New Gas Turbine Integration Options for ITM Oxygen in Gasification Applications

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Cryogenic Distillation is state-of-the-art for tonnage oxygen

- Mature, reliable technology
- Energy intensive
- Requires 100’s of equilibrium stages
- Represents ~15% of IGCC capital cost
- Consumes ~15% of IGCC gross power output
Ion Transport Membranes (ITMs) produce high-purity oxygen at high flux

- Mixed-conducting ceramic membranes (non-porous)
- Typically operate at 800-900 °C
- 100% selective for O₂
- \[ \text{O}_2 \text{ flux } \propto \frac{1}{L} \ln \left( \frac{P'_{O_2}}{P''_{O_2}} \right) \]
We are building ½-ton/day commercial-scale ITM modules ...

- Single-stage air separation yields compact designs
- Low ΔP on the air side
- All-ceramic construction
- High-temp process has better synergy w/ gasification systems
... and testing them in pilot plant

- Heat Exchangers
- 6 Independent Product Trains
- Vacuum Pumps
- Control Room
- Heater
- Make-up Streams
- ITM Vessel
- ITM Vessel Internals
- 2 Modules Installed
- Flow Duct Installed
Initial pilot plant testing highly successful

- Several trials with ½-ton/day modules during the last year
- Demonstrated >99% oxygen purity from commercial-scale module and seal
- Oxygen flux consistently met or exceeded expectations and has remained steady over multi-week tests
- Just completed retrofit of advanced control system to improve reliability during startup/shutdown cycles
ITM Oxygen integrates well with gas turbine power cycles

e.g., Siemens SGT6-6000G ~300 MW
Full integration with advanced gas turbine poses challenges ...

- ITM-SPECIFIC GAS TURBINE
- RECUPERATOR?
- OXYGEN COMP’R
- OXYGEN SUPPLY to GASIFIER
- OXYGEN COOLING
- SYNGAS
- VITIATED AIR
- OXYGEN
- ION TRANSPORT MEMBRANE
- ΔP
- ΔP
- ΔP
- ΔP
- 800 – 900 °C
- HRSG
- STEAM
- ELECTRIC POWER
- Air extraction limitations
- e.g., Siemens SGT6-6000G ~300 MW

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Multi-dimensional evaluation determined optimum configuration

Boost compressor / recuperator yields best overall IGCC
Boost compressor / recuperator minimizes GT design impact

Siemens SGT6-6000G ~300 MW

Oxygen supply to gasifier

Oxygen comp’r

Oxygen cooling

Recuperator

Vitiated air

Oxygen

ION transport membrane

Syngas

Syngas

Oxygen comp’r

Oxygen comp’r

Boost comp’r

Siemens

ITM-specific gas turbine

HRSG

Steam

Electric power
SGT6-6000G gas turbine modifications for ITM Oxygen

Compressor Section:
  Compressed air extraction (55%)

Combustion Section:
  Vitiated air injection
  Syngas combustion with vitiated air

Casings & Structural:
  Hot gas piping & manifolding
Partial integration with standard GT also achievable ...

... while preserving significant benefits for IGCC

- Integration with modified ITM Oxygen cycle can reduce IGCC specific capital cost by 9% and increase efficiency by 1.2%, with 25% capital savings in oxygen production.

<table>
<thead>
<tr>
<th>2-on-1 GE 7FA+e design basis</th>
<th>Cryo O2</th>
<th>ITM O2</th>
<th>Δ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGCC Net Output (MW)</td>
<td>543</td>
<td>627</td>
<td>+15</td>
</tr>
<tr>
<td>IGCC Net Efficiency (% HHV)</td>
<td>38.4</td>
<td>38.9</td>
<td>+1.2</td>
</tr>
<tr>
<td>Oxygen Plant Cost ($/sTPD O₂)</td>
<td>25,000</td>
<td>18,700</td>
<td>-25</td>
</tr>
<tr>
<td>IGCC Specific Capital Cost ($/kW)</td>
<td>1,500</td>
<td>1,368</td>
<td>-9</td>
</tr>
</tbody>
</table>

- ITM Oxygen plant capacity: 4,550 sTPD oxygen + 13,200 sTPD diluent
Minimal integration using dedicated ITM GT offers flexible flowsheet

“Stand-alone” ITM Oxygen plant with minimal power co-production:
10 MWe per 1000 TPD Oxygen
60 MWe per 4500 TPD Oxygen
(e.g., with Siemens GT35P, GT140P)

Oxygen-consuming application, e.g., IGCC, oxycoal combustion, etc...
GT35P/GT140P developed for full air extraction and off-board combustion

- 6 GT35P PFBC installations world-wide ('89-'98)
- 1 GT140P PFBC installation ('99)
ITM dev’t plan meets FutureGen schedule and market timing

(large energy applications)

FutureGen

Phase 3

Phase 2

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The future remains bright for ITM Oxygen

- Commercial-scale ITM Oxygen modules are being built and tested successfully

- Conceptual full integration with SGT6-6000G maximizes ITM benefits while minimizing GT design / development impact
  - Partial integration with standard OEM gas turbine preserves significant benefits
  - Minimal integration using dedicated ITM GT offers good early entry prospects

- Air Products and the DOE are accelerating development of ITM Oxygen to reach large-tonnage scale for FutureGen plant
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