Gas Flow
- Inadequate Filter Cleaning

Low Pressure can Indicate that Leaks and Holes Exist Across the Filters

FABRIC FILTER MAINTENANCE

High Routine Maintenance is Required

Simple Operation, Maintenance and Repair Compared to Electrostatic Precipitator

Periodic Inspection of Filter Bags for Tears, Holes, Abrasion, Leaks and Dust Build–Up

Cleaning Cycle Timing, Effectiveness and Equipment

Typical Bag Life is 10 Years but can be Reduced to 2 Years for Poorly Operated Device

LESSON PLAN

CHAPTER 25. NITROGEN OXIDES CONTROL

Goal: To present the participant the formation and control of NO_x emissions.

Objectives:

Upon completion of this unit an operator should be able to:

1. Describe the different oxides of nitrogen and their relative importance to NO_x.
2. Discuss the three sources of NO_x formation from the combustion of fossil fuels.
3. Describe the technologies available for NO_x control which employ combustion modifications.
4. Discuss NO_x reduction by stage combustion.
5. Discuss NO_x reduction by thermal NO_x control.
6. Discuss the SCR and SNCR NO_x control processes.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

Can you describe the NO_x control strategy / technology used at your facility?

How important is the fuel type to the NO_x control methods used at steam generating units?

Presentation Outline:

25.1 Nitrogen Oxides Control Overview
- A. Sources
- B. Species
- C. Environmental Concerns

25.2 NO_x Formation

Presentation Outline (Continued):

25.3 Control of NO_x Emissions
- A. Combustion Modifications
  1. Operation
  2. Operator Duties
- B. Post-Combustion Control
  1. Operation
  2. Operator Duties

CHAPTER 25. NITROGEN OXIDES CONTROL

25.1 Overview

25.2 NO_x Formation

25.3 Control of NO_x Emissions

SOURCES OF NITROGEN OXIDES

Mobile Combustion Sources
Automobiles, Trucks

Stationary Combustion Sources
Power Plants, Heaters

Natural Combustion Sources
Forest Fires, Volcanos

Non–Combustion Sources
Nitric Acid Manufacturing

NITROGEN OXIDES

Nitric Oxide (NO)

Nitrogen Dioxide (NO_2)

Nitrous Oxide (N_2O)

Nitrogen Trioxide (N_2O_3)

Nitrogen Pentoxide (N_2O_5)

ENVIRONMENTAL CONCERNS ABOUT NO_x

Acid Rain
- Damage to Structures
- Damage to Water Quality & Fish Life
- Sudden Release of Acids

Photochemical Smog
- Impairs Human Health, Respiration
- Stunts Growth of Vegetation
- Oxidizes Materials

NO_x FORMATION – FOSSIL FUEL FIRED BOILERS

FUEL NO_x

Combustion of Chemically–Bound Nitrogen in the Fuel with Oxygen

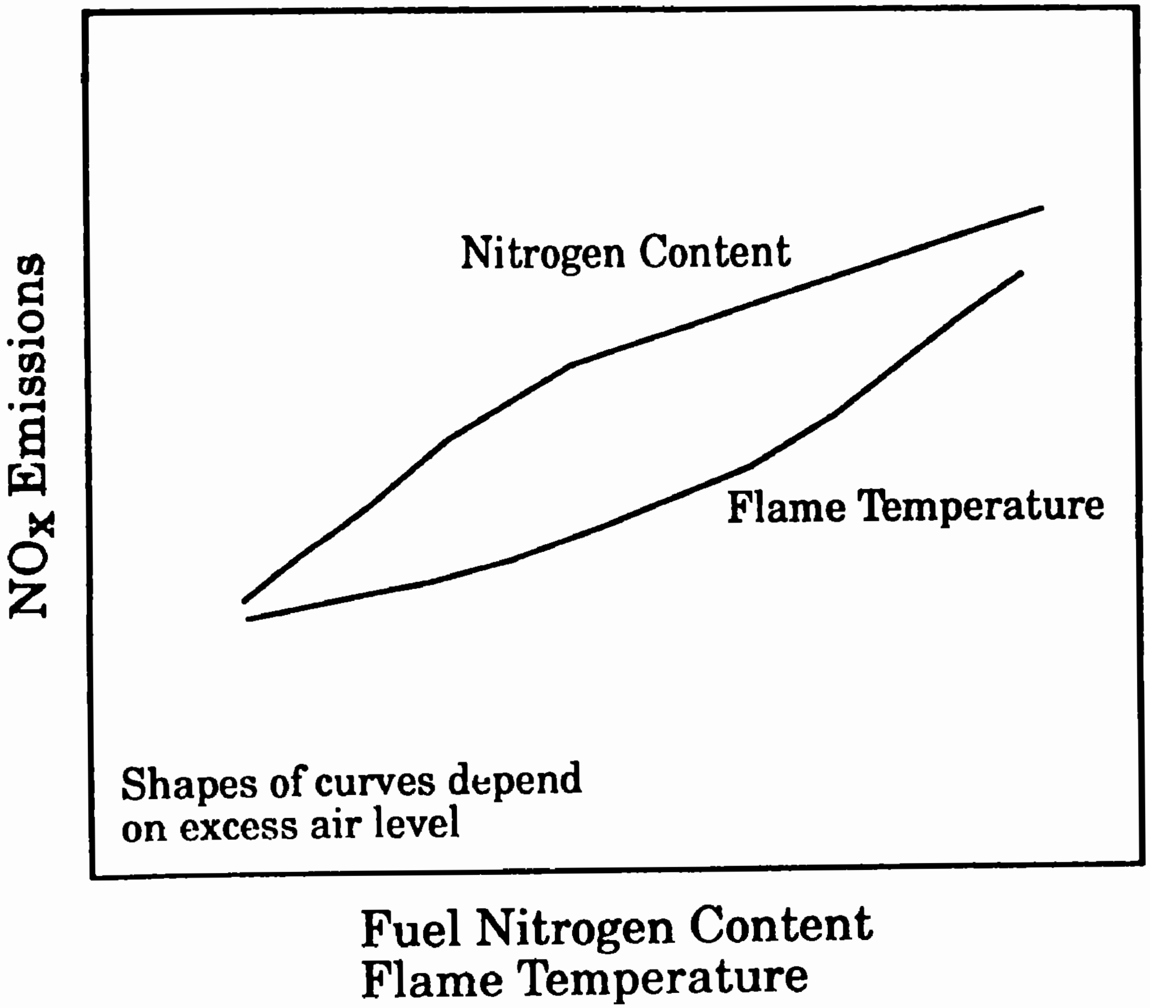
THERMAL NO_x

High Temperature Reaction of Nitrogen with the Oxygen and Nitrogen from Air

PROMPT NO_x

Oxidation of Fuel Bound Nitrogen under Fuel Rich Conditions

IMPACT OF TEMPERATURE AND FUEL NITROGEN ON NO_x EMISSIONS



NO_x FORMATION REDUCTION TECHNIQUES

1. Decrease Primary Flame Zone Oxygen Level
   a. Decrease Overall Oxygen Level
   b. Controlled Mixing of Fuel and Air
   c. Use of Fuel–Rich Primary Flame Zone

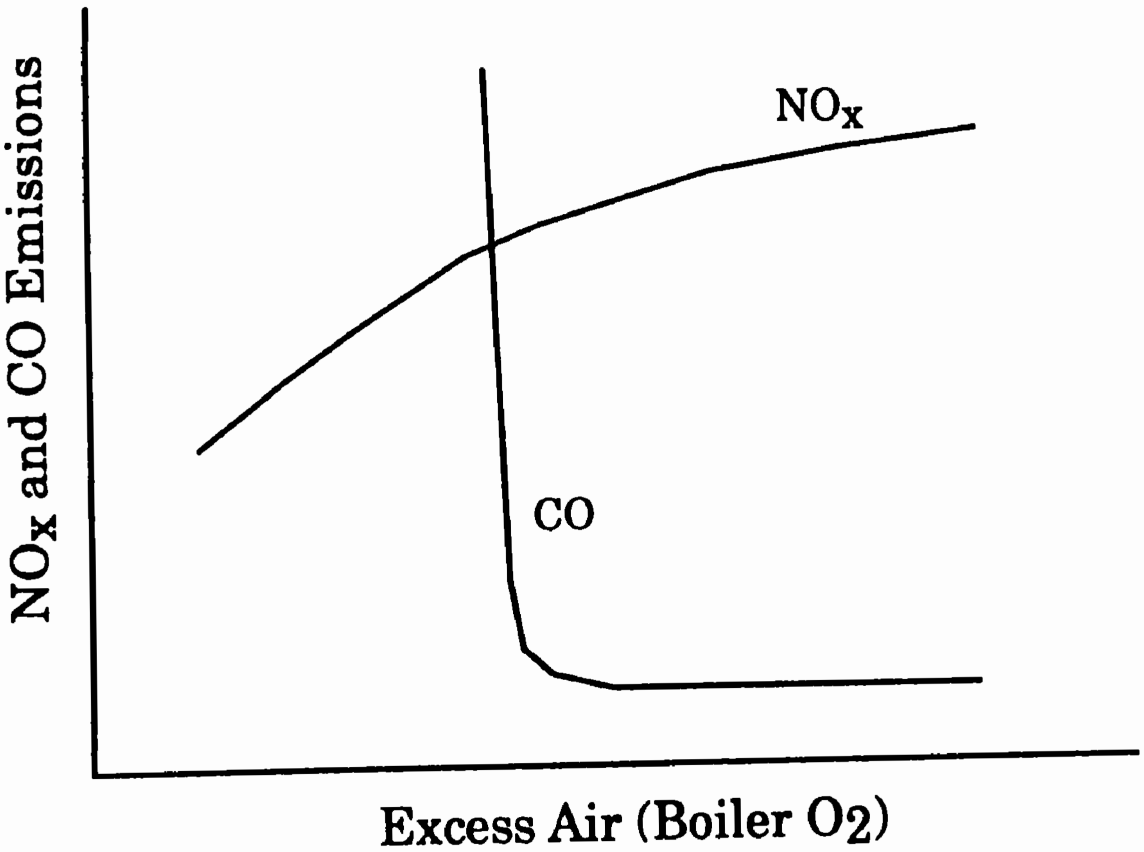
2. Decrease Time of Exposure at High Temperature
   a. Decreased Peak Temperature
   b. Decreased Adiabatic Flame Temperature
   c. Decreased Combustion Intensity
      – Increased Flame Cooling
      – Controlled Mixing of Fuel and Air
      – Fuel-Rich Primary Flame Zone
   d. Decreased Primary Flame Zone Residence Time

NO_x CONTROL TECHNIQUES

Combustion Modifications

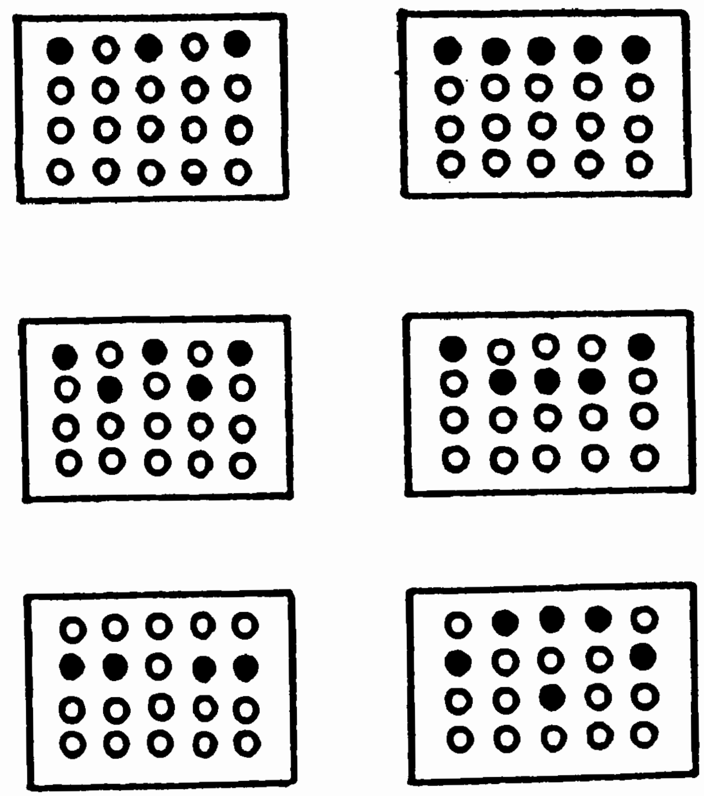
- **Low Excess Air Operation**
- **Burners–Out–of–Service (BOOS) Operation**
- **Overfire Air (OFA)**
- **Reduced Air Preheat**
- **Low NO_x Burners (LNB)**
- **Flue Gas Recirculation (FGR)**
- **Reburning**

