Doosan Babcock Oxyfuel R & D Activities

The Coal Research Forum
20th Annual Meeting And Meetings Of The Combustion And Advanced Power Generation Divisions

H R Seneviratne,
Date: 22nd April 2009
Department: Research and Development
• Oxyfuel technology

• Studies on oxyfuel technology
  – International Energy Agency (IEA)
  – European Commission
  – Department of Business, Enterprise & Regulatory Reform (BERR)
  – Technology Strategy Board (TSB)

• Test rig work on oxyfuel technology
  – NRTF oxyfuel testing
  – MBTF oxyfuel testing

• Modelling work on oxyfuel technology
  – European Commission
  – Technology Strategy Board (TSB)
  – Department of Business, Enterprise & Regulatory Reform (BERR)
    ✓ CFD modelling of MBTF
    ✓ CFD modelling of a Utility Plant
International Energy Agency (IEA)

- Oxy-Combustion Processes for CO₂ Capture from Power Plant
  - Study led by Doosan Babcock to confirm feasibility and projected costs for CO₂ capture using oxy-combustion technology
  - A new build 500 MWₑ advanced supercritical PF power generation plant firing bituminous coal
  - Paper presented at GHGT-7, Vancouver, September 2004
  - IEA GHG Report No. 2005/09

European Commission

- Enhanced Capture of CO₂ (ENCAP)
  - Development of oxyfuel and pre-combustion CO₂ capture options
  - 600 MWₑ advanced supercritical boiler firing a South African world-traded coal
  - Doosan Babcock lead on detailed PFD and boiler design for oxyfuel
  - Lab- and pilot-scale testing was also undertaken by other project partners
  - Paper presented at GHGT-8, Trondheim, June 2006
Studies On Oxyfuel Technology

Department for Business, Enterprise & Regulatory Reform (BERR)

• Project 366 : Future CO$_2$ Capture Technology Options for the Canadian Market
  – Technical options and economics of oxyfuel and amine scrubbing technology
  – New-build 500MW$_e$ advanced supercritical power plant or as a retrofit to an existing unit.
  – Lignite, sub-bituminous, and bituminous coals
  – BERR Report number COAL R309, BERR/Pub URN 07/1251

• Project 407 : Coal Fired Advanced Supercritical Boiler/Turbine with CO$_2$ Capture
  – Techno-economic evaluation of an advanced supercritical boiler/turbine retrofit; air firing, oxyfuel firing, and amine scrubbing options for CO$_2$ capture
  – Results were compared against the pre-retrofit sub-critical boiler (500 MW$_e$)
  – Paper presented at GHGT-8, Trondheim, June 2006
Test Rig Work On Oxyfuel Technology (NRTF)

European Commission

• JOULE Programme: first to test oxyfuel in Europe (At Doosan Babcock and IFRF)
  – Project started in 1992
• Modified an existing 160kWt combustion test facility
• Fired two bituminous coals under oxyfiring conditions
• Tested the impact of oxyfuel firing on NO\textsubscript{X}, SO\textsubscript{2}, burnout, in-furnace deposition, and convective pass fouling.
• A full report was prepared for the European Commission
  – “Pulverised Coal Combustion System for CO\textsubscript{2} Capture”
• Work included in an IEA review
  – Santos and Haines, Inaugural Workshop, IEAGHG International Oxy-fuel Combustion Network, 2005
Department for Business, Enterprise & Regulatory Reform (BERR)

- OxyCoal-UK phase 1
  - Upgraded the present 160 kWt NRTF
  - Completed a total of 18 test days in discrete periods
  - Used a Colombian word traded coal commonly fired by UK power plants
  - Flue gas cleaning evaluated by other project partners

Technology Strategy Board (TSB)

- Impact of high concentrations of SO$_2$ and SO$_3$ in carbon capture applications and mitigation
  - Understand how SO$_2$ and SO$_3$ interacts with corrosion and mercury under oxyfiring conditions
  - Start in 2009: an on-going project
Test Rig Work On Oxyfuel Technology (NRTF)
Test Rig Work On Oxyfuel Technology (NRTF)

OxyCoal-UK Phase 1: Project partners

- Lead Company
  
  Doosan Babcock Energy

- Industrial Participants
  
  Air Products, e.on UK, RWE, bp

- University Participants
  
  Imperial College London, The University of Nottingham

- Sponsors / Sponsor Participants
  
  Scottish and Southern Energy, ScottishPower, EDF Energy, Drax, DONG Energy, Vattenfall

