The EPSRC OxyCAP Project

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Summary

- The Oxy-CAP UK Consortium
- Gaps in the Knowledge of Oxy-fuel Technology
- Project Objectives
- Project Activities - Examples
- Conclusions and What Next?
The OxyCap Consortium

Oxyfuel Combustion - Academic Programme for the UK
(£1,789,493 from EPSRC-EON) 01/11/2009

• Project Partner:

UNIVERSITY OF LEEDS  e.on  UK

UNIVERSITY OF CAMBRIDGE  Cranfield University  Imperial College London  University of Kent  The University of Nottingham

ANSYS  DOOSAN  Doosan Babcock Energy  EPSRC  THE UNLEASHED GROUP

Oxy-CAP UK Consortium
Some Knowledge Gaps in Oxycoal PF Combustion - 2009

- **Combustion behaviour**: impact of different coals on ignition behaviour, impact of varying recycle, modelling, monitoring, etc.

- **Optimum recycled flue gas (RFG) ratio**: to achieve similar combustion and heat transfer characteristics to an air fired operation.

- **Carbon burnout**: this data are only limited to a certain range of coal in the pilot scale studies.

- **Ash formation, slagging and fouling**: the effect of CO$_2$-rich atmosphere on ash formation

- **Materials**: the impact of varying boiler and recycle environments on materials – water wall/superheater corrosion, acid dew-point corrosion

- **Fine particulates, SO$_3$, NO$_x$, trace metal emissions**: differences in conversion of fuel-S to SO$_2$, SO$_3$ etc. and sulphur remaining in ash, levels of unburned carbon, condensates in recycle, etc.

- **Radiative Heat Flux measurements**: changes in heat flux with operating conditions

- Etc.
Oxy-Cap Research Themes

Oxyfuel ($O_2/CO_2$ recycle) combustion capture

- Pilot Scale Tests at Cranfield & Leeds
- CFD Modelling Imperial, Cambridge and Leeds
- Ignition & Imaging Edinburgh, Kent
- Materials Cranfield
- Ash transformation, deposition and burn-out Imperial, Cranfield & Nottingham

Courtesy Vattenfall
OxyCap Objectives

- Develop a new generation of large-eddy simulation (LES) based, CFD models for coal combustion
- Develop a validation and verification environment that integrates experimental results
- Develop computational sub-models for key areas e.g. radiation, particle ignition, particle
- Measure the effect of the partial pressures of O2 and CO2 on oxy-coal combustion phenomena and establish novel experimental techniques for testing new coals and further sets of combustion conditions
- Analyse the interaction of oxy-combustion products with boiler materials, based on realistic flue gas environments and ash slagging behaviour under oxyfuel combustion conditions
- Increase UK advanced scientific capacity in this area
Oxy-CAP UK Tasks Distribution

Task 1
- Sub-Task 1A: Pulverised coal oxy-fuel combustion
- Sub-Task 1B: Coal property measurement for pulverized coal oxy-fuel combustion
- Sub-Task 1C: Oxy-fuel fluidized bed combustion

Task 2
- Sub-Task 2A: LES for pulverized coal combustion
- Sub-Task 2B: Development and validation of advanced sub-models for CFD
- Sub-Task 2C: Full process plant simulation for oxy-coal combustion

Task 3
- Sub-Task 3A: Ash transformation and deposition
- Sub-Task 3B: Corrosion issues in oxy-firing

Task 4
- Sub-Task 4A: Training and development of researchers
- Sub-Task 4B: Collaborations
- Sub-Task 4C: Oxyfuel combustion research forum

Task 5
- Sub-Task 5A & B: Overall financial & technical coordination
- Sub-Task 5C & D: Sub-Task coordination & website

Oxy-CAP UK 2010-2014
Coal/biomass dust ignition tests in oxyfuel atmospheres carried out at the University of Edinburgh.

**R-20 coal ignition experiments**

R-20 ignition chamber, El Cerrejon G145 Jul13 as received (2500J)

- **Pressure Ratio** vs. **Coal Concentration, g/m³**
- Ignition negative for all concentrations at 21 Oxy. Negatives for 25 Oxy 100-200 g/m³

**Ignition Test Chamber**
The impact of CO$_2$ and steam on devolatilisation and char burn-out in relation to normal air firing is being assessed by a comprehensive drop tube furnace (DTF) programme at the University of Nottingham.

The DTF operates up to 1450$^\circ$C which is high enough to achieve the maximum volatile matter yields for coals with relatively short residence times.