NO_x EMISSIONS AS A FUNCTION OF EXCESS AIR



Slide 25 - 9

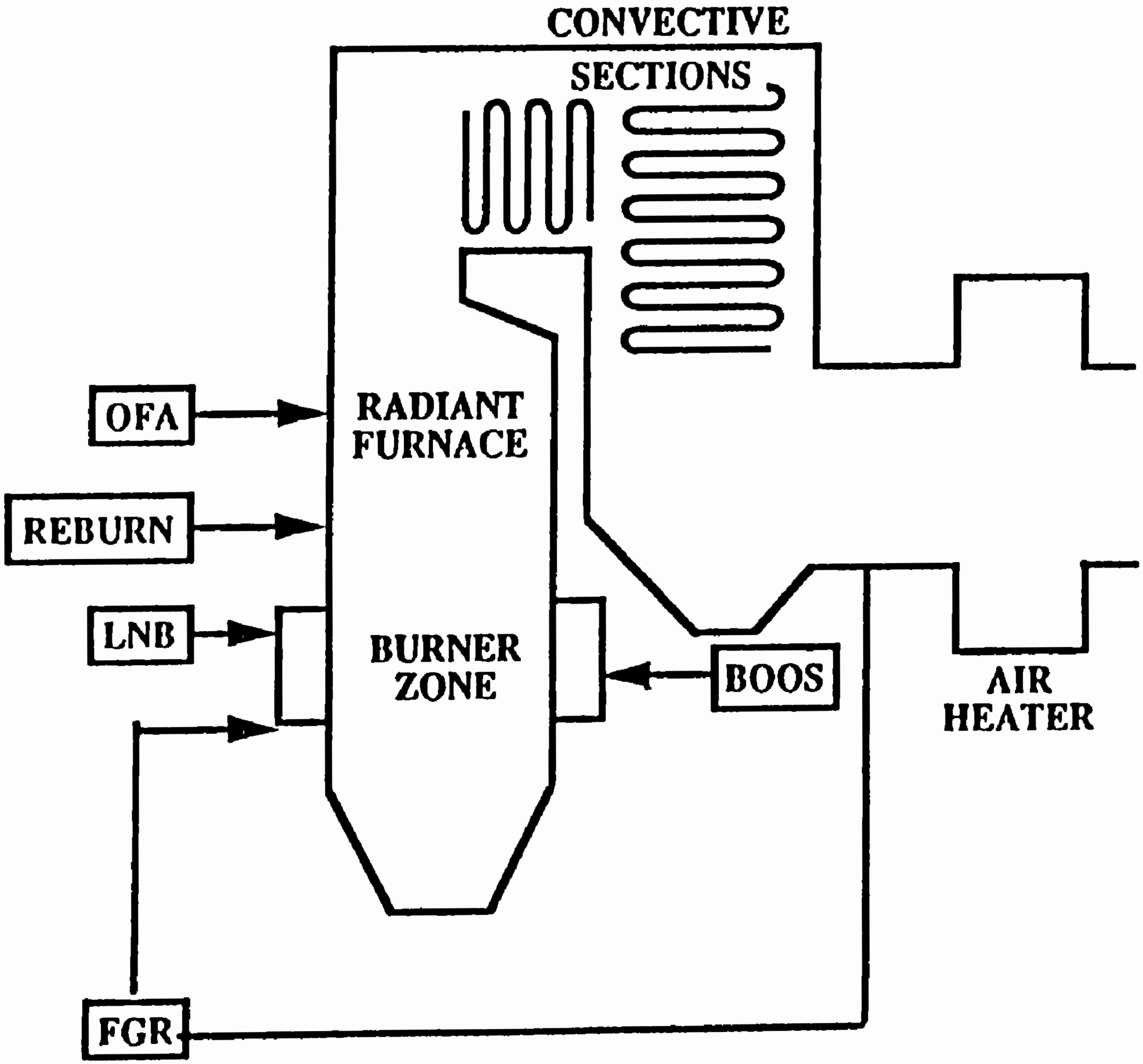
TYPICAL–BURNERS–OUT–OF–SERVICE PATTERNS FOR FACE FIRED UNITS



● Fuel Flow Terminated
○ Burner in Service

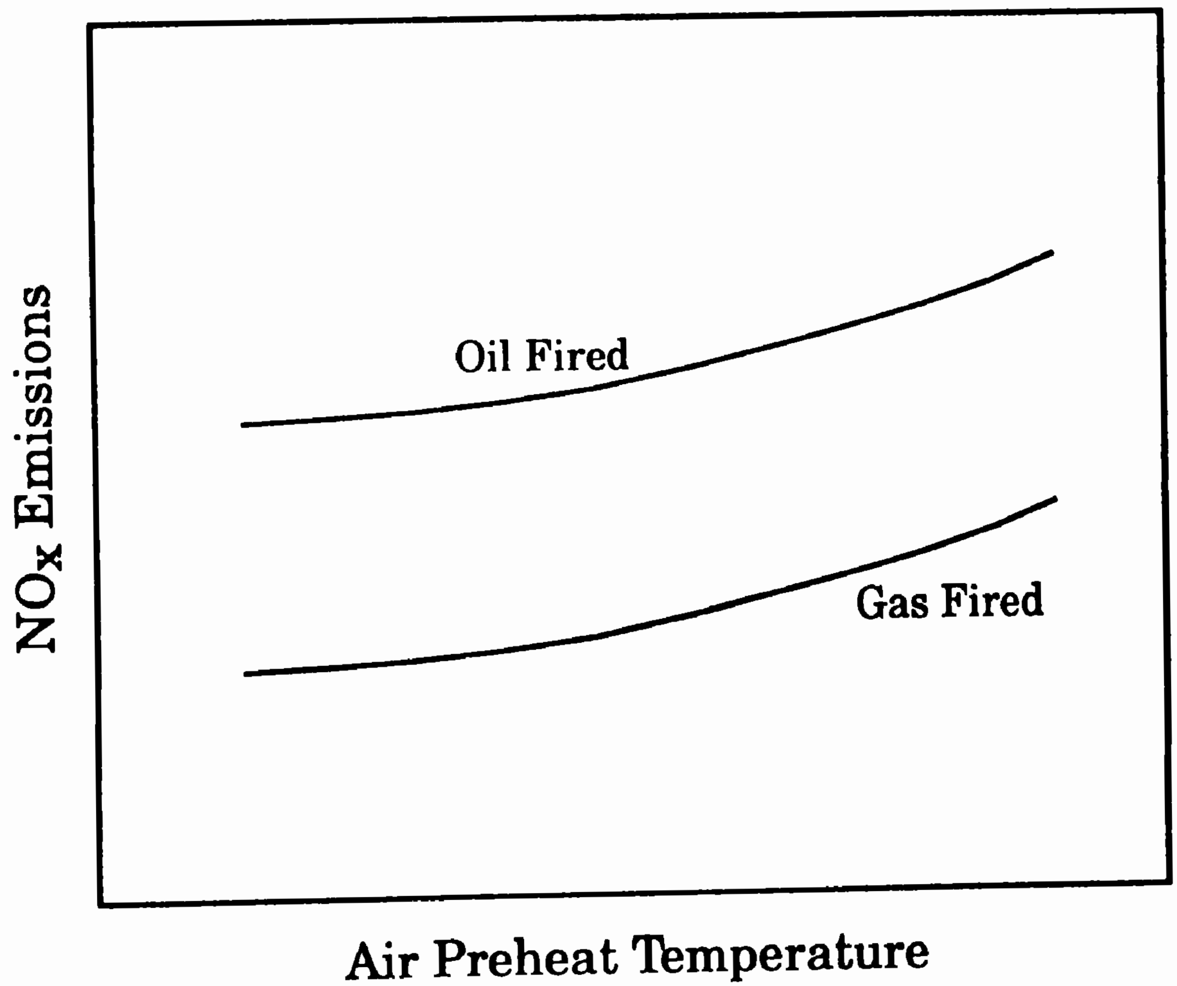
Slide 25 - 10

COMBUSTION ZONE NO_x CONTROL

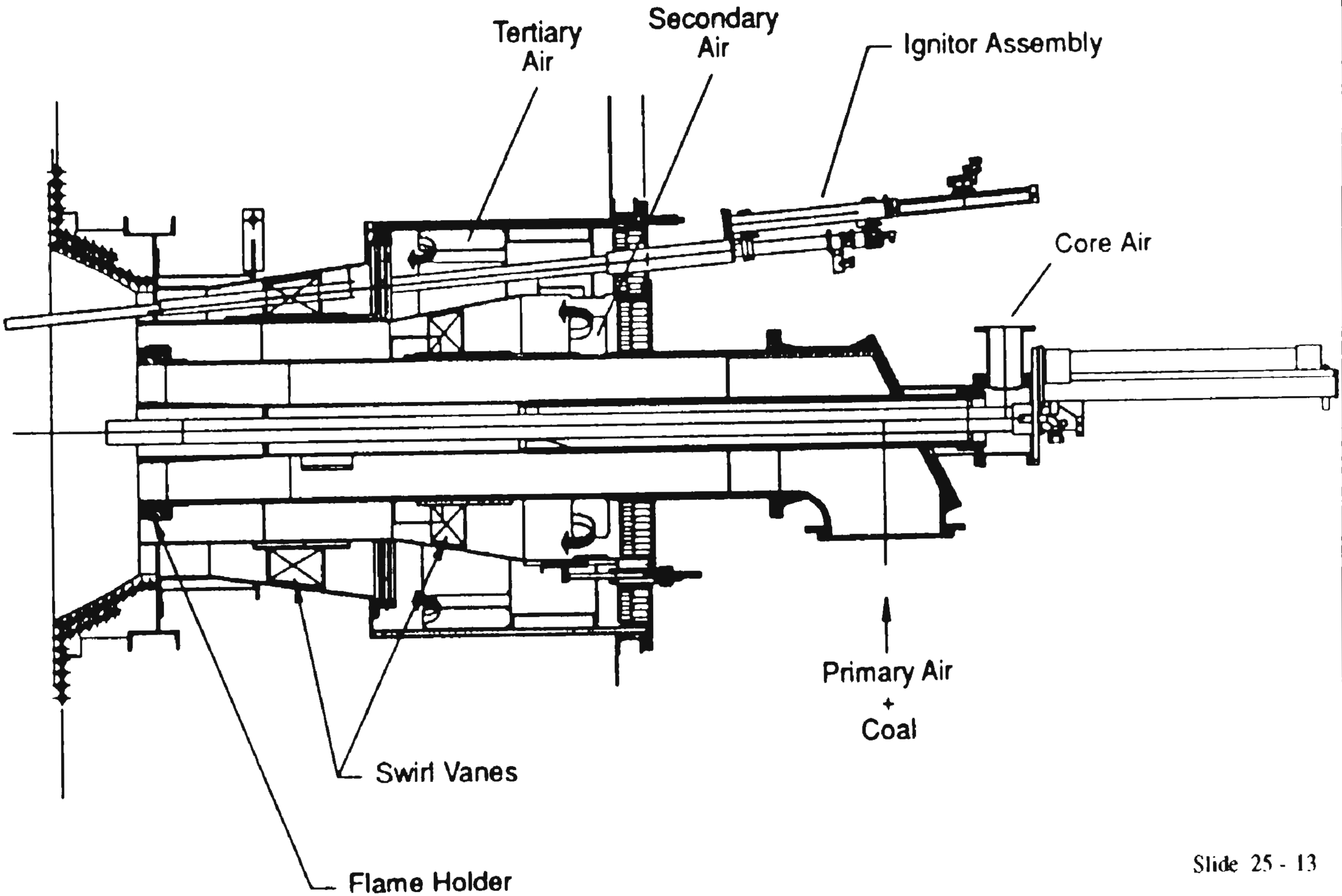


Slide 25 - 11

NO_x EMISSIONS AS A FUNCTION OF AIR PREHEAT TEMPERATURE

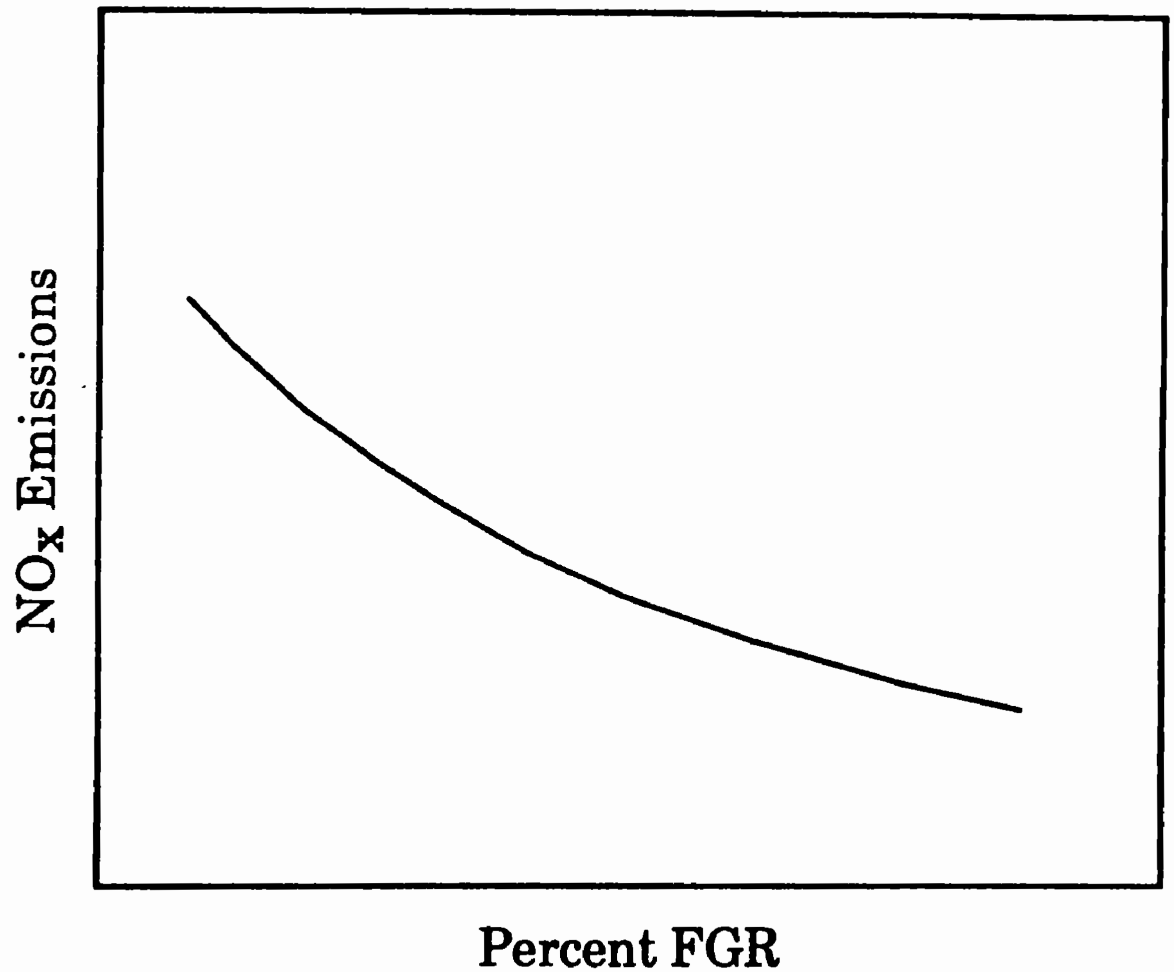


BWE LOW NO_X BURNER

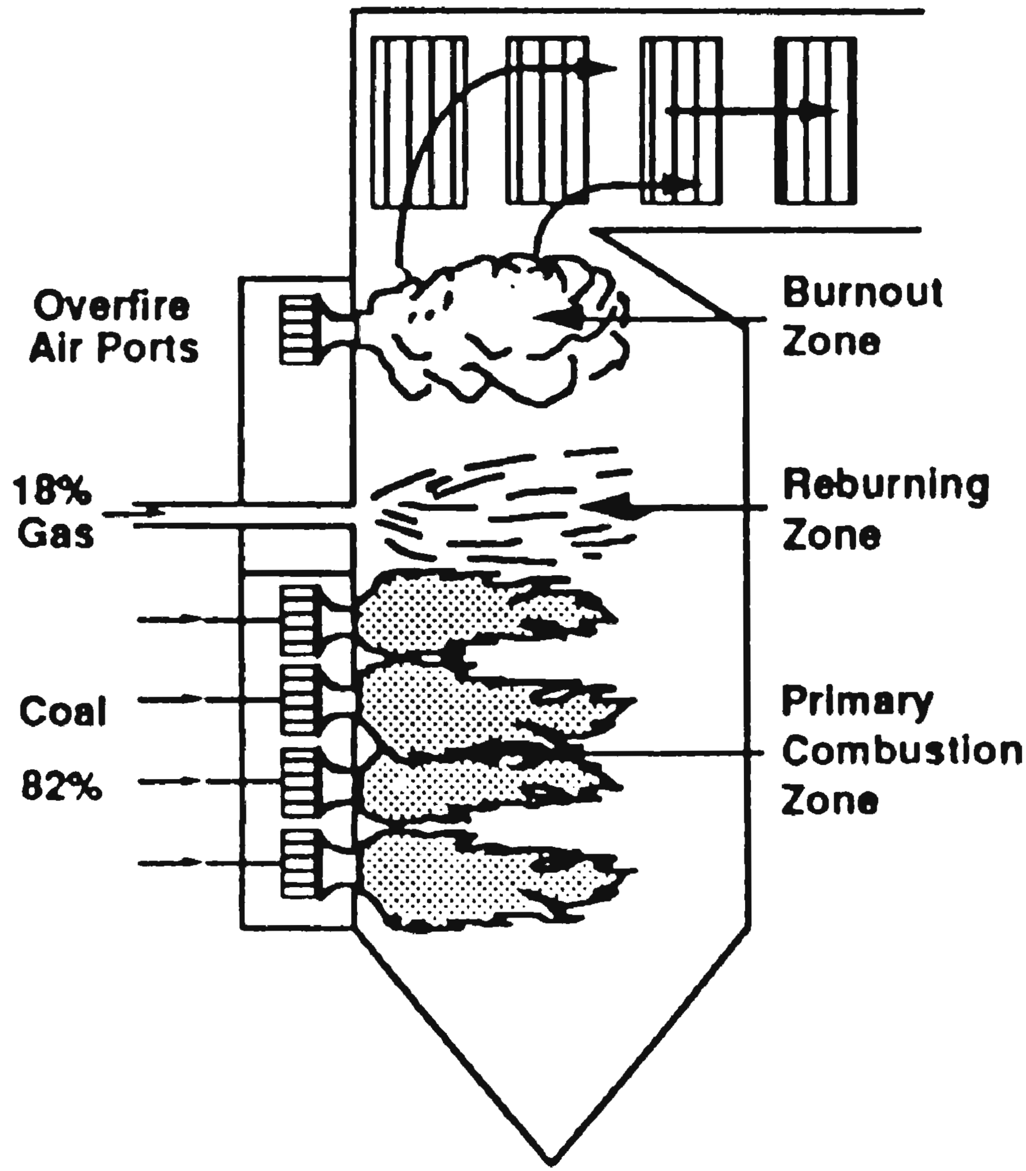


Slide 25 - 13

NO_x EMISSIONS AS A FUNCTION OF % FGR



GAS REBURNING CONFIGURATION



OPERATING PARAMETERS TO MONITOR

CO Emissions

O_2 Emissions

Superheater Steam Temperature

Reheater Steam Temperature

Boiler Efficiency

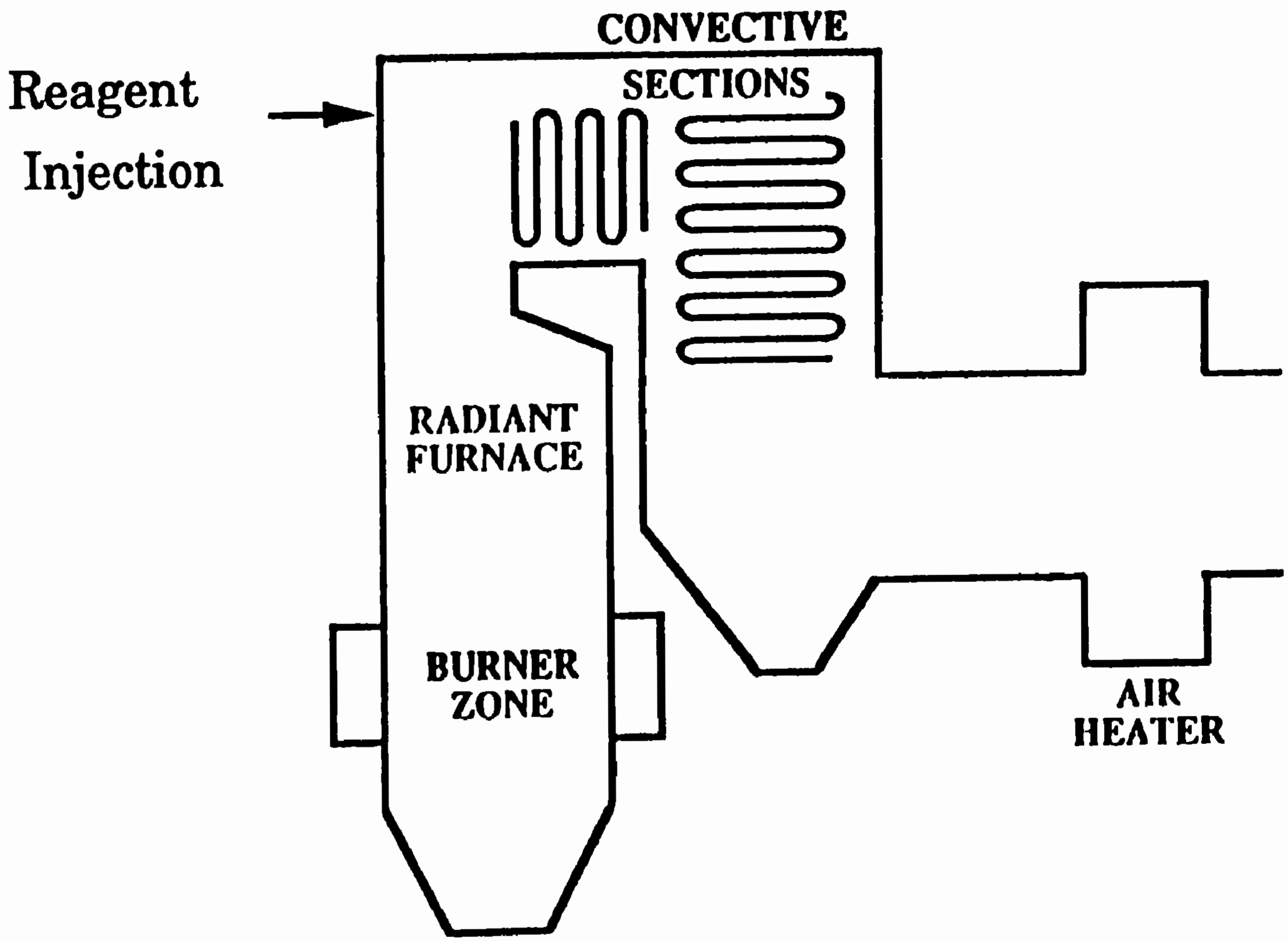
Soot/Slag Formation

NO_x CONTROL TECHNIQUES

Post–Combustion

Selective Non–Catalytic Reduction (SNCR)
Selective Catalytic Reduction (SCR)

POST COMBUSTION NO_x CONTROL SNCR



Slide 25 - 18

SNCR PERFORMANCE FACTORS

Reagent Selection

Temperature Region: 1,600° – 1,800°F

CO Concentration

Residence Time

Reagent Injection Rate Keyed to NO

Gas Mixing Efficiency

COMPETING REACTIONS OF AMMONIA

Reduction

$$4\,NH_3 + 4\,NO + O_2 \longrightarrow 4\,N_2 + 6\,H_2O$$

Oxidation (Flue Gas too Hot):

$$4\,NH_3 + 5\,O_2 \longrightarrow 4\,NO + 6\,H_2O$$

No Reaction (Cool Flue Gas, Ammonia Slip):

$$NH_3 \longrightarrow NH_3$$

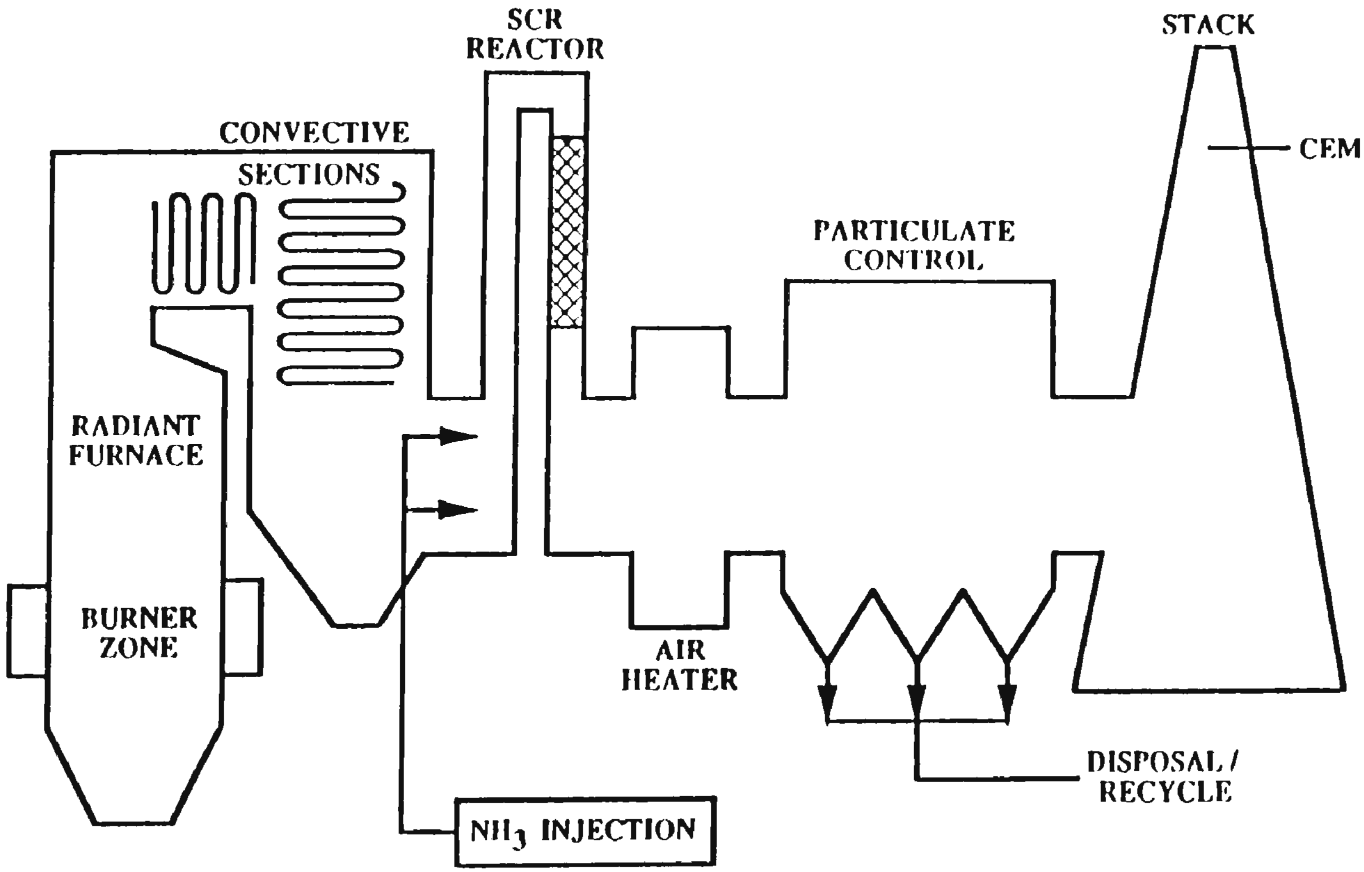
CHEMICAL DECOMPOSITION OF UREA, $CO(NH_2)_2$

$CO(NH_2)_2 \longrightarrow NH_3 + HNCO$ (Iso--Cyanuric acid)

SNCR POTENTIAL OPERATIONAL PROBLEMS

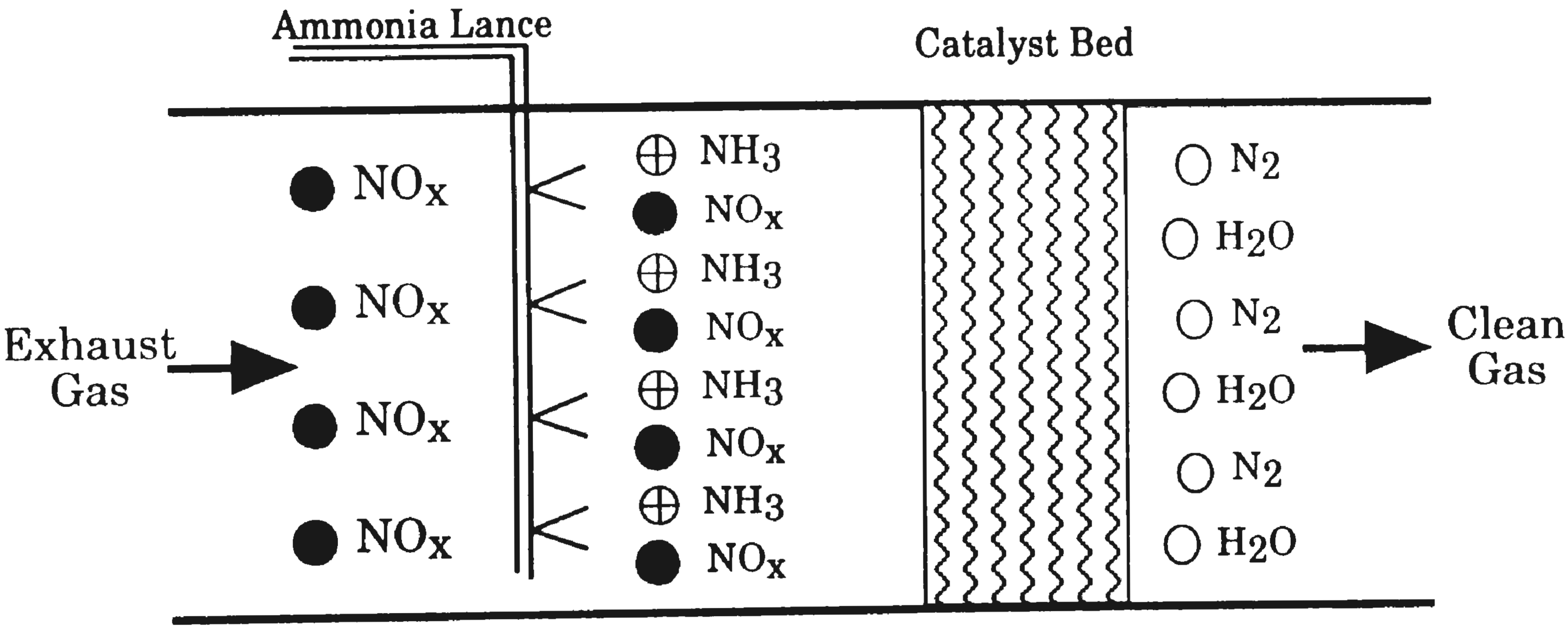
- **Furnace Temperature Variations**
- **Furnace Velocity Variations**
- **NO Increase if T > 2,000 °F**
- **Ammonia Slip – Can React to Form Ammonium Chloride & White Smoke**

POST COMBUSTION NO_X CONTROL SCR



Slide 25 - 23

SCR INJECTION GRID AND CATALYST BED



Slide 25 - 24

LESSON PLAN

CHAPTER 26. SO_x CONTROL

Goal: To give the participant an in-depth discussion of technologies available for the control of SO_x emissions.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the formation of acid rain from SO_x emissions.
2. Discuss the fundamental concepts of wet scrubber operation.
3. Describe the advantage and disadvantages of wet scrubbing.
4. Describe the components of a wet scrubber system.
5. Describe the key components of a dry scrubber system.
6. Discuss the concepts of dry scrubber operation and the advantages and disadvantages of dry scrubbing.

Lesson Time: Approximately 60 minutes.

Suggested Introductory Questions:

What is a flue gas scrubber?

What is the difference between a wet scrubber and dry scrubber?

Presentation Outline:

26.1 Introduction

26.2 Wet Scrubbers
- A. Operating Fundamentals
- B. System Hardware
- C. Operation and Maintenance

26.3 Dry Scrubbers

26.4 Furnace Injection

References for Presentation Slides

Slide 26-5 "Fossil Fuel Fired Industrial Boilers – Background Information Volume 1", EPA–450/3–82–006a, U.S. Environmental Protection Agency, March, 1982.

Slide 26-6 Ibid.

