An evaluation of fouling and deposition in demo plants

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DEBCO Final Conference, Brussels
December 10-11th, 2012
Introduction

- Fouling and deposit formation
- PF boilers – Rodenhuize, Kardia, Fusina
- On site measurements and methods
- Results
- Conclusions
Fouling of heat exchange surfaces - consequences

- Loss of plant capacity and/or efficiency 25% - 45%
- Excess fuel consumption
- Reduced service life and added energy costs
- Fouling cost yearly several billions $, £, €

The cost of fouling far exceeds the cost of eliminating it.

*Clyde Bergemann*
Fouling of heat exchange surfaces - understanding

<table>
<thead>
<tr>
<th>Mechanisms of the deposit formation:</th>
<th>Types of the ash deposit in the boiler [Ots. A]:</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Inertial impaction, Eddy deposition</td>
<td>– Loose deposit - LD</td>
</tr>
<tr>
<td>– Thermophoresis</td>
<td>– Bound-ash deposit - BD</td>
</tr>
<tr>
<td>– Diffusion followed by condensation</td>
<td>– Slag deposit - S</td>
</tr>
<tr>
<td>– Chemical reaction</td>
<td>– Bound slag deposit - BSD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indices for evaluation of slagging and fouling tendencies [Tortosa Masia and other s.]:</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Slagging index: Rs= (B/A)*S (bituminous coal)</td>
</tr>
<tr>
<td>– Fouling index: Fu = (B/A) * (Na₂O + K₂O) (bituminous coal ash)</td>
</tr>
<tr>
<td>– Slag viscosity index: Sr = (SiO₂*100)/(SiO₂+MgO+CaO+Fe₂O₃)</td>
</tr>
<tr>
<td>– Chlorine content</td>
</tr>
<tr>
<td>– Fouling index Rf: CaO+MgO+Fe₂O₃&gt; 20% (w) in dependence on Na₂O (lignite coal ash)</td>
</tr>
</tbody>
</table>
DEBCO Measurement Campaigns at Power Plants

RODENHUIZE, Belgium
Unit 4, 180 MWₑ

KARDIA, Greece
Unit I, 300 MWₑ

Andrea Palladio Plant - Italy
Unit 3&4, 320 MWₑ

PF boilers:
• 100% wood…&BFG
• Lignite/Cynara 90/10
• Coal/RDF 95/5
Mobile Diagnostic Probe (MDP)

- 4 separate heat flux/temperature sensors
- Detachable deposition coupon
- Flue gas sampling system
- Flue gas temperature measurement

• Features
  - Water cooled ash deposition probe
  - Closed (independent) cooling circuit
  - Air cooled tip with T control, 400-700 °C
  - Boiler penetration depth up to 2 meters
  - Outer diameter 60.4 mm
  - Flange installation
  - Cyclone with filter for dust sampling
Mobile Diagnostic Probe – performed measurements

- Ash deposition sampling in the SH area including the total dust sampling
- Online monitoring of the fouling ash behavior
- Flue gas temperature measurement

Results: chemical composition of build up deposit, morphology, fouling, slagging and corrosion indication

Deposition substrate: $T_{surf} = 630°C; 38m$
Results: Fuels, chemical composition and fouling/slagging prediction

<table>
<thead>
<tr>
<th>Fuel</th>
<th>coal RH</th>
<th>wood1</th>
<th>wood2</th>
<th>cyn+coal</th>
<th>wood3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>59.2</td>
<td>43.1</td>
<td>48.7</td>
<td>27</td>
<td>31.6</td>
</tr>
<tr>
<td>Al2O3</td>
<td>25.4</td>
<td>6.33</td>
<td>5.67</td>
<td>11.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>7.2</td>
<td>8.35</td>
<td>12.2</td>
<td>6.23</td>
<td>3.06</td>
</tr>
<tr>
<td>CaO</td>
<td>5.32</td>
<td>19</td>
<td>18</td>
<td>43.2</td>
<td>23.1</td>
</tr>
<tr>
<td>MgO</td>
<td>2.17</td>
<td>4.22</td>
<td>3.87</td>
<td>3.68</td>
<td>5.45</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.86</td>
<td>3.32</td>
<td>3.48</td>
<td>0.45</td>
<td>2.15</td>
</tr>
<tr>
<td>K2O</td>
<td>2.99</td>
<td>7.27</td>
<td>6.11</td>
<td>1.19</td>
<td>7.03</td>
</tr>
<tr>
<td>P2O5</td>
<td>1.03</td>
<td>2.02</td>
<td>1.52</td>
<td>0.32</td>
<td>1.83</td>
</tr>
<tr>
<td>TiO2</td>
<td>1.14</td>
<td>3.49</td>
<td>0.5</td>
<td>0.51</td>
<td>0.37</td>
</tr>
<tr>
<td>Cl</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S</td>
<td>1.00</td>
<td>1.44</td>
<td>0.74</td>
<td>2.32</td>
<td>0.17</td>
</tr>
<tr>
<td>Base acid ratio (B/A)</td>
<td>0.2</td>
<td>0.8</td>
<td>0.8</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Fe/Ca ratio</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Sr (Si percentage)</td>
<td>80</td>
<td>58</td>
<td>59</td>
<td>34</td>
<td>50</td>
</tr>
<tr>
<td>Rf for lignitic</td>
<td>32</td>
<td>34</td>
<td>53</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>Rs for bit</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fu for bit.</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: the ash deposition in the boilers - demo plants

