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
- $O₂$ flux $\propto \frac{1}{L} \ln \left( \frac{P^{'}_{O₂}}{P^{''}_{O₂}} \right)$

$$\frac{1}{2}O₂ + 2e^- \rightarrow O^{2-}$$

$$O^{2-} \rightarrow \frac{1}{2}O₂ + 2e^-$$

compressed air

L

O^{2-}

electrons

oxygen

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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
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

- **AIR**
- **HRSG**
- **STEAM**
- **ELECTRIC POWER**
- **SYNGAS**
- **NON-PERMEATE**
- **VITiated AIR**
- **OXYGEN**
- **ION TRANSPORT MEMBRANE**

- **SYNGAS OXYGEN SUPPLY to GASIFIER**
- **OXYGEN COMPR’R**
- **OXYGEN COOLING**

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

- **Air** extraction limitations
- **Oxygen Comp’r** limitations
- **Recuperator** limitations
- **Vitiated Air** limitations

**Equipment**:
- **ITM-Specific Gas Turbine**
- **HRSG**
- **SYNGAS**
- **STEAM**
- **Electric Power**
- **Oxygen Comp’r**
- **Oxygen Transport Membrane**
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

SIEMENS

Boost Comp’r

Recuperator

Oxygen Comp’r

Oxygen supply to gasifier

Oxygen cooling

Oxygen

Vitiated air

Ion transport membrane

Syngas

Syngas

Steam

Electric power

Air
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)

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Oxygen-consuming application, e.g., IGCC, oxycoal combustion, etc…

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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

Capacity (TPD)


5000+
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.
Acknowledgment: DOE/NETL

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