Oxygen Production Technologies: Cryogenic and ITM

by:

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Oxygen Production Technologies: Cryogenic and ITM

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Air Separation

- Cryogenic air separation includes these major steps:
  - Compressing air
  - Air impurity removal (Pretreatment)
  - Cooling/liquefying air
  - Distillation

- Scale up of advanced oxygen production technology – ITM Oxygen
The ASU Process

Main and Boost Air Compression

Air Cooling and Pretreatment

Cryogenic Separation

Storage

Main & Boost Air Compression

- Inlet air flow determines machine selection

Air Flow

Axial-Radial

Integral Gear Centrifugal

In-line Centrifugal

Oxygen
Cryogenic Heat Exchange

- Brazed aluminum plate fin exchangers
- Cools air streams against product streams to recover refrigeration
- Ambient to cryogenic temperatures

Separation by Distillation

- Gaseous Oxygen (Oxygen Compressor Option)
- Air
- Liquid Oxygen Nitrogen

- “Cold Box”
- Pure Nitrogen (Boils at -190°C / -310°F)
- Pure Oxygen (Boils at -177°C / -286°F)
- Pure Nitrogen (Boils at -175°C / -283°F)
- Enriched Air (Boils at -168°C / -270°F)
Manufacturing

- Manufacture/erection approach is project specific

- **Shop manufactured distillation columns**
- **Shop manufactured cold boxes**
- **Field erected column can**

ITM Oxygen Enables a Step-change Reduction in the Cost of Oxygen

- Conceptional ITM Oxygen vessel scaled to match cryogenic oxygen plant output
Ion Transport Membranes (ITM): High-flux, High-purity Oxygen

- Mixed-conducting ceramic membranes (non-porous)
- Typically operate at 800-900 °C
- Crystalline structure incorporates oxygen ion vacancies
- Oxygen ions diffuse through vacancies
- 100% selective for O₂

\[ O_2 \text{ flux} \propto \frac{1}{L} \ln \left( \frac{P_{O_2}}{P_{O_2}'} \right) \]

Compressed air decomposes:

\[ \frac{1}{2}O_2 + 2e^- \rightarrow O^2- \]

100% selective for O₂

Ceramic Membranes: Revolutionary Technology for Tonnage Oxygen Supply

- Single-stage air separation leads to compact designs
- Low pressure drop on the high-pressure side
- High-temperature process has better synergy with power generation systems
- Extraordinary flux enables large tonnage production economics

0.5 TPD module (commercial-scale)
ITM Oxygen integrates well with power generation cycles

ITM Oxygen separator integrated with a gas turbine-based power cycle

ITM Oxygen is Simpler and Requires Less Power

ITM O2 Has Much Simpler Flow Sheet and >35% Less Capital
ITM O2 Has 35-60% Less Compression Energy Associated with Oxygen Separation
ITM Oxygen has Excellent Economic Performance in Many Applications

<table>
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<th>Application</th>
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<th>Power (MW)</th>
<th>Capital for Oxygen</th>
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† enables carbon capture
* uses existing gas turbine offerings

ITM Oxygen Program

- **Goal:** Reduce Cost of Oxygen by One-Third
- **DOE/Air Products R&D started 1999 (11 year, $148 million)**
  - Phase 1: Technical Feasibility (0.1 TPD O2)
  - Phase 2: Prototype (1-5 TPD O2)
  - Phase 3: Pre-commercial Development (25+ TPD)
    - Planning 150 TPD
- **Development Team**
The SEP was started up in Oct. ’05, commissioned in April ‘06
Initial SEP work highly successful

- Several trials with 0.5-TPD modules since May
- Demonstrated >99% oxygen purity from commercial-scale module and seal
- Oxygen flux consistently has met or exceeded expectations, and has been steady
- Currently running modules through start-up/shutdown cycles to test reliability
Conclusions

- Cryogenic air separation proven and available at scale
- Major Phase 2 ITM Oxygen development objectives have been met
  - Built and tested commercial-scale ITM Oxygen modules successfully
- Air Products and the U.S. DOE are planning an expanded Phase 3 to enable ITM Oxygen to produce large-tonnage quantities of oxygen in the FutureGen plant

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