CHAPTER 26. SO_x CONTROL

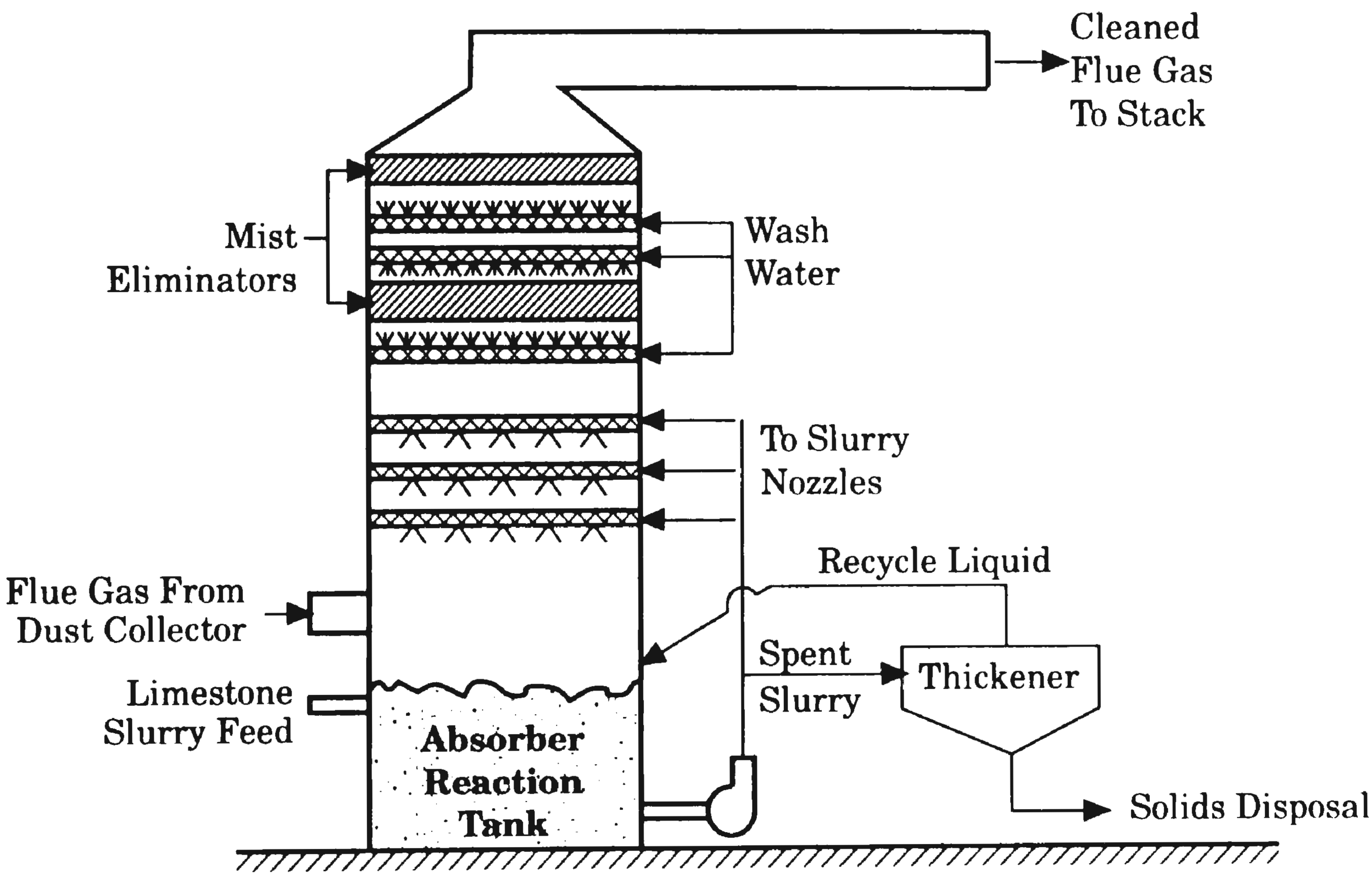
26.1 Introduction

26.2 Wet Scrubbers

26.3 Dry Scrubbers

26.4 Furnace Injection

SCHEMATIC OF WET SCRUBBING SPRAY TOWER SYSTEM



Slide 26 - 2

WET LIMESTONE SCRUBBER CHEMISTRY

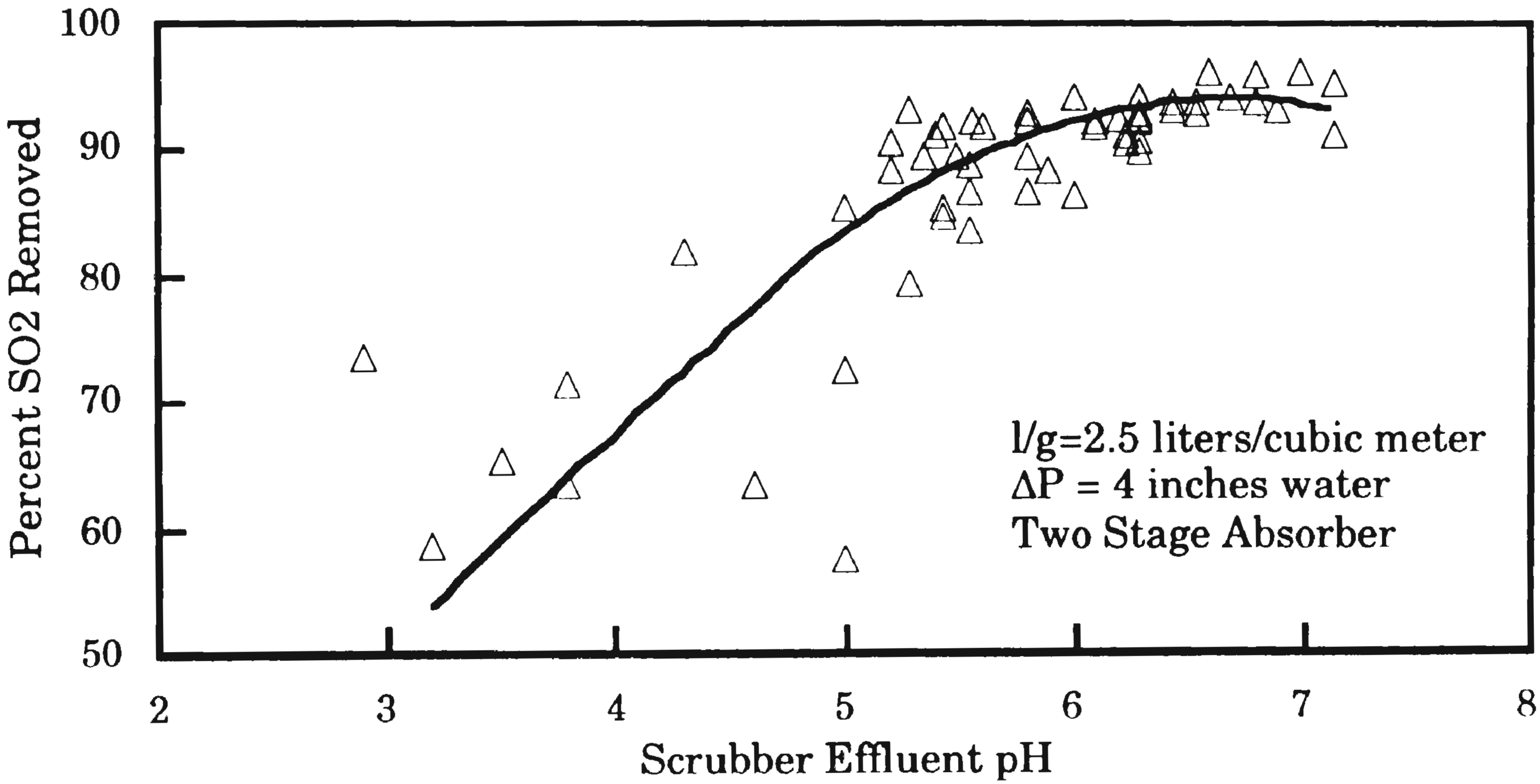
Gaseous SO_2	Limestone ($CaCO_3$)
SO_2 (gas) —> SO_2 (aqueous) SO_2(aqueous) + H_2O —> **HSO_3^-**	$CaCO_3 + H^+$ —> **Ca^{++}** + HCO_3^-

HSO_3^- + **Ca^{++}** + $1/2H_2O$ —> **$CaSO_3 \cdot 1/2H_2O$** + H^+

or

HSO_3^- + $1/2O_2$ + **Ca^{++}** + $2H_2O$ —> **Gypsum**

IMPACT OF SLURRY pH (ACIDITY) ON SO_2 REMOVAL EFFICIENCY[1]



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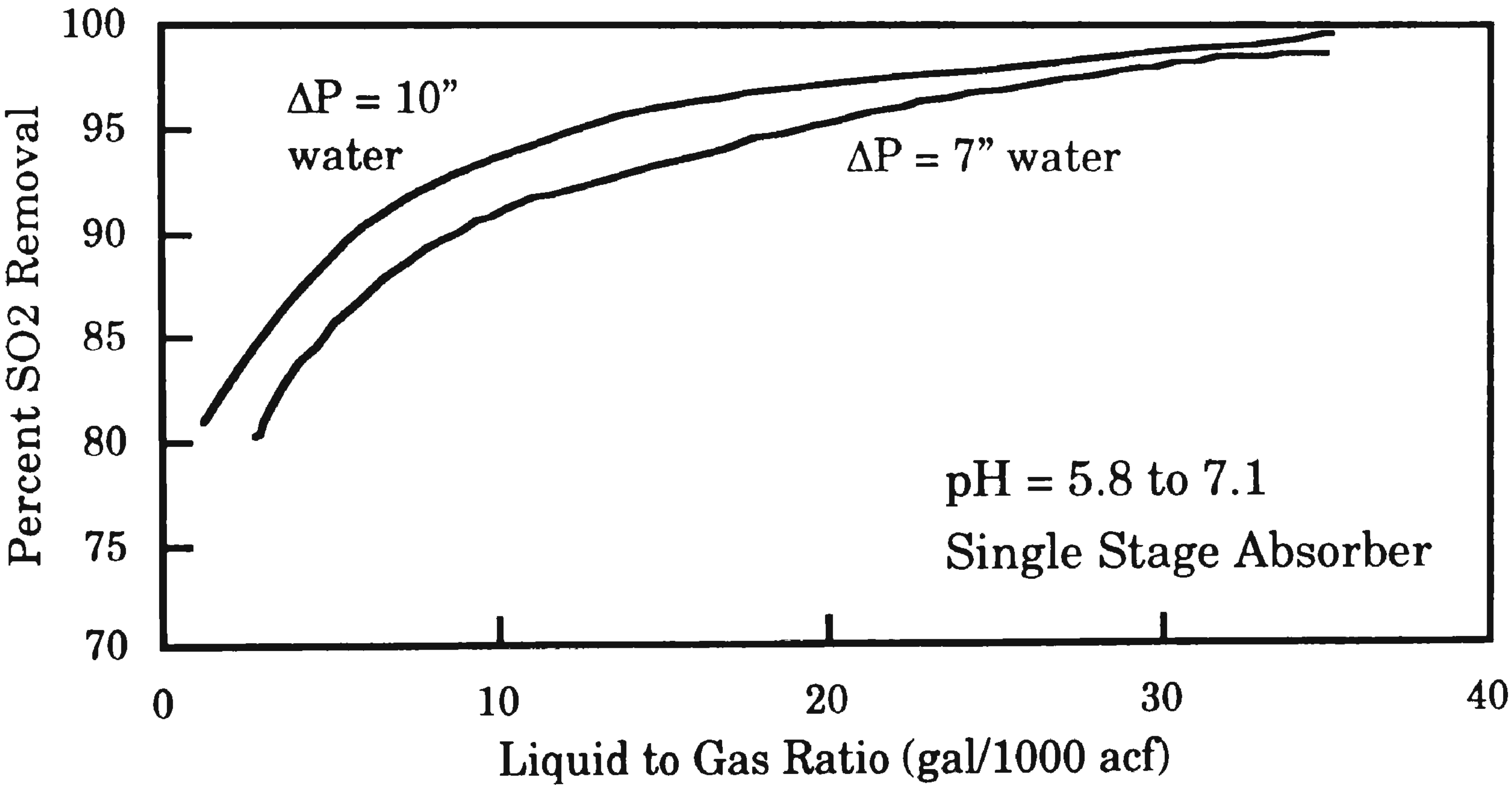
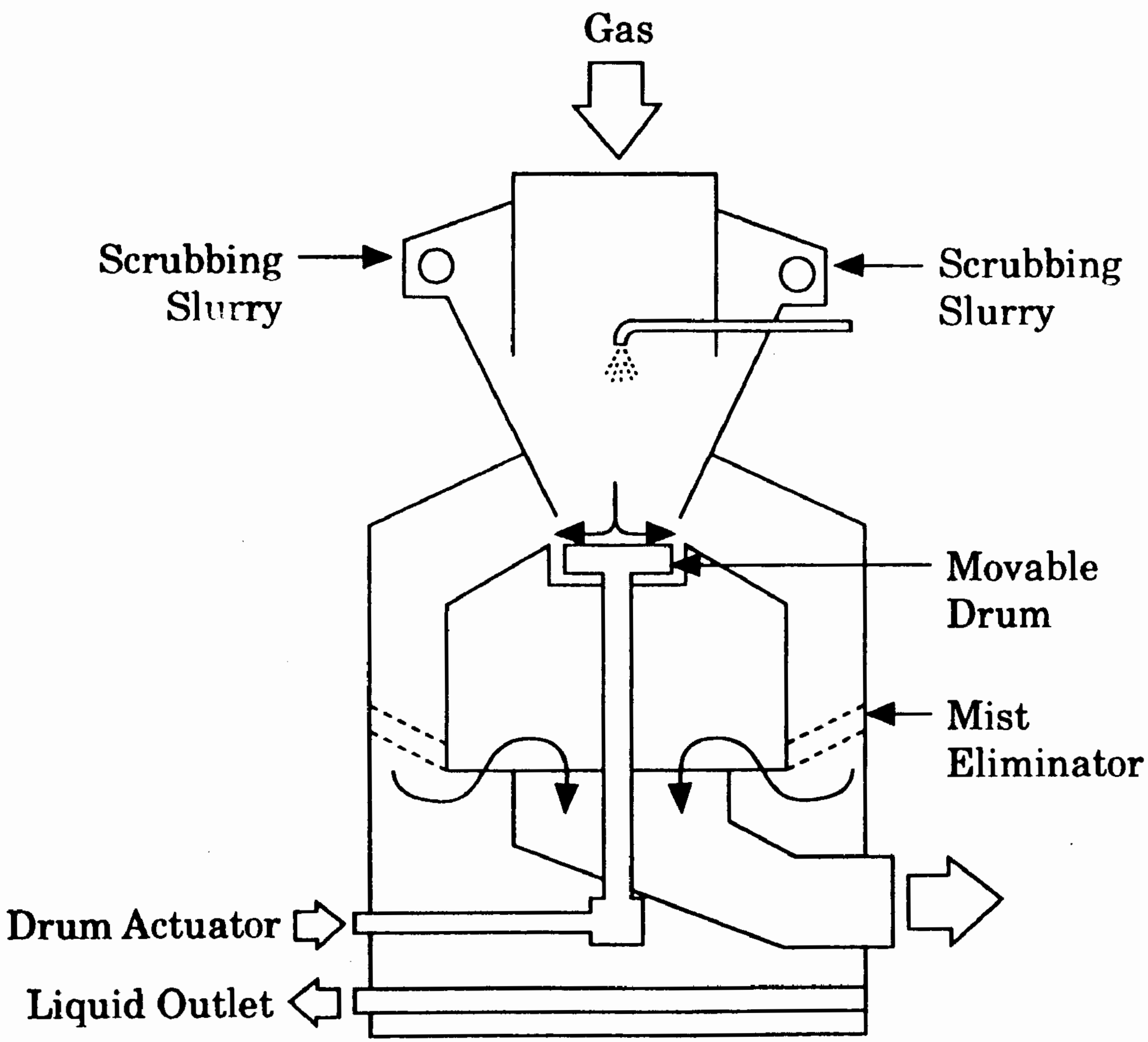
IMPACT OF LIQUID TO GAS RATIO ON SO_2 REMOVAL EFFICIENCY[1]

