Course Overview

- Air Pollution
- Boiler Uses
- Boiler Theory and Operation
- Air Pollution Formation
- Air Pollution Control Devices
- Boiler Regulations
- Typical Permit Conditions
- Inspection Procedures

Ozone Photochemistry

- NO
- HONO
- Volatile Organic Compounds (VOCs)
- Nitrile Oxides (NOx)
- Ozone (O₃)
- Oxygen (O₂)
- Sunlight Energy
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)

- Liquid water
- Saturated Steam
- Superheated Steam

Small Firetube Boiler

Industrial Boiler
History of Boilers: Ringelmann Chart

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

Boiler Ratings

- Millions of BTU/hr
- Boiler HP
- Pounds of Steam/hr
- Megawatts
- Tons per day
Boiler Fuels

- Natural gas
- Diesel fuel oils
- Tire Derived Fuel (TDF)
- Coal/Petroleum Coke
- Municipal waste
- Bio-Mass
- Waste gas
- Nuclear
Heat Transfer Methods

Let's Discuss Firetube & Watertube Boilers

Fire-Tube Boiler
Let's Discuss Boiler Air Requirements
Boiler Air Requirements

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

Forced Draft Fans

Induced Draft Fan
Let's Discuss Economizers & Air-Preheaters
Economizer – H₂O Inside Tubes

Air Pre-Heater

Air Pre-Heater: Ambient to 400°F +
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
Circulating Fluidized Bed Boiler

Interactive Exercise

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Circulating Fluidized Bed Boiler

Interactive Exercise

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Let's Discuss Power Generation

High Pressure Steam Lines
Generator Stator

Step-Up Transformers

Typical Electric Utility Plant
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

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

![Graph showing the relationship between NOx (ppm) and Temperature (°F)]

**Graphic Courtesy of Coen**

**COMBUSTION MODIFICATION**

- **NOx FORMATION**
  - \( N + O \rightarrow NO \)
  - \( N + OH \rightarrow NO + H \)

- **NOx REDUCTION**
  - \( CH + NO \rightarrow HCN + O_2 \) (Reversible)
  - \( CH_2 + NO \rightarrow HCN + OH \) (Reversible)
  - \( C + NO \rightarrow CN + O_2 \)
  - \( NH + NO \rightarrow N_2 + H_2O \)

These NOx reductants are formed by partial combustion in a reducing atmosphere. The intermediate species, HCN & CN, are converted to N\(_2\), CO\(_2\) & H\(_2O\) in the final burnout zone.

**PROMPT NOx**

- Rapid Formation <1ms.
- Little affect from temperature.
- Presence of CH\(_i\) & 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 & NH\(_i\) in initial combustion process reduces the formation of prompt NOx.
- Reactor combustion is controlled to a stoichiometry <.6 and a temperature <2400F.
PROMPT NOx

\[ \text{NO} + \text{O} \rightarrow \text{NO}_2 \]
\[ \text{NO} + \text{H}_2 \rightarrow \text{HOCN} \]
\[ \text{HOCN} + \text{H} \rightarrow \text{HNCO} \]
\[ \text{HNCO} + \text{H} \rightarrow \text{NH}_2 \text{O} \]

**NOx Production vs. Air/Fuel Ratio**

- **Stoic Air**
- **NOx Level**
- **NOx Limit**

- **Rich**
- **Lean**

**Industry Burner Definitions**

- **Modern conventional burners**
  - NOx less than 80 ppm (<0.1 lb/MBtu)
- **Low-NOx burners**
  - NOx less than 30 ppm (<0.04 lb/MBtu)
- **Ultra Low-NOx burners**
  - 9 ppm NOx (<0.01 lb/MBtu)
Let's Discuss FGR

Flue Gas Recirculation (FGR)

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

FGR : Flue Gas Recirculation

**FEATURES**

- Can use FGR flows as high as 40% of the total stack effluent.
- Some systems operate very close to the limits of flammability.
- Some systems operate with very rapid mixing, very close to stoichiometry.

**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

Graphic courtesy of Coen

FGR Impact

Graphic courtesy of Coen
Let's Discuss
Staged Combustion

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

Staged Combustion with Overfire Air
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

NEW BOILER SYSTEMS

POST COMBUSTION $ 24500 (SCR)
MASSIVE FGR $ 3676
POROUS MATRIX $ 2787
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>
</tr>
</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

Let’s Discuss
SCR Catalyst

- NOx control thru ammonia (NH₃) injection
- 4NO + 4NH₃ + O₂ → 4N₂ + 6H₂O
- 2NO₂ + 4NH₃ + O₂ → 3N₂ + 6H₂O
- 90-95% control

**Selective Catalytic Reduction (SCR)**

- Problems
  - Expensive
  - High maintenance
  - Ammonia “slip”
  - Catalyst replacement & disposal

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June 5, 2017
% NOx Removed vs. Vanadium Pentoxide Catalyst Temperature

Boilers & SNCR

June 5, 2017
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>
</tr>
</thead>
<tbody>
<tr>
<td>Standard burners</td>
<td>Base case</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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</tbody>
</table>
Let's Discuss SOx Control

Table 302
Sulfur Content of Various fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Sulfur Percent by Weight</th>
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</thead>
<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 0.5</td>
</tr>
<tr>
<td>Fuel Oil No. 2</td>
<td>0.05 to 1.0</td>
</tr>
<tr>
<td>Diesel Motor Fuel</td>
<td>0.05</td>
</tr>
<tr>
<td>Fuel Oil No. 4</td>
<td>0.2 to 2</td>
</tr>
<tr>
<td>Fuel Oil No. 5</td>
<td>0.5 to 3</td>
</tr>
<tr>
<td>Fuel Oil No. 6</td>
<td>0.5 to 3.5</td>
</tr>
<tr>
<td>Low Sulfur Fuel Oil No. 6</td>
<td>0.5</td>
</tr>
<tr>
<td>Subbituminous coal</td>
<td>0.3 to 1</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>2 to 10</td>
</tr>
</tbody>
</table>

Spray Tower Wet FGD Scrubber

Graphic Courtesy of B&W
Let's Discuss PM Control

Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers

Graphic Courtesy of B&W
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 – JJJJJJ & 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>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Fired with SCR or equal</td>
<td>6 - 9 ppmvd @3% O2 (0.011 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired with Ultra Low NOx Burner</td>
<td>15 ppmvd @3% O2 (0.018 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired with Low NOx Burner</td>
<td>20 ppmvd @3% O2 (0.024 lb/MMBTU)</td>
</tr>
</tbody>
</table>

BARCT & RACT

<table>
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<th>NOx Limits</th>
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<tbody>
<tr>
<td>Natural Gas Fired with Low NOx Burner</td>
<td>9 - 30 ppmvd @3% O2 (0.036 lb/MMBTU)</td>
</tr>
<tr>
<td>Natural Gas Fired Units (&lt; 40 MMBTU/hr)</td>
<td>74 ppmvd @3% O2 (0.085 lb/MMBTU)</td>
</tr>
<tr>
<td>Solid Fuel Fired Boilers</td>
<td>0.20 lb/MMBTU</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td>200 ppmv @12% CO2 (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

Alternative Monitoring

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

Portable Combustion Analyzer

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

**Plant 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 Safety

Plant Hazards

Confined Space