- RH-100% wood
- RH-50/50 wood/coal
- KAR-10/90 cynara/lignite
- KAR-100% lignite
- FUS-5/95 RDF/coal
- Rodenhuiize- 2009
- Kardia- 2010
- Fusina-2011
Results: Online heatflux data expressed in fouling factor

Rodenhuize 2009

T_{\text{flue gas}} = 750-850^\circ C
Results: Online heatflux data expressed in fouling factor

Kardia 2010

Fouling factor $R_f [K \cdot m^2/W]$ vs. Time [min]

- Lignite
- Cynara/lignite 10/90
- $T_{gas}$

$T_{flue \ gas} = 700-750^\circ C$
Results: Online heatflux data expressed in fouling factor

Fusina 2011

- B30-500C
- D9-630C
- B22-570C

\[ T_{\text{flue gas}} = 750-800^\circ C \]
Results: Chemical composition of the boiler ash deposits

Rodenuhize 2009

Composition of the deposit:
- Ca and Si oxides; Mg, Al silicates
- Fine particulates – K₂SO₄

Degradation of metal surface:
- Oxidation, Cr depletion, sulfidation

Deposit appearance
wood 100%:
- Thickness: ~100µm/3h
- BD, compact

Deposit appearance
wood/coal:
- Thickness: ~200µm/3h
- LD, fine powder
Results: Chemical composition of the boiler ash deposits

Kardia 2010

Deposit appearance lignite 100%:
- Thickness: ~1500µm/2h
- LD, fine particles

Deposit appearance Cynara/lignite 10/90:
- Thickness: ~2000µm/2h
- BD, softened agglomerates
Results: Chemical composition of the boiler ash deposits

Fusina 2011

Deposit appearance RDF/coal
- Thickness: ~2000µm/1.8h
- LD powdery to BD with sintered agglomerates; depends on surface T
Conclusions

• Rodenhuize 100% wood:
  – No significant build up of the deposit observed in RH, but fouling related compounds (KCl, K$_2$SO$_4$) were identified... Increase of sticking probability!
  – Potassium, sulphur and even lead was found on larger particles – indication of the heterogeneous condensation.

• Kardia 10% cardoon/ 90% lignite:
  – Significant deposit formation (L-side) and fouling has been observed
  – Current 10% of biomass does not influence the fouling propensity of lignite
  – Potassium detected in form of silicates; decrease of melting point of the ash
  – No sintering at SH level observed - deposit removal with conventional sootblowing technique
  – High concentration of S in the ash (SO$_2$ autocapture) - possible risk of corrosion under the deposits
Conclusions

- Fusina 5% RDF/ 95% coal:
  - Significant deposit formation, fouling and sintering has been observed at 38m level
  - Fine powdery ash deposit formation at 42m (SH level); No sintering
  - Fouling related to probe surface temperature identified
  - The main ash forming compounds – alumina-silicates with elevated amount of calcium, iron and phosphorus; potassium less than 5%wt.; barium
  - Unburnt carbon in raw ash detected; individual particles containing – Cl
Conclusions

• Fouling and ash deposit formation – Rodenhuize, Kardia, Fusina PP boilers
  – Dependent on: fuel chemical composition, the ash content, flue gas temperature and velocity; probe surface temperature
  – No significant increase of fouling and deposit formation during higher share (50%) biomass co-firing
  – can be eliminated using optimized sootblowing

• Fouling propensities related to surface temperature and fuel:
  Bio/coal @500°C > bio/coal @570 °C > 100% bio 500°C > 100% bio @570 °C

• Ash deposition in convective pass:
  – Loose Deposit to Bound Deposits identified; no Slag Deposit
  – Combination of mechanisms of deposit formation (impaction W-side; condensation and thermophoresis L-side)
Thank you for your attention. Questions?

The work on DEBCO project has been done in close collaboration with: