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

Ozone Photochemistry

- Sunlight Energy
- Oxygen (O2)
- Oxygen (O2)
- Nitrogen Oxides (NOx)
- Volatile Organic Compounds (VOCs)
- Nitrous Oxide (N2O)
- Nitric Oxide (NO)
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)

Small Firetube Boiler

Industrial Boiler
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 Fuels

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

Steam Plant Basic Elements

- Boiler
- Boiler Feedpump
- Heating and Process Use
Let’s Discuss Firetube & Watertube Boilers
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 – $H_2O$ Inside Tubes

Air Pre-Heater

Air Pre-Heater: Ambient to 400F +
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
Ash Loadout

High Pressure Steam Drums

Steam Drum w/Cyclone & Chevron Separators
STEAM DRUM INTERNALS
CYCLONES WITH MESH PAD

STEAM OUTLET
MESH PAD
RISERS
CONTINUOUS BLOWDOWN
FEEDWATER INLET
CHEMICAL FEED
VORTEX BREAKER
FEEDERS

STEAM DRUM INTERNALS
BAFFLE PLATE WITH MESH PAD

CHEMICAL FEED
STEAM OUTLET
MESH PAD
BAFFLE
RISER
RISER
CONTINUOUS BLOWDOWN
FEEDER

Circulating Fluidized
Bed Boiler

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Let's Discuss Power Generation

High Pressure Steam Lines
Let's Discuss Emissions & Controls

Emissions From Boilers

Fuel + Air ($N_2$, $O_2$)

- $H_2O$
- $CO_2$
- $CO$
- $NO_x$
- $HC$
- $SO_x$
- $PM$
- $CHO$

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

NOx Creation
Thermal NOx vs. Temperature

Graph Courtesy of Coen

COMBUSTION MODIFICATION

- NOx FORMATION
  \[ N + O \rightarrow NO \]
  \[ N + OH \rightarrow NO + H \]

- NOx REDUCTION
  \[ CH + NO \rightarrow HCN + O \] (Reversible)
  \[ CH_{2} + NO \rightarrow HCN + OH \] (Reversible)
  \[ C + NO \rightarrow CN + O_{2} \]
  \[ NH_{i} + NO \rightarrow N_{2} + H_{2}O \]

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.


**PROMPT NOx**

\[
\begin{align*}
\text{O}_2 & \text{ H}_2\text{O} \quad \text{NO}_2 \\
+\text{CH}_4 & +\text{C} \quad +\text{CN} \\
\text{H}_2\text{CN} & +\text{OH} \quad \text{HOCN} \\
\text{H}_2 & +\text{CNO} \quad \text{HNCO} \\
\text{N}_2 & +\text{NHi} \quad \text{NH}_2 \quad \text{NO} \\
& +\text{H}_2\text{O}, \quad \text{HOCN} \\
& +\text{NO}, \quad \text{H}_2\text{CN} \\
& +\text{NHi} \\
& +\text{H}_2\text{O}
\end{align*}
\]

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

*Graphic Courtesy of Coen*

- **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)
Flue Gas Recirculation (FGR)

- CAN USE FGR FLOWS AS HIGH AS 40% OF THE TOTAL STACK EFFLUENT
- SOME SYSTEMS OPERATE VERY CLOSE TO THE LIMITS OF FLAMIBILITY
- 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

[Graph showing the relationship between temperature and FGR]

FGR Impact

[Graph showing the impact of FGR on another variable]
Let's Discuss Staged Combustion

Gas Pre-mix Burner

Low-NOx Burner with Staged Fuel

June 5, 2017
TYPICAL COMPONENTS

A Look Down the Furnace

Rich Flame
Lean Flames (x4)
FGR
Burnout Zone

Staged Combustion with Overfire Air
Burners with Overfire Air

NOx Reduction by Boiler Configuration

COST $/ TON NOx REMOVED
NEW BOILER SYSTEMS
**Existing Emissions & Goals**

<table>
<thead>
<tr>
<th>Emission</th>
<th>Existing</th>
<th>Proposed</th>
</tr>
</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

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**Let’s Discuss**

**SCR Catalyst**

- NOx control thru ammonia (NH₃) injection
  
  \[4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}\]
  
  \[2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O}\]

- 90-95% control

**Problems**

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

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**Selective Catalytic Reduction (SCR)**
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>
</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>
</tr>
</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>
</tr>
</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 from Rocky Mt. states</td>
<td>0.3 to 1</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>2 to 10</td>
</tr>
</tbody>
</table>

Fuel Sulfur Content

Spray Tower Wet FGD Scrubber

Graphic Courtesy of B&W
Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers
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>
<thead>
<tr>
<th>Type of Control</th>
<th>NOx Limits</th>
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<tr>
<td>Natural Gas Fired with Low NOx Burner</td>
<td>9 - 30 ppmvd @3% O2 @0.035 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

### Inspector Safety
- Noise
- Moving parts
- Inhalation hazards
- Hazardous materials
- Machine disintegration
- Fires
- Other hazards & traps
Plant Safety

Plant Hazards

Confined Space