CLC, a promising concept with challenging development issues

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CLC, a promising concept with challenging development issues

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Fluidization XV : May 25th, 2016
Agenda

- **CCS**: CO$_2$ Capture and Storage
- CLC status
  - Concept
  - Economics
  - Materials
  - Pilot plant testing
- CLC technology and scale-up issues for solid fuels
  - CLC scales for coal power plants
  - Fuel reactor concept
  - Control of solid circulation
  - Control of PSD
  - Attrition procedures for oxygen carrier screening
  - Limit ΔP in the Air Reactor to minimize energy penalty
- Concluding Remarks
CO₂ Capture and Storage status

- **2°C Scenario →** Avoid 7 Gt by 2050 (50% from coal power plants)
  - 2016: 15 CCS projects in operation: 28 Mt CO₂ captured
    - this is about 0.4% of the « 2°C target »!!

- **Capture**: pre-combustion, post combustion, oxycombustion
  - Large additional investment, energy penalty

- **Transport** by boat or pipeline (≈1 M€/m(φ) /km (L))
  - Infrastructures are not there yet – permitting issue

- **Storage** in aquifers, oil and gas reservoir, coal beds
  - Storage capacity estimates are very encouraging
  - Public acceptance can be a challenge

- **CCS is a cost with no benefit** (except for EOR projects or CO₂ use)

  - CO₂ storage cost: 15 €/tCO₂ (1 Mt/an) / 5 €/tCO₂ (10 Mt/an)
  - CO₂ capture cost: > 30-40 €/t CO₂ avoided
  - CO₂ transport cost: > 1-3 €/t CO₂ avoided

CO2 market / policy

- Huge investments will happen only with strong CO2 market perspectives
- There are encouraging signs …
  - Regional strategies (China, US, EU, Japan…)
  - Recent global COP 21 Consensus reached in Paris

but only 12% of CO2 emissions under local market regulations yet

Reaching consensus takes time
A time to market delay of 10 -15 years is expected for CCS
Chemical Looping Combustion concept

**CLC for CCS applications first proposed by Ishida (1987, 1994)**

- **Benefits**
  - Low energy penalty
    - (5% with 4% related to CO2 compression cost)
  - Low CO2 avoidance cost
    - our estimate 37€/t CO2

A promising G2 concept to be demonstrated

**Impacts of CCS for a 630 MWe Coal power plant**

**IFPEN Total study (basis: France 2012)**

<table>
<thead>
<tr>
<th>Reference CFB unit</th>
<th>Amine MEA30%</th>
<th>CLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Electric production (MWe)</td>
<td>630</td>
<td>630</td>
</tr>
<tr>
<td>Net Electric yield (%)</td>
<td>44.9</td>
<td>34.9</td>
</tr>
<tr>
<td>Coal consumption (t/h)</td>
<td>198</td>
<td>255</td>
</tr>
<tr>
<td>Capex (M€)</td>
<td>1215</td>
<td>2064</td>
</tr>
<tr>
<td>Opex (M€)</td>
<td>156</td>
<td>220</td>
</tr>
<tr>
<td>Cost of Electricity (€/MWh)</td>
<td>63</td>
<td>98</td>
</tr>
<tr>
<td>CO2 avoidance cost [€/t/CO2]</td>
<td>53</td>
<td>37</td>
</tr>
</tbody>
</table>
CLC material: oxygen carrier

- Several potential oxygen carrier materials (hundreds evaluated already)
  - Metal oxides: Ni, Fe, Mn, Co, Cu (…), perovskites ….

- Several points to consider
  - Oxygen transfer capacity, Reactivity, Aging, Availability, syn.materials or mining ores?

<table>
<thead>
<tr>
<th>Mining Ore</th>
<th>Synthetic material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>spray drying / granulation</td>
</tr>
<tr>
<td>Price</td>
<td>granulation in the range of 10 €/kg</td>
</tr>
<tr>
<td>Recycling</td>
<td>Treatment (hydro/pyrometallurgy? 3-5 €/kg)</td>
</tr>
<tr>
<td>Shape</td>
<td>high sphericity</td>
</tr>
<tr>
<td>Price</td>
<td>0.15 (crude) → 1 €/kg prepared</td>
</tr>
<tr>
<td>Price</td>
<td>back to the ore industry ?</td>
</tr>
<tr>
<td>Price</td>
<td>low sphericity</td>
</tr>
</tbody>
</table>

- Redox aging is the issue
  - No report of successful operation > 500 cycles
  - Relates to ionic migration and volume changes (Fan, 2015)

