Using CFD to Reduce Unburned Carbon during Installation of Low NO\textsubscript{x} Burners

CoalGen September 2009

CoalGen Europe 2009 – Sosnowiec, Poland
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Outline

• Background
• Review Coal Modeling
  – Overview of CFD Model
  – Carbon in Ash (CIA) Model
• Existing Operation
• Low NO$_x$ Burners & CIA Minimization
• Conclusions
Background

• Numerous Methods for Coal NO$_x$ Reduction
  – Low NO$_x$ Burners
  – Over Fire Air (OFA)
  – Selective Non-Catalytic Reduction (SNCR)
  – Advance Reburn
  – Selective Catalytic Reduction (SCR)
  – Etc.

• Low NO$_x$ Burners & OFA tend to be most economical
Background

• Low NO\textsubscript{x} Burners & OFA produce local reducing conditions
• Tend to increase CO and CIA
• Expect 50% increase in CIA over existing level
Background – AES Kilroot

• AES Kilroot Power
  – (2) 220 MW Coal (near Belfast)
  – T-fired
  – Current mandate – 650 mg/Nm³
  – New Mandate – 500 mg/Nm³

• RJM Site Survey
  – Optimize existing OFA
  – Low NOₓ Burners
  – 430 mg/Nm³ (~ 33% Reduction)
Background – AES Kilroot

- Current CIA ~ 8.0 - 6.5%, fuel dependant
- Must be below 7% to sell
- Can’t accept a 50% CIA increase
- Use CFD to verify $\text{NO}_x$ performance & Estimate CIA
Review Coal Modelling

• RJM Coal Modelling, over 10 years
  – FLUENT

• RJM has been very successful in estimating $\text{NO}_x$ and CO trends
Review Coal Modelling

• Standard RJM Practice:
  – FLUENT
  – Lagrangian Coal Particle tracking
  • “Path dependent”, 4 stages
Review Coal Modelling

• COAL MODEL STAGES

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Review Coal Modelling

• Previous CIA predictions
  – FLUENT allowed 1 product
  – Either too high (~ 25% CIA with CO₂)
  – Too low (~ 0.01% with CO)

• FLUENT 6.2 allows multiple char reactions

  Reaction 1 - C + O₂ => CO₂
  Reaction 2 - C + CO₂ => 2CO
  Reaction 3 - C + H₂O => CO + H₂
Existing LNCFS Corner Arrangement

- Worst case NOx is Top Mills
Existing Operation

- Three levels only
- Increases on-line reliability
- Have two sets of current operation data
  - a,b,c (upper mills)
  - b,c,d (lower mills)
- Corner numbers shown
## Existing Operation – Upper Mills

<table>
<thead>
<tr>
<th></th>
<th>DATA</th>
<th>CFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>641 mg/Nm\textsuperscript{3}</td>
<td>649 mg/Nm\textsuperscript{3}</td>
</tr>
<tr>
<td>CIA</td>
<td>6.2%</td>
<td>6.48%</td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
<td>4.3%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>

Coal Injection Levels

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# Existing Operation – Lower Mills

<table>
<thead>
<tr>
<th></th>
<th>DATA</th>
<th>CFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{NO}_x$</td>
<td>554 mg/Nm$^3$</td>
<td>560 mg/Nm$^3$</td>
</tr>
<tr>
<td>CIA</td>
<td>4.4%</td>
<td>5.98%</td>
</tr>
<tr>
<td>$\text{O}_2$</td>
<td>3.7%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>
## Existing Operation

<table>
<thead>
<tr>
<th></th>
<th>DATA</th>
<th>CFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIA Upper Mills</td>
<td>6.2%</td>
<td>6.48%</td>
</tr>
<tr>
<td>CIA Lower Mills</td>
<td>4.4%</td>
<td>5.98%</td>
</tr>
</tbody>
</table>

- Improved char model allows prediction of CIA trends!

