Understanding the boiler operation under oxyfuel combustion conditions – Impact to Material Selection

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London, June 18th, 2014
Why oxy-combustion:

Robust:
- ✔ developed from existing components

Flexible:
- ✔ All types boilers, firing systems, fuels
- ✔ Options for operational flexibility
- ✔ Retrofit and “Oxy-Ready” can be addressed

Scale-up:
- ✔ No constraints anticipated for large commercial units up to 1000 MWe, high efficiency with ultra-supercritical steam cycles

Cost competitive:
- ✔ With other CCS & other low carbon generation

Environmentally-friendly:
- ✔ Near Zero Emissions
- ✔ No new chemicals introduced to plant
- ✔ High CO₂ capture rates (>90%)
Oxy-Combustion Plant - Areas of Focus

Air Separation Options
- Cryogenic
- Membranes
- Oxide Carrier Materials

Components
- Scaling
- Integration
- Optimisation

Steam Generator
- Oxyfuel PF Firing
- Oxy CFB
- Chemical Looping

Flue Gas Cleaning
- Particle Removal
- NOx-Removal
- Desulphurisation
- Mercury Removal
- Flue Gas Drying
- Separation of N₂, O₂, ...

Vent Gases
Quality & Efficiency of CO₂ Separation

Materials

Dynamic Behaviour

Air Inleakage

Flue Gas Recirculation

Control & Safety Concepts

Transport & Sequestration

Capture

Oxy-fired Boiler – Impact on material selection- B. Bordenet et al. 17/06/2014– P 3
Alstom oxy-combustion technology
Development steps

Reference Design Studies

Scale-Up

2013

2019

Lab Scale
<3 MWth

Large Pilot Plants
15-30 MWth

Demonstration
150-400 MWe

Full-Scale
600-1100 MWe

Modeling & Tool Dev.

1990s

2008
30MWth Oxy-combustion pilot plant at Vattenfall’s Schwarze Pumpe, Germany

First oxy pilot plant with complete train for CO₂ separation and capture

- Alstom supplied the Boiler, ESP and other components of the flue gas path
- Single Burner down-fired furnace
- Technology partnership with Vattenfall to advance oxyfuel technology

Operation started September 2008

- More than 11,700 operation hours and >10,600 tons of CO₂
- Tests with two lignites (low/high sulfur)
- Test phases with Alstom Burners (Design A+B) finished
- Data on combustion and boiler performance, and component interactions
15MW<sub>th</sub> Oxyfuel pilot plant (BSF)
Alstom Boiler Laboratories, Windsor, CT

Multi-burner, Tangential Fired facility to develop oxy boiler system and generate detailed design and performance data.

Comprehensive Test Program with US DOE ($21.5M USD)

- Testing started Sept. 2009 until 2014
- Evaluate the impacts of different oxy process options and boiler design parameters
- Evaluate the performance of different 8 coals: Subbituminous, Low S bituminous, High S Illinois bituminous coal, North Dakota Lignite & Lausatian Lignite
  - combustion, heat transfer, pollutant emissions, deposition, corrosion …
- Evaluate, improve, and validate engineering and computational tools
- Development of design guidelines
- Commercial Reference Designs
- Demonstration Design
Oxyfuel Prozess - Air vs. Oxy Combustion
Differences of Flue Gas Qualities

Air combustion:

- Air: 21 Vol.-% O₂
  - 79 Vol.-% N₂

Oxyfuel combustion:

- Oxidant: > 21 Vol.-% O₂ < 79 Vol.-% FG

Flue gas compositions:

<table>
<thead>
<tr>
<th>Oxidant</th>
<th>Vol.</th>
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<tbody>
<tr>
<td>Air</td>
<td>21 Vol.-% O₂ 79 Vol.-% N₂</td>
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<tr>
<td>ASU</td>
<td>N₂</td>
</tr>
<tr>
<td>Oxidant</td>
<td>O₂</td>
</tr>
<tr>
<td>SOFO</td>
<td>CO₂</td>
</tr>
<tr>
<td>SOFO</td>
<td>Ar+Inerts</td>
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<tr>
<td>SOFO</td>
<td>H₂O</td>
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<tr>
<td>SOFO</td>
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<table>
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<th>Oxidant</th>
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<tbody>
<tr>
<td>Oxyfuel</td>
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<tr>
<td>O₂</td>
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<td>CO₂</td>
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<td>27.7</td>
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<tr>
<td>SO₂</td>
<td>0.3</td>
</tr>
</tbody>
</table>
30MWth Oxy-combustion pilot plant (Schwarze Pumpe)

