California Environmental Protection Agency

Biomass Boilers
Course # 274

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

- NO
- NO₂
- O₂
- N₂O₅
- HO₂
- RO₂
- Oxygen (O₂)
- Oxygen Atom (O)
- Sunlight Energy

Boilers
Uses of Boilers

- Electrical generation High Pressure (1,800 - 3,800 psi)
- Space heating Low Pressure (150 – 1,600 psi)
- Food preparation
- Commercial laundries
- Pulp & paper industry
- Petroleum industry
- Chemical industry
Boilers

Phase Changes of Water

- Boiling Point
- Saturated Steam
- Liquid Water
- Superheated Steam
- Liquid Water and Steam (Quality 0 – 1)
- Melting Point
- Ice
- Liquid Water and Ice

Hot Numbers

- British Thermal Unit (BTU)
  - 1 BTU: the amount of energy needed to heat one pound of water one degree Fahrenheit or the 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
Boilers

Boiler Ratings

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

COMBUSTION ENGINEERING, INC.
C-E STEAM GENERATOR

Typical Boiler Rating

Let's Discuss Firetube & Watertube Boilers
Boilers

Boiler Tubes with Fins

Boiler Circulation

Water to Steam Circulation Loop
Let's Discuss Boiler Air Requirements

Boiler Air Requirements
- Draft
  - Natural
  - Forced
  - Induced
- Combustion air
  - Primary
  - Secondary
  - Excess

Forced Draft Fans
Boilers

Induced Draft Fans

Let's Discuss Economizers, Feedwater Heaters & Air-Preheaters

Feedwater Heater
Let's Discuss Fluidized Bed Boilers
Boilers

Fluidized Bed Modes

Start
No Air Flow

Fixed Bed

Minimum Fluidization

Bubbling Bed

Circulating Bed

Bubbling Fluidized Bed (BFB)

Circulating Fluidized Bed (CFB) Boilers
Let's Discuss Stoker Boilers

I'm a STOKER jack and I'm Ok

I sleep all night and I work all day
Combustion Using a Stoker Boiler

- “Stoker” involves combustion on a grate
- Fuel Distribution Onto the Grate
- Undergrate or Underfire Air
- Overfire Air
- Three Steps of Biomass Combustion
  - Step 1 - Drying
  - Step 2 - Gasification and Volatile burnout
  - Step 3 - Char Burnout (Step #3) on the grate
Boilers

Pneumatic Distribution

Classified by Grate Designs

- Fixed Grate (Pinhole)
- Vibrating Grate
- Watercooled Hydrograte
- Reciprocating Grate
- Kablitz Grate
- Traveling Grate
Boilers

Traveling Grate

Let's Discuss Power Generation

Typical Electric Utility Plant
Boilers

Typical Control Room

Moss Landing

2,600 MW
2 – 750 MW boilers
4 – Gas turbines and
2 steam turbines in a
2 to 1 arrangement

Let's Discuss Biomass
Wood is man’s oldest fuel

- Until very recently, wood was considered industrially as a waste material to be disposed of
- Escalating fuel costs and environmental concerns have changed things
- Wood use has opened up other “biofuels”

**History**

- 200,000 to 300,000 years - Controlled Use of Fire
- 10,000 to 20,000 years – Domesticated (living area)
- 800 years ago - First wood fuel shortages
- 400 years ago - Coal use in Europe
- 250 years ago - Industrial Revolution
- 150 years ago - Oil use
- 130 years ago - Natural gas use and electrification
- 70 years ago - Industrial wood-firing
- 50 years ago - Air pollutant investigations
- 20 years - Biofuels and “space age” investigations
Wood differs from conventional fossil fuels
- Physical structure
- Chemical structure
- Moisture content
- “It’s alive” when harvested
- Therefore it burns and must be burnt differently
- Commercially viable for other uses
- Relatively scarce resource
- Development of “urban wood wastes”

Wood Fuel Physical Characteristics
- Xylem interior “white wood”
  - Board lumber
  - Chips
- Cambium layer
  - new growth
  - source of nutrients
- Bark

Wood Fuel Physical Characteristics
- Debarking removes the Cambium layer and bark
- Yard wastes
- Processed through a hammermill (“hog”) for size reduction
- White wood
  - Sawdust
  - Sanderdust
  - Chip fines
- Other - plywood trim
Wood Fuel Variability

- Random reclaim operations will result in significant variations in fuel quality
- Emphasizes the importance of good fuel management and blending
- Selective fuel purchasing is also very important
- But ... generally, you burn what you got
**Fuel Quality**

