Study of oxy-fuel CFB combustion at high oxygen concentrations at IET-CAS

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  - TGA study of oxy-fuel combustion of coal/biomass blends
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Background

- Oxy-fuel CFB is a promising CCS technology in China.
- The total power capacity of CFB boiler is more than 10% of total Chinese coal fire power installation.
- IET-CAS has researched CFB combustion for nearly 30 years.

Main advantages of oxy-fuel CFB combustion

- Efficient heat transfer and uniform heat flux.
- The established CFB advantages also exist in oxy-fuel CFB combustion: low furnace temperatures, hot circulating solids, long solid residence time, etc.
- Reduce boiler size (~50%) using high O$_2$ concentration.
- Multi-fuel capability (coal, petroleum coke, biomass).
- NOx and SOx reduction without back-end cleaning.
- Good fuel burnout and sorbent utilization.
- The same boiler can be operated in air combustion or oxygen combustion mode with CCS.
Oxy-fuel CFB activities at IET-CAS

- Work on oxy-fuel CFB combustion at high oxygen concentrations within the frame of the CAS "Strategic Priority Research Program” Demonstration of Key Technologies for Clean and Efficient Utilization of Low-rank Coal (funded by Ministry of Science and Technology of the People’s Republic of China, 2013-2016)
  - Oxy-fuel circulating fluidized bed combustion technology

- Main research of IET-CAS
  - Build the test facilities for different scale: from bench scale to pilot plant
  - Study of combustion characteristics, operational strategies, heat transfer, hydrodynamics of solid circulation, pollutant formation and control, ash characteristics at high oxygen concentration (up to 55%)
Oxy-fuel CFB test facilities at IET-CAS

- **Bench-scale CFBC 100mm**: 30-50kW, $O_2$: 21-50%
- **Bench-scale CFBC 140mm**: 0.1MW, $O_2$: 35-55%
- **Pilot Plant CFBC 420mm**: 1MW, $O_2$: 21-50%

2014, Commissioning

Scale-up
It was built in 2010 and retrofitted to use recycled flue gas (RFG) in 2012.

- Height: 6 m
- Diameter: 100 mm, 140 mm
- Water cooling tubes embed in the Refractory material to cool the furnace
- Input thermal power: 0.1-0.15 MW
- Total O\textsubscript{2} concentration: 35-55%
- O\textsubscript{2} source: Air separate unit and liquid O\textsubscript{2} tank
1 MWth pilot scale oxy-CFBC facility

Current status: Under construction
Commissioning: June, 2014

Technical data:
- Height: 15 m
- Temperature: up to 950°C
- Total O₂ concentration: 21%-50%
- External Heat Exchanger (EHE) and bayonet exchanger
- Oxygen/flue gas staging: primary, secondary, tertiary injection
Study of oxy-fuel coal combustion in a 0.1 MWth Oxy-CFBC at high oxygen concentrations

Start-up stage

Overall O₂ concentration of inlet gas and coal feed

Combustor temperature

O₂/RFG-mode operation

CO₂ and O₂ concentrations

Pressure drop and temperature
Study of oxy-fuel coal combustion in a 0.1 MWth Oxy-CFBC at high oxygen concentrations

### Experimental conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
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<th>7</th>
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</thead>
<tbody>
<tr>
<td>Combustion mode</td>
<td>O₂/ RFG</td>
<td>O₂/CO₂</td>
<td>O₂/N₂</td>
<td></td>
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<tr>
<td>Average combustor temperature (°C)</td>
<td>850</td>
<td>852</td>
<td>851</td>
<td>856</td>
<td>850</td>
<td>863</td>
<td>850</td>
<td>852</td>
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<td>O₂ source</td>
<td>ASU</td>
<td>LOT</td>
<td>LOT</td>
<td>LOT</td>
<td>ASU</td>
<td>LOT</td>
<td>ASU</td>
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<tr>
<td>O₂ purity (%)</td>
<td>79.1</td>
<td>99.9</td>
<td>99.9</td>
<td>99.9</td>
<td>79.0</td>
<td>99.9</td>
<td>94.9</td>
<td>90.1</td>
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<td>Primary O₂ concentration (%)</td>
<td>49.5</td>
<td>56.7</td>
<td>55.2</td>
<td>55.3</td>
<td>46.6</td>
<td>50.0</td>
<td>52.2</td>
<td>50.1</td>
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<td>Secondary O₂ concentration (%)</td>
<td>45.3</td>
<td>51.5</td>
<td>51.7</td>
<td>51.1</td>
<td>46.2</td>
<td>50.1</td>
<td>51.7</td>
<td>49.9</td>
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<td>Overall O₂ concentration (%)</td>
<td>48.0</td>
<td>54.6</td>
<td>53.8</td>
<td>53.6</td>
<td>46.4</td>
<td>50.0</td>
<td>52.0</td>
<td>50.1</td>
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<td>Ca/S</td>
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<td>2.6</td>
<td>3</td>
<td>0</td>
<td>2.2</td>
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<td>Flue-gas recycle ratio (%)</td>
<td>37.5</td>
<td>47.3</td>
<td>48.0</td>
<td>49.2</td>
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<td>Flue-gas O₂ concentration (%)</td>
<td>1.1</td>
<td>7.51</td>
<td>7.2</td>
<td>5.9</td>
<td>4.3</td>
<td>7.45</td>
<td>5.3</td>
<td>6.57</td>
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<td>RFG O₂ concentration (%)</td>
<td>2.1</td>
<td>7.28</td>
<td>6.7</td>
<td>5.9</td>
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<td>—</td>
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<tr>
<td>CO₂ in flue gas (dry vol%)</td>
<td>67.1</td>
<td>84.1</td>
<td>92.2</td>
<td>93.9</td>
<td>84.1</td>
<td>91.0</td>
<td>44.4</td>
<td>43.3</td>
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<td>Fuel (kg/h)</td>
<td>17.8</td>
<td>17.9</td>
<td>17.9</td>
<td>18.2</td>
<td>17.2</td>
<td>16.5</td>
<td>16.8</td>
<td>17.3</td>
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<td>Fluidization velocity at upper part (m/s)</td>
<td>3.5</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
<td>3.6</td>
<td>3.32</td>
<td>3.6</td>
<td>3.4</td>
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<tr>
<td>Fluidization velocity at lower part (m/s)</td>
<td>4.5</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>4.3</td>
<td>3.93</td>
<td>4.4</td>
<td>4.0</td>
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<tr>
<td>CO (mg/MJ)</td>
<td>803.4</td>
<td>92.2</td>
<td>71.2</td>
<td>99.6</td>
<td>166.6</td>
<td>43.7</td>
<td>104.7</td>
<td>164.5</td>
</tr>
<tr>
<td>NO (mg/MJ)</td>
<td>19.0</td>
<td>21.3</td>
<td>19.4</td>
<td>15.9</td>
<td>36.0</td>
<td>38.0</td>
<td>42.0</td>
<td>41.5</td>
</tr>
<tr>
<td>SO₂ (mg/MJ)</td>
<td>197.0</td>
<td>227.6</td>
<td>159.0</td>
<td>118.8</td>
<td>87.0</td>
<td>52.2</td>
<td>231.0</td>
<td>51.1</td>
</tr>
<tr>
<td>Sulfur capture efficiency (%)</td>
<td>70.7</td>
<td>70.2</td>
<td>79.7</td>
<td>83.9</td>
<td>80.1</td>
<td>92.6</td>
<td>71.6</td>
<td>93.7</td>
</tr>
</tbody>
</table>
Effect of operation parameters on pollutant emission at O$_2$/CO$_2$ fire mode

