Simulation of Oxy-combustion co-firing Coal and Biomass with ASU and Steam Turbine using Aspen Plus

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Study the oxy-combustion process, co-firing blends of coal and biomass, through a rate-based simulation model.

The validated model will be used as a tool to select future test parameters.

Pulverised coal / biomass + air or CO2/O2 or natural gas + air

Diagram of 100kWth Multi-fuel Oxy-Combustor at CERT
Simulation Process

BASICS

Limitations of Aspen Plus

- Prediction of adiabatic flame temperature (without considering composition of the gas for the heat transfer)
- Solid residue same composition as ash defined as input (inability to simulate reaction involving solid phase)
Simulations using Aspen Plus® STAGES

<table>
<thead>
<tr>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
<th>STAGE 4</th>
<th>STAGE 5</th>
<th>STAGE 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-firing case</td>
<td>Oxy-firing case with wet recirculation, heat loss and air leakage</td>
<td>Oxy-firing case with partial condensation in RFG, heat loss and air leakage</td>
<td>Oxy-firing case with dry recirculation, heat loss, air leakage</td>
<td>Air-firing case with power generation unit</td>
<td>Oxy-firing case with dry recirculation, heat loss, air leakage, ASU and power generation unit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AIR/ OXY-FIRING</th>
<th>Air-firing</th>
<th>Oxy-firing</th>
<th>Oxy-firing</th>
<th>Oxy-firing</th>
<th>Air-firing</th>
<th>Oxy-firing</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFG (%)</td>
<td>--</td>
<td>55, 60, 65, 70</td>
<td>55, 60, 65, 70</td>
<td>55, 60, 65</td>
<td>--</td>
<td>55, 60, 65</td>
</tr>
<tr>
<td>$O_2$ Exc (%) (v/v)</td>
<td>21</td>
<td>0, 5, 10</td>
<td>0, 5</td>
<td>0, 5</td>
<td>21</td>
<td>0, 5</td>
</tr>
<tr>
<td>$T_{RFG}$ (°C)</td>
<td>--</td>
<td>130</td>
<td>75, 90</td>
<td>130</td>
<td>--</td>
<td>130-200</td>
</tr>
<tr>
<td>Air Leakage (% of Total Gas fed)</td>
<td>--</td>
<td>1.7</td>
<td>0, 2, 10, 18</td>
<td>10</td>
<td>--</td>
<td>10</td>
</tr>
<tr>
<td>Fuel</td>
<td>Coal</td>
<td>Coal (El Cerrejon, Daw Mill), Biomass(Cereal Co-Product, Miscanthus), blends of coal and biomass (75/25; 50/50; 25/75)</td>
<td>Daw Mill coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)</td>
<td>El Cerrejon coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)</td>
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<td>El Cerrejon coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)</td>
</tr>
<tr>
<td>RFG Purification</td>
<td>Particle removal</td>
<td>Particle removal</td>
<td>Particle removal</td>
<td>Particle removal, acid species and water vapour condensation</td>
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</tr>
</tbody>
</table>

- Establish reference cases (Stages 1 and 5)
- Validation of the model by applying similar conditions to experiments (Stage 3)
- Simulations with condenser implemented to include dry RFG (Stage 4)
- Simulation of the entire system including ASU and steam turbine (Stage 6)
Simulations using Aspen Plus®: MODEL VALIDATION

Box-plot of the Rate-based Model (Stage 3)

Interface of the rate-based model with partial condensation on the RFG in Aspen Plus (Stage 3)
Simulations using Aspen Plus®:
AIR INGRESS COMPARISON

2% AIR INGRESS

10% AIR INGRESS

18% AIR INGRESS

10% AIR INGRESS and PARTIAL CONDENSATION
On-going modifications in the Pilot Plant:
WATER AND ACID SPECIES REMOVAL

Diagram of 100kWth Oxy-Combustor with Condenser
Simulations: OXY-COMBUSTION PLANT

Box-plot of the ASU, oxy-combustor and steam turbine (Stage 6)
Simulations: OXY-COMBUSTION PLANT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Air-firing</th>
<th>Oxy-firing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generated (kW)</td>
<td>24.01</td>
<td>25.07</td>
</tr>
<tr>
<td>Power consumed ASU (kW)</td>
<td>--</td>
<td>8.06</td>
</tr>
<tr>
<td>Net power generated (kW)</td>
<td>24.01</td>
<td>17.01</td>
</tr>
<tr>
<td>Net fuel input (kW)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$O_2$ stoichiometric (kmol/h)</td>
<td>0.8973</td>
<td>0.8973</td>
</tr>
<tr>
<td>$O_2$ excess supplied (%)</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>Raw air to ASU (kmol/h)</td>
<td>--</td>
<td>4.70</td>
</tr>
</tbody>
</table>

Simulation results for air and oxy-firing base case
Dry recycle flue gas
EFFECT ON THE EXHAUST
EL CERREJON COAL

- CO₂ increases 20% (v/v) as consequence of implementation of the condenser
- H₂O decreases at the same proportion to the increase of CO₂
- All minor species drop to near zero content in the exhaust gas, in the cases where the condenser was used

EL CERREJON: MAIN SPECIES- Exhaust Gas

EL CERREJON: MINOR SPECIES-Exhaust Gas

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (%)</th>
<th>H₂O (%)</th>
<th>O₂ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Cerrejon (CC)</td>
<td>15.32</td>
<td>0.32</td>
<td>3.64</td>
</tr>
<tr>
<td>El Cerrejon (OC)</td>
<td>68.18</td>
<td>0.58</td>
<td>8.43</td>
</tr>
<tr>
<td>El Cerrejon50%-CCP50% (OC)</td>
<td>66.12</td>
<td>0.85</td>
<td>8.54</td>
</tr>
<tr>
<td>Cereal Co-Product (OC)</td>
<td>72.46</td>
<td>1.48</td>
<td>3.47</td>
</tr>
</tbody>
</table>
Max. CO₂ decreases in the combustion products with higher content of biomass oxy-fired.

H₂O content when burning CCP increases:
- By 10% comparing to oxy-firing 100% coal.
- By 14% comparing to air-firing case.

Marked decrease for SO₂ and NO contents when increasing the percentage of biomass.

Increase in the HCl content as result of the higher content of Cl in the elemental analysis of the biomass (0.17% (w/w) in CCP vs 0.02% (w/w) El Cerrejon).

No significant variation for NO₂ contents.
Power generation decreases generally with higher content of biomass (exception: 60% RFG and 5% exc O₂)

- Power generation is enhanced when a lower %RFG is used.
- Higher power levels achieved when burning without excess of oxygen.

**POWER GENERATION**

- 0% exc O₂-55% RFG
- 5% exc O₂-55% RFG
- 0% exc O₂-60% RFG
- 5% exc O₂-60% RFG
- 0% exc O₂-65% RFG
- 5% exc O₂-65% RFG

KW vs. Fuel Composition:

- 100% EL CERREJON
- 50% EL CERREJON-50% CCP
- 100% CCP
Kinetic Simulation Model has been developed with acceptable agreement with experimental results.

Model validation has been carried out and helped to deduce the amount of air ingress into the process (10% of the total flue gas fed to the combustor).

Simulation model including equipment for CO$_2$ purification predicts remarkable increase of the %CO$_2$ contents.

Last step fulfilled for simulations: delivering of kinetic model including dry RFG, ASU, and steam turbine. Study the effects caused by the variation of the fuel and %RFG on the power generated.


Thanks for your attention

Any questions?

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