- Poor combustion performance and high CO
- Small wood particles
  - Not handled well in the feed and distribution systems
  - Rapidly entrained with insufficient time to complete the 3-Step combustion process within the furnace
- High moisture content
  - Tends to pile on the grate
  - Causes "thick-bed" grate conditions
  - Disrupts undergrate airflow

**Fuel Preparation**

- Screening
- Metal Removal
- Drying
- Deicing
- Sizing
- Blending

**Wood Fuel Sizing**

- "Overs" (> 3 inches) => Plug fuel chutes
  - Screen out
  - Mill to a smaller size
- "Fines" (<1/4 in) => Not completely burned
  - Segregate
  - Blend up to 20% with larger materials
Boilers

Wood Fuel Screening

Tub Grinder for Gross Size Reduction

Hammermill for Fine Size Reduction
Wood Fuel Drying

- Part of another wood processing operation
  - Kiln dried trim
  - Dried planer shavings
  - Sander dust
- MC > 65% requires some type of drying or blending with drier fuel
- MC < 15% is potentially explosive

Fuel Blending

Importance of Blending

- Control moisture content
- Improve fines burnout
- Implement by:
  - Gross mixing using a front-end loader
  - Separate fuel bins feeding a common feed system
Wood Fuel Characteristics - Moisture Content

- Water needed for life
- Present in the cell structure and on surface
- Moisture content varies with
  - Species
  - Location
  - Season
  - Handling practices
- Nature levels of 30% to 65%+
- Kiln dried to less than 10%

Effect of Moisture

- Decreases combustion temperatures
- Leads to incomplete combustion and the generation of higher levels of CO and ash C
- Decreases boiler efficiency
- Leads to more fuel use, higher energy costs and increased air pollutants

Wood Fuel Characteristics - Volatility

- 70% to 80% of dry wood is “volatile” hydrocarbons
- Released from the wood structure at relatively low temperatures (500 F)
- Volatiles burn “in suspension” away from the wood particles
- Balance is “fixed carbon” or “char”
Wood Chemistry

Hydrocarbons

- Methane \( \text{CH}_4 \)
- Ethane \( \text{C}_2\text{H}_6 \)
- Propane \( \text{C}_3\text{H}_8 \)
- Complex Fuels \( \text{C}_x\text{H}_y \)
- More Complex Fuels \( \text{C}_x\text{H}_y\text{S}_z\text{N}_a \)

Wood Species

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pine</th>
<th>Redwood</th>
<th>Hemlock</th>
<th>Fir</th>
</tr>
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<tbody>
<tr>
<td>C (%wt,dry)</td>
<td>50.3</td>
<td>53.5</td>
<td>50.4</td>
<td>52.3</td>
</tr>
<tr>
<td>H (%wt,dry)</td>
<td>6.2</td>
<td>5.9</td>
<td>5.8</td>
<td>6.3</td>
</tr>
<tr>
<td>O (%wt,dry)</td>
<td>43.1</td>
<td>40.3</td>
<td>41.4</td>
<td>40.5</td>
</tr>
<tr>
<td>N (%wt,dry)</td>
<td>0.04</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>S (%wt,dry)</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Ash (%wt,dry)</td>
<td>0.3</td>
<td>0.2</td>
<td>2.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>30 - 60</td>
<td>30 - 60</td>
<td>30 - 60</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Btu/lb</td>
<td>9,153</td>
<td>9,220</td>
<td>8,620</td>
<td>9,058</td>
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</tbody>
</table>

3-Step Combustion Process

Step #1 - Drying

- Fresh wood particles absorb heat by convection and radiation from the ongoing combustion processes
- Initially, the heat energy evaporates the water in the cells and on the surface
- The evaporated water vapor diffuses away and mixes with the combustion products
Boilers

3-Step Combustion Process
Step #2 – Devolatilization

- The wood fuel particles continue to absorb heat
- The energy absorbed releases the volatile combustibles
- The volatiles diffuse away, mix with air (oxygen), and burn
- The energy released radiates back and helps to sustain combustion

3-Step Combustion Process
Step #3 - Char Burnout

- The char remains after the volatiles have been released
- Char is primarily pure carbon and requires:
  - An extended time period to burn
  - Air (oxygen) transported to it
- Inert ash remains after the char burnout
Ash

- Intrinsic ash (potassium) can combine with alumina and silica to form a relatively low melting point temperature ash (1600 to 1800°F).
- Potassium also volatilizes at low temperatures (1500°F) and reacts with ash in the boiler flue gas stream contributing to fouling problems.
- Ash accumulation causes:
  - Airflow problems
  - High draft levels and fan horsepower
  - Reduced superheat temperatures
  - Boiler shutdowns
Let's Discuss Emissions & Controls

