The Characteristics of Black Liquor Sprays

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The properties of the spray determine in which part of the furnace drying, devolatilization and char burning take place.

Too small drops → Carry-over

Too large drops → Hit the char bed without drying
**MOTIVATION**

**BLACK LIQUOR**
- Solids content 75-85%,
- Viscosity 100-500 mPas
- Temperature 125-140 °C

**SPRAYING**
- Nozzle diameter 18-42 mm
- Mass flow rate 2-8 kg/s
- Excess temperature 0-25°C

New challenges of spraying

Experiments & modeling necessary
Operating parameters

- Dry solids content
- Temperature
- Mass flow rate
- Nozzle geometry

Spray properties

- Velocity
- Opening angle
- Disintegration mechanisms
- Drop size and size distribution
OBJECTIVE

To study the effect of operating parameters to spray properties

Focus on:

- Atomization performance
- Velocity
- Drop size distribution
Overview

• Spraying experiments at the mill
• Sheet disintegration mechanisms
• Flashing accelerates the flow
• Resulting drop size and size distribution
• Modeling of velocity and drop size
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EXPERIMENTS

• Furnace and Test Chamber
• Softwood liquor
• Dry solids content 75 - 80 %
• Two types of mill scale nozzles, A and B
• Spraying temperature: 129 - 135 °C
• $dT_b$ (13 - 19 °C)
• Mass flow rates: 4.3, 5.2, 6.1 kg/s
EXPERIMENTAL CONFIGURATION

- Sprayer chamber
- Drop size measurement
- Control window
- Stroboscope
- Camera
- VCR
- Endoscope
- Liquor gun hole
- Black liquor hose from the ring header
- 3.0 m
- 5.5 m

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HORIZONTAL SPRAYING CHAMBER
FURNACE ENDOSCOPE
Nozzles

A

$\alpha$

$h$

$d_p = 27 \text{ mm}$

B

$\alpha$

$h$

$d_p = 28 \text{ mm}$
Overview

- Spraying experiments at the mill
- **Sheet disintegration mechanisms**
- Flashing accelerates the flow
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- Modeling of velocity and drop size
Black liquor sheet disintegration mechanisms

The effect of excess temperature at constant mass flow rate

\( \Delta T_b = -4.1 \, ^\circ C \)

\( \Delta T_b = 4.7 \, ^\circ C \)

\( \Delta T_b = 14.8 \, ^\circ C \)
Nozzle A

\[ dT_b \ [\degree C] \]

\[ m [\text{kg/s}] \]

2.6 3.4 4.3 5.2 6.1
Nozzle B, 5.2 kg/s

Minor change in excess temperature can cause remarkable change in sheet disintegration

\[ u = 12.2 \text{ m/s} \]
\[ dT_b = 16.1 \text{ °C} \]

\[ u = 8.9 \text{ m/s} \]
\[ dT_b = 14.3 \text{ °C} \]
Nozzle B, 5.2 kg/s

\[
\begin{align*}
    u &= 12.2 \text{ m/s} \\
    dT_b &= 16.1 ^\circ \text{C} \\
    u &= 8.9 \text{ m/s} \\
    dT_b &= 14.3 ^\circ \text{C}
\end{align*}
\]

Minor change in excess temperature can cause remarkable change in sheet disintegration.
Overview

- Spraying experiments at the mill
- Changing disintegration mechanisms
- Flashing accelerates the flow
- Resulting drop size and size distribution
- Modeling of velocity and drop size
Velocity of the spray

- **Nozzle A**
  - Velocity of the spray vs. excess temperature (°C)
  - Data points for different flow rates: 4.3 kg/s, 5.2 kg/s, 6.1 kg/s

- **Nozzle B**
  - Same as Nozzle A, but for different spray conditions

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DIMENSIONLESS VELOCITY

\[ u^* = \frac{u_{\text{spray}}}{m} = \frac{u_{\text{spray}}}{u_{\text{pipe}}} \]

\[ = \frac{u_{\text{spray}}}{A \rho_{BL}} \]

\( u^* \) = Measured velocity at the spray centerline

\( u^* \) = Calculated velocity for liquid only at A
Dimensionless velocity and drop size, Nozzle A

[Graph showing the relationship between dimensionless velocity and excess temperature for different mass flows (4.3 kg/s, 5.2 kg/s, 6.1 kg/s), with a legend indicating the data points for each mass flow rate.]
Dimensionless velocity and drop size, Nozzle B

Excess temperature, °C

Nozzle B
- 4.3 kg/s
- 5.2 kg/s
- 6.1 kg/s

Dimensionless velocity, -

Mass median diameter, mm

Excess temperature, °C

4.3 kg/s
- 5.2 kg/s
- 6.1 kg/s
The effect of mass flow rate on droplet size

![Graph showing the effect of mass flow rate on droplet size for Nozzle A and Nozzle B.](image)
Drop size and shape

$S = 76\%$
$dT_b = 14\, ^\circ C$
$m = 6.1\, kg/s$
$u^* = 1.5$

$S = 76\%$
$dT_b = 18\, ^\circ C$
$m = 4.3\, kg/s$
$u^* = 2.9$
Distribution functions were fitted to experimental data (assuming spherical droplets)

Rosin-Rammler

Normal distribution

Square-root normal distribution

Log-normal distribution
Particle size distribution

- Measured
- RR
- Normal
- Sqrt
- LogNor

Volume fraction of particles [1/mm]

D_{ekv} [mm]
Application of the results for estimating the performance of the boiler.
Overview

• Spraying experiments at the mill
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• Flashing accelerates the flow
• Resulting drop size and size distribution

• Modeling of velocity and drop size
\[ u^* = u_c^* + \left( \Delta T_b - \Delta T_{bc} \right) \frac{a}{\dot{m}''_b} \]
DROP SIZE

\[ MMD = c \Delta T_b^d u^e \]

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Conclusions I

• Flashing accelerates the flow
• Flash-breakup is the dominating atomization process
• 2-3 °C decrease in temperature
  → long black liquor sheet
  → the mass median drop size doubles
  → more non-spherical drops
Conclusions II

- Square-root normal distribution function fits best when assuming spherical droplets
- The fraction of non-spherical particles was very high

→ Different trajectories and the differing combustion behavior must be taken into account
Conclusions III

• Drop size correlates best with spray velocity
• The application range of the developed empirical correlation models is limited
• Physical or semi-physical models are required
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