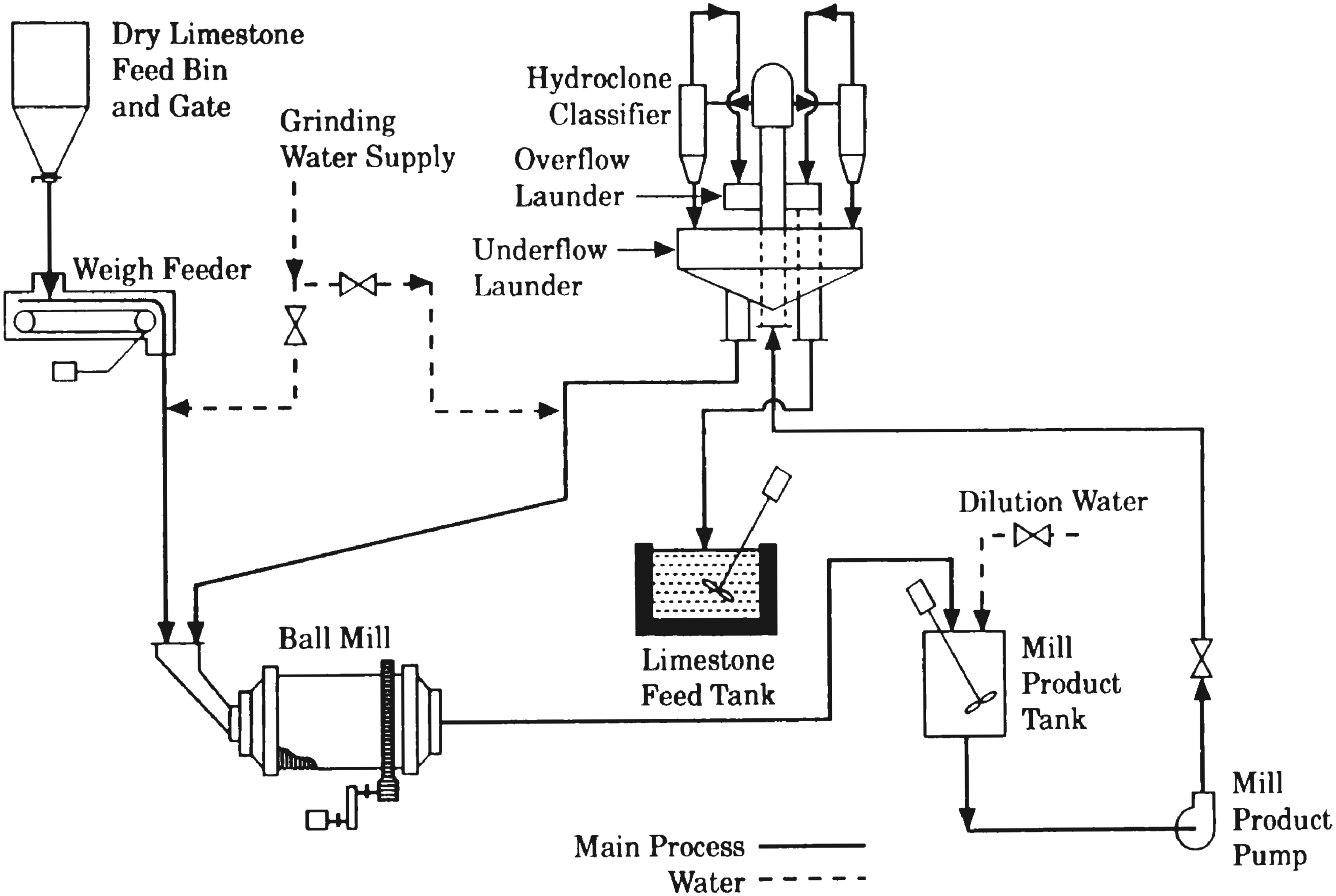


VENTURI SCRUBBER SCHEMATIC



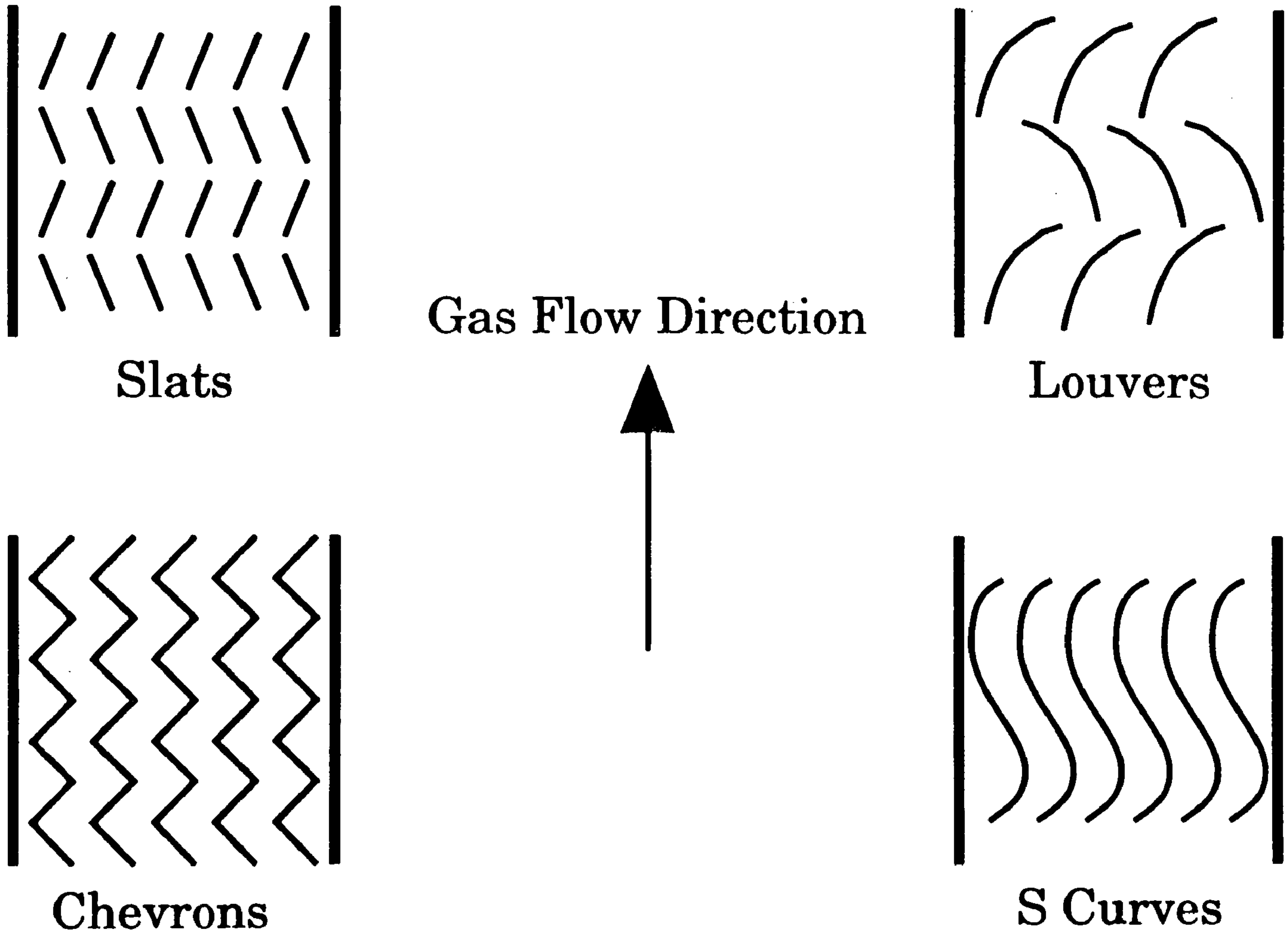
Slide 26 - 6

LIMESTONE REAGENT PREPARATION SYSTEM



Slide 26 - 7

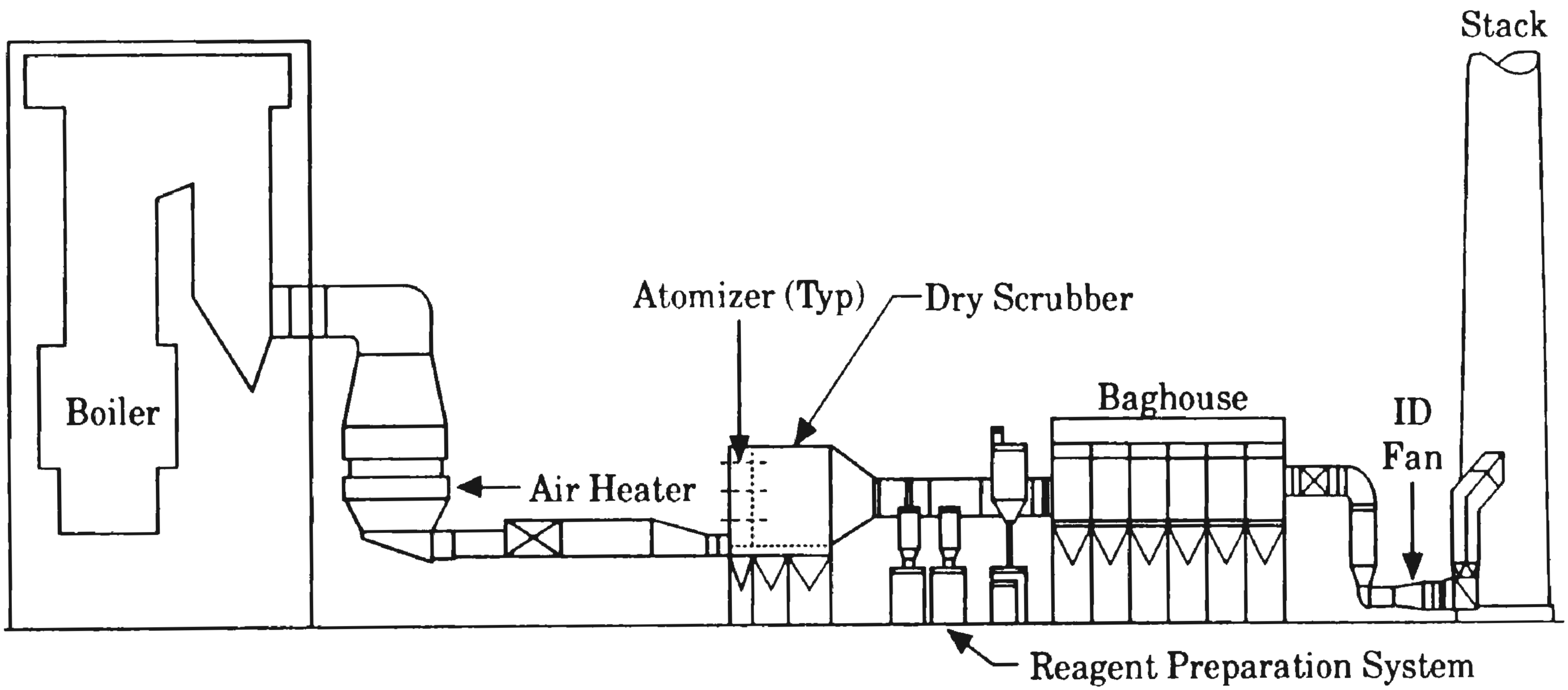
EXAMPLES OF MIST ELIMINATOR PATTERNS



WET SCRUBBER INSPECTION CHECKLIST

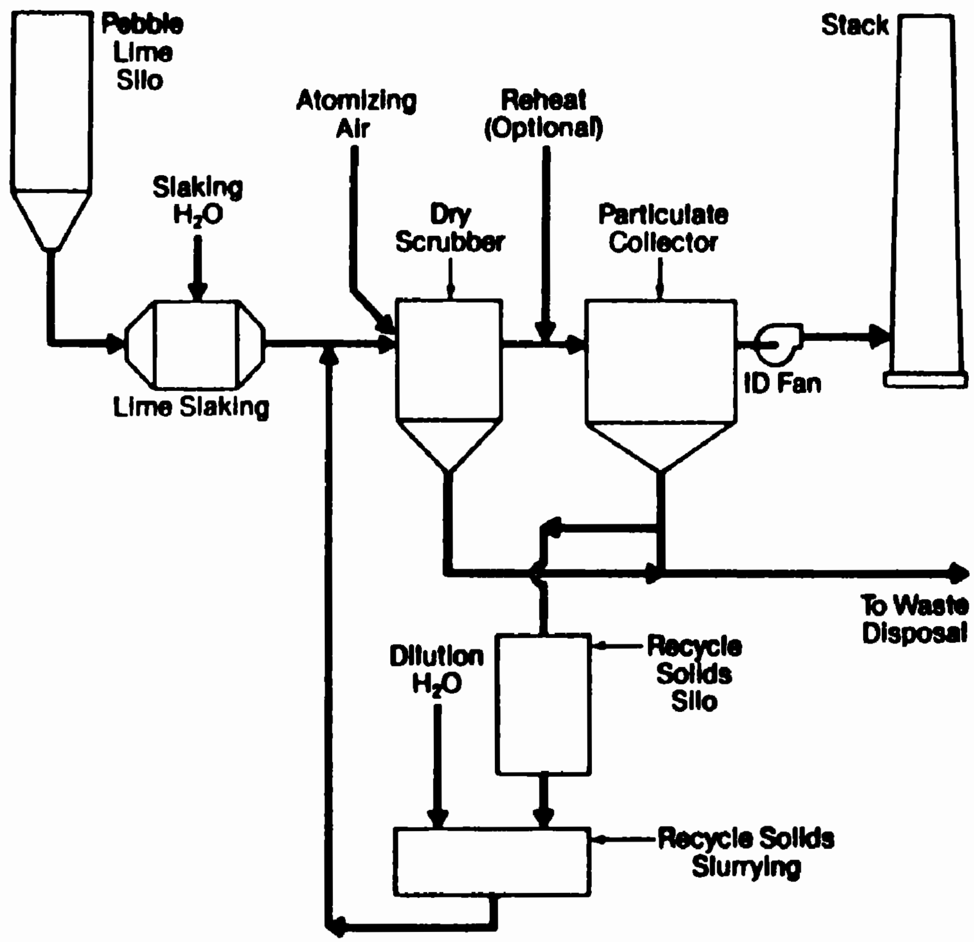
Equipment	Action	Frequency
Scrubber Module	Visually inspect for scale & corrosion	Annually
Agitators	Inspect for corrosion and erosion Check bearings and seals.	Annually
Mist Eliminators	Check for scale	Based on history
Wash Water Nozzles	Monitor pressure	Once per shift
Dampers, Fans, Ducts	Inspect for corrosion and erosion	Annually
Limestone Mill	Inspect visually, lubricate	Each usage
Slurry pump	Check lining, bearings and seals	Annually
Slurry pipes	Check for deposits and wear	Annually
Valves	Test functionality, leakage, packing	Annually
Thickener	Check coating for corrosion Check moving parts for wear Lubricate motor	Annually Annually Frequently
Instrumentation	Flush slurry lines Calibrate	Daily Once per shift

CONFIGURATION OF DRY SCRUBBING SYSTEM



Slide 26 - 10

DRY FGR SCRUBBER SYSTEM SCHEMATIC[3]



Slide 26 - 11

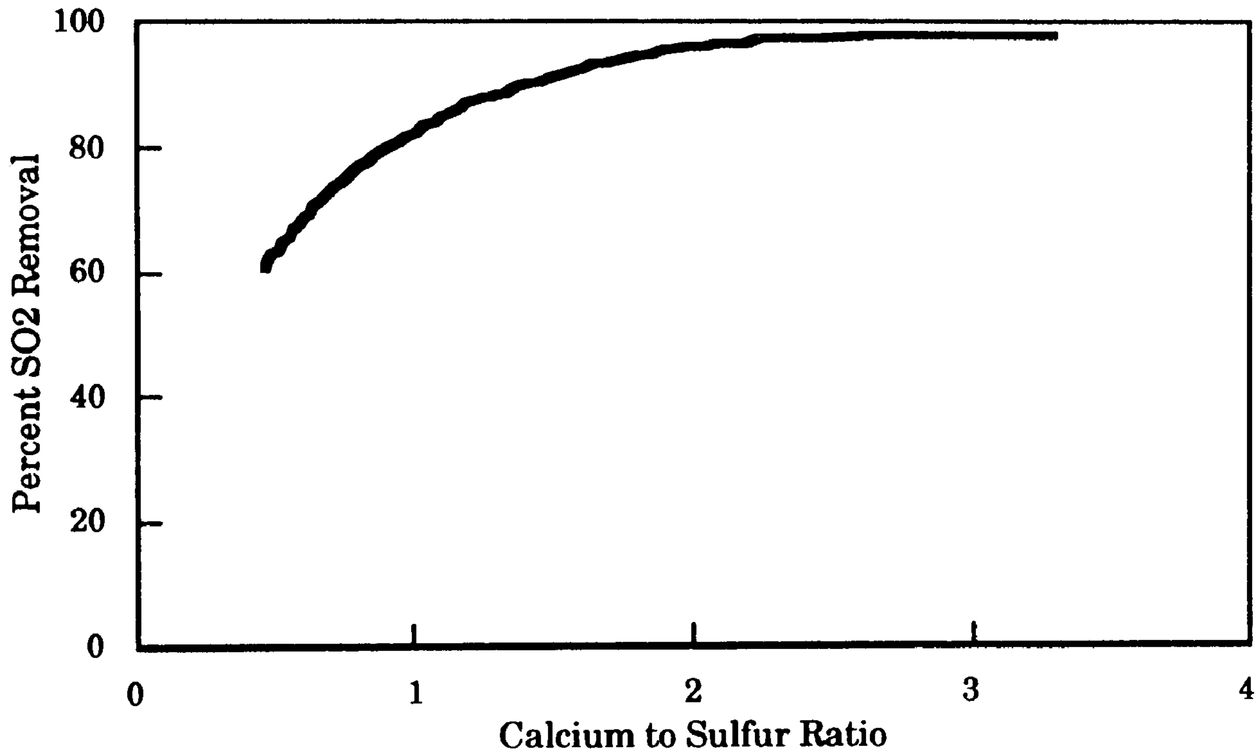
DRY SCRUBBING CHEMICAL REACTIONS

Gaseous SO_2	Slaked Lime – $Ca(OH)_2$
SO_2 (gas) —> SO_2 (aqueous)	$Ca(OH)_2$ —> $\mathbf{Ca^{++}}$ + $2OH^-$
SO_2(aqueous) + H_2O —> HSO_3^-	
HSO_3^- + OH^- —> $\mathbf{SO_3^{=}}$ + H_2O	

$\mathbf{Ca^{++}}$ + $\mathbf{SO_3^{=}}$ + $1/2H_2O$ —> $\mathbf{CaSO_3 \cdot 1/2H_2O}$

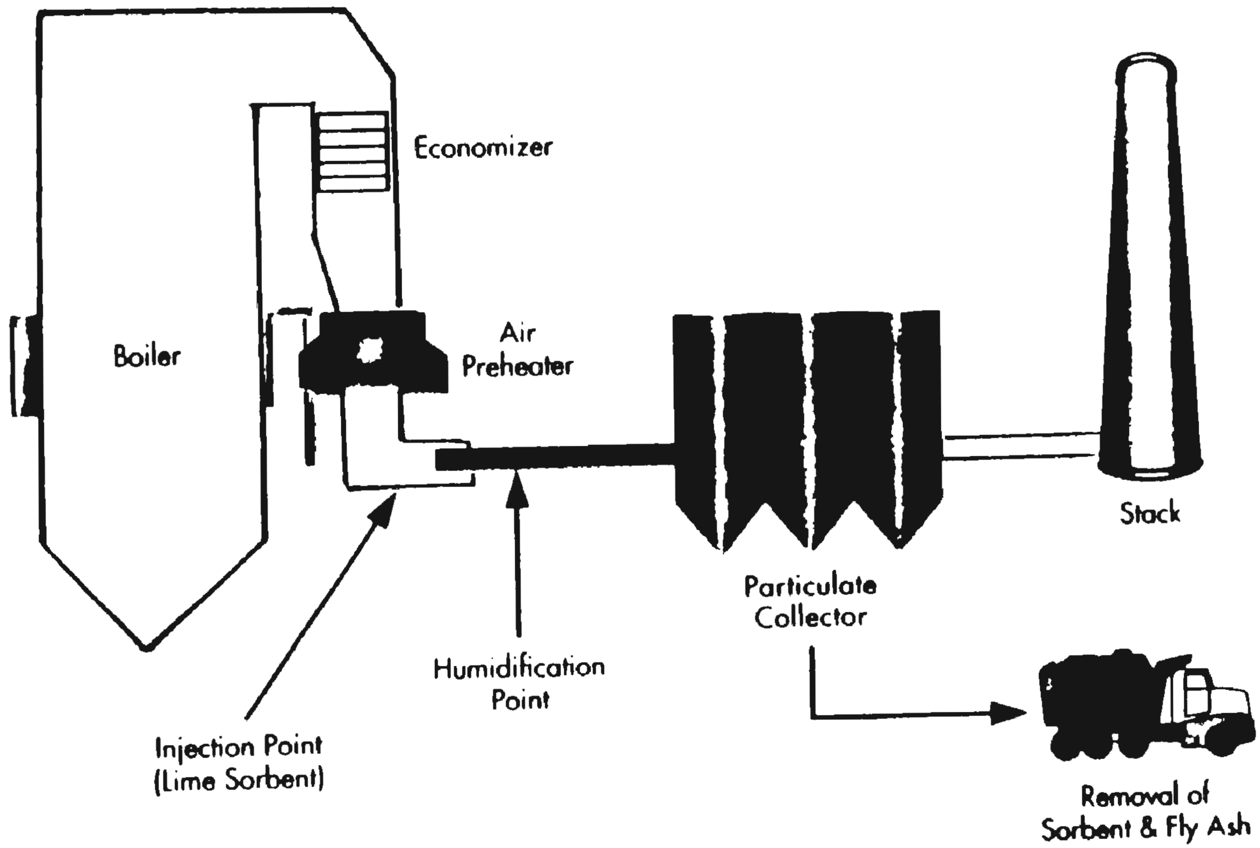
Slide 26 - 12

EFFECT OF CALCIUM TO SULFUR RATIO ON SO_2 REMOVAL EFFICIENCY



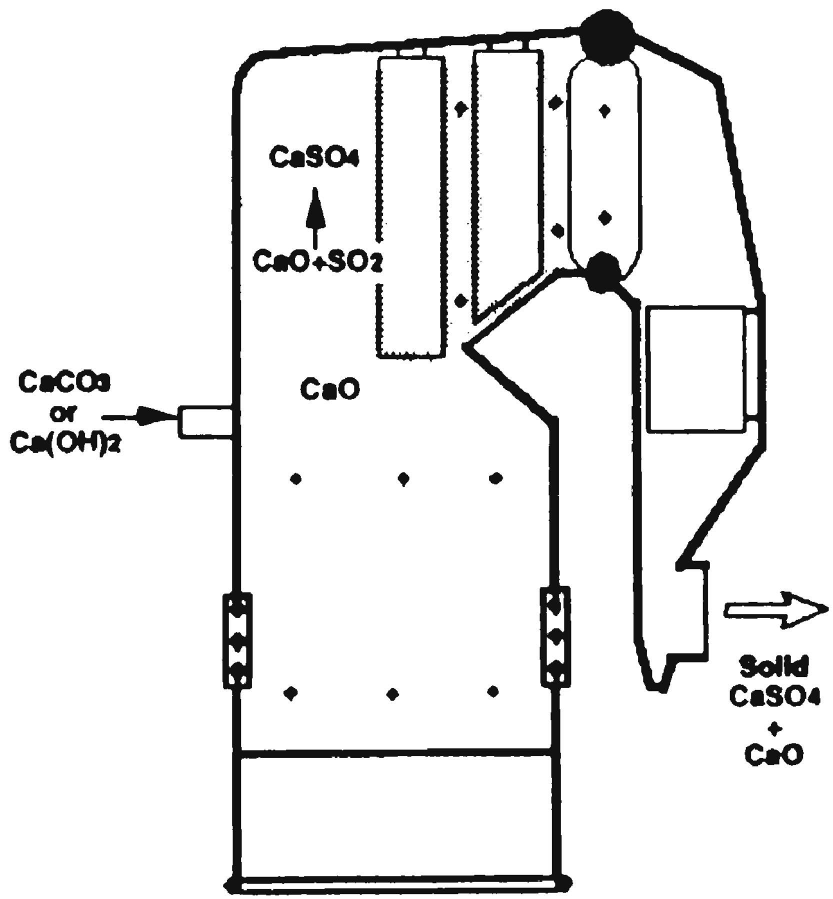
Slide 26 - 13

DRY FGD SCRUBBER SYSTEM SCHEMATIC[6]



Slide 26 - 14

FURNACE SORBENT INJECTION



Slide 26 - 15

LESSON PLAN

CHAPTER 27. WATER POLLUTION

Goal: To describe to the participants the issues and causes of water pollution relating to the operation of steam generating systems.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss EPA groupings of wastewater categories.
2. Describe the potential sources of aqueous discharge streams from a utility boiler.

Lesson Time: Approximately 45 minutes.

Suggested Introductory Questions:

What are some possible causes of water pollution from a steam generating facility?

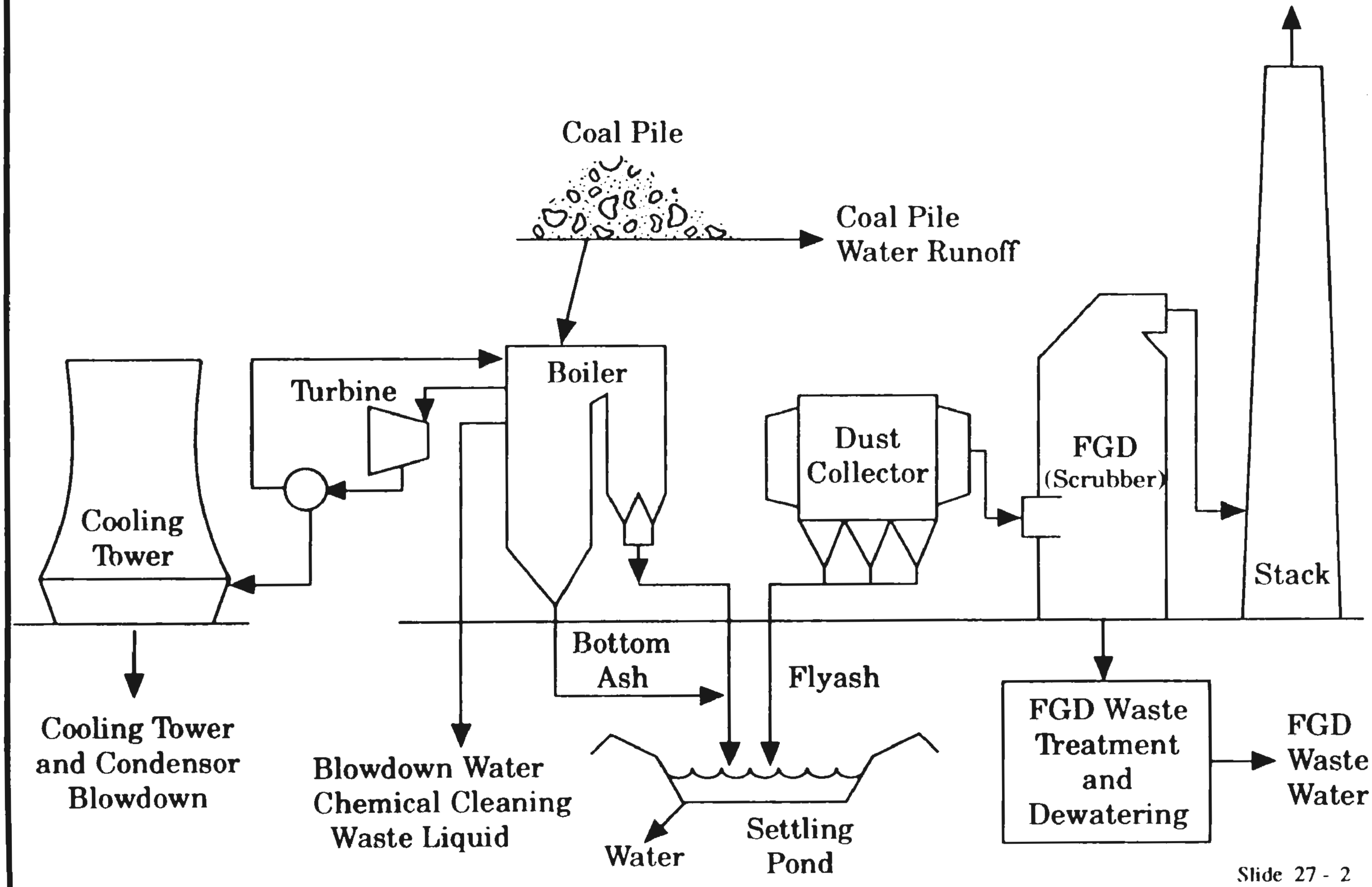
Presentation Outline:

27.1 Aqueous Discharge Streams

27.2 Discharge Categories

CHAPTER 27. WATER POLLUTION

AQUEOUS DISCHARGES FROM UTILITY BOILERS



Slide 27 - 2

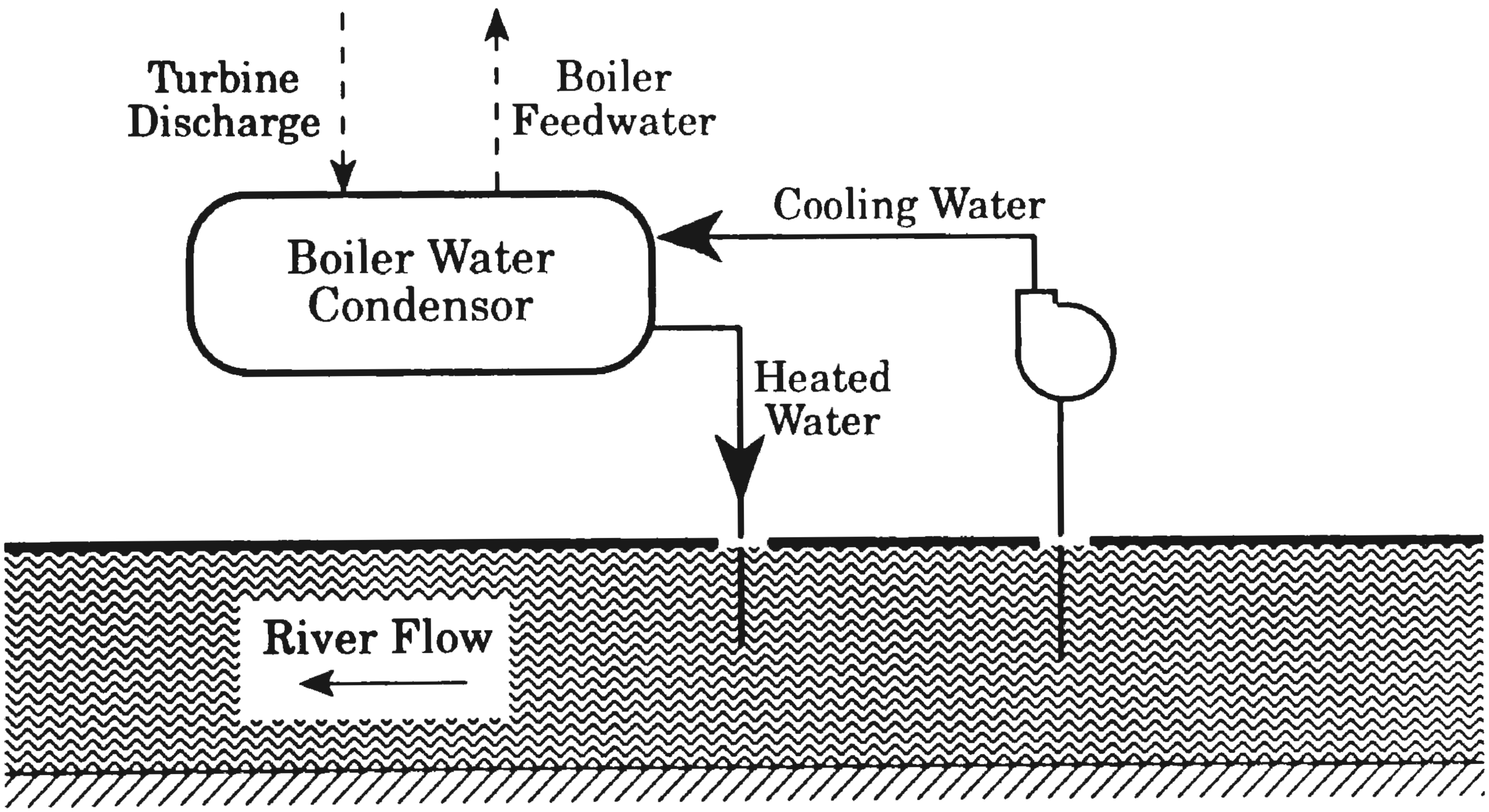
ALLOWABLE CONCENTRATIONS OF POLLUTANTS

Waste Streams and Pollutants	Concentration Limits (mg/liter)	
	Daily Maximum	30 Day Rolling Average
All Discharges		
pH (except once through cooling)	6 – 9	6 – 9
PCBs	0	0
Low Volume Waste*		
Total Suspended Solids	100	30
Oil and Grease	20	15
Bottom and Flyash Transport Water		
Total Suspended Solids	100	30
Oil and Grease	20	15
Chemical Metal Cleaning Waste		
Total Suspended Solids	100	30
Oil and Grease	20	15
Copper	1.0	—
Iron	1.0	—
Once Through Cooling Water		
Total Residual Chlorine	0.2	—
Cooling Tower Blowdown		
Free Available Chlorine	0.5	0.2
Zinc	1.0	1.0
Chromium	0.2	0.2
Other 126 Priority Pollutants	0	0.0
Coal Pile Runoff		
Total Suspended Solids	50	—

* Includes: water treatment, evaporator and boiler blowdown, lab and floor drains, FGD waste water.