The results have indicated the enhanced volatile matter yields and char burn-out rates that can be achieved in CO$_2$. 
Oxy-Coal combustion in a CH$_4$/O$_2$/CO$_2$ burner (Experimental work and providing data for LES modelling)

<table>
<thead>
<tr>
<th>LDV</th>
<th>PIV</th>
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<tbody>
<tr>
<td>System: Dantec Dynamics</td>
<td>System: LaVision</td>
</tr>
<tr>
<td>Probe volume: 0.91 X 0.14 X 0.14 mm$^3$</td>
<td>Imaging area: 60.5 X 52.4 mm$^2$</td>
</tr>
<tr>
<td>Data rate: ~10,000 Hz</td>
<td>Data rate: 3,000 Hz</td>
</tr>
<tr>
<td>Samples: 10,000</td>
<td>Samples: 4,096</td>
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High-speed stereo particle image velocimetry

Oxy-CAP UK 2010-2014
Coal Flame and OH*/CH* Images

Pilot flame

Plain

Air

21% O₂

79% CO₂

25% O₂

75% CO₂

30% O₂

70% CO₂

Plain

Air

OH* Mean

CH* Mean

OH* RMS

CH* RMS

21% O₂ / 79% CO₂
Large Eddy Simulation of the CRIEPI Pulverised Coal Burner
Ash transformation and deposition in oxyfuel environments
- Development of a 250 kW Solid Fuel Combustion Test Facility
- LES CFD modelling of the Oxy-fuel combustion
- 2D and 3-D Flame imaging
- Flow metering and on-line sizing of pulverised coal

Schematic of the 2-D and 3-D flame imaging system

Flame image and temperature distribution
Two main activities are experimental trials in a 100kW retrofitted oxy-combustor, and the development of a kinetic model using Aspen Plus.
100% Daw Mill Coal-52%Recycled Flue Gas (wet)

The recirculation flue gas (RFG) rate was set to be of 52% of the total flue gas. The maximum percentage of CO$_2$ observed was 56.7% wet-based (73.6% in dry-based) when 100% Daw Mill coal was fired.

Aspen Plus Box- plot of the Rate-based Model with Partial Condensation in the RFG
Conclusions and What Next?

**Oxy-Cap progress**
- new data generated on combustion behaviour, new models developed, ignition/burn-out, recycle behaviour, ash behaviour, etc.
- many new skilled researchers trained, and
- increased UK capacity for oxy-combustion research

**Oxy-Cap2 – ‘To accelerate progress towards achieving Operational Excellence for Flexible, Efficient, Controllable, Safe and Environmentally Sustainable Oxy-fuel fired Power Plants.’**
- Oxy-combustion burner design for new and retrofit applications
- Impacts of fuel (coal and biomass) and load changes on boiler/recycle environments and ash behaviour
- Improved understanding of the behaviour of S-, N- and metals including Hg and their impacts on corrosion, gas cleaning requirements and downstream CO₂ separation
- High temperature (fireside) and low temperature (acid dew-point) corrosion, improved materials and component life prediction.
- Development of predictive computational modelling integrated with a dynamic system simulation capability
Thank you for your attention
PACT CO$_2$ Flow Loop Facility at Cranfield

- Current configuration - >90 bar, <40 deg (but capable <700 bar & -50 to 150 deg) in flow mode (fluid flow rates up to 5l/min)
- High pressure observation window - provide detailed information on phase separation, hydrodynamic flows, contamination etc.
- Automated operation
- Continuous monitoring of corrosion by electro chemical noise & Linear polarization resistance
- Measurement and monitoring of physical properties - density, pH, temp, pressure
- Impurities – H$_2$O, H$_2$, H$_2$S, NOx, SO$_2$ and O$_2$ etc.; dedicated MFCs to maintain the proportions
PACT Facilities: Chemical Looping

- **Approx. 50 KW\textsubscript{th}** pilot scale chemical looping facility - **largest UK facility**
- 100 mm ID riser for chemical (adjustable height to assess the scale up effects, 7.3 m ht) and Ca looping (4.3 m ht)
- Flexible in configuration, either as
  - Twin CFB legs or
  - Single entrained flow riser with bubbling bed (2\textsuperscript{nd} reactor)
- Chemical looping mode—either for **oxy-combustion** or for **H\textsubscript{2} production**
- Flexible controls to enable a range of operating modes
- Rig supplied with different bulk gas mixtures---\textit{O\textsubscript{2}, CO\textsubscript{2}, N\textsubscript{2}, H\textsubscript{2} and CO}
- Dedicated **MFCs** for each bulk gas
- Dedicated safety system with controls