Pressurised Oxygen Supply for CO₂ Capture Applications

Paul Higginbotham and Vince White

Air Products PLC, Hersham Place, Molesey Road, Walton-on-Thames, Surrey, KT12 4RZ, UK
Purpose of this presentation

- To identify some CO₂ capture processes that need high pressure oxygen
- To explain the elements of the power consumption of an Air Separation Unit (ASU)
- To describe the differences between pumped liquid oxygen (internal compression) and gaseous oxygen compression plants
- To explain why most modern Air Separation Units (ASUs) use the pumped liquid oxygen process
- To dispel the myth that pumping liquid oxygen (LOX) is much more efficient than compressing gaseous oxygen (GOX)
Some CO₂ capture applications that need pressurised oxygen

- **Oxyfuel combustion power generation (coal or natural gas)**
  - 10000 tonnes/day for 500MW
  - 1.3 to 100+ bar
  - 95-98+% purity

- **IGCC power (or syngas) generation**
  - 5000 tonnes/day for 500MW
  - 40 to 100+ bar
  - 95-99.5% purity

- **Oxy-blast furnace**
  - 3500 tonnes/day for 4 million tonnes/annum hot metal
  - 3 to 8 bar
  - 90-97% purity
Elements of ASU power

• Overall power can be expressed as sum of three conceptual processes
  - Theoretical power depends only on feed and product conditions \((T,P,F,x)\)
  - Actual process used affects efficiency

1) Separation of air to oxygen and nitrogen at atmospheric pressure
   - e.g. 130-250 kWhr/tonne \(O_2\) depending on purity, process, capital cost

2) Product compression from atmospheric to required pressure (see graph)
   - e.g. 10 kWh/te at 1.4 bar, 70 kWh/te at 10 bar, 140 kWh/te at 100 bar

3) Product liquefaction - cool and condense any liquid products
   - e.g. 320 to 400 kWhr/tonne \(O_2\)

• Efficiency depends on process selection, power/capital evaluation, operating conditions compared to design point

• Powers can be quoted at different points – shaft power, electric power at motor terminals, at incomer, process users only etc.
Oxygen Specific Compression Power

- Typical values at ISO conditions, based on total flow of oxygen stream
Comparison of processes for pressurised gaseous oxygen

- Basis: typical double column ASU with air expander to low pressure (LP) column
  - Same compression processes can be used with other distillation systems
    - e.g. for three column cycles

- We will:
  - Compare features of each process
  - Look at safety of each process
  - Compare efficiency of processes over a range of pressures
  - Consider effect of oxygen purity
“Traditional” ASU for LP or HP O₂ – GOX from LP Column, optional compression
Features of LP column GOX compression process

- Main air compressor only (no booster air compressor)
- All air enters column system as vapour
- GOX product from LP column - Condensing nitrogen in reboiler-condenser boils LOX in column
- Refrigeration provided by expander to LP column
- If pressurised GOX is needed, add compressor - atmospheric pressure suction means large suction volume
“Modern” ASU for low pressure O₂
LOXBOIL process
Features of LOXBOIL process

• Main air compressor (MAC) only (no booster air compressor)
• LOX pressurised by static head
• LOX boiled in separate reboiler by condensing MAC air
• Air from LOX boiler enters columns as liquid (heat balance)
• Refrigeration provided by expander to LP column

• Compared to GOX from LP column
  - GOX pressure can be higher (air condenses hotter than N$_2$)
  - Column system is more efficient (intermediate liquid air reflux) (typically saves ~ 1-3% of separation power)
  - Smaller HP column and main reboiler, additional LOX boiler
Separation efficiency – McCabe-Thiele diagrams for GOX vs. LOX
Upper LP column - GOX

Profile (G)

No liquid air feed
Upper LP column - LOX

Liquid air feed
“Modern” ASU for high pressure $O_2$
Pumped-LOX process
Features of pumped-LOX process

- Similar to LOXBOIL but:
- Booster Air Compressor (BAC) added
- Pump increases LOX pressure
- LOX boiled at pressure in main heat exchanger by condensing boosted air
- Liquid air may be expanded in dense fluid expander (DFE)
- Refrigeration may also be provided by expander to HP column (from BAC)
- Flexible to design for wide range of liquid production (liquefaction power can be added to BAC)
Both Pumped-LOX and GOX compression are safe

<table>
<thead>
<tr>
<th>Safety measure</th>
<th>Pumped-LOX</th>
<th>GOX compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon control</td>
<td>Inherent concentration ratio limited to 5:1</td>
<td>Limit concentration with LOX purge ( &gt;0.2% air, &lt;500:1)</td>
</tr>
<tr>
<td>CO\textsubscript{2}/N\textsubscript{2}O freeze-out control</td>
<td>Limit breakthrough from front end TSA</td>
<td>Limit breakthrough from front end TSA</td>
</tr>
<tr>
<td>Safety standards – Remove ignition Remove promoter Prevent propagation Protect Personnel</td>
<td>Filtration Min. O\textsubscript{2} velocity Min. air pressure Cold box relief</td>
<td>Minimum clearances Non-contact seals Oil/Grease-free Compatible materials Compressor barriers</td>
</tr>
</tbody>
</table>
Power Comparison – Loxboil with compression vs. pumped-LOX

• Compare powers over a range of oxygen pressures
• Pumped-LOX vs. LOXBOIL with compression to eliminate differences due to intermediate liquid air feed
• With and without dense fluid expander (DFE)
• Plant optimised for typical balance of power and capital cost

• Pumped-LOX 3% better to 3% worse depending on oxygen pressure and plant configuration
Low purity oxygen has optimum purity

- Compare compression and separation power
  - When is it better to separate impurities than compress them?
- Considering ASU alone, delivering same contained oxygen
  - Separation power increases with purity (not pressure)
  - But power to compress impurities increases with pressure
  - For oxygen at any pressure, there is an optimum purity
    - total power increases above and below this purity
  - Optimum purity ~97% above ~80bar
    - separation power increases steeply above 97% purity
- Should also consider overall CO$_2$ capture system
  - CO$_2$ purification/compression power vs. O$_2$ separation power
    (no air leaks in pressurised systems, but impurities in fuel)
  - Usually increases optimum O$_2$ purity
Optimal $O_2$ purity increases as pressure increases (ASU only)

- 30 bar, 90% purity
- 60 bar, 95% purity
- $>80$ bar, 97% purity

- Typical curve – details depend on process selection
Conclusions

- A number of oxyfuel processes need high pressure oxygen
- ASU power depends mainly on ambient and product conditions
- Pumped-LOX and GOX compression have similar efficiencies
  - BAC power balances GOX compressor power
  - Varies ± few% with oxygen pressure and plant configuration
- Taking LOX vs. GOX from the LP column is a few % more efficient due to the benefit of liquid air reflux
- Both Pumped-LOX and GOX compression processes are safe
- Most modern ASUs use pumped-LOX cycles because of:
  - more flexibility in design and operation
  - benefits in capital cost and availability
- Optimum O₂ purity increases to ~97% above ~80bar
Thank you...
tell me more