Course Overview

- Air Pollution  Why
- Boiler Uses  What
- Boiler Theory and Operation
- Air Pollution Formation
- Air Pollution Control Devices
- Boiler Regulations  How
- Typical Permit Conditions
- Inspection Procedures
Uses of Boilers

- Electrical generation
- Space heating
- Food preparation
- Commercial laundries
- Pulp & paper industry
- Petroleum industry
- Chemical industry
- Municipalities: Water, Sewage & Garbage

High Pressure (2,000 - 3,800 psi)
Low Pressure (150 – 1,600 psi)
Hot Numbers

♦ British Thermal Unit (BTU)
  ♦ 1 BTU the amount of energy needed to heat one pound of water one degree Fahrenheit or ~ energy given off by burning one wooden match

♦ Lower Heating Value (LHV)
  ♦ Heating value of a fuel not counting heat needed to vaporize water

♦ Higher Heating Value (HHV)
  ♦ Heating value of a fuel including heat needed to vaporize water
Typical Boiler Rating

Boiler Fuels

- Natural gas
- Diesel fuel oils
- Tire Derived Fuel (TDF)
- Coal/Petroleum Coke
- Municipal waste
- Bio-Mass
- Waste gas
- Nuclear
Steam Plant Basic Elements

Heat Transfer Methods

CONVECTION
HOT GASES
TRANSFER HEAT
TO THE TUBE

RADIATION
HEAT TRANSFER
THRU SPACE

CONDUCTION
HEAT TRANSFER
THRU THE
METAL TUBE WALL
Let’s Discuss Firetube & Watertube Boilers
Water-Tube Boiler

Boiler Construction

Graphics Courtesy of ERI
Water to Steam Circulation Loop

Boilers

Steam Drum

Risers

Upper Headers

Downcomer

Tubes

Lower Headers

Feeder

Feeder Manifold
Natural Circulation

- Water
- Steam & Water
- Saturated Steam

Forced Circulation

- Saturated Steam
- Steam & Water
- Water
- TEG Flow
Let’s Discuss Boiler Air Requirements

Boiler Air Requirements

- Draft
  - Natural
  - Forced
  - Induced
- Combustion air
  - Primary
  - Secondary
  - Excess
Induced Draft Fans

Gas Fired Water Tube Boiler
Let’s Discuss Economizers & Air-Preheaters

Economizer – H₂O Inside Tubes
Air Pre-Heater: Ambient to 400°F +
Boiler Tubes

Let's Discuss Fluidized Bed Boilers
Fluidized Bed Modes

- Start No Air Flow
- Fixed Bed
- Minimum Fluidization
- Bubbling Bed
- Circulating Bed

Circulating Fluidized Bed (CFB)
Circulating Fluidized Bed Boiler

Interactive Exercise

1. Steam Drum
2. Primary Air
3. Secondary Air
4. Economizer
5. Startup Burner
6. Forced Draft Fan
7. Superheater
8. Multi-cyclone
9. Furnace
10. Air Heater
Fluidized Bed
Distributor Plate & Bubble Caps

Graphic Courtesy of B&W

Enclosed Conveyors

Feed Lot
Fuel Storage Silo

Enclosed Conveyor

Water to Steam Loop
NACT Industrial Boilers #273

Furnace
Superheater
Economizer
Air Preheater

Pulverized Coal Lines: Gravity Fed
Distributor Plates & Bubble Caps
High Pressure Steam Drums

Steam Drum w/Cyclone & Chevron Separators
Circulating Fluidized Bed Boiler

Interactive Exercise

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Circulating Fluidized Bed Boiler

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Let’s Discuss Power Generation

High Pressure Steam Lines
Typical Control Room

Utility Boiler

Steam Turbine
HP Steam Turbine

Generator

Steam Turbine
Step-Up Transformers

Typical Electric Utility Plant

Stack
Boiler
Steam turbine
Condenser
Fuel
Deaerator
HP Feedwater Heaters
LP Feedwater Heaters
Pump
Cooling Media
Let’s Discuss Emissions & Controls

Emissions From Boilers

Fuel + Air (N₂, O₂)

- H₂O
- CO₂
- CO
- NOₓ
- HC
- SOₓ
- PM
- CHO
Emissions Control Methods

- Boiler design
- Proper maintenance
- Operating conditions
- Fuel types
- Combustion modifications
- Exhaust treatment