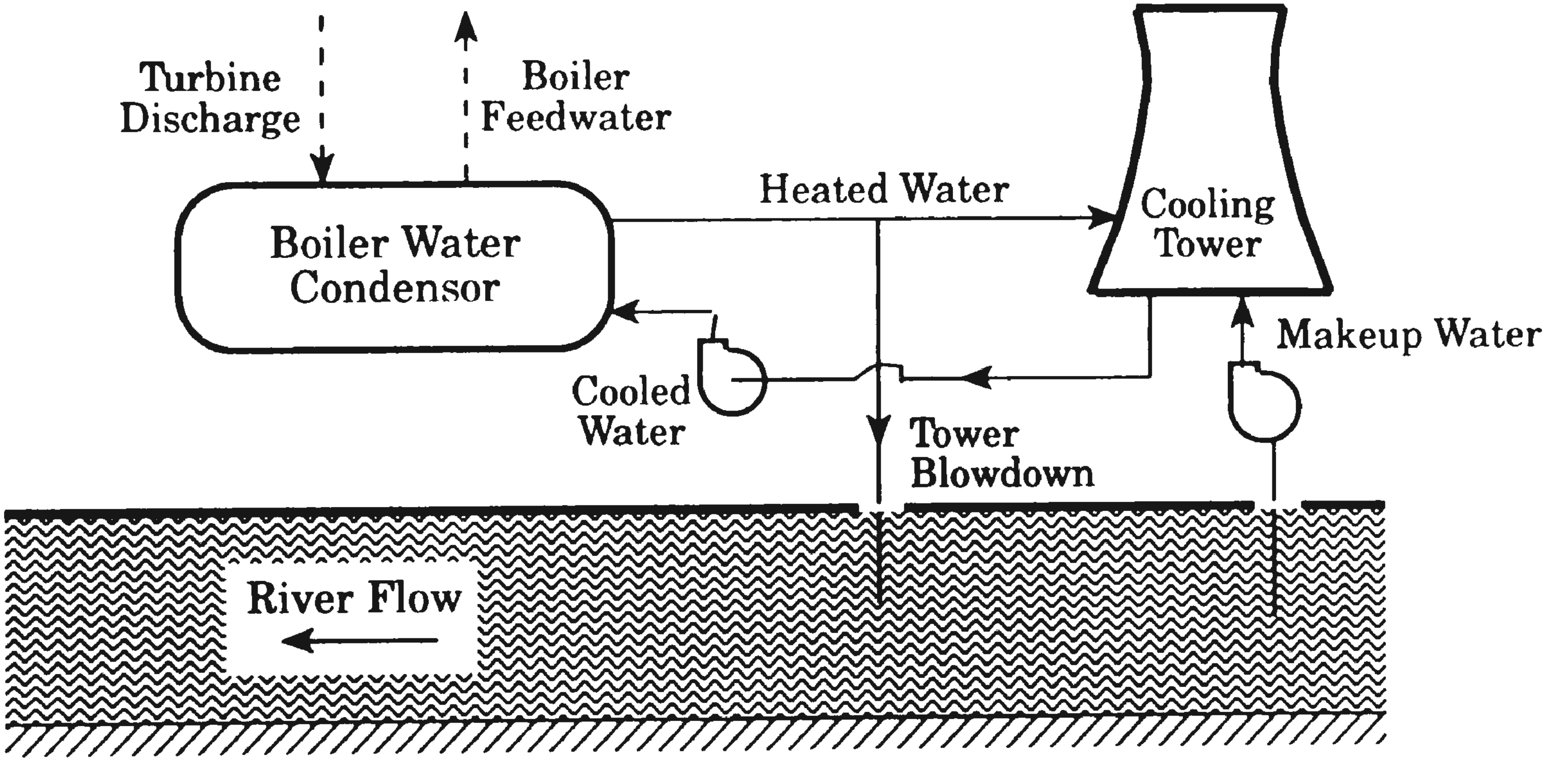
Slide 27 - 3

SCHEMATIC OF ONCE THROUGH COOLING SYSTEM



Slide 27 - 4

SCHEMATIC OF A COOLING TOWER WATER CIRCULATION



Slide 27 - 5

LESSON PLAN

CHAPTER 28. WASTEWATER TREATMENT

Goal: To describe to the participant the typical methods for wastewater treatment.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss the methods commonly used for the removal of suspended solids.
2. Discuss the methods of neutralization of pH and dechlorination of wastewaters.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

What is the difference between acid and base solutions?

How can you control pH of a solution?

How does a settling basin operate?

Presentation Outline:

28.1. Removal of Suspended Solids

28.2. Neutralization

28.3. Dechlorination

Reference for Presentation Slides

R. A. Corbitt, "Standard Handbook of Environmental Engineering", McGraw Hill Publishing Company, 1990.

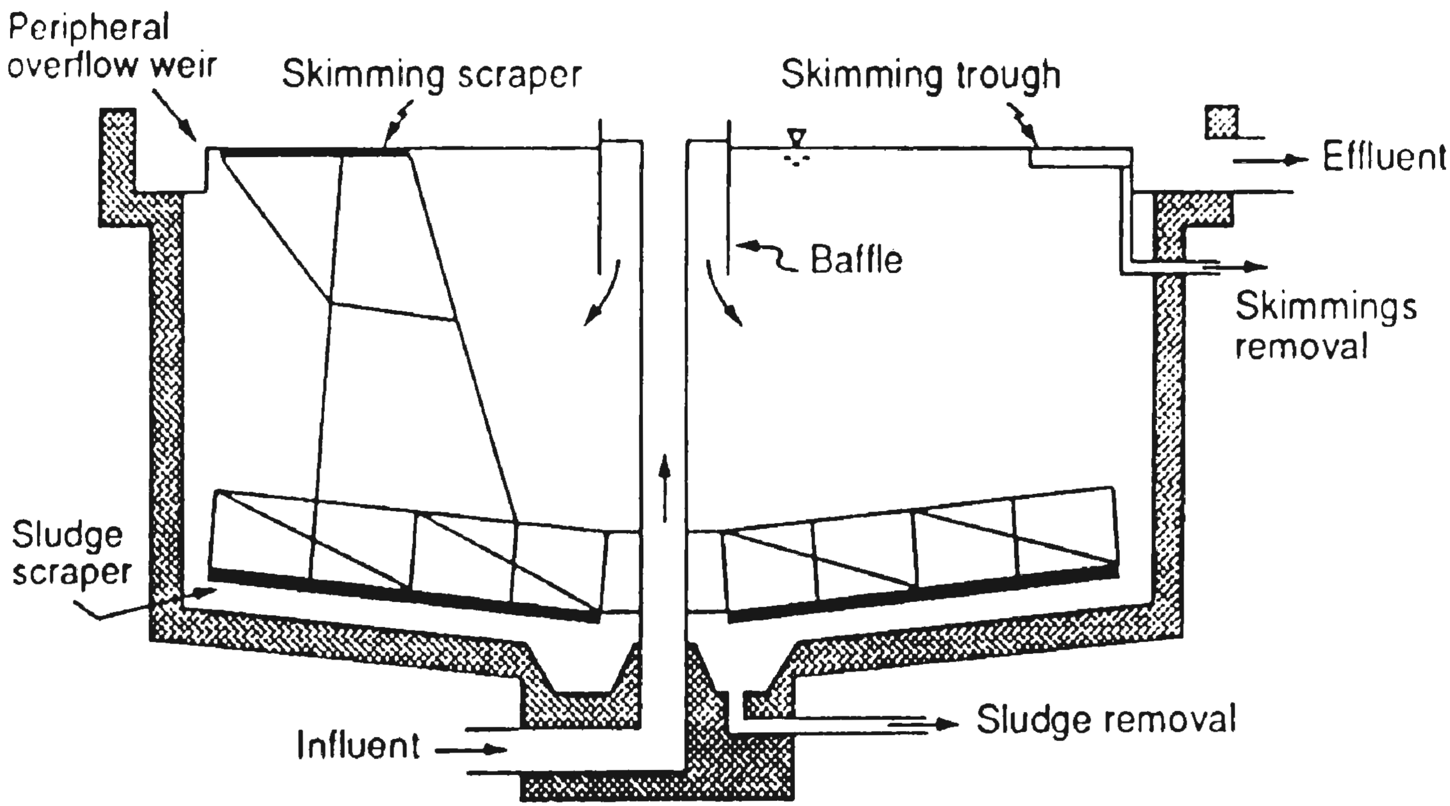
CHAPTER 28. WASTEWATER TREATMENT

28.1 Removal of Suspended Solids

28.2 Neutralization

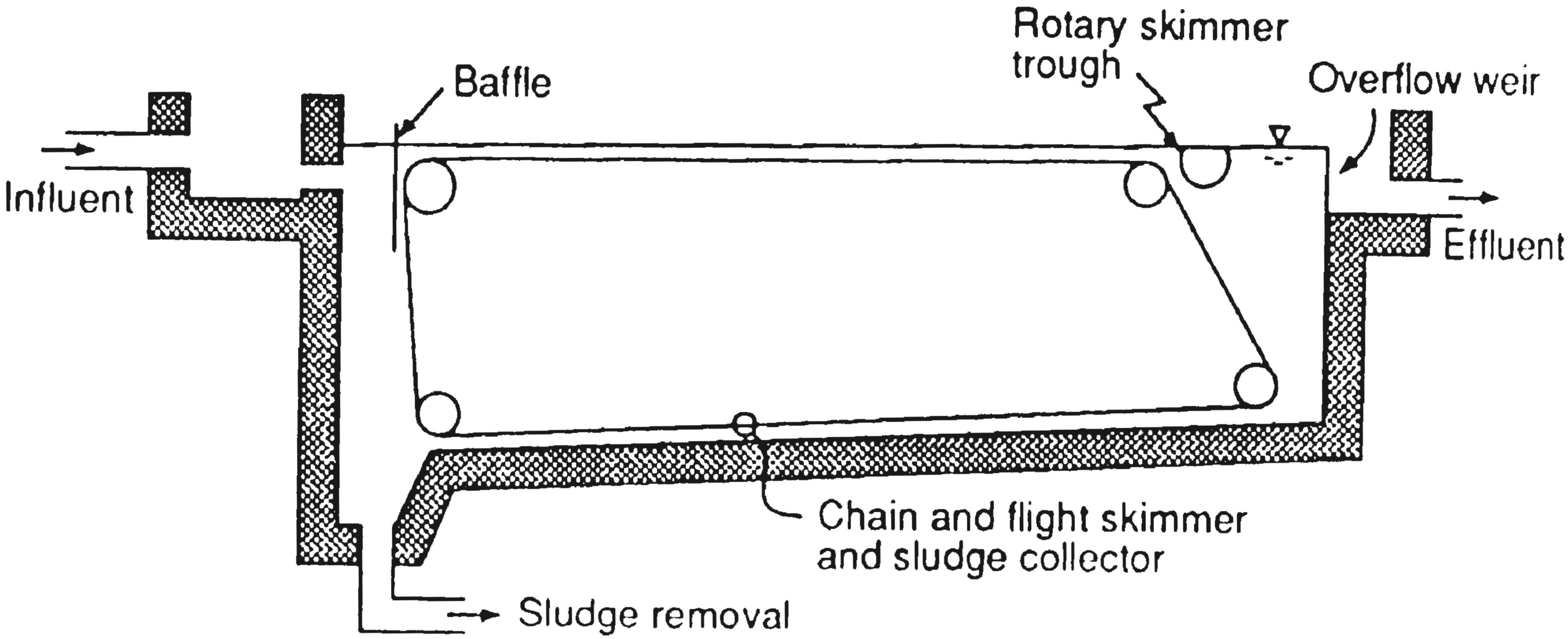
28.3 Dechlorination

CIRCULAR SETTLING BASIN[1]



Slide 28 - 2

HORIZONTAL SETTLING BASIN[1]



BASIN DESIGN PRINCIPLES

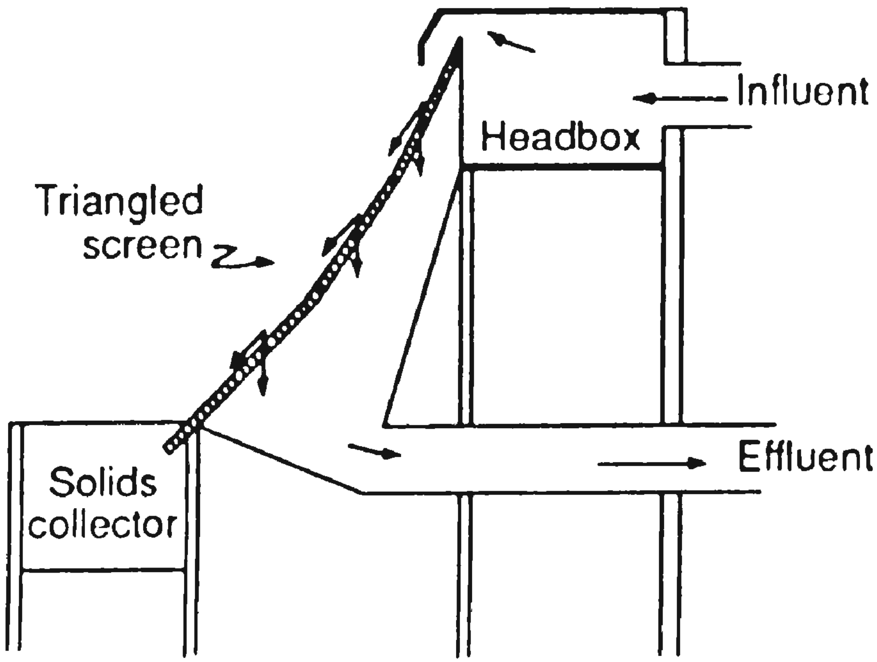
1. **Inlet Design**
   Minimize inlet velocities to avoid turbulence and short circuiting

2. **Settling Zone**
   Provide for calm conditions

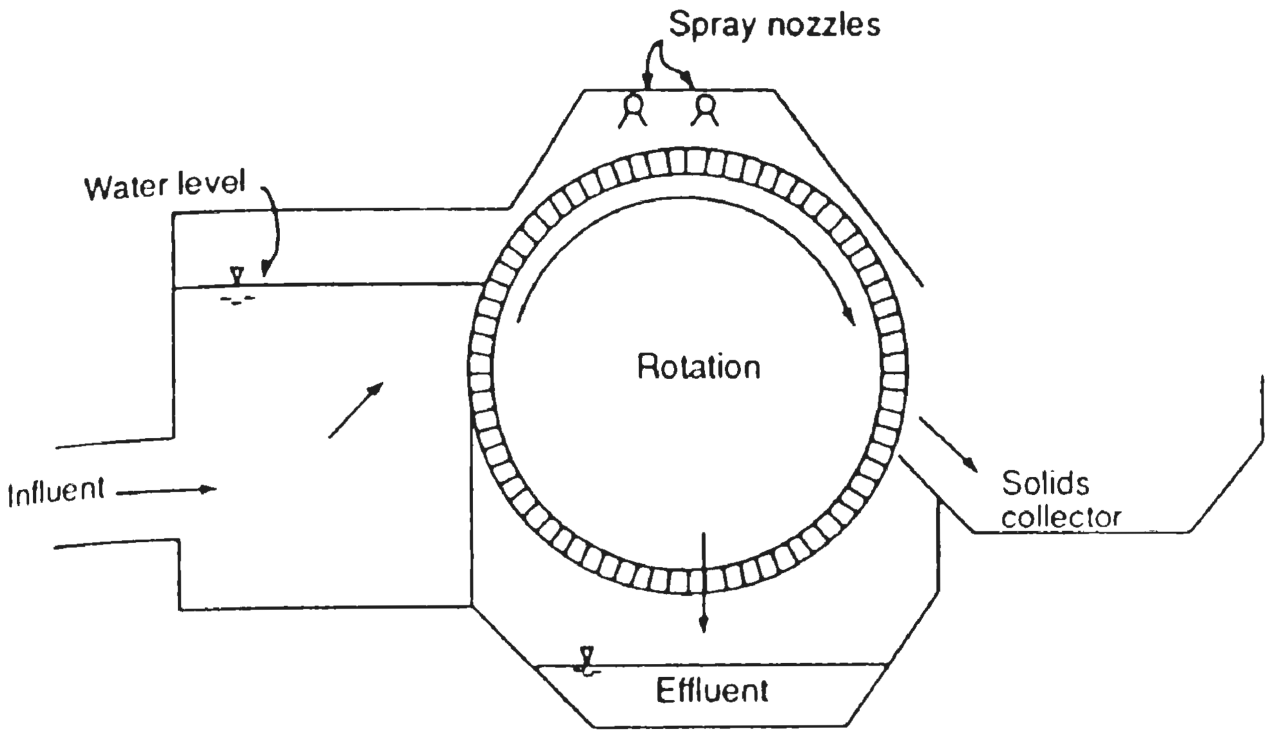
3. **Sludge Zone**
   Allow sufficient depth to allow sludge thickening

4. **Exit Design**
   Minimize exit velocities to prevent short circuiting

STATIC SCREEN SCHEMATIC[1]

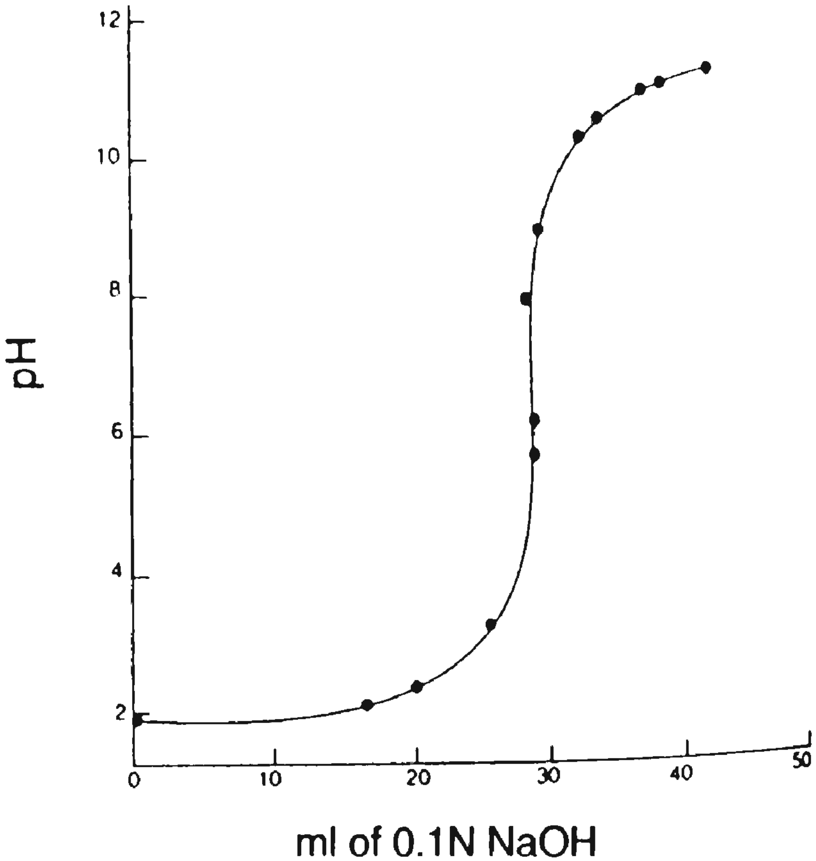


ROTARY SCREEN SCHEMATIC[1]



Slide 28 - 6

TITRATION CURVE FOR ACIDIC WASTEWATER[1]



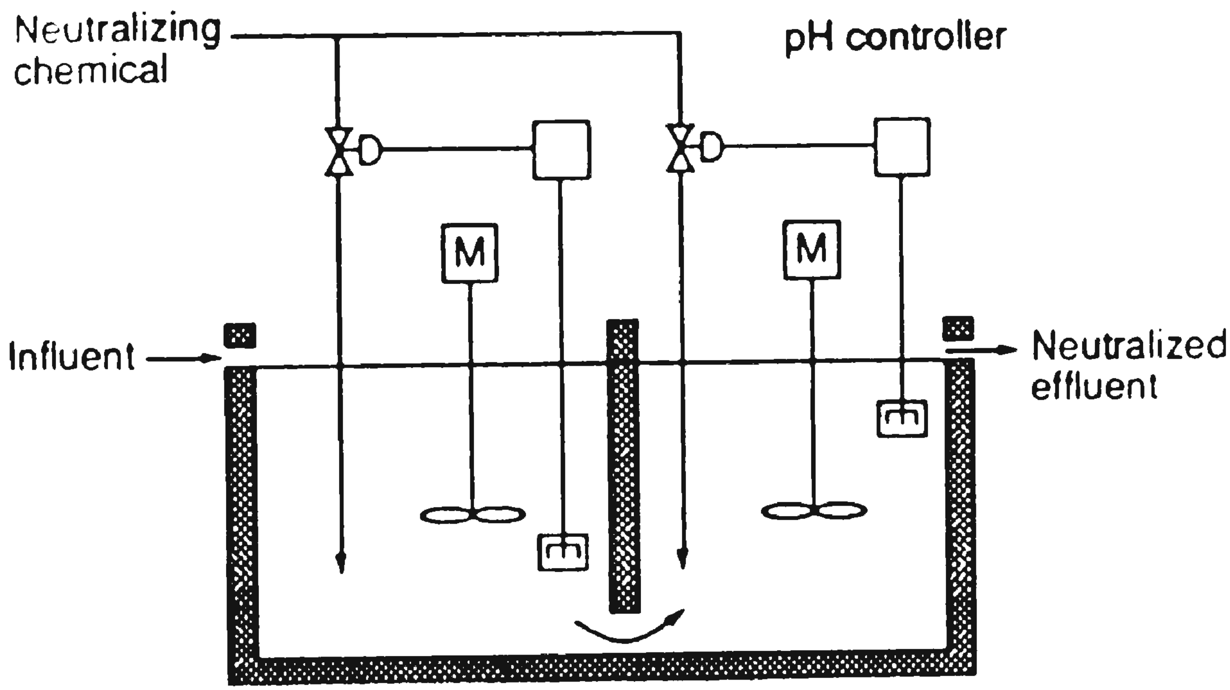
NEUTRALIZATION AGENTS

Chemical Reagent	Formula	Neutralization Requirements, mg/L*	Neutralization Factor†
		Basicity	
Calcium carbonate	$CaCO_3$	1.0	1.0/0.56 = 1.786
Calcium oxide	CaO	0.560	0.56/0.56 = 1.000
Calcium hydroxide	$Ca(OH)_2$	0.740	0.74/0.56 = 1.321
Magnesium oxide	MgO	0.403	0.403/0.56 = 0 720
Magnesium hydroxide	$Mg(OH)_2$	0.583	0.583/0.56 = 1.041
Dolomitic quicklime	$[(CaO)_{0\,6}(MgO)_{0\,4}]$	0.497	0.497/0.56 = 0.888
Dolomitic hydrated lime	$\{[Ca(OH)_2]_{0\,6}$ $[Mg(OH)_2]_{0\,4}\}$	0.677	0.677/0.56 = 1.209
Sodium hydroxide	NaOH	0.799	0.799/0.56 = 1.427
Sodium carbonate	Na_2CO_3	1.059	1.059/0.56 = 1.891
		Acidity	
Sulfuric acid	H_2SO_4	0.98	0.98/0.56 = 1.750
Hydrochloric acid	HCl	0.72	0.72/0.56 = 1.285
Nitric acid	HNO_3	0.63	0.63/0.56 = 1.125

* The quantity of reagent required to neutralize 1 mg/L of acidity or alkalinity, expressed as calcium carbonate.