- The experiments were conducted in 0.1MWth Oxy-CFBC facility.
- The objective is to obtain the data at different operation parameters and evaluate the effect on combustion and emission.

**Operation parameters:**

- **Combustion temperature:** 800°C, 850°C, 900°C
- **Overall O$_2$ concentration:** 35%, 40%, 45%, 50%
- **O$_2$ concentration in primary gas:** 30%~55%
- **excess oxygen/ O$_2$ concentration in flue gas:** 3-8.5%
- **Gas staging**
Effect of operation parameters on pollutant emission at O$_2$/CO$_2$ fire mode

**Effect of overall O$_2$ concentration**

- SO$_2$ (mg/MJ)
- NO (mg/MJ)
- CO (mg/MJ)

**Effect of excess oxygen rate**

- SO$_2$ (mg/MJ)
- NO (mg/MJ)
- CO (mg/MJ)

**Effect of gas staging**

- SO$_2$ (mg/MJ)
- NO (mg/MJ)
- CO (mg/MJ)

**Effect of oxygen staging**

- SO$_2$ (mg/MJ)
- NO (mg/MJ)
- CO (mg/MJ)
TGA study of oxy-fuel combustion of coal/biomass blends

- TGA well established tool for predicting apparent activation energy of combustion of coal/biomass blends.
- Experiment designed to obtain data that can be analyzed in wide variety of ways.

### Experiment conditions

<table>
<thead>
<tr>
<th>Coal</th>
<th>Biomass</th>
<th>Biomass ratio</th>
<th>Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>An semi-coke (SE)</td>
<td>cornstalk</td>
<td></td>
<td>20%O₂/80%N₂</td>
</tr>
<tr>
<td>Two anthracites (AN)</td>
<td>corncob</td>
<td>10%</td>
<td>20%O₂/80%CO₂</td>
</tr>
<tr>
<td>Two bituminous coals (BC)</td>
<td>cotton stalk</td>
<td>20%</td>
<td>30%O₂/70%CO₂</td>
</tr>
<tr>
<td>Two lignites (LI)</td>
<td>wheat-straw</td>
<td>30%</td>
<td>50%O₂/50%CO₂</td>
</tr>
<tr>
<td></td>
<td>rice straw</td>
<td>40%</td>
<td>70%O₂/30%CO₂</td>
</tr>
<tr>
<td></td>
<td>rice husk</td>
<td>50%</td>
<td>90%O₂/10%CO₂</td>
</tr>
<tr>
<td></td>
<td>furfural-residue</td>
<td></td>
<td>100%O₂</td>
</tr>
</tbody>
</table>
While biomass ratio below a certain proportion, the ignition temperature of blend decreases obviously with the increase of oxygen concentration.

It is related with the level of volatiles content and ash content in biomass.
Conclusion/Future work

- Oxy-fuel combustion experiments employing high oxygen concentrations under various gaseous atmospheres were successfully carried out at the IET-CAS facility using the 0.1 MWth oxy-fuel CFBC unit.

- The total experimental oxygen concentration used was in the range of 46.4–54.6%, while oxygen concentration of the primary gas was in the range of 46.6–56.7%. It has been shown that this facility operates reliably in a high-concentration oxy-fuel mode and is able to produce flue gas highly concentrated in CO$_2$ (93.9%).

- The project is supported by Chinese Academy of Sciences from 2013 to 2016. The important study of this project is the building of MWth pilot plant oxy-CFBC facility which can test at high oxygen concentration (up to 50%).

- The current status of 1 MWth pilot scale oxy-CFBC facility is under construction. The commissioning will start on June, 2014.
THANK YOU FOR YOUR ATTENTION!

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