Air Separation Unit for Oxy-Coal Combustion Systems

Jean-Pierre Tranier
Richard Dubettier
Nicolas Perrin
Air Liquide

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Current state of the art for ASU

- ASU optimized for oxycombustion
- Integration of ASU in overall oxycombustion solution
- Net Plant Efficiency Comparison
- Gross/Net power consumption of ASU
ASU optimized for oxycombustion

Cryogenic production of oxygen has been used for more than 100 years but is still improving
From today’s most efficient ASUs & the world’s largest ASUs

ISAB IGCC (2x 1800 tpd O₂)
Operation since 1999

Sasol Train 15 (4200 tpd O₂ MSL)
Operation since 2003 (copy order in 2007)

... to a new specific design for oxycombustion

...with additional power reduction through cycle integration
ASU optimized for oxycombustion

20% improvement has already been achieved today in specific energy consumption.
Integration: process simulation

CPU

FG Cleaning & Recycle

Boiler

Pulverizer

ASU

Steam Turbine Cycle

Performance
Net Plant Efficiency Comparison

CO₂ capture from pulverized coal plants is possible with penalty of only ~6 percentage pts

<table>
<thead>
<tr>
<th>Technology</th>
<th>Net Plant Efficiency % (HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC PC Air-Fired</td>
<td>39.4</td>
</tr>
<tr>
<td>IGCC Avg</td>
<td>39.4</td>
</tr>
<tr>
<td>SC PC Air-Fired</td>
<td>28.3</td>
</tr>
<tr>
<td>SC PC Oxy-Fired</td>
<td>29.3</td>
</tr>
<tr>
<td>B&amp;W / AL SC PC Oxy-Fired</td>
<td>33.6</td>
</tr>
<tr>
<td>IGCC Avg</td>
<td>32.1</td>
</tr>
</tbody>
</table>

Sp PC = Super Critical Pulverized Coal – IGCC = Integrated Gasification Combined Cycle

Data from DOE/NETL reports and B&W – Air Liquide studies (2007 – 2008)

Babcock & Wilcox / Air Liquide 2008 results
Cycle analysis

For a 550 MWe net, an HHV efficiency of 33.6% can be achieved today with the following results:

<table>
<thead>
<tr>
<th>Description</th>
<th>MW</th>
<th>Esep ASU (kWh/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross power from steam</td>
<td>724.1</td>
<td></td>
</tr>
<tr>
<td>Gross power for ASU</td>
<td>75.8</td>
<td>160</td>
</tr>
<tr>
<td>Gross power for CO2 CPU</td>
<td>62.4</td>
<td></td>
</tr>
<tr>
<td>Primary, FD &amp; ID fans &amp; miscellaneous</td>
<td>35.9</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-total Auxiliary load</strong></td>
<td>174.1</td>
<td></td>
</tr>
<tr>
<td><strong>Net plant power</strong></td>
<td>550.0</td>
<td></td>
</tr>
</tbody>
</table>
Gross/Net power consumption of ASU

Heat integration:
- Adiabatic compression
- Oxygen preheating to approx. 150 °C
- Condensates preheating to approximately 150 °C
- Gain: 5.6 MW

Net power of ASU: 70.2 MW (i.e. Esep = 145 kWh/t)

Another benefit of oxycombustion is to decrease the flue gas flow and therefore the heat losses associated with the flue gas condenser; this gain has been evaluated at 8.1 MW for a 550 MWe net plant

Therefore the net penalty associated with the oxycombustion route (without CCS) is 62.1 MW
Further ASU improvements

- Specific energy reduction
- Capital expenditure reduction
- Advanced cryogenic ASU concept
Specific energy reduction

- Higher efficiency of new large air compressors
- Additional power savings with new process cycles
- Further reduction with the development of new technologies

A further gain of 10% is targeted for 2015
### Specific energy reduction

<table>
<thead>
<tr>
<th></th>
<th>MW 2008 study</th>
<th>MW 2015 target</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross power from steam</td>
<td>724.1</td>
<td>729.8</td>
<td>+0.8%</td>
</tr>
<tr>
<td>Gross power for ASU</td>
<td>75.8</td>
<td>68.2</td>
<td>-10%</td>
</tr>
<tr>
<td>Gross power for CO2 CPU</td>
<td>62.4</td>
<td>56.2</td>
<td>-10%</td>
</tr>
<tr>
<td>Primary, FD &amp; ID fans &amp; miscellaneous</td>
<td>35.9</td>
<td>37.3</td>
<td>+3.9%</td>
</tr>
<tr>
<td>Sub-total Auxiliary load</td>
<td>174.1</td>
<td>161.7</td>
<td>-8%</td>
</tr>
<tr>
<td>Net plant power</td>
<td>550.0</td>
<td>568.1</td>
<td>+3.3%</td>
</tr>
<tr>
<td>HHV efficiency</td>
<td>33.6%</td>
<td>34.7%</td>
<td>+1.1pt</td>
</tr>
</tbody>
</table>

- Net power of ASU with heat integration is targeted at **130 kWh/t**
- CO₂ capture from pulverized coal plants is expected to achieve **only 4.7 percentage pts penalty**
- With USC cycle (700°C), the HHV efficiency could be above **40%**
Capital expenditure reduction

A capital expenditure reduction program has been launched on the ASU for oxycombustion with a target of -20%
Advanced ASU concept

High pressure cycle with nitrogen production at high pressure instead of atmospheric pressure

11 bar abs

330°C

ASU

Hot nitrogen 5 bar abs

350°C

Adiabatic compression

Hot oxygen

Air
Advanced ASU concept

ASU integration to produce additional power with a dual Rankine (steam) / Brayton (N2) cycle

- Boiler
- Steam turbine
- Nitrogen out 620°C or higher
- Nitrogen at 330°C
- Nitrogen turbine
- ASU
- Oxygen at 330°C
- BFW
- 350+°C
- Air compressor

ASU Oxygen at 330°C Air compressor
Advanced ASU concept

- Lower specific energy of separation: approx. -15% i.e. 110 kWh/t
- Lower CAPEX for the Air Separation Unit: higher pressure means smaller equipment and increased train size (up to 7500 t/d)
- Compressor and turbine offer has to be developed
- High pressure cycle already demonstrated for IGCC application

Puertollano (Spain) Yokohama (Japan)

Most efficient ASU in the world
Conclusions

- Oxycombustion is today the most efficient route for CCS
- Further improvements in the Air Separation Unit are targeted both in term of Power consumption and Capital expenditure reduction
- Advanced cryogenic Air Separation Unit concept is a potential breakthrough for the oxycombustion route
Acknowledgement

Babcock & Wilcox for heat integration studies

Contacts
jean-pierre.tranier@airliquide.com
nicolas.perrin@airliquide.com
richard.dubettier@airliquide.com
Specific energy of separation: definition

- Power required to produce 1 metric ton of pure oxygen contained in a gaseous oxygen stream at a given oxygen purity at atmospheric pressure (101325 Pa) under ISO conditions (15°C, RH 60%)

- Driver efficiency (EM, ST, GT) not taken into account: power at shaft

- Heat of regeneration of driers (steam, natural gas or electrical) not included

- Power consumption of cooling system (CW pumps, fans,...) not included

- Specific energy of production = Specific energy of separation + specific energy of compression

- Specific energy of compression ≈ 0.1xQ(Nm3/h)xlog10(PGOX/PATM)
  - 1 t/h of GOX ≈ 1000 / 1.427637 ≈ 700 Nm3/h
  - For 1.4 bar abs: 10 kWh/t of pure O₂