† Assumes 100 percent purity of all compounds

TWO–STAGE, CONTINUOUS NEUTRALIZATION SYSTEM[1]



Slide 28 - 9

LESSON PLAN

CHAPTER 29. SOLID WASTES

Goal: To present the participant with discussion of solid wastes generated from a boiler system and the impact of solid waste on water contamination.

Objectives:

Upon completion of this unit an operator should be able to:

1. Identify fuel ash and flue gas desulfurization wastes as the primary sources of solid waste from a boiler system.
2. Describe the distribution of ash typically found in an ash producing boiler system.
3. Discuss ash handling systems commonly used to remove bottom ash and fly ash.
4. Discuss the importance of ash characteristics and ash testing methods.
5. Understand the concept of leaching of pollutants from ash into groundwater.
6. Discuss methods of flue gas desulfurization waste handling and disposal.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

How are boiler solid wastes disposed?

Why are the melting characteristics of ash important to boiler design and ash handling system design?

Presentation Outline:

29.1 Introduction

29.2 Bottom Ash and Fly Ash

Presentation Outline (Continued):

29.3 Ash Removal and Handling Techniques
- A. Bottom Ash Removal and Handling
- B. Boiler Back Pass Ash Handling
- C. Fly Ash Removal and Handling

29.4 Ash Characterization and Testing
- A. Classification of Coal Ash
- B. Elemental Analysis
- C. Fusion Temperatures
- D. Fuel Oil Ash Characteristics

29.5 Flue Gas Desulfurization Wastes

29.6 Handling of FGD Wastes
- A. Wet Scrubbing Waste Handling
- B. Dry Scrubbing Waste Handling
- C. Sorbent Injection Waste Handling

29.7 Groundwater Contamination from Ponds and Landfills

Reference for Presentation Slides

Singer, J. G., *Combustion: Fossil Power Systems*, 3rd edition, Combustion Engineering, Inc., 1981.

CHAPTER 29. SOLID WASTES

29.1 Introduction

29.2 Bottom Ash and Fly Ash

29.3 Ash Removal and Handling Techniques

29.4 Ash Characterization and Testing

29.5 Flue Gas Desulfurization Wastes

29.6 Handling of FGD Wastes

29.7 Groundwater Contamination from Ponds and Landfills

SOURCE OF SOLID WASTES

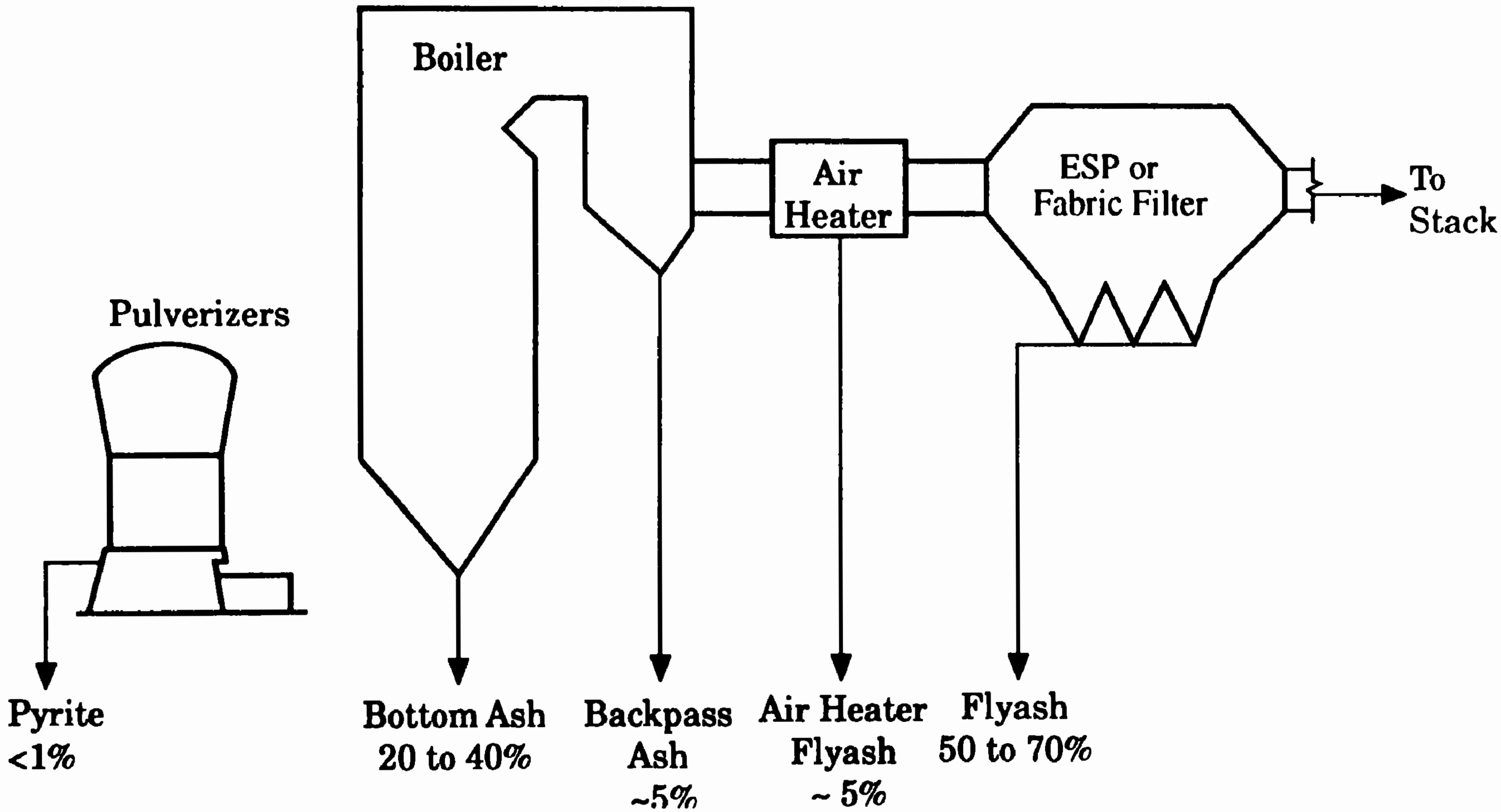
Fuel Ash

Flue Gas Desulfurization Waste

BOTTOM ASH AND FLY ASH

Source of Ash
Definition of Bottom Ash
Definition of Fly Ash

ASH DISTRIBUTION FROM A COAL–FIRED BOILER[1]

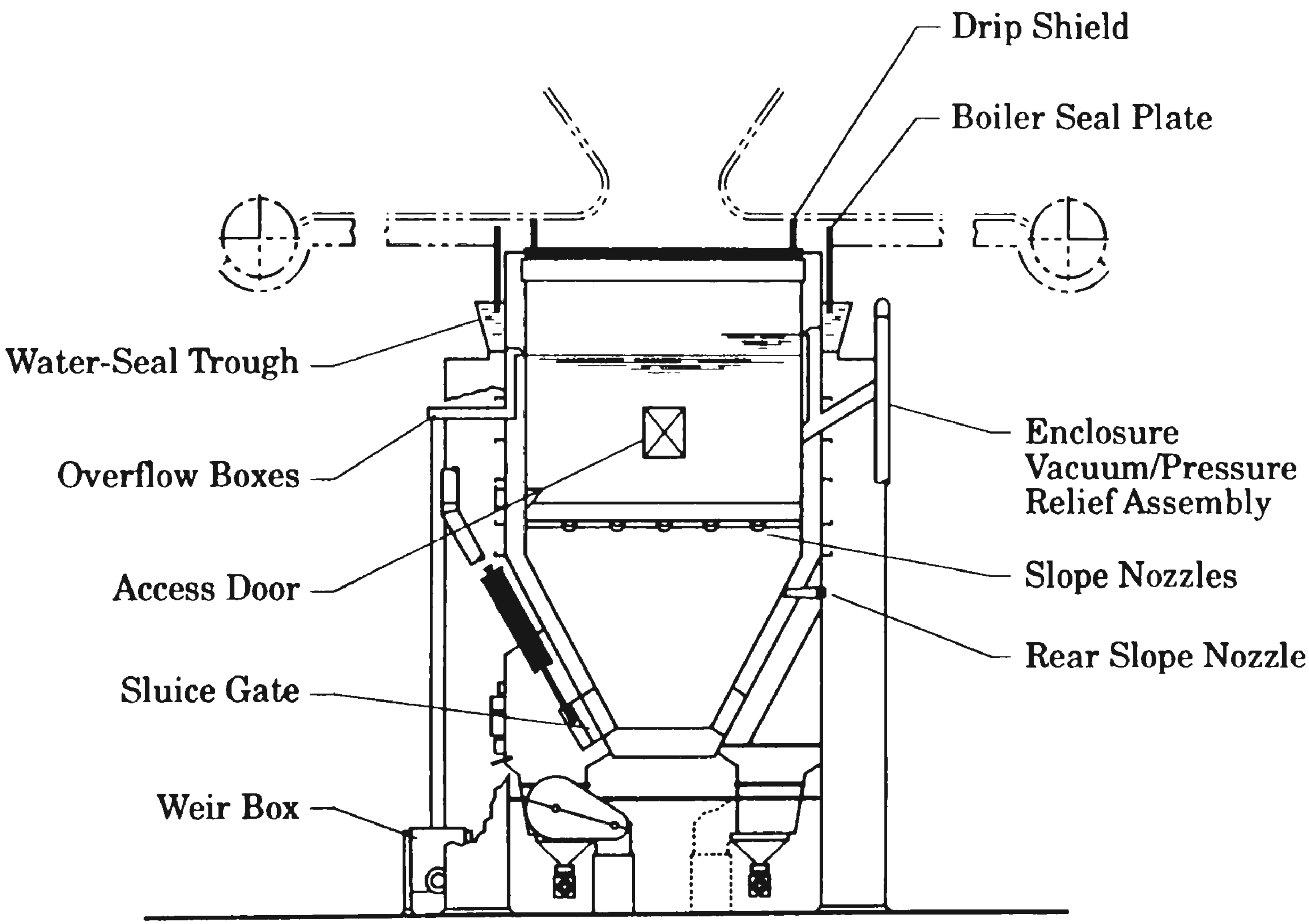


ASH REMOVAL AND HANDLING

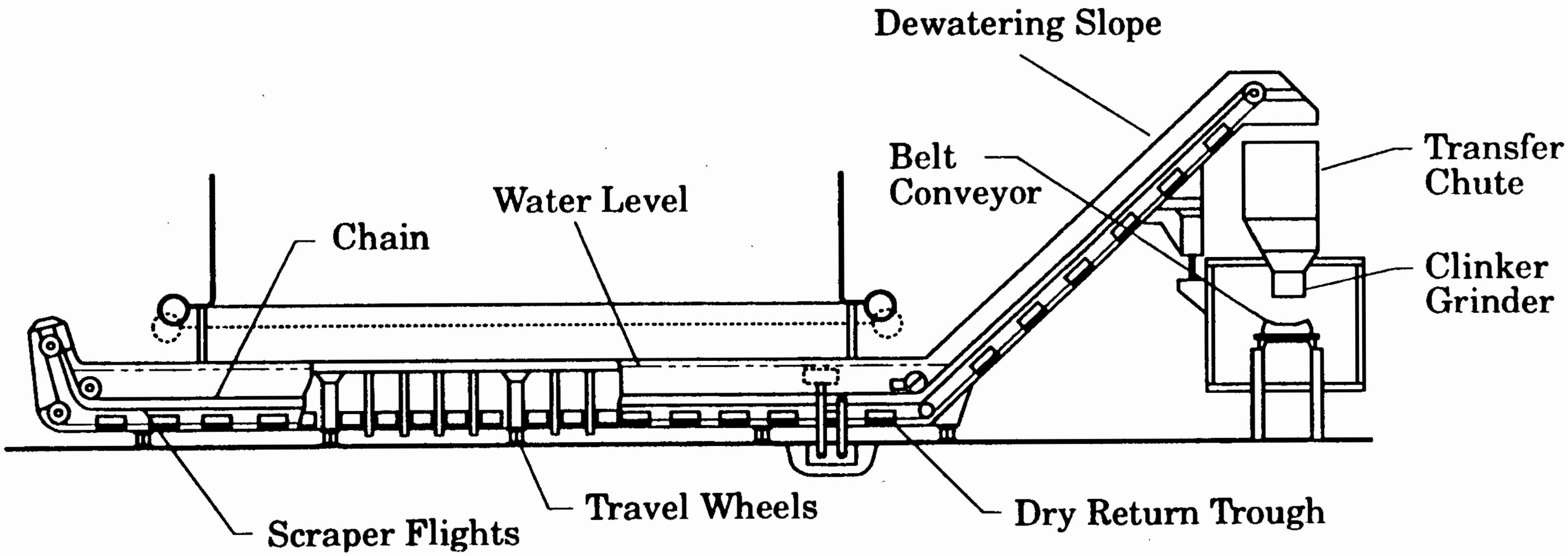
Bottom Ash Removal
- **Wet Bottom Systems**
- **Dry Bottom Systems**

Fly Ash Removal
- **Vacuum Pneumatic Systems**
- **Pressure Pneumatic Systems**

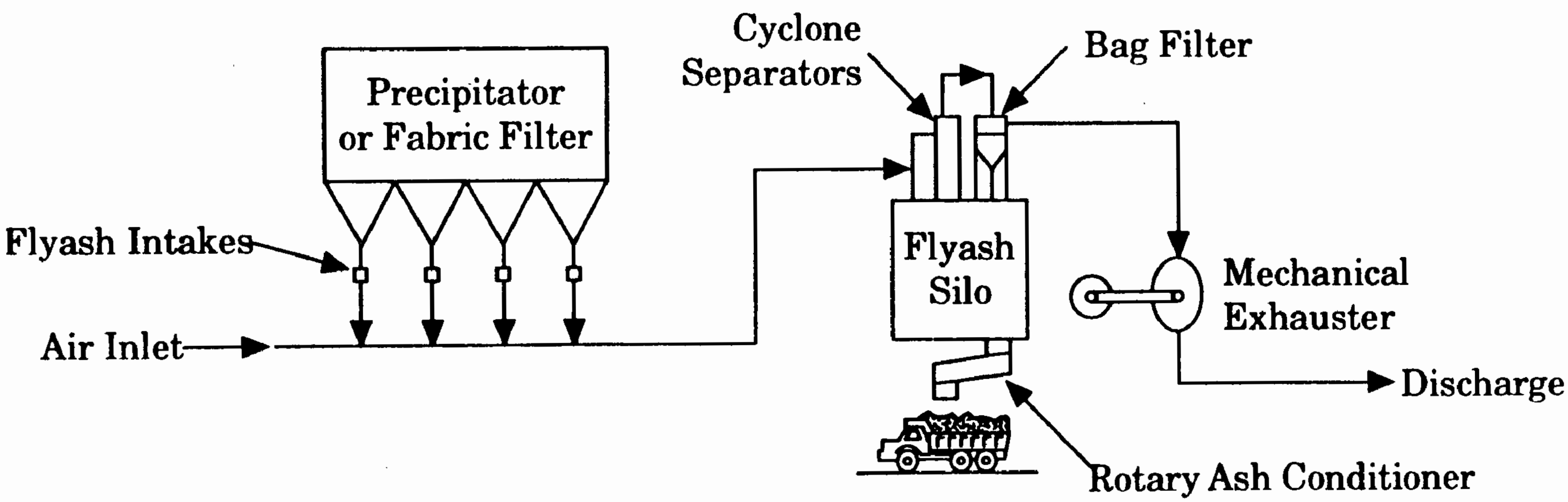
TYPICAL WET BOTTOM ASH SYSTEM[1]



SUBMERGED SCRAPER CONVEYOR FOR BOTTOM ASH[1]

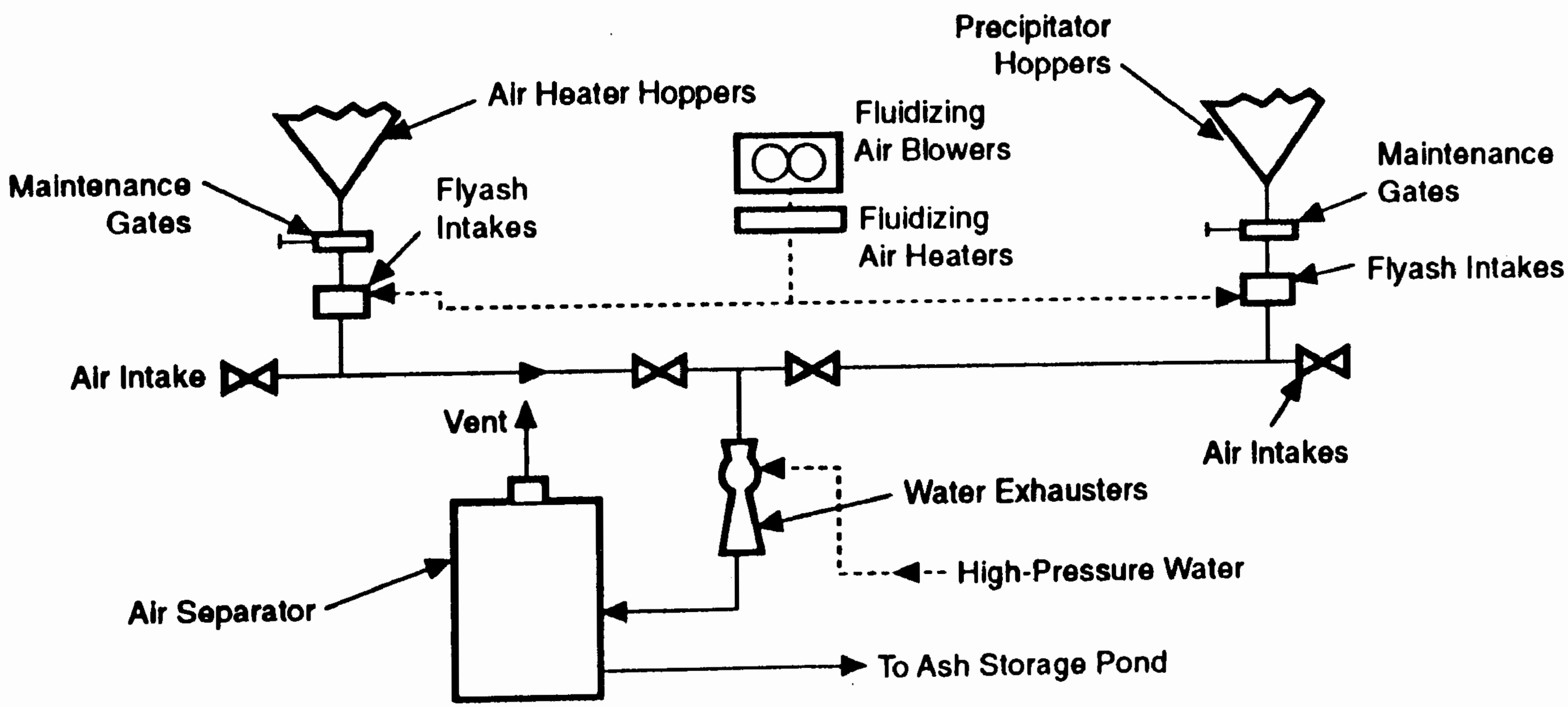


DRY PNEUMATIC VACUUM FLYASH SYSTEM[1]



