Influence of liquor to liquor differences on recovery boiler operation –
A CFD based study

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Objectives

• Liquor-to-Liquor Differences Lead to Operational Challenges
• Study of Liquor Properties in the ÅA Single Droplet Experiment
• Utilise Liquor Property Data in CFD Simulations
• Study of Liquor-to-Liquor Differences and Their Influence on Operational Conditions by Means of CFD
Outline

• ÅA Recovery Furnace Model
  Simplified Black Liquor Droplet Model
  Simplified Black Liquor Char Bed Model
• Test Case: Domsjö Recovery Furnace
• Results
• Conclusions
ÅA Recovery Furnace Model

**CFD Code**

Fluent 6.1

- **Turbulence**
  Standard $k-\varepsilon$ Model

- **Chemistry**
  Modified $C_xH_yO_z$-Air 4-Step Scheme

\[
C_xH_yO_z + a\ O_2 \rightarrow b\ CO + c\ H_2 + d\ H_2O
\]

\[
C_xH_yO_z + e\ H_2O \rightarrow f\ CO + g\ H_2 + h\ H_2O
\]

\[
H_2 + 0.5\ O_2 \rightarrow H_2O
\]

\[
CO + H_2O \leftrightarrow CO_2 + H_2
\]

- **Turbulence-Chemistry**
  Eddy Dissipation Combustion Model

- **BL-Droplets/CharBed**
  ÅA-BLC Model

- **Radiation**
  Discrete Ordinates Radiation Model
Simplified Black Liquor Single Droplet Model

- Swelling Droplet
  - Devolatilisation (2)
- Char Particle
  - Char Burning (3)
- Black Liquor Droplet
- Drying (1)
- Drying Droplet
- Smelt Bead Formation (4)
- Smelt Bead

Single Droplet Model after Frederick & Hupa, 1993
Simplified Black Liquor Char Bed Model

- Fixed char bed shape and temperature: 1300 K

- Droplet landing on wall or char bed:
  Immediate release of the remaining water, volatiles and conversion of char carbon to CO
Test Case – Domsjö Boiler

Height: 28 m
Nose tip height: 17.5 m
Length and width: ~6.5 m

Total air feed: 28.34 kg/s
Mass flow of black liquor: 7.23 kg/s
Rota-Firing Mode

Air level 3 (11 m, 22% of total air)
Black liquor guns (7 m)
Air level 2 (3 m, 45% of total air)
Air level 1 (1 m, 33% of total air)
Black Liquor Properties – Case Setup

- Volatile yield: 25.7% / BLS
- Char carbon: 13.7% / BLS

- Devolatilization parameters:
  \[ A = 3.12 \times 10^5 \text{ } \text{1/s} \]
  \[ E_a = 7.4 \times 10^7 \text{ } \text{J/kmol} \]

- Droplet size distribution:
  Rosin-Rammler type
  Droplet diameter range 0.7 – 5 mm
  Mean diameter size 2.8 mm

| Black Liquor Composition [\%DS] |
|-----------------------------|-------------------|
| C  | 37.7 |
| H  | 3.6  |
| N  | < 0.1|
| Na | 18.8 |
| K  | 1.4  |
| S  | 3.8  |
| Cl | 0.46 |
## Case Study

<table>
<thead>
<tr>
<th>Case</th>
<th>Swelling ($d_{max}/d_0$)</th>
<th>Dry Solids Content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
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<td>82</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>82</td>
</tr>
</tbody>
</table>
Temperature Distribution [K] – Center Cross-Section

Low DS    High DS
Low SW    High SW
Low SW    High SW
Temperature Distribution [K] – Horizontal Plane (4.5 m)
Temperature Distribution [K] – Horizontal Plane (8 m)

Low DS

Low SW

High SW

High DS

K

Legend:
- 1858.000
- 1711.300
- 1664.600
- 1517.900
- 1271.200
- 1124.500
- 977.800
- 831.100
- 684.400
- 537.700
- 391.000
Drying – Water Release – Center Cross-Section

Low DS

Low SW

High SW

High DS

kg/m³s

1.00e-03
9.00e-04
8.00e-04
7.00e-04
6.00e-04
5.00e-04
4.00e-04
3.00e-04
2.00e-04
1.00e-04
0.00e+00
Devolatilisation – Volatile Release – Center Cross-Section

Low DS

Low SW

High SW

High DS

kg/m³s

1.73e-04
1.56e-04
1.39e-04
1.21e-04
1.04e-04
8.66e-05
6.93e-05
5.19e-05
3.46e-05
1.73e-05
0.00e+00
Char-Carbon Conversion – Center Cross-Section

Low DS

Low SW

High SW

High DS

kg/m$^3$s

0.00e+00

9.00e-06

1.80e-05

2.70e-05

3.60e-05

4.50e-05

5.40e-05

6.30e-05

7.20e-05

8.10e-05

9.00e-05
Conclusions (1)

• Obvious influence of DS-content on furnace performance

• Minor influence of liquor swelling tendency
  - almost no influence for low DS liquor
  - stronger influences for high DS liquor

• Massive char-carbon conversion on the rear wall (up to 35%)
Droplet Trajectories – Volatile Release – Front Liquor Gun

kg/s

High DS
High SW
Droplet Trajectories – Volatile Release – Front Liquor Gun

kg/s

Low DS
High SW
Droplet Trajectories – Volatile Release – Right Liquor Gun

kg/s

High DS
High SW
Velocity Distribution [m/s] – Secondary Air Level

m/s

High DS
High SW
Velocity Distribution [m/s] – Center Cross-Section

High DS
High SW
Temperature Distribution [K] – Side Walls

- Rear wall
- Left wall
- Right wall
- Front wall

Temperature Color Scale:
- 1858.000
- 1711.300
- 1564.600
- 1417.900
- 1271.200
- 1124.500
- 977.800
- 831.100
- 684.400
- 537.700
- 391.000

High DS
High SW
Velocity Distribution [m/s] – Liquor Gun Air Level

- High DS
- High SW
Conclusions (2)

- **Influence of swelling on the furnace performance**
  Low DS: Most droplets devolatilize at the secondary air level or on the char bed → Minor influence of swelling
  High DS: Devolatilization higher up in the furnace
    Low upward flowing gas streams → Little influence of swelling

- **Massive char-carbon conversion on the rear wall**
  Liquor spraying (right liquor gun) and air distribution responsible for liquor conversion on the rear wall
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