Black Liquor Sprays

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Outline

- Objectives and key variables
- Black liquor spray nozzles
- Droplet size distribution
- Spray distribution
- Implications for recovery boilers
Black Liquor Guns

Key Parameters for BL Spray

**Process Variables**
- Liquor dry solids
- Liquor elevated boiling point
- Physical properties (density, viscosity, etc)
- Liquor burning characteristics (swelling)

**Operating Parameters**
- Number and arrangement of guns
- Tilt or oscillation of gun barrels
- Nozzle type and size
- Firing temperature
- Liquor flow rate and pressure
Spray Characteristics

- Median droplet diameter
- Droplet size distribution
- Spray velocity
- Flow distribution

Impact of Droplet Size on Trajectory

Initial Droplet Diameter

- Small (< 1mm)
- Medium (1 to 2 mm)
- Large (> 2 mm)
Objectives for Effective Spraying

- Control droplet size (2 to 4 mm)
  - Minimize particle carryover
  - Deliver mostly dry liquor to bed
  - Control height of char bed
- Distribute liquor spray
  - Minimize liquor on furnace walls
  - Create a uniform symmetrical bed shape

Nozzle Types

- Swirlcone Nozzle
- V-Type Nozzle
- Splash Plate Nozzle
- Typical Nozzle Gun Assembly
Splash Plate Nozzle Geometry

Looking down on a splash plate nozzle

35° plate angle

45° plate angle

Swirlcone and V-Type Nozzles

Swirlcone

V-Type
BL Nozzle Operating Conditions

<table>
<thead>
<tr>
<th></th>
<th>Splash Plate</th>
<th>Swirlcone &amp; V-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orifice size, in.</td>
<td>0.7 – 1.25</td>
<td>0.4 – 0.75</td>
</tr>
<tr>
<td>Pressure, psi</td>
<td>15 – 45</td>
<td>12 – 18</td>
</tr>
<tr>
<td>Flow, GPM</td>
<td>25 – 75</td>
<td>20 – 40</td>
</tr>
<tr>
<td>Median droplet size, mm</td>
<td>2 – 4</td>
<td>2 - 4</td>
</tr>
</tbody>
</table>

Black Liquor Spray Breakup

Splash plate tip

Direction of spray
**Spray Size Distribution for BL Nozzles**

![Graph showing spray size distribution with data points.]

**Median Droplet Size**

\[ D_{\text{median}} = 0.290 K_L K_N \frac{D_n^{1.23} S^{0.62}}{Q^{0.23} T^{0.14}} \]

- Splash plate, swirlcone, and V-type nozzles
- \( D_{\text{median}} \) = median droplet diameter
- \( K_N, K_L \) = nozzle and liquor constants
- \( S \) = liquor dry solids (weight fraction)
- \( T \) = liquor temperature, °C (non-flashing)
- \( D_n \) = nozzle diameter, m
- \( Q \) = volume flow rate, m³/s
Elevated Boiling Point

Liquor Temperature or Elevated Boiling Point

Flashing

\[ T - T_{BP} > 9 \, ^\circ F (5 \, ^\circ C) \]

Typical Range of Operation

Non-Flash

Solids Content (%)

210 220 230 240 250 260 270 280 290 300

50 60 70 80 90

Elevated Boiling Point

Non-Flash

Transitional

Flashing

\[ \Delta T_e = T - T_{EBP} \]

Solids = 69%, EBP = 115°C

Excess Temperature, \(\Delta T_e = T - T_{EBP}\)
Black Liquor Flashing

- Higher nozzle velocity due to expansion of steam bubbles

Non-flashing

Flashing

Example Nozzle Spray Conditions

- Splash plate nozzle
- Nozzle diameter – 30/32 in (24 mm)
- Solids content – 70 %
- Temperature – 245°F (118°C), transitional
- Volume flow rate – 74.5 gpm (4.7 l/s)
- Liquor pressure – 16.4 psig (1.13 bar)

- Median droplet diameter – 3.3 mm
- Spray velocity – 30 ft/s (9.1 m/s)
Effect of Nozzle Diameter on Drop Size

\[ D_{\text{median}} \propto D_n^{1.23} \]

Note: liquor mass flow rate, temperature and solids are fixed

Effect of Nozzle Diameter on Velocity

\[ V \propto 1/D_n^2 \]

Note: liquor mass flow rate, temperature and solids are fixed
Effect of Temperature on Drop Size

\[ D_{\text{median}} \propto \frac{1}{T^{0.14}} \]

Note: liquor mass flow rate, solids, and nozzle diameter are fixed

Effect of Temperature on Velocity

Note: liquor mass flow rate, solids, and nozzle diameter are fixed
Liquor Spray Distribution

**Wall Firing**
- Small boilers
- 1 or 2 oscillating guns

**Stationary Firing**
- Large boilers
- 4 to 12 fixed guns

Predicting Spray Distribution and Deposits

- Based on computational analysis of the trajectories of large drops
- Useful for sensitivity studies
- Useful for initial optimization
- Examples for one particular boiler
  - Demonstrates sensitivity to operating parameters
  - Can show interactions between parameters
Recovery Boiler Used in Examples

<table>
<thead>
<tr>
<th>Floor dimensions</th>
<th>31.5 x 28.4 ft (9.6 x 8.7 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firing method</td>
<td>Stationary firing</td>
</tr>
<tr>
<td>Number of guns</td>
<td>4, one at center of each wall</td>
</tr>
<tr>
<td>Barrel tilt</td>
<td>- 20° (median)</td>
</tr>
<tr>
<td>Nozzle size</td>
<td>#38 (38/32 inches or 1 3/16&quot;)</td>
</tr>
<tr>
<td>Splash plate angle</td>
<td>49° (median)</td>
</tr>
<tr>
<td>Liquor dry solids</td>
<td>65.8%</td>
</tr>
<tr>
<td>Liquor temperature</td>
<td>220°F (104.4°C) non-flashing</td>
</tr>
</tbody>
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Impact of Barrel Tilt on Bed Shape

- 10°
- 20°
- 30°
Impact of Nozzle Size

#34 nozzle

Deposition Rate (kg/hr-m²)

<table>
<thead>
<tr>
<th>Rate</th>
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<tbody>
<tr>
<td>2500</td>
<td>2300</td>
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<td>1900</td>
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<td>1500</td>
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<tr>
<td>1300</td>
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#40 nozzle

Deposition Rate (kg/hr-m²)

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<td>100</td>
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Impact of Splash Plate Angle

35°

Deposition Rate (kg/hr-m²)

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49°
Impact of Flashing

Non-Flash Flashed

Deposition Rate [kg/hr-m²]

BL SA PA TA

Front Wall Left Wall

Implications for Recovery Boilers

- Select nozzle type, number, arrangement, and barrel tilt for liquor spray distribution
- Select nozzle size for required flow, liquor pressure and median droplet size
- Recognize and control flashing
  - Flashing impacts spray velocity and droplet size
  - Stay above or below flashing temperature
  - If above, use temperature to control droplet size