- Government Support
  
  Technology Strategy Board
  Engineering and Physical Sciences Research Council
  Doosan Babcock Energy
Oxyfuel combustion generates a $\text{CO}_2$ rich flue gas typically 80% v/v dry.
Oxyfuel combustion reduces NO emissions by approximately 50% on a heat input basis (mg/MJ).
Test Rig Work On Oxyfuel Technology (MBTF)
OxyCoal-UK Phase 2: Project partners

- Lead Company
  - Doosan Babcock Energy

- University Participants
  - Imperial College London
  - The University of Nottingham

- Prime Sponsor
  - Scottish and Southern Energy

- Sponsors
  - AIR PRODUCTS
  - e-on UK
  - SCOTTISHPOWER
  - EDF Energy
  - Drax Energy
  - DONG Energy
  - VATTENFALL
  - UK Coal

- Government Support
  - Department of Energy and Climate Change
Test Rig Work On Oxyfuel Technology (MBTF)

Oxygen Storage Area

Oxygen Control Skid
Test Rig Work On Oxyfuel Technology (MBTF)

FGR duct from grit arrestor

Spray cooling system
Test Rig Work On Oxyfuel Technology (MBTF)

PFGR fan

SFGR fan
Plan for OxyCoal™ testing on the MBTF

• Cold commissioning of the new systems
  – Primary flue gas recycle line
  – Secondary flue gas recycle line
  – Transport flue gas recycle line
  – Spray cooling system

• Isothermal testing of the new 40 MWt OxyCoal™ burner

• Hot commissioning of the MBTF
  – Air firing with oil
  – Air firing with coal

• 40 MWt OxyCoal™ testing on the MBTF
  – flue gas recycle rates
  – flue gas recycle oxygen enrichment
  – thermal load
Modelling Work On Oxyfuel Technology

European Commission

• Mathematical Modelling for Oxyfuel Combustion (OxyMod)
  – Development of modelling tools for oxyfuel combustion (CFD and engineering models)
  – Lab- and pilot-scale testing also being undertaken by other project partners

Technology Strategy Board (TSB)

• Optimisation of Oxyfuel PF Power Plant for Transient Behaviour
  – Develop a dynamical model of ultra-supercritical power station with applied oxyfuel combustion

Department for Business, Enterprise & Regulatory Reform (BERR)

• OxyCoal-UK phase 1
  – MBTF OxyCoal™ CFD modelling
  – Utility plant OxyCoal™ CFD modelling

• OxyCoal-UK phase 2
  – MBTF OxyCoal™ CFD modelling
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

- CFD input: Drop tube furnace (University of Nottingham) and PC Coal Lab

- UK bituminous coal, high firing pattern

- Air Firing
  - Low NOx burners
  - Two stage with Boosted Overfire Air
  - Known boiler performance

- Oxyfuel Firing
  - OxyCoal™ burners
  - Single stage operation
  - Maintain PFGR O2 and volumetric flow
  - Stoichiometry 1.17
  - Flue gas weight significantly reduced

- Uniform coal and air distribution,
- Utility plant case: idle burner in-leakage only

<table>
<thead>
<tr>
<th>Component (vol%)</th>
<th>Air</th>
<th>Primary FGR</th>
<th>Secondary FGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2</td>
<td>21.0</td>
<td>18.48</td>
<td>47.23</td>
</tr>
<tr>
<td>CO2</td>
<td>-</td>
<td>75.97</td>
<td>40.96</td>
</tr>
<tr>
<td>H2O</td>
<td>-</td>
<td>2.73</td>
<td>9.62</td>
</tr>
<tr>
<td>N2 (plus inerts)</td>
<td>79.0</td>
<td>2.81</td>
<td>2.19</td>
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</tbody>
</table>

Gas Compositions
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

MBTF modelling

- A single 40 MWt OxyCoal™ burner
- Overfire Air system
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

Oxycoal™ case has higher peak temperature but reduced FEGT
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

OxyCoal™ case has higher local flame CO concentrations but lower furnace exit CO concentrations.
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

OxyCoal™ case has improved char burnout and a narrower flame
Utility plant modelling

- 500 MW<sub>e</sub> front wall fired furnace
- Forty-eight 37 MW<sub>t</sub> burners
- Boosted Overfire Air system

Burner and Furnace Mesh Detail

Furnace Grid Outline
OxyCoal™ case has increased gas temperatures and an elongated flame shape.
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

OxyCoal™ case has increased peak CO, increased exit CO but similar burnout
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

OxyCoal™ case has earlier heat release and higher heat transferred to the furnace.
Modelling Work On Oxyfuel Technology (OxyCoal-UK Phase 1)

