Biomass Boilers
Course # 274

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

Ozone Photochemistry

- Volatile Organic Compounds (VOCs)
- Nitrogen Oxides (NOx)
- Oxygen (O2)
- Ozone (O3)

Air Resources Board

Sunlight Energy
Uses of Boilers

- Electrical generation
- Space heating
- Food preparation
- Commercial laundries
- Pulp & paper industry
- Petroleum industry
- Chemical industry

High Pressure (1,800 - 3,800 psi)
Low Pressure (150 – 1,600 psi)
Phase Changes of Water

Melting Point

Boiling Point

Saturated Steam

Liquid Water

Liquid Water and Ice

Ice

Superheated Steam

热数值

• 英制热量单位（BTU）
  1 BTU 是加热一磅水温度升高一度华氏度所需的能量或≈能量抵消燃烧一根木匹配。

• 低位热值（LHV）
  燃料的热值不计水所需蒸发所需的热量。

• 高位热值（HHV）
  燃料的热值包括水所需蒸发的热量。
Boiler Ratings

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

Let’s Discuss Firetube & Watertube Boilers
NACT 274 Boilers

Fire-Tube Boiler

Water-Tube Boiler
Let's Discuss Boiler Air Requirements

Boiler Air Requirements

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

Forced Draft Fans
Let's Discuss Fluidized Bed Boilers
Fluidized Bed Modes

- Fixed Bed
- Minimum Fluidization
- Bubbling Bed
- Circulating Bed

Bubbling Fluidized Bed (BFB)

Circulating Fluidized Bed (CFB) Boilers
Circulating Fluidized Bed Boiler

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
Fuel Metering

Fuel Chute and Simple Distribution
Pneumatic Distribution

Classified by Grate Designs

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

Let's Discuss Power Generation

Typical Electric Utility Plant
NACT 274 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 As A Fuel

- 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
- Cambria layer
  - new growth
  - source of nutrients
- Bark

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

- Part of another wood processing operation
  - Kiln dried trim
  - Dried planer shavings
  - Sanderdust
- 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 \( \text{C}_x\text{H}_y\text{S}_z\text{N}_a \)

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**Wood Species**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pine</th>
<th>Redwood</th>
<th>Hemlock</th>
<th>Fir</th>
</tr>
</thead>
<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>
</tr>
</tbody>
</table>

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**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
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

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
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

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Let’s Discuss
Emissions & Controls

Emissions From Boilers

Fuel + Air
\(N_2, O_2\)

- H\(_2\)O
- CO\(_2\)
- CO
- NO\(_X\)
- HC
- SO\(_X\)
- 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

Thermal NOx
Fuel-bound NOx
Prompt NOx

NOx Creation
Let's Discuss Staged Combustion
Let’s Discuss SCR, SNCR and RSCR

What is SCR?

( 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)
SCR @ Typical Utility Boiler

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
SCR Catalyst & NH₃ Tubes

Catalyst Degrades With Time

Reason for Degradation: Fuel Dependent
- Bituminous Coal: Arsenic Poisoning
- Other Coal: Calcium sulfate blinding
- Potassium & Chlorine Poisoning
Typical Catalyst Deactivation Rates

![Typical Catalyst Deactivation Rates Diagram]

Ammonia Injection Grid

SCR & NH₃ Tubes
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

- **Image:** Ammonia Storage Tank

### Anhydrous Ammonia Storage Tank

- **Image:** 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/29.4% Aqueous - safety issues 19% Aqueous - fewer safety issues</td>
<td>No Safety Issues</td>
</tr>
<tr>
<td>Storage</td>
<td>Anhydrous-Pressure Vessel Atmospheric Pressure</td>
<td>Atmospheric Pressure Crystalization at Low Temperature</td>
</tr>
<tr>
<td>Injectors</td>
<td>Needs Carrier Gas</td>
<td>Ammonia Pressure or Yarn Fluid</td>
</tr>
<tr>
<td>Temperature</td>
<td>Peak Removal @ 1750 F</td>
<td>Peak Removal @ 1850 F Large Dilute Drops Shield Urea</td>
</tr>
<tr>
<td>System Complexity</td>
<td>Relatively Simple</td>
<td>Relatively Simple</td>
</tr>
</tbody>
</table>
Bio-Mass Boiler

Disconnected NH₃ Line

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 NOₓ will selectively react with NH₃ in the presence of Oxygen, similar to SCR with a catalyst to help the reaction and two thermal transfer beds)

Ammonia Slip

- NH₃ + OH => NH₂ + H₂O
- NH₂ + NO => N₂ + H₂O
- 2NH₃ + OH + NO => 2H₂O + N₂ + NH₃
- 10 to 25 ppm NH₃ Slip
- Could be higher
- Always have Some NH₃ slip

NH₄Cl 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**
## 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 PM Control

PM Control refers to the control of particulate matter (PM) in emissions from industrial processes. PM control is crucial for improving air quality and reducing health risks associated with particulate matter exposure.

### 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 PM

- 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, SO₂, NH₄Cl) which are also considered as "particulates"
Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers

Water Spray

Soot Blowing
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

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>
<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>

### 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
Inspector Safety
- Proper equipment
- Plant warnings
- Heat
- High pressure steam
- Electrical hazards

Plant Hazards
- Noise
- Moving parts
- Inhalation hazards
- Hazardous materials
- Machine disintegration
- Fires
- Other hazards & traps

Plant Safety