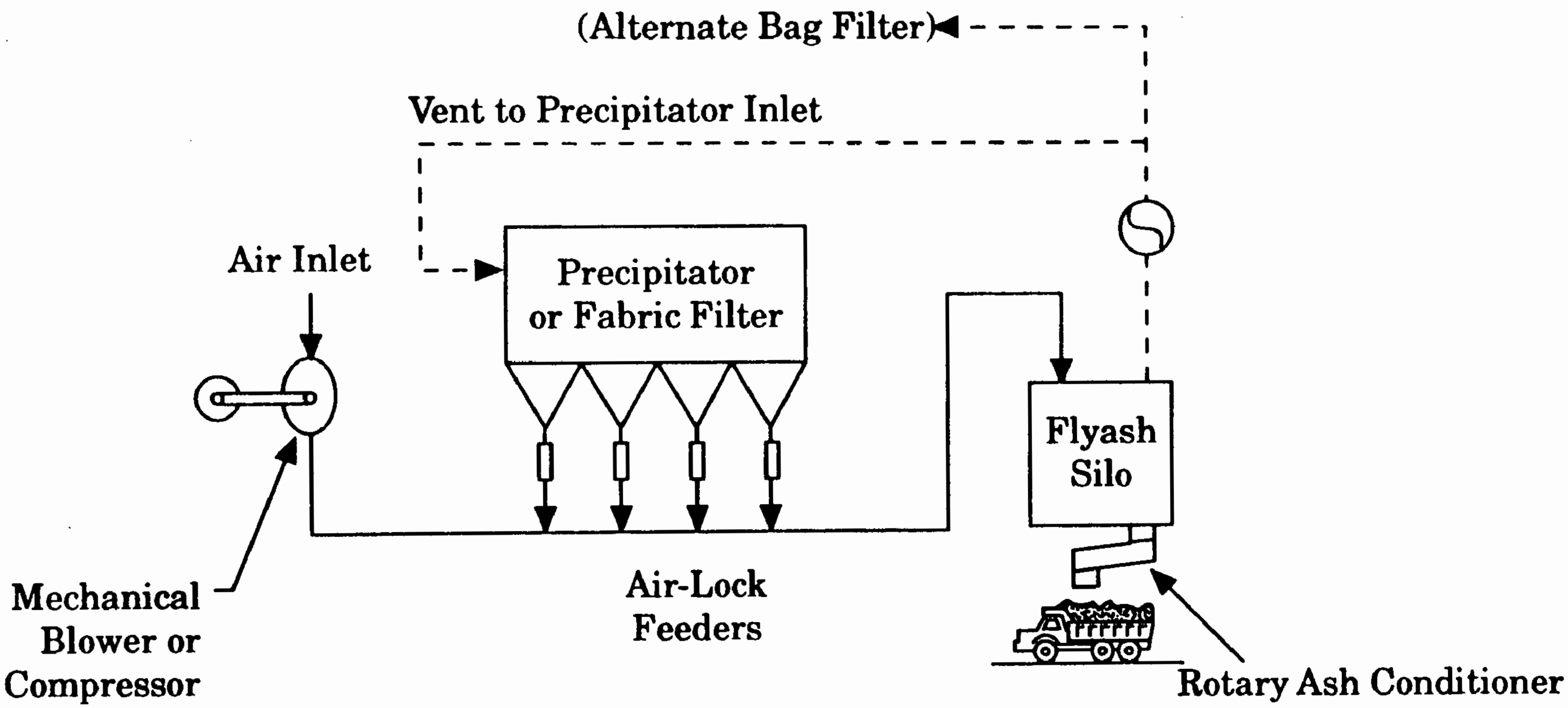
Slide 29 - 8

DRY PNEUMATIC FLYASH TRANSPORT SYSTEM USING WATER EXHAUSTERS AS VACUUM PRODUCERS



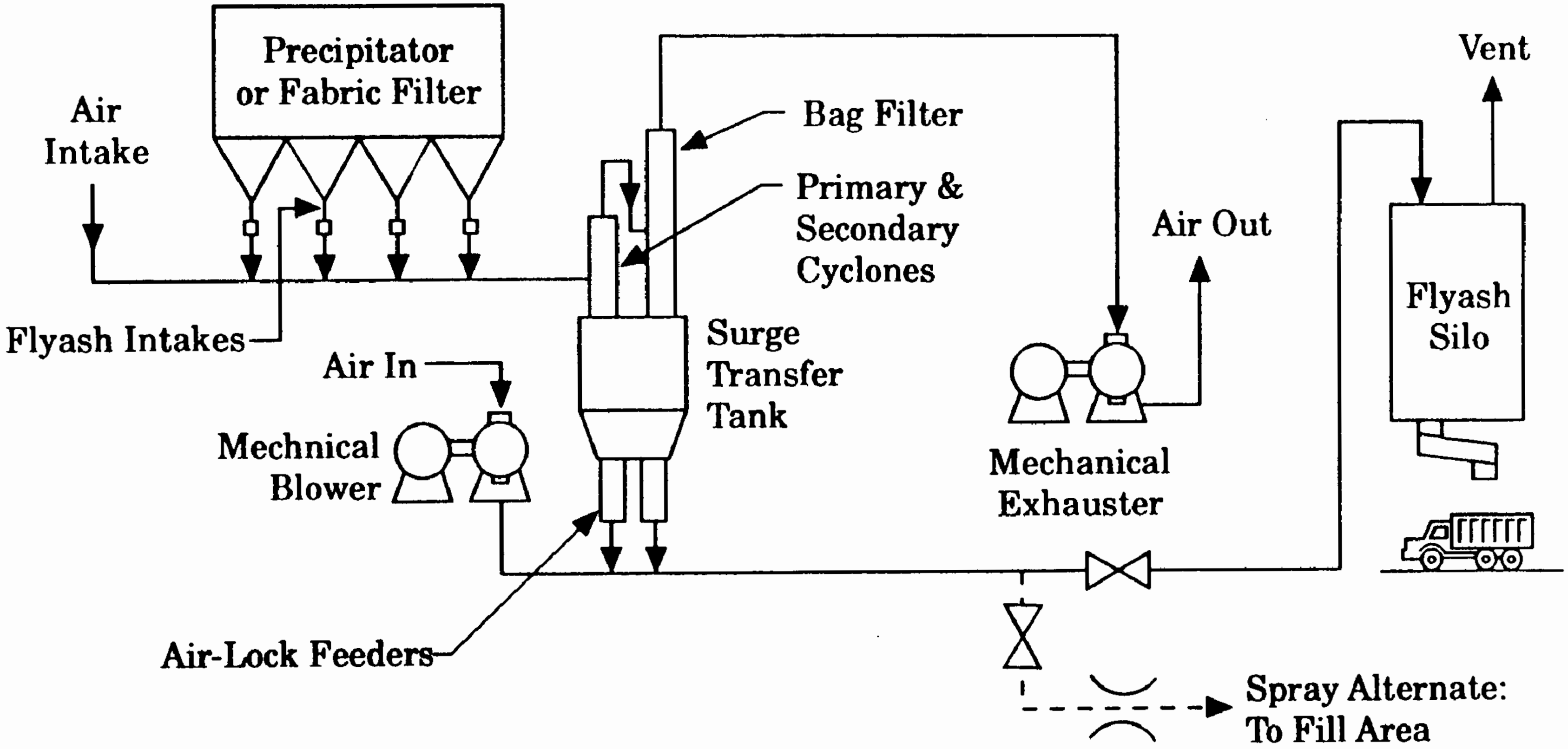
Slide 29 - 9

DRY PNEUMATIC–PRESSURE FLYASH SYSTEM[1]



Slide 29 - 10

VACUUM–TO–PRESSURE DRY PNEUMATIC FLYASH SYSTEM[1]



Slide 29 - 11

ASH CHARACTERIZATION AND TESTING

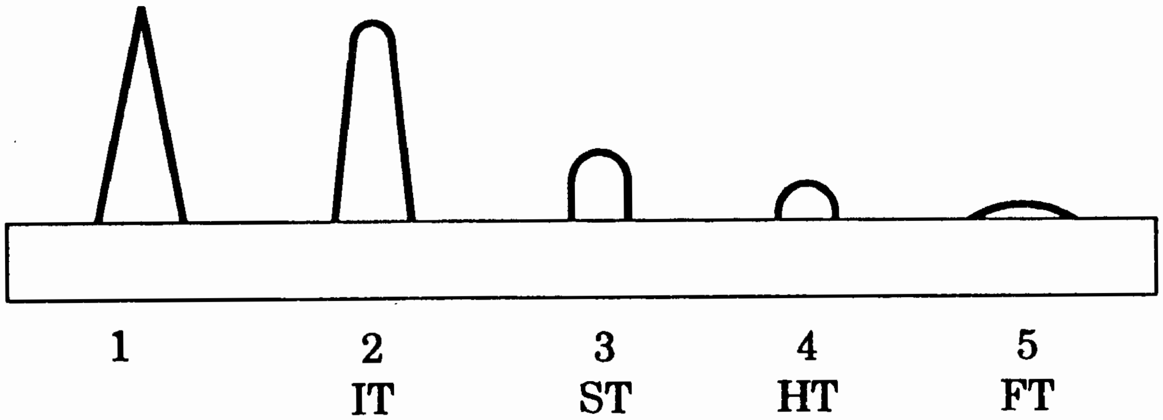
Classification of Coal Ash
Elemental Analysis
Fusion Temperatures
Fuel Oil Ash

EXAMPLE ELEMENTAL ANALYSIS OF COAL ASH

Analysis of ash, % by wt.

SiO_2	46.34
Al_2O_3	33.34
TiO_2	1.24
Fe_2O_3	11.62
CaO	1.76
MgO	1.75
Na_2O	0.25
K_2O	1.27
SO_3	2.08
P_2O_5	0.17
Mn_3O	0.11
Other	0.07
Total	**100.00**

INFLUENCE OF TEMPERATURE ON SPECIFIC ASH SHAPES[1]



1.	Cone before heating
2. IT	Initial deformation temperature
3. ST	Softening temperature (H=W)
4. HT	Hemisherical temperature (H=0.5W)
5. FT	Fluid temperature

FUEL OIL ASH CHARACTERISTICS

Vanadium

Sulfur

Sodium

FLUE GAS DESULFURIZATION WASTES

Wet Scrubbing
- **Wet Sludge**
- **Gypsum**

Dry Scrubbing
- **Dry Sludge**

Sorbent Injection
- **Dry Waste**

FGD WASTE HANDLING

Pneumatic Systems

Hydraulic Systems

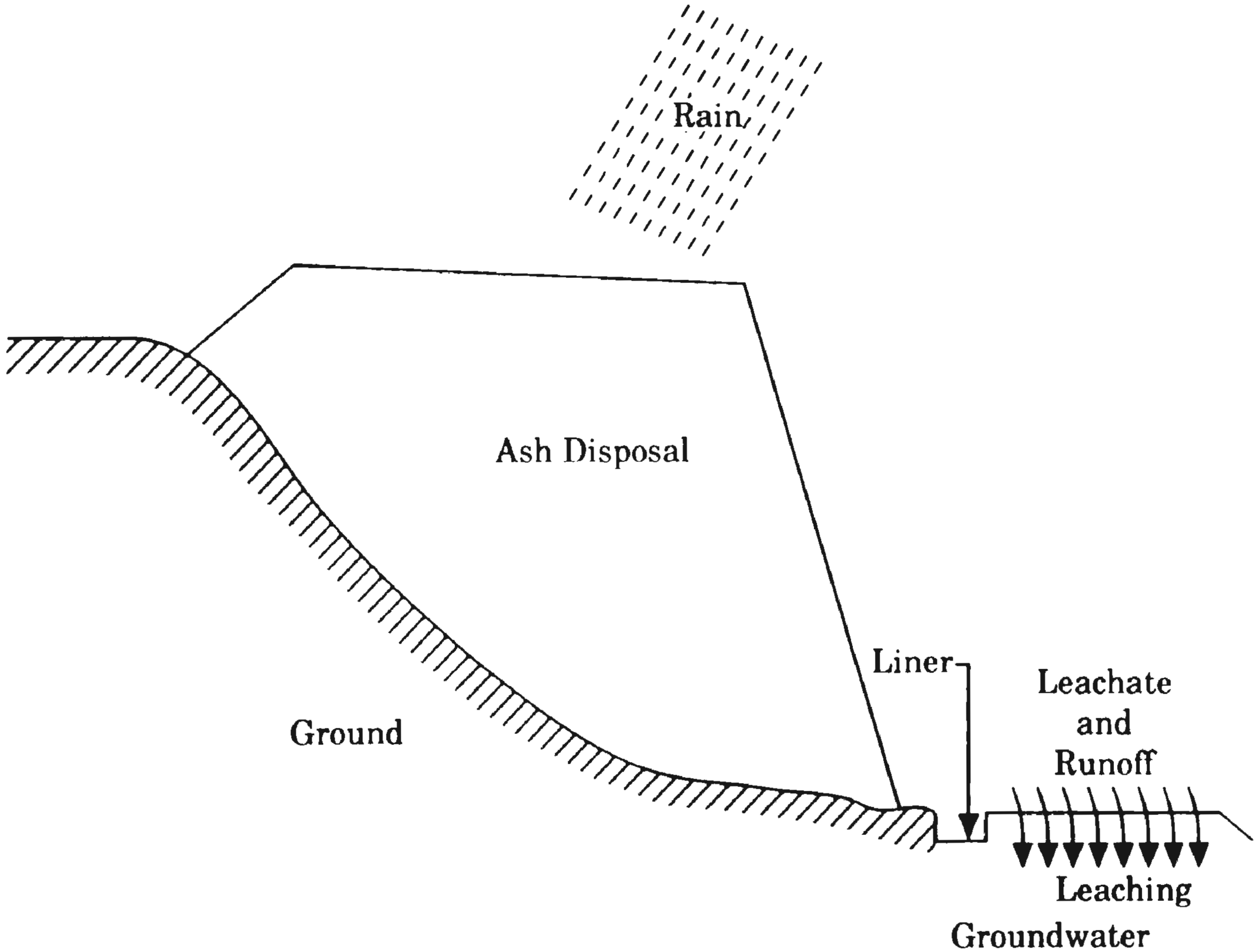
Pipelines

Conveyors, Aerial Trams

Trucks, Off–Road Vehicles

Railroads

GROUNDWATER CONTAMINATION



LESSON PLAN

CHAPTER 30. SOLID WASTE MANAGEMENT

Goal: To present the participant with the methods of solid waste management including disposal, treatment, and utilization of solid wastes from coal burning boiler systems.

Objectives:

Upon completion of this unit an operator should be able to:

1. Discuss wet disposal methods including ponds and reservoirs.
2. Discuss dry disposal methods and landfills.
3. Describe waste treatment methods such as dewatering, stabilizing, and fixating.
4. Discuss possible utilization of solid wastes from boiler operations.

Lesson Time: Approximately 30 minutes.

Suggested Introductory Questions:

What methods of solid waste disposal does your facility use?

Presentation Outline:

30.1 Introduction

30.2 Disposal Methods

30.3 Wet Disposal — Ponds
A. Pond Configurations
B. Pond Design

30.4 Dry Disposal — Landfills
A. Landfill Configurations
B. Landfill Design

30.5 Treatment Methods

Presentation Outline (Continue):

30.6 Dewatering
- A. Settling Ponds
- B. Dewatering Bins
- C. Thickeners
- D. Cyclones
- E. Centrifuges
- F. Vacuum Filters

30.7 Stabilization

30.8 Fixation

30.9 Utilization
- A. Ash Utilization
- B. FGD By–Product Utilization
- C. Site Utilization

CHAPTER 30. SOLID WASTE MANAGEMENT

SOLID WASTE MANAGEMENT

Disposal

Treatment

Utilization

DISPOSAL METHODS

Wet Disposal

Ponds or Reservoirs

Dry Disposal

Landfills

POND CONFIGURATIONS

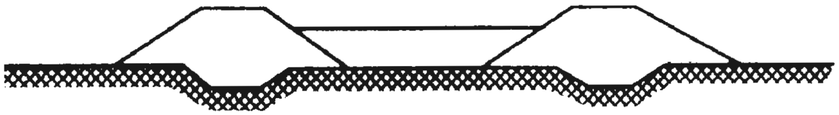
Diked Disposal Ponds

Incised Disposal Ponds

Sidehill Disposal Ponds

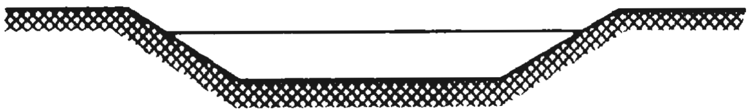
Cross–Valley Disposal Ponds

GRAPHICAL ILLUSTRATION OF POND CONFIGURATIONS[1]

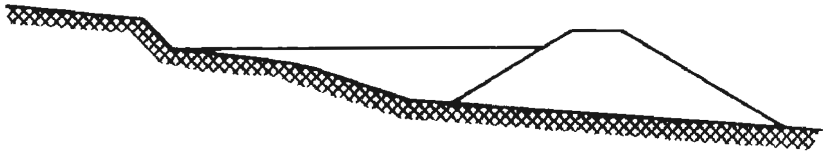


Diked pond constructed above grade.

Diked pond partially excavated below grade.



An incised disposal pond.



A sidehill disposal pond.

A cross-valley pond configuration.

LANDFILL CONFIGURATIONS

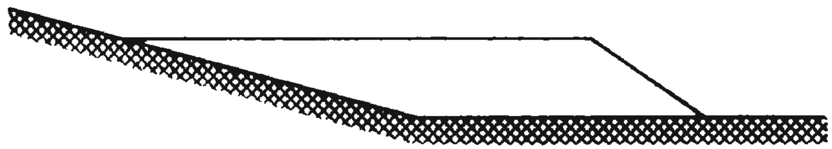
Heaped Landfill Configuration

Sidehill Landfill Configuration

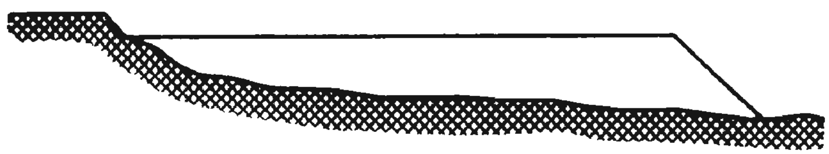
Valley–Fill Disposal Configuration

GRAPHICAL ILLUSTRATION OF LANDFILL CONFIGURATIONS[1]

A heaped landfill configuration.



A sidehill landfill.



A valley-fill disposal configuration.

WASTE TREATMENT METHODS

Dewatering

Stabilizing

Fixating

DEWATERING METHODS

Settling Ponds

Dewatering Bins

Thickeners

Cyclones

Centrifuges

Vacuum Filters

SELLING PONDS

Range of Solid Concentrations
- 10–50% FGD Slurry
- 20–70% Ash

Advantages
- Simple Operation
- Not Sensitive to Inlet Solid Content
- Low Maintenance Costs
- High Reliability

Disadvantages
- Substantial Land Area
- Unpopular with Regulatory Agencies
- Solid Removal Difficult

DEWATERING BINS

Range of Solid Concentrations
- 15–25% FGD Slurry
- 25–75% Ash

Advantages
- Reduced Land Area
- Relatively Simple Maintenance
- Clear Water Produced
- Attractive First–Stage Treatment

Disadvantages
- Low Slurry Product Solids
- Sensitive to Inflow Characteristics
- New Technology
- Complicated Operation Controls

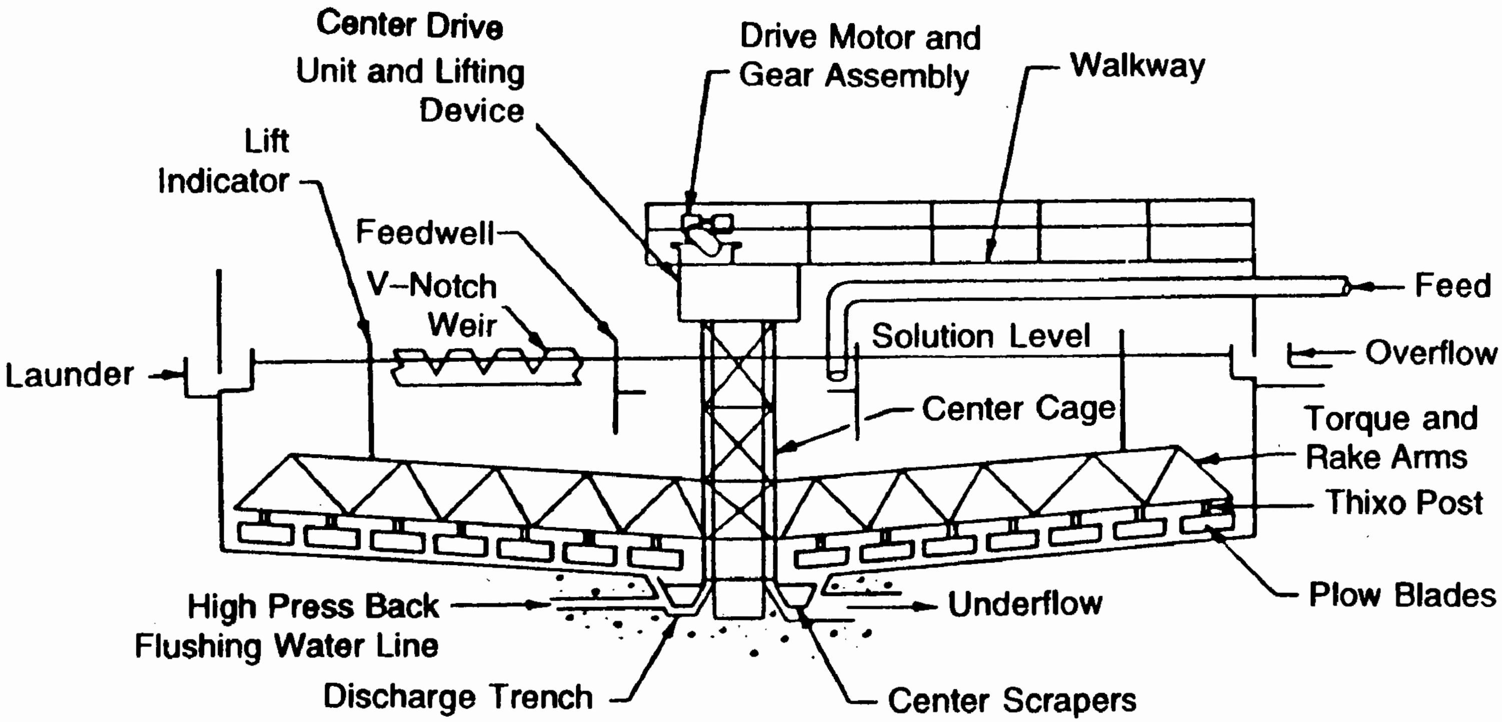
THICKENERS

Range of Solid Concentrations
- 20–45% FGD Slurry

Advantages
- Reduced Land Area
- High Throughput Rates
- Established Technology

Disadvantages
- Higher Capital Cost
- Higher Maintenance Cost
- More Complicated Operation

A CONVENTIONAL GRAVITY THICKENER



Slide 30 - 13

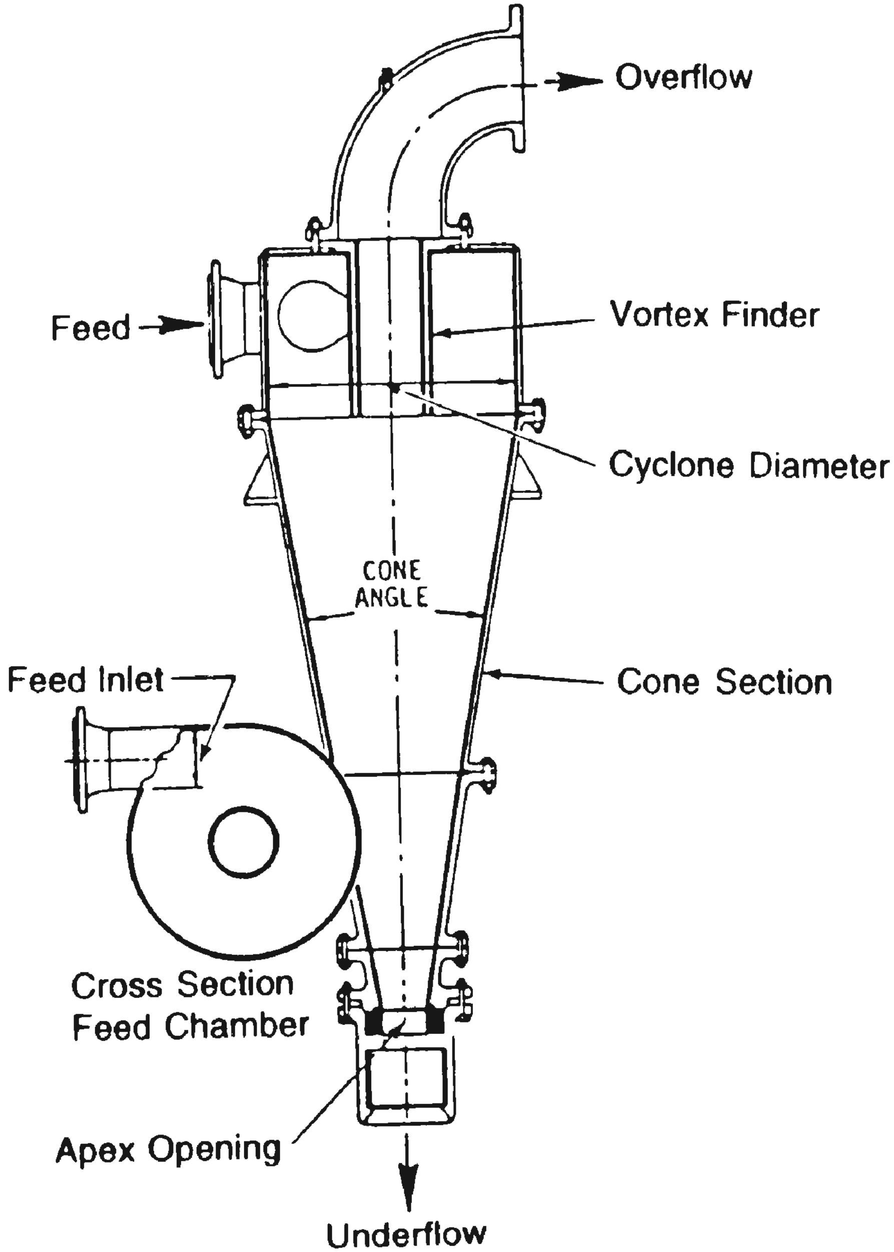
CYCLONES

Range of Solid Concentrations
- 35–65% FGD Slurry

Advantages
- Low Space Requirements
- Relatively Low Cost
- Recover high Portion of Large Particles
- Low Solid Content in Liquid Fraction

Disadvantages
- Do Not Recover Fine Particles
- Inefficient with Feeds over 15% Solids
- Susceptible to Abrasion and Corrosion
- High Liquid Content in Solid Fraction

A CYCLONE[3]


Overflow
Feed
Vortex Finder
Cyclone Diameter
CONE ANGLE
Feed Inlet
Cone Section
Cross Section
Feed Chamber
Apex Opening
Underflow