Thermal Performance

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Air, Two Stage</th>
<th>OxyCoal™ Single Stage</th>
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</thead>
<tbody>
<tr>
<td>Arch Temperature (°C)</td>
<td>1418</td>
<td>1513</td>
</tr>
<tr>
<td>Furnace Exit Gas Temperature (°C)</td>
<td>1072</td>
<td>1061</td>
</tr>
<tr>
<td>Outlet Temperature (°C)</td>
<td>843</td>
<td>790</td>
</tr>
<tr>
<td>Total Heat In (MW)</td>
<td>1413.6</td>
<td>1411.5</td>
</tr>
<tr>
<td>Heat to Walls (MW)</td>
<td>440.2</td>
<td>544.0</td>
</tr>
<tr>
<td>Heat to Pri and Sec Platen SH (MW)</td>
<td>239.0</td>
<td>270.2</td>
</tr>
<tr>
<td>Heat to SH Inlet and Outlet (MW)</td>
<td>105.4</td>
<td>122.6</td>
</tr>
<tr>
<td>Heat to RH Outlet (MW)</td>
<td>74.2</td>
<td>61.2</td>
</tr>
<tr>
<td>Heat in Flue Gas (MW)</td>
<td>532.0</td>
<td>393.2</td>
</tr>
<tr>
<td>Unburned Loss (MW)</td>
<td>7.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Imbalance (%)</td>
<td>-1.0</td>
<td>-1.4</td>
</tr>
</tbody>
</table>

• Compared to air firing, the OxyCoal™ case gives
  – Higher arch level temperature
  – Similar FEGT, reduced outlet temperatures
  – Increased heat absorption by furnace walls (+24% air case)
  – Increased absorption by platen superheater surfaces (+13% air case)
  – Reduced reheater pick-up

• Radiative heat transfer in oxyfuel case is increased through increased flame temperatures and gas emissivity
## Emissions Performance

<table>
<thead>
<tr>
<th>Plant</th>
<th>MBTF</th>
<th>Utility Plant</th>
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</thead>
<tbody>
<tr>
<td>Scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen (% v/v dry)</td>
<td>2.93</td>
<td>5.30</td>
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<tr>
<td>OxyCoal™</td>
<td>2.98</td>
<td>5.60</td>
</tr>
<tr>
<td>CO (ppm @ 6% O₂)</td>
<td>145</td>
<td>114</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>291</td>
<td>1001</td>
</tr>
<tr>
<td>CO (mg/MJ)</td>
<td>82</td>
<td>12</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>59</td>
<td>122</td>
</tr>
<tr>
<td>Unburned Loss (% GCV)</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Carbon in Ash (%)</td>
<td>1.5</td>
<td>0.1</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>NOₓ (ppm @ 6% O₂)</td>
<td>207</td>
<td>111</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>156</td>
<td>92</td>
</tr>
<tr>
<td>NOₓ (mg/MJ)</td>
<td>94</td>
<td>14</td>
</tr>
<tr>
<td>OxyCoal™</td>
<td>40</td>
<td>10</td>
</tr>
</tbody>
</table>

- **Different CO results**
  - Lower CO emissions for MBTF OxyCoal™
  - Higher CO emissions for utility plant OxyCoal™

- **Different CIA results**
  - Lower CIA for MBTF OxyCoal™
  - Similar CIA for utility plant

- **Reduced NOₓ emission**
  - Negligible thermal source
  - Fuel NOₓ generation limited by flame structure

- **Lower than expected baseline**
  NOₓ and high burnouts may also relate to assumption of ideal furnace operation
  - Fuel/air distribution
  - Air ingress
Concluding Remarks

Doosan Babcock are taking a proactive role in the development and implementation of oxyfuel combustion and carbon capture technologies.

• Started investigating oxyfuel technology since 1992

• Completed numerous studies, rig tests and CFD analysis on oxyfuel technology

• OxyCoal-UK Phase 1: Fundamentals and Underpinning Technologies
  – Theoretical modelling, laboratory and pilot-scale testing to address critical technology gaps
  – Operating experience of the oxyfuel combustion process has been extended

• OxyCoal-UK Phase 2: Demonstration of an Oxyfuel Combustion System
  – MBTF oxyfuel upgrade
  – 40 MWt Oxycoal™ burner testing will be carried out in the near future

• Demonstration of our full-scale (40 MWt) OxyCoal™ burner will form the foundation for an oxyfuel boiler reference design
Contact Details

Thank you for your attention.

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