Control of Gaseous Emissions

- Low-NOx burners
- OFA
- Ammonia injection (SNCR)
- Catalysts (SCR)
- FGR
- FGD
Combustion Considerations

- Time
- Temperature
- Turbulence
- Oxygen
- Nitrogen

NOx Creation

- Thermal NOx
- Fuel-bound NOx
- Prompt NOx
Thermal NOx vs. Temperature

Graphic Courtesy of Coen

NOx FORMATION

N + O → NO
N + OH → NO + H

NOx REDUCTION

CH + NO → HCN + O2 (Reversible)
CH2 + NO → HCN + OH (Reversible)
C + NO → CN + O2
NH2 + NO → N2 + H2O

THESE NOx REDUCTANTS ARE FORMED BY PARTIAL COMBUSTION IN A REDUCING ATMOSPHERE.
THE INTERMEDIATE SPECIES, HCN & CN, ARE CONVERTED TO N2, CO2 & H2O IN THE FINAL BURNOUT ZONE.
PROMPT NOx

- Rapid Formation <1ms.
- Little affect from temperature.
- Presence of CHi & HCN during initial combustion can contribute to prompt NOx formation in an oxidizing environment, but will inhibit NOx formation in a reducing environment.
- Presence of C & NHi in initial combustion process reduces the formation of prompt NOx.
- Reactor combustion is controlled to a stoichiometry <.6 and a temperature <2400F.
NOx Production vs. Air/Fuel Ratio

Graphic Courtesy of Coen

Industry Burner Definitions

- **Modern conventional burners**
  - NOx less than 80 ppm (<0.1 lb/MMBtu)

- **Low-NOx burners**
  - NOx less than 30 ppm (<0.04 lb/MMBtu)

- **Ultra Low-NOx burners**
  - 9 ppm NOx (<0.01 lb/MMBtu)
Let’s Discuss FGR

Flue Gas Recirculation (FGR)
Flue Gas Recirculation (FGR)
FGR : Flue Gas Recirculation

FGR BURNERS

FEATURES

- CAN USE FGR FLOWS AS HIGH AS 40% OF THE TOTAL STACK EFFLUENT
- SOME SYSTEMS OPERATE VERY CLOSE TO THE LIMITS OF FLAMABILITY
- SOME SYSTEMS OPERATE WITH VERY RAPID MIXING, VERY CLOSE TO STOICHIOMETERY.

CON’S

- HIGH ELECTRICAL USAGE (FGR fan HP doubled compared to RX system)
- LOW TEMPERATURE, TRANSLUCENT, FLAME REDUCES HEAT TRANSFER & EFFICIENCY.
- COMBUSTION INSTABILITY
- CAN’T CHANGE FIRING RATE FAST ENOUGH TO FOLLOW CHANGING LOAD DEMANDS
Lower Cost to Industry

- Simple durable refractory and steel construction results in:
  - Lower initial cost
  - Lower maintenance costs

- Lower operating cost
  - Less stack losses due to low excess air and low FGR requirements
  - Lower fan costs
  - Eliminates the need for chemicals & catalysts

Flame Temperature vs. FGR

[Graph showing the relationship between Flame Temperature (°F) and FGR (%)]

Graphic Courtesy of Coen
Let's Discuss Staged Combustion

FGR Impact

Graph showing the impact of FGR on NOx ppm.
Gas Pre-mix Burner

Low-NOx Burner with Staged Fuel
Low-NOx Burner with Staged Fuel

Ultra Low-NOx Burner (9 ppm)
TYPICAL COMPONENTS

A Look Down the Furnace

- Rich Flame
- Lean Flames (x4)
- FGR
- Burnout Zone
Staged Combustion with Overfire Air

Graphic Courtesy of B&W
NOx Reduction by Boiler Configuration

A: Low-NOx burner only, no overfire air (OFA)
B: Low-NOx burner with OFA
C: Low-NOx burner with OFA and FGR

COST $/ TON NOx REMOVED

1. POST COMBUSTION $24,500 (SCR)
2. MASSIVE FGR $3,676
3. POROUS MATRIX $2,787
4. ULTRA LOW NOx TECHNOLOGY $258

Graphic Courtesy of B&W
### Existing Emissions & Goals

<table>
<thead>
<tr>
<th>Emission</th>
<th>Existing</th>
<th>Proposed</th>
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</thead>
<tbody>
<tr>
<td>NOx ppm@3% O2</td>
<td>25.3</td>
<td>5 - 6</td>
</tr>
<tr>
<td>CO ppm@3% O2</td>
<td>70.2</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Stack O2, %</td>
<td>6.2</td>
<td>2.5 – 3.2</td>
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</tbody>
</table>