SO₂-concentration Air vs. Oxy

- SO₂ concentration in the flue gas is depending on the availability of sulphur sink in the secondary recycle

- Secondary recycle location in the pilot plant is downstream of ESP, also w/o a sulphur sink

- SO₂ concentration in oxy-combustion is approx. 4 times the value in air combustion

- SO₂ loading [mg/MWh] in oxy-combustion is the same as for air-combustion

Specific SO₂-loading is the same for air and oxy
SO\textsubscript{X} in the flue gas – impact of oxy-firing

- Absolute SO\textsubscript{X}-concentration depends on recycling scheme

- Air-firing: reference

- Oxy w/o sulfur capture: increase of factor 3-4 due to flue gas recirculation

- Oxy w/ sulfur capture: small increase as massflow is smaller (= less dilution) in oxy to keep heat input constant

Illinois high sulfur coal @ 15MWth Oxy pilot

Increase in SO\textsubscript{2} even with sulfur capture from recycle
Similar $\text{SO}_3$ Conversion Rate As Air Firing - Economizer Outlet Measurements in 15MWth oxyfuel pilot plant (BSF)

North Dakota Economizer Outlet $\text{SO}_3$ results

Illinois Bituminous Economizer Outlet $\text{SO}_3$ results

Similar $\text{SO}_2$ to $\text{SO}_3$ conversion rates
Similar ash composition

- Ash measurement from 15MWth oxy-pilot (BSF) with North Dakota lignite: no S capture in recirculation loop

- Ash samples from 30MWth Schwarze Pumpe with German (Lausatian) lignite from air- and oxy-firing: show comparable X-ray diffraction spectrum (= mineral composition)

Ash composition similar with higher SO$_3$-content when no S is captured in recirculation loop
Impact on boiler operation

• Heat transfer
  – Comparable to heat transfer experienced in air-combustion
  – Heat transfer profile in the pilot can be adjusted by firing system parameters (e.g. flue gas recycle)

• Burnout
  – Comparable to burnout experienced in air combustion

• Fouling & Slagging:
  – Similar behaviour in air- and oxy-combustion
  – Fly ash and bottom ash do have similar composition in air-and oxy-combustion
Impact on Furnace corrosion

• Waterwall & Fireside corrosion:
  – Similar ash composition:
    ⇒ Similar corrosion mechanisms expected
  – Absolute SO$_X$-content in flue gas and ash is dependent on recycling scheme:
    • w/ sulfur capture in recirculation loop: SOX-content in flue gas only slightly higher than in air
  – Corrosion experience from air-fired could be transferred to oxy-fuel, if SO$_X$-content is maintained within experience range
  – More details in presentation ‘Fireside corrosion under oxyfuel combustion conditions ‘ on June 19th

⇒ oxy-fuel plant can be equipped with standard materials, with monitoring of metal wastage to confirm statements by long-term experience
Impact on ESP / Flue gas recirculation

Prevention of cold end corrosion

- Acid dew point vs. cold end of Regenerative-Gas-Heater:
  - Sulfuric acid formation: $\text{SO}_2$ to $\text{SO}_3$ conversion influenced by reactive surfaces (ash compounds, membrane wall, ...)
  - High moisture and high $\text{SO}_2$ concentrations impact level of acid dew point temperature

Mitigations:
- Proper selection of location for flue gas recycle:
  - Secondary recycle downstream FGD (reduced $\text{SO}_2$ content),
  - Primary recycle downstream FGC (reduced moisture)
- Adjusting temperature according $\text{SO}_X$-level to be above acid dew point by appropriate insulation
Concluding remarks

• Material experience from air-firing can be transferred to oxy-firing, when SO$_x$-content is within experience regime or S capture is installed in the recirculation loop
  – Long term operation and evaluation of material performance in large-scale will be collected to confirm lab / pilot plant results

• Oxy-combustion has successfully achieved development steps over the past ten years.

• Alstom and other oxy pilots across the world provided design data and confirmed robustness of the process.

• We are prepared to demonstrate oxy-combustion at large-scale under real commercial conditions.

• The White Rose project in UK is a promising opportunity and providing a key step for commercialization.
Outlook: White Rose Large Scale oxy-demo project, UK

Location: Drax Power Station, North Yorkshire, UK

- Largest Oxy-Combustion CCS project worldwide: 450MW_e (gross)
- New ultra-supercritical coal-fired power plant with full stream treatment
- Biomass co-firing: zero- or negative - CO_2 emissions
- CO_2 Transport and offshore Storage network by National Grid Carbon Limited
- 90% CO_2 capture-rate
- A Front End Engineering and Design (FEED) Contract has been awarded for the White Rose CCS project, signed by the UK Government on 20th December 2013
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