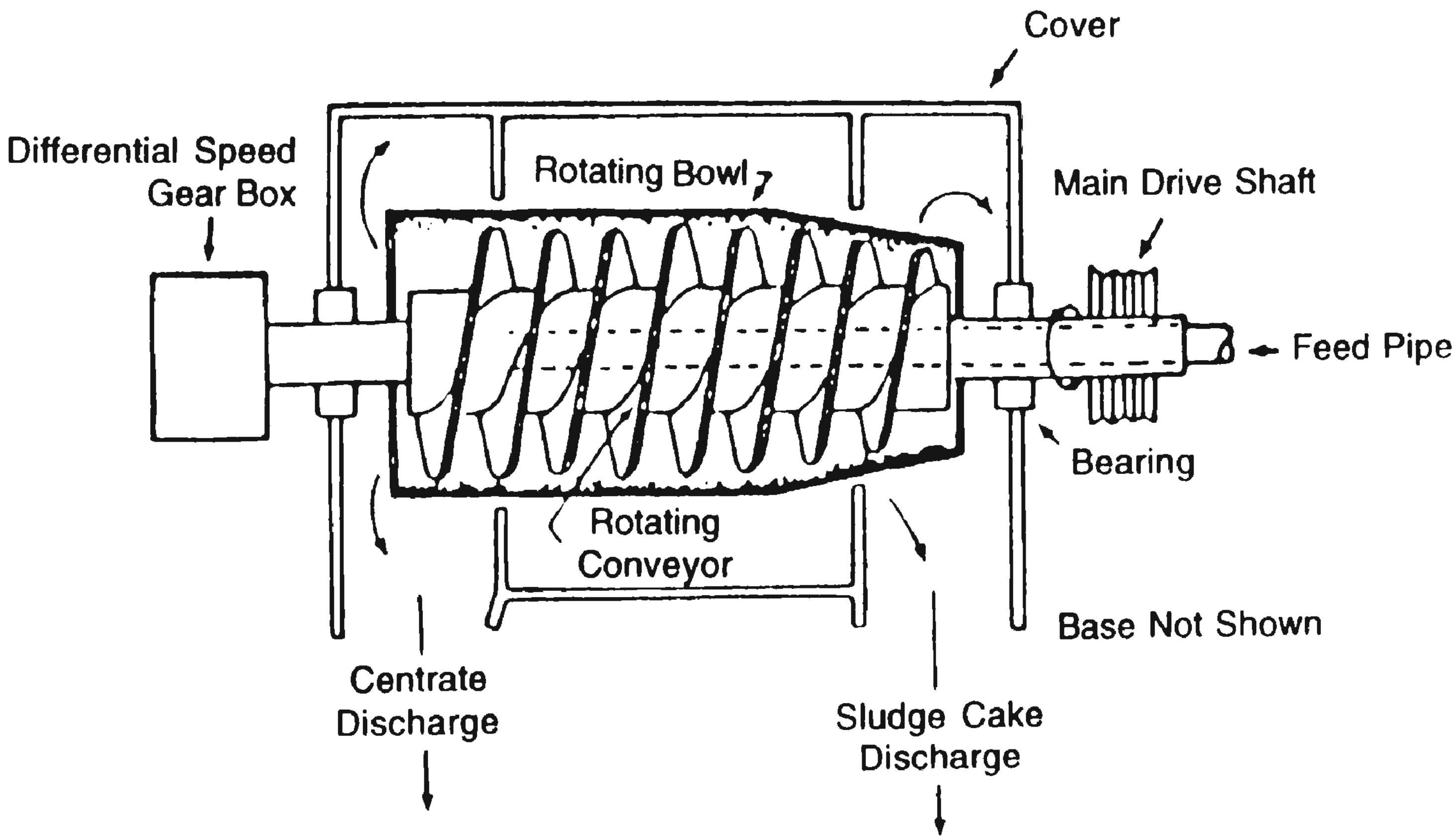
CENTRIFUGES

Range of Solid Concentrations
- 40–65% FGD Slurry

Advantages
- Low Space Requirements
- Accept Variation in Inflow
- High Product Solid Content
- Established Technology

Disadvantages
- Do Not Produce Clear Liquid
- High Cost
- High Maintenance
- Subject to Abrasion and Corrosion

A SOLID–BOWL CENTRIFUGE[3]



Slide 30 - 17

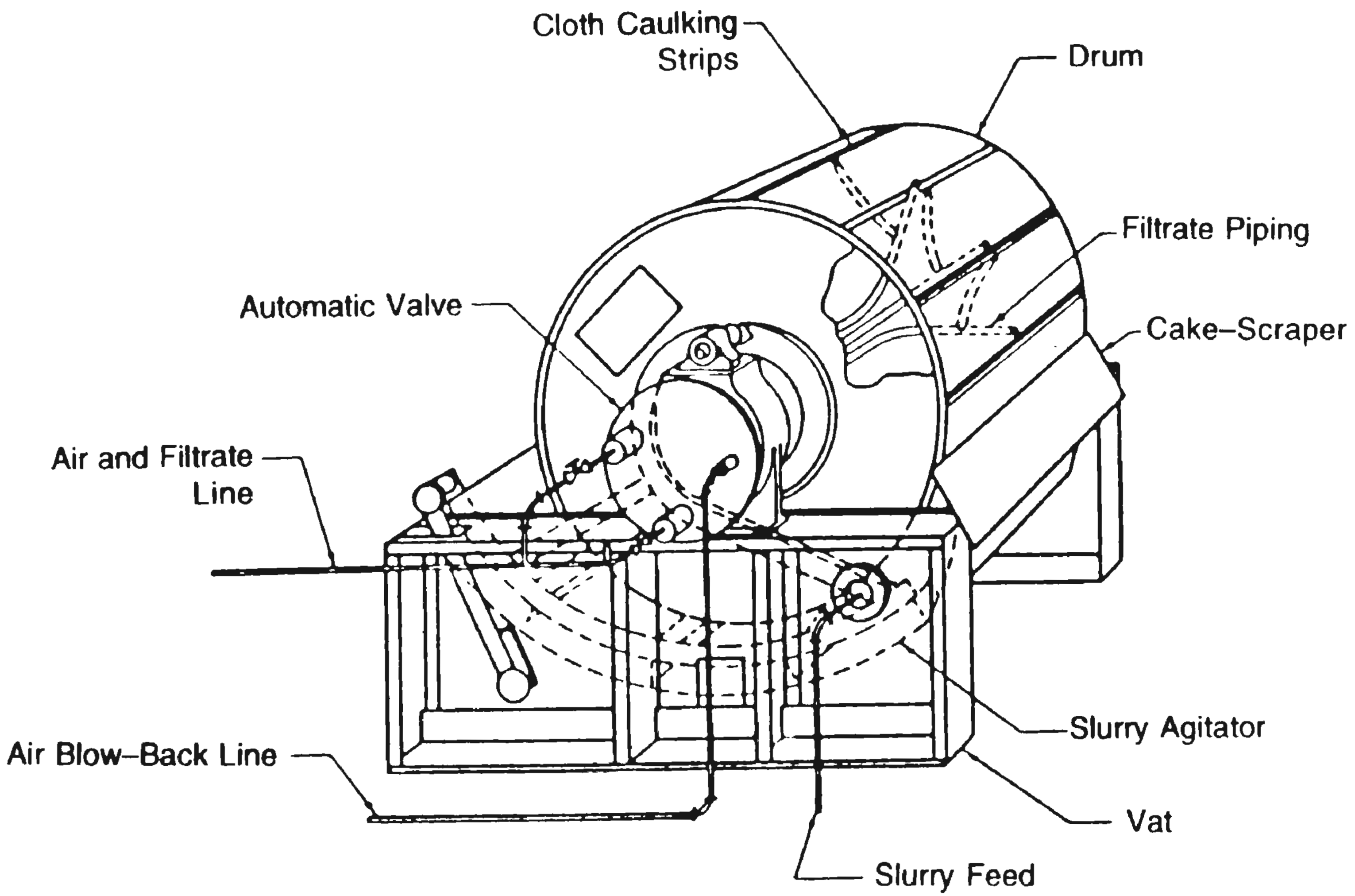
VACUUM FILTERS

Range of Solid Concentrations
- 35–65% FGD Slurry
- 60–75% Ash

Advantages
- Low Space Requirements
- High Products Solid Content
- Consistent Product Quality

Disadvantages
- High Cost
- High Maintenance
- Complicated Operation
- Do Not Produce Clear Liquid

A ROTARY DRUM VACUUM FILTER[3]



Slide 30 - 19

STABILIZATION

- Addition of Dry Solids
- Increase Shear Strength
- Lower Permeability
- Lower Volume
- Can Be Rewetted

FIXATION

Mixing with Alkaline Flyash

Mixing with Lime and Flyash

Mixing with Blast Furnace Slag

Mixing with Portland Cement

UTILIZATION

Ash Utilization
- Cement Manufacturing
- Concrete Materials
- Substituted for Sand or Gravel

FGD By–Product Utilization
- Agriculture
- Metals Recovery
- Sulfur Recovery
- Gypsum

Site Utilization
- Landfill Construction Material

BOILER OPERATOR TRAINING
POST-TEST

Instructions The entire test is to be taken as a closed book test.
Write in your answer or circle the best answer on this sheet.

1. Identify which of the following that is not a fossil fuel boiler design.
   a. fluidized bed
   b. watertube
   c. stoker
   d. firetube
   e. carnot

2. The fuel delivery system for a fossil fuel boiler
   a. only delivers fuel to the burners
   b. prepares fuel for combustion
   c. prepares fuel for combustion and transports it to the steam generator
   d. transports steam to the steam turbines.

3. Name three air pollutants of concern generated by fossil fuel fired boilers.
   a. ________________
   b. ________________
   c. ________________

4. When steam pressure reaches the MAWP, the boiler
   a. may burst or explode.
   b. steam pressure is at the highest level allowable for safe operation.
   c. will produce steam that is too hot.
   d. will not produce steam at all.

5. The proper order for the convective pass components in a utility boiler from the furnace section to the stack is
   a. Superheater, reheater, economizer, air heater.
   b. Reheater, superheater, air heater, economizer.
   c. Superheater, reheater, air heater, economizer.
   d. Reheater, superheater, economizer, air heater.

6. Radiant heat transfer predominantly occurs in the ________ of a watertube boiler.
   a. reheater
   b. convective pass section
   c. stack
   d. furnace section

7. A rich fuel mixture will produce an oxidizing flame.

   T
   F

8. Which of the following is not a balanced combustion equation?

a. 1 mol C + 1 mol O_2 -------> 2 mol CO_2

b. 12 lb C + 32 lb O_2 -------> 44 lb CO_2

c. 1 ft3 C + 1 ft3 O_2 -------> 1 ft3 CO_2

d. 1 molecule C + 1 molecule O_2 -------> 1 molecule CO_2

9. Correct the concentration measurement of CO at 100 ppm to the standard dilution rate of 3% excess O_2, given the measurement was made with an actual excess O_2 concentration of 9%. ________

10. Which item is not included in a coal proximate analysis.

a. volatile matter.

b. sulfur content.

c. heating value.

d. ash content.

11. What is the density of a fuel oil at 32 F if its specific gravity is 0.742, given that the density of water is 8.328 lb/gal at 60 F and 8.335 lb/gal at 32 F? _____ lb/gal

12. Which of the following is never a part of the fuel preparation and delivery system for oil fired boilers?

a. heating

b. steam atomization

c. mechanical atomization

d. pulverization

13. The low gas pressure switch in a natural gas fuel system is also known as a vaporstat

T

F

14. Why are lignite coals which are very soft and anthracite which is very hard, both very difficult to grind? ____

____

____

15. The two general types of stoker boiler are the ______ stoker and the ______ stoker.

a. overfeed, underfeed

b. massfeed, tuyere feed

c. spreader, pulverized coal

d. none of the above.

16 Natural gas combustion can never produce soot or black smoke. Even when operated with insufficient oxygen or incomplete combustion.

T

F

17 O_2. SO_2. and CO are used to measure the efficiency of the combustion process and the thermal heat transfer between the hot flue gasses and the steam

T
F

18. Stoker boilers are uniquely different from pulverized coal burners in that the fuel particle size is ______ for stokers.
a. smaller
b. much smaller
c. larger
d. much larger

19. A "D" style package boiler is a watertube boiler.

T
F

20. Gas turbines are comprised of three major components. The air is drawn into the _______ before being mixed with fuel in the _________. Energy is extracted from the hot gas stream by the axial flow _______ in the form of shaft horsepower.

21. The primary mechanism for NOx formation in gas turbines is
a. prompt NO_x.
b. fuel bound Nitrogen.
c. thermal NO_x.
d. none of the above.

22. Use Ohm's law to determine the current through a device with a resistance of 8 ohms when a voltage of 24 volts is applied. The current would be ____.
a. 3 amps
b. 0.67 amps
c. 1.50 amps
d. 36 amps

23. Using the above information, what is the power consumed by the device?
a. 36 watts
b. 24 watts
c. 10.67 watts
d. 72 watts

24. A two element control system can be configured into either a feed forward type control system or a cascade type control system.

T
F

25. Most pressure gauges are of the _____ tube type
   a. Bourdon
   b. thermo-
   c. straight
   d. "a" and "c" above.

26. When a restriction such as an orifice. or a venturi is placed in the flow stream in an enclosed duct or pipeline, the restriction will create a pressure drop in the line that is linearly proportional to the velocity.

   T
   F

27. Exposure to low levels of carbon monoxide over an extended period of time is not as dangerous as exposure to high levels of carbon monoxide for a short period of time.

   T
   F

28. During turbine generator start-up the turbine metal temperature will rise to the temperature of the steam supplied by the boiler. The turbine casing must be warmed very slowly and carefully to avoid _______.
   a. motoring
   b. thermal expansion
   c. excessive steam pressure
   d. severe thermal stress

29. Critical turbine speed is the optimum speed for low turbine maintenance and long life.

   T
   F

30. The power factor is

   a. the cosine of the phase angle difference between the voltage and current.
   b. the ratio of the real power to the apparent power.
   c. current times voltage
   d. "a" and "b" above.

31. MSDSs should only be available to supervisors and managers.

   T
   F

32. Examples of primary air pollutants are
   a. particulate matter, sulfur dioxide and hydrocarbons
   b. photochemical oxidants and sulfates
   c. hazardous metals and hazardous organics
   d all of the above.

33 Nitrogen oxides result from the combustion of all fossil fuels

T
F

34. Monitoring systems are categorized as either ______ or _______ CEMS according to the location of the detection device used and the mean by which sample gas is delivered to the analyzers.

35. Two levels of emission controls have been established for hazardous air pollutants. These are?
a. LAER and BACT
b. RACT and BACT
c. MACT and GACT
d. BACT and GACT

36. Electrostatic precipitators are less efficient at removing fine particulate than cyclones.

T
F

37. NO_x emissions typically decrease as a function of increasing excess combustion air.

T
F

38. Which of the following is not a particulate control device?
a. Cyclone
b. Electrostatic precipitator
c. Wet scrubber
d. SCR device

39. Name three species or parameters typically analyzed in utility and industrial boiler CEMSs.
a. ______________.
b. ______________.
c. ______________.

40. Combustion of chemically-bound nitrogen in the fuel can form
a. Fuel NO_x
b. Thermal NO_x
c. Prompt NO_x
d. Both "a" and "c"

41. Three techniques to reduce NO_x in fossil fuel fired boilers are

a. ______________.
b. ______________.
c. ______________.

42. Two techniques to control SO_x emissions are

a ______________.

b. ______________.

43. Suspended solids can be removed from waste water streams by

a. blowdown.
b. agitation.
c. clarification.
d. neutralization.

44. Wet scrubbing technologies use a _____ based scrubbing slurry.

a. limestone
b. ammonia
c. ash

45. Sunlight is an agent available for dechlorination of water and waste water.

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46. A properly operating in situ monitor indicates 150 ppm of SO_2 in the flue gas, and the moisture in the flue gas is known to be 12%. If and extractive instrument which has and in-line dryer indicated 190 ppm of SO_2, then

a the two instruments are reading consistently.
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47. Two advantages of fluidized-bed combustion is that the system can be operated at low combustion temperatures, and higher heat transfer rates from the fuel to the watertubes can be achieved.

T
F

48. The Clean Air Act

a. allows the states to establish boiler emissions regulations that are more strict than the federal standards.
b. prohibits the states from having emissions regulations that are more strict than the federal standard.
c. instructs the USEPA to set boiler emission standards which correspond to the maximum degree of control possible.
d. does not allow the consideration of economics in the setting of new source performance standards.

49 Adding dry solids to waste slurry to increase the solids content of the product is

a. dewatering
b. stabilizing
c. fixating
d. neutralizing

50. High ash fusion temperatures will generally indicate low slagging potential.

T
F

BOILER OPERATOR TRAINING
POST-TEST
Answer Key

1 Identify which of the following that is not a fossil fuel boiler design.
   a. fluidized bed
   b. watertube
   c. stoker
   d. firetube
   e. carnot

2. The fuel delivery system for a fossil fuel boiler
   a. only delivers fuel to the burners
   b. prepares fuel for combustion
   c. prepares fuel for combustion and transports it to the steam generator
   d. transports steam to the steam turbines.

3. Name three air pollutants of concern generated by fossil fuel fired boilers.
   a. ***nitrogen oxides*** ***carbon monoxide***
   b. ***sulfur oxides*** ***particulate matter***
   c. ***hydrocarbons***

4. When steam pressure reaches the MAWP, the boiler
   a. may burst or explode.
   b. steam pressure is at the highest level allowable for safe operation.
   c. will produce steam that is too hot.
   d. will not produce steam at all.

5. The proper order for the convective pass components in a utility boiler from the furnace section to the stack is
   a. Superheater, reheater, economizer, air heater.
   b. Reheater, superheater, air heater. economizer.
   c. Superheater, reheater, air heater. economizer.
   d. Reheater, superheater, economizer, air heater.

6. Radiant heat transfer predominantly occurs in the ________ of a watertube boiler.
   a. reheater
   b. convective pass section
   c. stack
   d. furnace section

7. A rich fuel mixture will produce an oxidizing flame.

   False

8. Which of the following is not a balanced combustion equation?

a.	***1 mol C + 1 mol O_2***	***------->***	***2 mol CO_2***
b.	12 lb C + 32 lb O_2	------->	44 lb CO_2
c.	1 ft3 C + 1 ft3 O_2	------->	1 ft3 CO_2
d.	1 molecule C + 1 molecule O_2	------->	1 molecule CO_2

9. Correct the concentration measurement of CO at 100 ppm to the standard dilution rate of 3% excess O_2, given the measurement was made with an actual excess O_2 concentration of 9%. ***150 ppm***

10. Which item is not included in a coal proximate analysis.
    - a. volatile matter.
    - ***b. sulfur content.***
    - c. heating value.
    - d. ash content.

11. What is the density of a fuel oil at 32 F if its specific gravity is 0.742, given that the density of water is 8.328 lb/gal at 60 F and 8.335 lb/gal at 32 F? ***6.18*** lb/gal

12. Which of the following is never a part of the fuel preparation and delivery system for oil fired boilers?
    - a. heating
    - b. steam atomization
    - c. mechanical atomization
    - ***d. pulverization***

13. The low gas pressure switch in a natural gas fuel system is also known as a vaporstat.

    True

14. Why are lignite coals which are very soft and anthracite which is very hard, both very difficult to grind? ***Anthracite is difficult to grind because it is very hard, however lignite typically has a very high moisture content causing it to have a high tendency for agglomeration and making it difficult to process through grinding equipment.***

15. The two general types of stoker boiler are the ______ stoker and the ______ stoker.
    - ***a. overfeed, underfeed***
    - b. massfeed, tuyere feed
    - c. spreader, pulverized coal
    - d. none of the above.

16 Natural gas combustion can never produce soot or black smoke. Even when operated with insufficient oxygen or incomplete combustion.

    False

17 O_2, SO_2, and CO are used to measure the efficiency of the combustion process and the thermal heat transfer between the hot flue gasses and the steam

False

18. Stoker boilers are uniquely different from pulverized coal burners in that the fuel particle size is ______ for stokers.
   a. smaller
   b. much smaller
   c. larger
   d. much larger

19. A "D" style package boiler is a watertube boiler.

True

20. Gas turbines are comprised of three major components. The air is drawn into the ***compressor*** before being mixed with fuel in the ***combustor***. Energy is extracted from the hot gas stream by the axial flow ***turbine*** in the form of shaft horsepower.

21. The primary mechanism for NOx formation in gas turbines is
   a. prompt NO_x.
   b. fuel bound Nitrogen.
   c. thermal NO_x.
   d. none of the above.

22 Use Ohm's law to determine the current through a device with a resistance of 8 ohms when a voltage of 24 volts is applied. The current would be ____.
   a. 3 amps
   b. 0.67 amps
   c. 1.50 amps
   d. 36 amps

23. Using the above information, what is the power consumed by the device?
   a. 36 watts
   b. 24 watts
   c. 10.67 watts
   d. 72 watts

24. A two element control system can be configured into either a feed forward type control system or a cascade type control system.

True

25 Most pressure gauges are of the _____ tube type

a. ***Bourdon***

b. thermo-

c. straight

d. "a" and "c" above

26. When a restriction such as an orifice, or a venturi is placed in the flow stream in an enclosed duct or pipeline, the restriction will create a pressure drop in the line that is linearly proportional to the velocity.

False

27. Exposure to low levels of carbon monoxide over an extended period of time is not as dangerous as exposure to high levels of carbon monoxide for a short period of time.

False

28. During turbine generator start-up the turbine metal temperature will rise to the temperature of the steam supplied by the boiler. The turbine casing must be warmed very slowly and carefully to avoid _______.

a. motoring

b. thermal expansion

c. excessive steam pressure

d. severe thermal stress

29. Critical turbine speed is the optimum speed for low turbine maintenance and long life.

False

30. The power factor is

a. the cosine of the phase angle difference between the voltage and current.

b. the ratio of the real power to the apparent power.

c. current times voltage

d. "a" and "b" above.

31. MSDSs should only be available to supervisors and managers.

False

32. Examples of primary air pollutants are

a. particulate matter, sulfur dioxide and hydrocarbons

b. photochemical oxidants and sulfates

c. hazardous metals and hazardous organics

d all of the above.

33. Nitrogen oxides result from the combustion of all fossil fuels.

True

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    d. ***oxygen.***
    e. ***carbon dioxide.***
    f. ***opacity.***

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    b. Thermal NO_x
    c. Prompt NO_x
    d. Both "a" and "c"

41. Three techniques to reduce NO_x in fossil fuel fired boilers are
    a. ***low NOx burners***
    b. ***low excess air operation***
    c. ***reduced air preheat***
    d. ***reburning***
    e. ***burners out of service operation***
    f. ***flue gas recirculation***
    g. ***overfire air***
    h. ***selective catalytic reduction***
    i. ***selective non-catalytic reduction***

42. Two techniques to control SO_x emissions are

    a. ***wet scrubbing.***
    b. ***dry scrubbing.***
    c. ***furnace injection.***

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16. ABSTRACT

This Instructor's Guide is part of a model State training program which addresses the training needs of high capacity fossil-fuel fired plant (boiler) operators. Included are generic equipment design features, combustion control relationships, and operating and maintenance procedures which are designed to be consistent with the purposes of the Clean Air Act Amendments of 1990. This training program is not designed to replace the site-specific, on-the-job training programs which are crucial to proper operation and maintenance of boilers.

The Instructor's Guide provides the basic materials for use by the course instructor. It presents the course description and agenda, course goals, lesson plans, and pretest and post-test materials.

17. KEY WORDS AND DOCUMENT ANALYSIS

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