- Reduce NOx by 75%
- Reduce O2 by 48 - 60%

Reducing O2 from 6% to 3% saves this customer 273 CFH of nat gas

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**Let’s Discuss**

**SCR Catalyst**
Selective Catalytic Reduction (SCR)

- NOx control thru ammonia (NH₃) injection
  - 4NO + 4NH₃ + O₂ \rightarrow 4N₂ + 6H₂O
  - 2NO₂ + 4NH₃ + O₂ \rightarrow 3N₂ + 6H₂O
- 90-95% control
- Problems
  - Expensive
  - High maintenance
  - Ammonia “slip”
  - Catalyst replacement & disposal
Anhydrous Ammonia Storage Tank

Utility Boiler NH₃ Manifold
% NOx Removed vs. Vanadium Pentoxide Catalyst Temperature

MOST EFFECTIVE OPERATING RANGE
Boiler With SNCR

Selective Non-Catalytic Reduction

- **NOx control through ammonia or urea injection**
- No catalyst necessary
- Temperature range 1400 °F – 1700 °F
- Injected upstream of convection section
- 80% control under normal conditions
- **Problems:**
  - Changing flue temperatures with changing load
  - Formation of ammonium salts
  - Ammonia slip
### Comparison of NOx Reduction Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Approx. Reduction</th>
<th>Approx. lbs/MMBTU</th>
<th>Approx. ppmv @ 3% O2</th>
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<tbody>
<tr>
<td>Standard burners Base case</td>
<td></td>
<td>0.14</td>
<td>120</td>
</tr>
<tr>
<td>Low NOx burners</td>
<td>60%</td>
<td>0.06</td>
<td>45</td>
</tr>
<tr>
<td>Ultra Low NOx burners – 1st gen.</td>
<td>80%</td>
<td>0.03</td>
<td>25 - 30</td>
</tr>
<tr>
<td>Ultra Low NOx burners – 2nd gen.</td>
<td>95%</td>
<td>0.007</td>
<td>6 - 9</td>
</tr>
<tr>
<td>FGR</td>
<td>55%</td>
<td>0.025</td>
<td>20</td>
</tr>
<tr>
<td>Compu- NOx w/ FGR</td>
<td>90%</td>
<td>0.015</td>
<td>15 - 20</td>
</tr>
<tr>
<td>SNCR</td>
<td>80%</td>
<td>0.033 - 0.085</td>
<td>27 - 70</td>
</tr>
<tr>
<td>Catalytic Scrubbing</td>
<td>70%</td>
<td>0.017 - 0.044</td>
<td>14 - 36</td>
</tr>
<tr>
<td>SCR</td>
<td>90 – 95%</td>
<td>0.006 - 0.015</td>
<td>5 - 12</td>
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Let’s Discuss SOx Control
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Sulfur Percent by Weight</th>
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<tbody>
<tr>
<td>Natural gas</td>
<td>0.0005</td>
</tr>
<tr>
<td>LPG</td>
<td>0.001</td>
</tr>
<tr>
<td>Fuel Oil No. 1</td>
<td>0.01 to 0.3</td>
</tr>
<tr>
<td>Fuel Oil No. 2</td>
<td>0.05 to 0.5</td>
</tr>
<tr>
<td>Diesel Motor Fuel</td>
<td>0.0015</td>
</tr>
<tr>
<td>Fuel Oil No. 4</td>
<td>0.2 to 1.75</td>
</tr>
<tr>
<td>Fuel Oil No. 5</td>
<td>0.5 to 1.75</td>
</tr>
<tr>
<td>Fuel Oil No. 6</td>
<td>0.5 to 1.75</td>
</tr>
<tr>
<td>Low Sulfur Fuel Oil No. 6</td>
<td>0.5</td>
</tr>
<tr>
<td>Subbituminous coal</td>
<td></td>
</tr>
<tr>
<td>from Rocky Mt. states</td>
<td>0.3 to 1</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>2 to 10</td>
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**Spray Tower Wet FGD Scrubber**

**Graphic Courtesy of B&W**
Five FGD Scrubber Modules on Utility Boiler

Graphic Courtesy of B&W

Let’s Discuss PM Control
Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers

