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
Overview

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

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

- **Spray chamber**
- **Liquor gun hole**
- **Black liquor hose from the ring header**
- **Nozzle**
- **Spray chamber**
- **Drop size measurement**
- **Control window**
- **Top view**
- **Stroboscope**
- **Camera**
- **VCR**

HORIZONTAL SPRAYING CHAMBER
FURNACE ENDSOCPE

Nozzles

A

\[ d_p = 27 \text{ mm} \]

B

\[ d_p = 28 \text{ mm} \]
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

ΔT_b = -4.1 °C  ΔT_b = 4.7 °C  ΔT_b = 14.8 °C
Nozzle A

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

**Nozzle B, 5.2 kg/s**

\[
u = 12.2 \text{ m/s} \\
\Delta T_b = 16.1 \degree\text{C}
\]

\[
u = 8.9 \text{ m/s} \\
\Delta T_b = 14.3 \degree\text{C}
\]
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
- Nozzle B

Excess temperature, °C

Velocity, m/s

- 4.3 kg/s
- 5.2 kg/s
- 6.1 kg/s
DIMENSIONLESS VELOCITY

\[ u^* = \frac{u_{spray}}{m} = \frac{u_{spray}}{u_{pipe}} = \frac{u_{spray}}{A \rho_{BL}} \]

Dimensionless velocity and drop size, Nozzle A

[Graph showing the relationship between excess temperature and dimensionless velocity and mass median diameter for different mass flow rates.]
Dimensionless velocity and drop size, Nozzle B

The effect of mass flow rate on droplet size

Colloquium on Black Liquor Combustion and Gasification, 2003
Drop size and shape

\[ S = 76\% \quad dT_b = 14\,^\circ C \quad m = 6.1\,\text{kg/s} \quad u^* = 1.5 \]

\[ S = 76\% \quad dT_b = 18\,^\circ C \quad m = 4.3\,\text{kg/s} \quad u^* = 2.9 \]

Distribution functions were fitted to experimental data (assuming spherical droplets)

Rosin-Rammler

Normal distribution

Square-root normal distribution

Log-normal distribution
Particle size distribution

Application of the results for estimating the performance of the boiler
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**

**DIMENSIONLESS VELOCITY**

\[ u^* = \frac{u^*_c + (\Delta T_b - \Delta T_{bc}) a}{m^b} \]

- Excess temperature, °C
- Dimensionless velocity
- Predicted vs. Measured

\[ R^2 = 0.89 \quad u^* \]
DROP SIZE

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

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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