Development of 2nd generation oxyfuel CFB technology – laboratory and pilot scale combustion experiments in high oxygen concentration

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Content

- Introduction to O2Gen – project
- Experimental work and preliminary results:
  - Bench scale BFB
  - Pilot scale CFB
- What next
O₂Gen
Optimization of Oxygen-based CFBC Technology with CO₂ capture

- Project under EU 7\textsuperscript{th} FP
  - started 10/2012, duration 3 years
  - total budget 11.9 M€ (EU contribution 6.6 M€)
- Consortium contains 11 partners
  - 4 companies and 7 research organisations
  - from Spain (5), Finland (3), France (1), Italy (1) and Poland (1)
The project objective is to demonstrate the concept of the 2nd generation oxyfuel combustion that reduce significantly (around 50%) the overall efficiency penalty of CO\textsubscript{2} capture into power plants, from approximately 12 to 6 %-points.

The efficiency improvements will be achieved by

- the use of higher O\textsubscript{2} concentrations in oxyfuel combustion reducing the flue gas recirculation and energy penalty (also enabling boiler size reduction and thus cost reductions)
- integration of ASU (air separation unit) and CPU (CO\textsubscript{2} processing unit) with the power plant reducing energy penalties
- more efficient oxygen production, and CO\textsubscript{2} purification and compression steps

As a result, conceptual design for 600 MWe scale 2nd generation oxygen-fired CFB power plant will be created
Motivation:
Decrease the costs of CCS and making the way towards competitive commercialization of oxy-CFB based CCS technology.
Fluidised bed test facilities
Bench scale BFB and pilot scale CFB

http://www.vtt.fi/img/research/ene/combustion/VTT.html
### Fuel impulse tests

#### Objectives and test matrix

- **Objectives in fuel impulse tests** are to solve how high O$_2$ concentrations affect the
  - char reactivity of coal
  - emission (NO, CO, SO$_2$) formation

<table>
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<th>Test</th>
<th>Fraction, mm</th>
<th>O$_2$ feed (%)</th>
<th>CO$_2$ feed (%)</th>
<th>T</th>
<th>prim, (CO$_2$+O$_2$), Nl/min</th>
<th>sec, (CO$_2$+O$_2$), Nl/min</th>
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Bench scale fuel impulse tests: $O_2$ responses

- When the oxygen concentration in primary and secondary gas increases combustion rate increases.

- Combustion of volatiles, char gasification and combustion occur almost simultaneously in high oxygen combustion, whereas in low concentrations and with larger particles these phases separate.

- Combustion of bituminous coal occurs faster compared to anthracite due to higher volatile content of fuel.
Bench scale fuel impulse tests: Temperature, CO

- Peak temperature increases along with the increase in oxygen concentration
- Char gasification in CO\(_2\) environment increases CO formation
  - CO formation is controlled by feeding secondary gas
- The less oxygen is fed
  - the more CO forms
  - the longer CO forms
Fuel impulse tests: Nitrogen emission formation

NO formation:
- The rate of NO formation increases along with the increase in oxygen feed.
- Formation of NO strictly follows the increase in temperature.
- There no significant change in total amount of N released although the rate of NO formation increases
  - In 50% oxygen feed N$_2$O formation increases and NO formation decreases
Test matrix with anthracite/petcoke blend contained 7 tests:

- Test 1: air reference, medium temperature
- Test 2: oxyfuel 28% (ref. to 1\textsuperscript{st} generation design), medium temperature
- Tests 3-5: oxyfuel 42% (ref. to 2\textsuperscript{nd} generation design), 3 temperature levels
- Test 6-7: Oxyfuel 42%, oxygen staging (prim. O\textsubscript{2} share 60...80%)

- Total feed gas flow and prim./sec. gas share (fluidisation conditions) were constant
- Also Ca/S-ratio (limestone calcium to fuel sulphur ratio, mol/mol) was kept as constant as possible
In all tests UBC losses were low, <1.6 % of fuel LHV
The lowest UBC was measured from high temperature, high-O$_2$ test 3, as expected
CFB-pilot tests
SO₂ formation and capture – tests at medium temperature

- Lower SO₂ emissions and better sulphur capture in high-O₂ oxyfuel conditions (at ~860ºC)
- Also at 28% oxyfuel conditions the sulphur capture was better than in air-firing
CFB-pilot tests
SO₂ formation and capture – high-O₂ oxyfuel conditions

- Clear effect of temperature (tests 3-5), temperatures >850°C were favored
- O₂-staging had no significant effect (tests 4 and 6-7)
At low temperature and high CO$_2$ partial pressure, CaCO$_3$ is not calcined to CaO (direct sulfation to CaSO$_4$).

From the bottom ash analysis it can be seen that poor sulphur capture in test 5 was due to slow direct sulfation of CaCO$_3$ (main part remained as CaCO$_3$).
CaCO₃ – CaO equilibrium

Equilibrium curve according to Marion et al.

- Test 1 Air
- Test 2 Oxy 28%
- Test 3 Oxy 42% - high T
- Test 4 Oxy 42% - medium T
- Test 5 Oxy 42% - low T
- Test 6 Oxy 42% - high prim. O2
- Test 7 Oxy 42% - low prim. O2
CFB-pilot tests
Formation of nitrogen oxides

- NO and N\textsubscript{2}O emissions were clearly higher in air-firing
- In high-O\textsubscript{2} tests:
  - NO was higher and N\textsubscript{2}O lower than in 28% oxyfuel at comparable conditions
  - NO increased and N\textsubscript{2}O decreased with increasing temperature
  - O\textsubscript{2}-staging had relatively small effect on NO or N\textsubscript{2}O
Second set of bench scale tests
  - Temperature changes (750°C & 950°C) in high oxygen concentration combustion

Model for bench scale combustor under development
  - Target: to obtain parameters for pyrolysis, char gasification, char combustion and reactions of nitrogen species
  - Particle model approach for bench scale results

Bench scale modelling results will be implemented to one dimensional CFB furnace model for pilot scale CFB
  - Validation of the model with the data from air-firing and oxy-firing tests under widened operation range (O₂ concentration 21...42 %)
ACKNOWLEDGEMENT

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Projects’ website:
www.o2genproject.eu

More about VTT’s combustion research and services:
http://www.vtt.fi/img/research/ene/combustion/VTT.html