Optical monitoring of KCl vapor in 4 MW CFB boiler during straw combustion and ferric sulfate injection

Tapio Sorvajärvi¹, Joni Maunula², Jaani Silvennoinen² and Juha Toivonen¹

¹ Optics Laboratory, Department of Physics, Tampere University of Technology, P.O.Box 692, FI-33101 Tampere, Finland
² Valmet Oy P.O. Box 109, FI-33101 Tampere, Finland

corresponding author: tapio.sorvajarvi@tut.fi
Content

- Background
- Optical detection of KCl
- Experiments and results
- Conclusions
Background

- Industrial side flows are potential low-cost fuels for heat and power production

- Combustion of low-grade fuels such as straw may produce corrosive alkali chloride vapors

- Proper additives may be used to convert alkali chlorides to less harmful alkali sulfates

- Hot, corrosive and fluctuating conditions make the real-time diagnostics from boilers challenging
Optical detection of KCl

1. IR laser transmission
2. KCl fragmentation
3. Vapor relaxation
Calibration of technique

\[ \frac{I_k}{I_{k0}} = \exp \left[ -\left( 1 - \exp \left( -x'_{KCl} \frac{p}{k_b T} \sigma_{KCl} L \right) \right) \frac{E_p \sigma_K}{\frac{h c}{\lambda_p} A_p} \right] \]

\[ x'_{KCl} = -\ln \left[ 1 + \ln \left( \frac{I_k}{I_{k0}} \right) \frac{A_p}{E_0} \frac{hc/\lambda_p}{\sigma_K} \frac{M_{KCl}}{N_a \sigma_{KCl} L} \right] \frac{1}{L} \left[ x'_{KCl} \right] = \frac{g}{m^3} \]

Tunable parameters:

Physical constants:

Sample specific quantity:
Calibration of technique

- Saturation vapor pressures calculated using HSC 5.1 database.
- DOAS (Differential optical absorption spectroscopy) used as a reference.
- CPFAAS (Collinear photofragmentation and atomic absorption spectroscopy) our technique.
Experiments

- R&D center Valmet (Metso)
- 4 MW CFB boiler
- KCl measurements through 1-m-wide flue gas channel
- Flue gas temperature ~ 850 °C
# Fuel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Wood</th>
<th>Straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total moisture</td>
<td>6.5</td>
<td>9.7</td>
</tr>
<tr>
<td>Bulk density</td>
<td>680</td>
<td>570</td>
</tr>
<tr>
<td>Analysis moisture</td>
<td>2.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Ash 815 °C, Dry basis</td>
<td>0.49</td>
<td>7.5</td>
</tr>
<tr>
<td>Volatile matter, dry</td>
<td>85.1</td>
<td>74.1</td>
</tr>
<tr>
<td>Carbon, C dry</td>
<td>51.8</td>
<td>45.5</td>
</tr>
<tr>
<td>Hydrogen, H dry</td>
<td>6.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Nitrogen, N dry</td>
<td>0.22</td>
<td>0.61</td>
</tr>
<tr>
<td>Oxygen, O dry, calculated</td>
<td>41.3</td>
<td>39.8</td>
</tr>
<tr>
<td>Fluoride, F dry</td>
<td>&lt;0.005</td>
<td>0.01</td>
</tr>
<tr>
<td>Chloride, Cl dry</td>
<td>0.005</td>
<td>0.29</td>
</tr>
<tr>
<td>Sulfur, S dry</td>
<td>0.016</td>
<td>0.13</td>
</tr>
<tr>
<td>Net calorific value</td>
<td>18.51</td>
<td>15</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>390</td>
<td>7600</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>680</td>
<td>3700</td>
</tr>
</tbody>
</table>
Results

Effect of straw on KCl concentration
Results

Effect of ferric sulfate on KCl and HCl concentrations

- HCl measured using sampling FTIR analyzer
- Sulfation reaction: \(2\text{KCl} + \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{K}_2\text{SO}_4 + 2\text{HCl}\)
- Result: \(\Delta\text{KCl} \approx 0.75 \Delta\text{HCl}\)
Conclusions

- In-situ measurement technique for detection of KCl vapor was presented.
- The effect of the straw content in fuel on KCl concentration was monitored.
- The effect of the ferric sulfate injection into the boiler on $\Delta KCl$ and $\Delta HCl$ was monitored real-time.