Emissions From Boilers

- Fuel + Air (N₂, O₂)
- H₂O
- CO₂
- CO
- NOₓ
- HC
- SOₓ
- PM
- Cl⁻

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)
- RSCR
- FGR

Combustion Considerations

- Time
- Temperature
- Turbulence
- Oxygen
- Nitrogen

NOx Creation
- Thermal NOx
- Fuel-bound NOx
- Prompt NOx
Boilers

Thermal NOx vs. Temperature

<table>
<thead>
<tr>
<th>Temperature, °F</th>
<th>Thermal NOx Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>2400</td>
<td></td>
</tr>
<tr>
<td>2800</td>
<td></td>
</tr>
<tr>
<td>3200</td>
<td></td>
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</tbody>
</table>

NOx Production vs. Air/Fuel Ratio

- NOx Production
- Stoic Air
- NOx Level
- NOx Limit
- Air Fuel Ratio
- Rich
- Lean

Let’s Discuss FGR
Let's Discuss

Staged Combustion
Let’s Discuss SCR, SNCR and RSCR

What is SCR?

(SCR) Selective Catalytic Reduction

(This means that NOx will selectively react with NH3 in the presence of Oxygen, similar to SNCR but a catalyst is needed to help the reaction which takes place at a lower temperature than SNCR)
Where is SCR Used

- Widespread Use
  - Coal and Gas Fired Utility Boilers
  - Gas Turbine Electric Generators (Simple and Combined Cycle)
- More Recently
  - Refinery Combustion Systems
  - Smaller Industrial Boilers (Gas, Biomass Fired)
Boilers

**SCR @ Typical Utility Boiler**

**SCR**

NH₃ Injection:
(Uniform NH₃/NOₓ Critical)

Turning Vanes to give uniform Velocity across the Catalyst

Catalyst Layer(s)

**SCR Catalyst Types**

Extruded Ceramic: Honeycomb

Corrugated: (Haldor-Topsoe)

Plate

Composition:
- Vanadium Pentoxide (V₂O₅)
- Titanium Dioxide (TiO₂)
- Molybdenum
- Tungsten
Boilers

Catalyst Degradation With Time

Reason for Degradation Fuel Dependent

- Bituminous Coal: Arsenic Poisoning
- Other Coal: Calcium sulfate blinding
- Potassium & Chlorine Poisoning
Boilers

Typical Catalyst Deactivation Rates

Ammonia Injection Grid

SCR & NH₃ Tubes
SNCR vs SCR

<table>
<thead>
<tr>
<th></th>
<th>SNCR</th>
<th>SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx Reduction</td>
<td>20-50%</td>
<td>50-95%</td>
</tr>
<tr>
<td>Hardware</td>
<td>Simple</td>
<td>More Complex</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>Low (1)</td>
<td>High (5-10)</td>
</tr>
<tr>
<td>Reagent Utilization</td>
<td>Typ. 30%</td>
<td>Almost 100%</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Reagent</td>
<td>Reagent/Catalyst</td>
</tr>
<tr>
<td>Designability</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>NH3 slip</td>
<td>5-20 ppm</td>
<td>&lt;10 ppm</td>
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Let's Discuss Particulate & NH₃ Controls

What is SNCR?

SNCR
Selective Non-Catalytic Reduction

(Means that a chemical will selectively react with NOₓ in the presence of Oxygen)

• Ammonia (NH₃)
• Urea (NH₂CONH₂)
Ammonia Storage Tank

Anhydrous Ammonia Storage Tank

Ammonia vs. Urea

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ammonia</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>High Vapor Pressure Liquid Ammonia Water Solution</td>
<td>Liquid Solution</td>
</tr>
<tr>
<td>Safety</td>
<td>Anhydrous or 35.4% Aqueous solution; safer than 99% Aqueous - fewer safety issues</td>
<td>No safety issues</td>
</tr>
<tr>
<td>Storage</td>
<td>Anhydrous Pressure Vessel, Aqueous or Atmospheric Pressure</td>
<td>Atmospheric Pressure, Crystalization at Low Temperature</td>
</tr>
<tr>
<td>Injectors</td>
<td>Needs Carrier Gas</td>
<td>Atomizers (Pressure or Twin Rod)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Peak Removal @ 1750°F</td>
<td>Peak Removal @ 1800°F</td>
</tr>
<tr>
<td></td>
<td>Large Valve Drops, Shield Urea</td>
<td></td>
</tr>
<tr>
<td>System Complexity</td>
<td>Relatively Simple</td>
<td>Relatively Simple</td>
</tr>
</tbody>
</table>
Boilers

```
Balance-of-Plant Impacts

- NH₃ Slip
- SO₂/NH₃ Reactions (APH Deposition)
- HCl/NH₃ Reactions (Plume Visibility)
- Ash/NH₃ Absorption (Ash Sales, General Nuisance)
- N₂O Emissions
```
**What is RSCR?**