- Industrial perspective = 15000–30000 cycles per year
  - Impact of aging on process economics is significant

We need to improve oxygen carrier aging performance

Knutsson and Linderholm, 3rd International Conference on CLC, Chalmers (2014)
CLC tools for testing

- Nature of the feedstock greatly impacts design aspects
- For solid fuels: gasification is a limiting step and fuel reactor design is critical
Several pilot plants all over the world

CLC continuous operation successfully achieved (100-200 redox cycles max)
There is a need for optimisation of technology

Investigation of new concepts
- Staged Fluidized bed (TU Hamburg)
- CFB fuel reactor with internals (TU Vienna)

Combustion of volatile materials is an issue

Autothermal operation. Fuel Reactor design?

Ifpen–Total CLC process concepts

**Process constraints**

- to maximize CO$_2$ capture (coal application)
- enough contact for syngas and volatiles combustion
- enough time for gasification reaction (coal application)

**Key Features**

- Carbon conversion per pass > 60%
- CO$_2$ capture rate > 90%
- Oxygen captured from the Air >90%

**Diagram**

- Fuel Reactor
- Oxygen carrier from Air Reactor
- Gasification Zone with Steam and Coal inputs
- Syngas Conversion Zone
- Carbon Stripper zone
- Flue gas flow with Fly ashes And Fines
- Unburnt Coal recycle

Ref: Bourgeon et al., 2nd Int. Conf CLC, Darmstadt (2012)
Control of solid circulation

- **Large flowrates in between interconnected reactors**
  - Control of temperature / oxygen carrier reduction rate

- **CLC is high temperature > 850°C**
  - Not suitable for mechanical valves (FCC Slide valves...)
  - Use of non mechanical L-valves
  - Use group B material oxygen carrier

Gas flow in standpipe relates to $\Delta P$

Solid flow relates to actual gas flow in the valve

Ref: Knowlton and Hirsan, Hydrocarbon Processing (1978) 27, 149-156
Yazdanpanah et al., Powder Technol. (2012), 221, 236-244
Control of PSD: 3 different solids to consider

- **Oxygen carrier** (100–300 microns – design choice)
  Large PSD (L-Valve, carbon stripper separation)

- **Coal** (50–100 microns – design choice)
  Small PSD (Fast gasification, carbon stripper separation)
  → high efficiency cyclones to keep char in the FR

- **Ash**
  - **Fly Ash** (0–100 microns – no choice)
    Avoid accumulation in the unit (L-valve)
    Fly ash elutriation has to be considered
  - **Agglomerated Ash**? (depends from coal and $T_{Fuel~reactor}$)
    Relates to coal composition and $T$ fuel reactor
    Avoid settling at the fuel reactor bottom

Account for PSD changes:
- along the loop
- function of aging
Attrition procedures for oxygen carrier screening

Screening → small samples available with different physical properties \((d_{sv}, \rho_p)\)

Challenge: use a workable attrition index
use comparable testing conditions with similar stress

<table>
<thead>
<tr>
<th></th>
<th>Group A particles</th>
<th>Group B particles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Al</strong>(20) (wt%)</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td><strong>Al</strong>(44) (wt%)</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td><strong>TPGI</strong> (wt%)</td>
<td>27</td>
<td>15</td>
</tr>
</tbody>
</table>

Minimize $\Delta P$ in the air reactor

CLC energy penalty is strongly depending upon air compression:
$\Delta P$ air reactor = 100 mb $\iff$ 0.5% energy penalty

**objective:** find operating conditions that minimize $\Delta P$ in air reactor while maximizing air / oxygen carrier contact

RISER D=0.3m

Data collection

Modelling

Strong unexpected impact of particle shape!

1D model prediction

1D: Drag adjustment needed

CFD: Difficulty to well predict
Core annulus structure

Conclusions

- **CLC is a promising G2 concept for CCS**
  - Favourable economics and limited energy penalty
  - Demonstrated at pilot scale with a limited number of redox cycles (<500)

- **Next step is demonstration:**
  - But aging of oxygen carrier is an important issue to be solved
  - Efforts needed for process optimization, scaling up and other aspects such as flexibility of operation

- **CLC future in the CCS perspective?**
  - Demos are very expensive
    - We need a clear CO2 market perspective
  - Time to market delay to 2025–2030 for CCS?
    - Opportunity to optimize oxygen carrier materials and technology
Acknowledgement to Total and Ifpen research teams that were actively involved and collaborating in the CLC project over the past eight years