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

Christian Mueller, Kaj Eklund, Mikael Forssén, Mikko Hupa  
Åbo Akademi Process Chemistry Group  
Combustion and Materials Chemistry  
Turku, Finland

Karin Eriksson, Jan Eriksson  
Vattenfall Utveckling AB  
Älvkarleby, Sweden

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

- 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 = 3.12e+5 1/s
  E_a = 7.4e+7 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]
<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>37.7</td>
</tr>
<tr>
<td>H</td>
<td>3.6</td>
</tr>
<tr>
<td>N</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Na</td>
<td>18.8</td>
</tr>
<tr>
<td>K</td>
<td>1.4</td>
</tr>
<tr>
<td>S</td>
<td>3.8</td>
</tr>
<tr>
<td>Cl</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Case Study

<table>
<thead>
<tr>
<th>Case</th>
<th>Swelling ($d_{\text{max}}/d_0$)</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>
<td>1</td>
<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 DS  High DS

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

Low DS

Low SW

High SW

High DS

Temperature Distribution [K] – Horizontal Plane (8 m)

Low DS

Low SW

High SW

High DS
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

High DS
High SW

kg/s

Low DS
High SW

kg/s
Droplet Trajectories – Volatile Release – Right Liquor Gun

High DS
High SW

Droplet Trajectories – Volatile Release – Right Liquor Gun

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

m/s

High DS
High SW

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

m/s

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

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

Acknowledgement

Akademi of Finland
Tekes
Andritz Oy
Kvaerner Power Oy