RSCR

Regenerative Selective Catalytic Reduction

(This means that NO\textsubscript{x} will selectively react with NH\textsubscript{3} in the presence of Oxygen, similar to SCR with a catalyst to help the reaction and two thermal transfer beds)

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**Ammonia Slip**

- \( \text{NH}_3 + \text{OH} \Rightarrow \text{NH}_2 + \text{H}_2\text{O} \)
- \( \text{NH}_2 + \text{NO} \Rightarrow \text{N}_2 + \text{H}_2\text{O} \)
- \( 2\text{NH}_3 + \text{OH} + \text{NO} \Rightarrow 2\text{H}_2\text{O} + \text{N}_2 + \text{NH}_3 \)
- 10 to 25 ppm NH\textsubscript{3} Slip
- Could be higher
- Always have Some NH\textsubscript{3} slip

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**NH\textsubscript{4}Cl Formation**
**NH₄Cl Formation**

- Function of the concentrations of NH₃ and HCl
- Concentrations decrease as air is mixed into the plume
- Lower concentrations => less NH₄Cl formed
- Therefore: air dilution is good

**What Can Be Done??**

- Minimize (eliminate Cl) in fuel
- Install acid gas controls
- Minimize NH₃ slip <= monitor
- High stack gas temperatures
- High ambient air temperatures (winter time a problem??)
- Promote rapid gas/air mixing ??
- Install high gas temperature concentric stack annulus ??

**Continuous NH₃ Analyzer**

- Laser & Detector
- Retro Reflector
### Comparison of NOx Reduction Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Approx. Reduction</th>
<th>Approx. lbs/MMBTU @ 3% O2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard burners</td>
<td>Base case</td>
<td>0.14</td>
</tr>
<tr>
<td>Low NOx burners</td>
<td>60%</td>
<td>0.06</td>
</tr>
<tr>
<td>Ultra Low NOx burners – 1st gen.</td>
<td>80%</td>
<td>0.03</td>
</tr>
<tr>
<td>Ultra Low NOx burners – 2nd gen.</td>
<td>95%</td>
<td>0.007</td>
</tr>
<tr>
<td>FGR</td>
<td>55%</td>
<td>0.025</td>
</tr>
<tr>
<td>Compu-NOx w/ FGR</td>
<td>90%</td>
<td>0.015</td>
</tr>
<tr>
<td>SNCR</td>
<td>80%</td>
<td>0.033 - 0.085</td>
</tr>
<tr>
<td>Catalytic Scrubbing</td>
<td>70%</td>
<td>0.017 - 0.044</td>
</tr>
<tr>
<td>SCR</td>
<td>90 – 95%</td>
<td>0.006 - 0.015</td>
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### Let's Discuss PM Control

**What is Particulate Matter??**

- It is what the test measurement says it is
- **Meaning:**
  - Solid particles that are captured on a filter
  - Condensable matter collected in a set of impingers
- What eventually condenses in the atmosphere is also considered as particulate matter along with “solid” particulate in the gas stream
Sources of "Particulate Matter"

- Ash in the fuel
  - Silica and Alumina - generally large particles that are retained or collected in the boiler/precipitator
  - Intrinsic ash - generates the small particles that are more troublesome to control
  - Alkalis - potassium, sodium and calcium
- Condensables (HCl, SO₃, NH₄Cl) which are also considered as "particulates"
Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers

Water Spray

Soot Blowing
Boilers

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
- MACT DDDDD & JJJJJJ

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
Boilers

### BACT

<table>
<thead>
<tr>
<th>Type of Control</th>
<th>NOx Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Fired with SCR &amp; Low NOx Burner</td>
<td>0.010 lb/MBTU</td>
</tr>
<tr>
<td>Natural Gas Fired Units (&lt; 60 MMBTU/hr)</td>
<td>0.035 lb/MBTU</td>
</tr>
<tr>
<td>Biomass Fuel Fired Boilers (Large), SNCR</td>
<td>0.10 lb/MBTU</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td>110 ppmv @7% O2</td>
</tr>
</tbody>
</table>

### Permit Condition 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]
Boilers

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
Boilers

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 Safety

Plant Hazards
Boilers

HP Gas Lines

Ruptured Steam Line

Steam Exhaust