Water Spray
Soot Blowing

Soot Blowers
Soot Blowing/Rapping

Cyclone
Regulatory Requirements

- Federal, state, and local requirements
- Boiler specific limits
- Permit requirements
- Monitoring requirements
- Visible emission limits
- Nuisance regulations
- Breakdowns & variances
Boiler Regulations

- NSPS 40 CFR Part 60 Subpart D, Da, Db, Dc, Ea
- Acid Rain Provisions (Parts 72, 73, 74, 75, 76, 77, 78)
- RCRA 40 CFR Parts 264 & 266
- State Regulations including VE
- SIP Requirements
- Local Regulations
- MACTs – JJJJJJJ & DDDDD

Boiler Emission Limits

- NOx, SO2, particulate, and opacity values for boilers are based on applicable subpart, heat input, date built or modified, and fuel used
- States and districts may have more stringent limits
### BACT in CA

<table>
<thead>
<tr>
<th>Type of Control</th>
<th>NOx Limits</th>
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</thead>
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<tr>
<td>Natural Gas Fired with SCR or equal</td>
<td>6 - 9 ppmvd @3% O$_2$ (0.011 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired with Ultra Low NOx Burner</td>
<td>15 ppmvd @3% O$_2$ (0.018 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired with Low NOx Burner</td>
<td>20 ppmvd @3% O$_2$ (0.024 lb/MMBTU)</td>
</tr>
</tbody>
</table>

### BARCT & RACT

<table>
<thead>
<tr>
<th>Type of Control</th>
<th>NOx Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Fired with Low NOx Burner</td>
<td>9 - 30 ppmvd @3% O$_2$ (0.036 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired Units (&lt; 40 MMBTU/hr)</td>
<td>74 ppmvd @3% O$_2$ (0.085 lb/MMBTU)</td>
</tr>
<tr>
<td>Solid Fuel Fired Boilers</td>
<td>0.20 Ib/MMBTU</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td>200 ppmv @12% CO$_2$ (0.24 lb/MMBTU)</td>
</tr>
</tbody>
</table>
Permit Categories

1. Emissions Limitations
2. Equipment Requirements
3. Operating Conditions
4. Monitoring and Recording Requirements
5. Compliance Testing
6. General Requirements

Testing and Monitoring

- Continuous Monitoring System
- Stack Testing
- Process Monitors
- Recordkeeping
Continuous Monitoring Types

- Opacity Transmissometers
- NO\textsubscript{x}
- SO\textsubscript{2}
- CO
- O\textsubscript{2} and/or CO\textsubscript{2}
- Ammonia
- Mercury Semi-Continuous

Source Testing

- Particulate Matter (PM, PM10, PM2.5)
- NO\textsubscript{x}, SO\textsubscript{2}, CO, Ammonia
- Mercury and Other Metals
- Hydrogen Chloride
- Formaldehyde
- Visible Emissions (Method 9)
Control Device Parameters

- ESP Spark Rate and Fields in service
- Baghouse Pressure Drop
- Scrubber Pressure Drop and Liquor Flow Rate
- Fuel Usage

Alternative Monitoring

- Portable analyzer monitoring of NOx, CO, O₂
- Determination of FGR rate
- Burner mechanical adjustments
- O₂ Trim concentration
- FGR valve(s) setting
Boiler Inspections

Points of Inspection

- Capture
- Transport
- Air mover
- Control device
- Instrumentation
- Subsystem
- Records
Pre-Inspection

- Prepare inspection form
- File review
- Regulation review
- Equipment check
- Pre-entry & entry
- Pre-inspection meeting
- Permit check

Reasons for Inspections

- Compliance determination
- Complaint investigation
- Source plan approval
- Review or renewal of permits
- Special studies
Inspection

- Visible emission evaluation
- General upkeep & maintenance
- Monitoring instruments & records
- Fuel type and quality
- Maintenance records
- Operational records
- Source tests
Inspector Safety

- Proper equipment
- Plant warnings
- Heat
- High pressure steam
- Electrical hazards
- Noise
- Moving parts
- Inhalation hazards
- Hazardous materials
- Machine disintegration
- Fires
- Other hazards & traps
Plant Hazards

Confined Space
Confined Space

- Possible nitrogen atmosphere
- Accumulation of carbonaceous material
- Ventilation required

DANGER

Contains asbestos fibers
Avoid creating dust
Cancer and lung disease hazard
Avoid breathing airborne asbestos

October 2020
Steam Exhaust

Access
Access

Thank You!