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Low NOx Burners & CIA Minimization

• Upper Mill Operation – CFD Modelling

<table>
<thead>
<tr>
<th></th>
<th>Existing Operation</th>
<th>Low NO\textsubscript{x} Burners</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>649 mg/Nm\textsuperscript{3}</td>
<td>430 mg/Nm\textsuperscript{3}</td>
<td>(-) 34%</td>
</tr>
<tr>
<td>CIA</td>
<td>6.48%</td>
<td>14.7%</td>
<td>(+) 127%</td>
</tr>
</tbody>
</table>
Low NOx Burners & CIA Minimization

Upper Mill Operation – CFD Modelling

• CIA predicted to increase

• Use CFD model as diagnostic tool
Low NOx Burners & CIA Minimization

CIA Modelling - Diagnostics

Blue is 100% char Oxidation

Red is no char Oxidation
Low NOx Burners & CIA Minimization

Upper Mill Operation – Optimization of SOFA’s

CIA Burnout higher in furnace

Existing Operation

Low NOx Burner Operation

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Low NOx Burners & CIA Minimization

Upper Mill Operation – Combination of CIA Sources

Coal Inj. C
Coal Inj. C & B
Coal Inj. C & B & A
Exit “C” Concentration

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Upper Mill Operation – Change of SOFA “Yaw”

Reduction and Concentration of CIA

Change SOFA “Yaw” angle

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Low NOx Burners & CIA Minimization

Upper Mill Operation – Change of SOFA “Yaw”

Final angle change:

**Predicted CIA 4.7% !**

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Low NOx Burners & CIA Minimiziation

Lower Mill Operation – CIA sources

• Wanted to maintain upper mill Yaw angles
• Upper mill “Yaw”, lower mill operation CIA: 7.5%
• Good value, but too high
# Low NOx Burners & CIA Minimization

## Lower Mill Operation – CIA sources

<table>
<thead>
<tr>
<th>Injection</th>
<th>Mass Flow</th>
<th>% of CIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>d4</td>
<td>0.0672</td>
<td>26.6%</td>
</tr>
<tr>
<td>d3</td>
<td>0.0272</td>
<td>10.8%</td>
</tr>
<tr>
<td>d2</td>
<td>0.0575</td>
<td>22.8%</td>
</tr>
<tr>
<td>d1</td>
<td>0.0226</td>
<td>8.9%</td>
</tr>
<tr>
<td>c4</td>
<td>0.0083</td>
<td>3.3%</td>
</tr>
<tr>
<td>c3</td>
<td>0.00766</td>
<td>3.0%</td>
</tr>
<tr>
<td>c2</td>
<td>0.0131</td>
<td>5.2%</td>
</tr>
<tr>
<td>c1</td>
<td>0.0323</td>
<td>12.8%</td>
</tr>
<tr>
<td>b4</td>
<td>0.00025</td>
<td>0.1%</td>
</tr>
<tr>
<td>b3</td>
<td>0.0055</td>
<td>2.2%</td>
</tr>
<tr>
<td>b2</td>
<td>0.0048</td>
<td>1.9%</td>
</tr>
<tr>
<td>b1</td>
<td>0.00616</td>
<td>2.4%</td>
</tr>
</tbody>
</table>

69% of CIA is from “d” level.
Low NOx Burners & CIA Minimization

Lower Mill Operation – CIA sources

• Modification to lower secondary air supply

• CIA Prediction: 3.45%
AES Kilroot – CFD vs RJM PGT, South African

<table>
<thead>
<tr>
<th></th>
<th>CFD Upper Mills</th>
<th>RJM PGT Upper Mills</th>
<th>CFD Lower Mills</th>
<th>RJM PGT Lower Mills</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx mg/m_0^3 @ 6% O_2 dry</td>
<td>418</td>
<td>444</td>
<td>416</td>
<td>418</td>
</tr>
<tr>
<td>CIA %</td>
<td>4.65%</td>
<td>5.5%</td>
<td>3.45%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>
 AES Kilroot – Final Performance, Upper Mills

<table>
<thead>
<tr>
<th></th>
<th>Baseline - SA</th>
<th>RJM - SA</th>
<th>Baseline - Colombian</th>
<th>RJM - Colombian</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx mg/Nm³ @ 6% O₂ dry</td>
<td>648</td>
<td>444</td>
<td>638</td>
<td>339</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31% Redn</td>
<td></td>
<td>47% Redn</td>
</tr>
<tr>
<td>CIA %</td>
<td>8.0%</td>
<td>5.5%</td>
<td>4.1%</td>
<td>1.25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31% Redn</td>
<td></td>
<td>69% Redn</td>
</tr>
</tbody>
</table>
Kilroot – Low NOx Coal Injection – 110MWe
Conclusions

- Carbon in Ash (CIA) model predicted trends from field
- Model estimated CIA increases due to low $\text{NO}_x$ burners
- Model identified reduction strategies
- Model identified additional equipment modification requirements
- Final field results showed very close agreement with the Model