the ENERGY lab

PROJECT FACTS

Existing Plants, Emissions & Capture

Oxy-combustion: Oxygen Transport Membrane Development

Background

The mission of the U.S. Department of Energy's (DOE) Existing Plants, Emissions & Capture (EPEC) Research & Development (R&D) Program is to develop innovative environmental control technologies to enable full use of the nation's vast coal reserves, while at the same time allowing the current fleet of coal-fired power plants to comply with existing and emerging environmental regulations. The EPEC R&D Program portfolio of post- and oxy-combustion carbon dioxide (CO_2) emissions control technologies and CO_2 compression is focused on advancing technological options for the existing fleet of coal-fired power plants in the event of carbon constraints. This project is one of six R&D carbon capture projects from the EPEC program that were selected by DOE to receive funding from the American Recovery and Reinvestment Act of 2009 (ARRA). These projects will accelerate carbon capture R&D for industrial sources toward the goal of cost-effective carbon capture within 10 years.

Laboratory-scale OTM Coal Reactor

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PARTNERS

University of Utah
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PERFORMANCE PERIOD

Start Date
04/01/2007

End Date
09/30/2015

U.S. DEPARTMENT OF ENERGY

Oxy-combustion, or burning of fuel in an atmosphere of nearly pure oxygen to generate flue gas consisting primarily of CO_2 and water, has been established as a credible means to facilitate CO_2 capture from coal power plants. The economics of conventional oxy-combustion processes are currently limited by the parasitic power required for cryogenic oxygen production in conventional air separation units (ASU). A further limitation of oxy-combustion is the requirement that a portion of the CO_2 in the exhaust must be cooled and recycled in order to maintain the temperature in the combustion chamber within practical limits. Praxair has developed a novel oxygen transport membrane (OTM) technology that has the potential to solve both of these issues. OTMs can be integrated such that there is minimal need for air compression, which can reduce the parasitic power consumption required for oxygen production by 70 to 80 percent compared to cryogenic ASU. The cost-effective production of oxygen will likewise benefit the generation of synthesis gas (syngas), which is produced by the gasification of carbon-based fuels combined with steam and oxygen. The syngas can then be converted into separate hydrogen and CO_2 gas streams as a way to make electricity, fuels, or chemicals while preventing the release of CO_2.

The basic principle behind the OTM oxy-combustion system is the use of chemical potential instead of pressure as the oxygen separation driving force. In conceptual designs, the OTM is integrated directly with the boiler. The combustion reaction on the fuel side of the membrane creates a very low oxygen partial pressure compared to the air side of the membrane. This difference in chemical potential drives oxygen through the membrane without the need for additional air compression.

A key step toward the commercialization of OTM technology for utility-scale power generation is the demonstration of OTM devices in industrial-scale applications. Development and commercialization of reactively-driven OTM devices at this smaller scale will provide real-world experience and exhibit the operability, maintenance requirements, and robustness required to accelerate future investment at a utility power plant. The lower-cost production of oxygen through OTM technology can be utilized in industrial applications such as syngas generation as well as oxy-combustion technologies.

Project Description

Under a prior agreement with DOE, Praxair determined that the cost of CO_2 capture utilizing OTM air separation integrated with oxy-combustion is competitive with other CO_2 capture processes when applied to large power plants. This work also demonstrated that durable OTMs for oxy-combustion can be fabricated to survive and maintain reliability in a fuel environment. During prior testing, Praxair observed a zero percent failure rate for the OTM membranes. However, the highly durable materials selected for the OTM reactors require substantial development in order to improve the oxygen flux through the system while maintaining durability and reducing manufacturing costs. In the first stage of this project, Praxair will further develop high-performance materials used for OTMs, optimize and test process configurations, validate manufacturing capabilities, and produce a preliminary engineering design for an OTM pilot plant system.

With the addition of ARRA funding, the second stage of this project will operate OTM modules in syngas and oxy-combustion development- and pilot-scale tests incorporating critical system components that would be required of commercial systems. Praxair will develop and operate a robust and reliable OTM module that will be the building block for commercial deployment of reactively driven ceramic membrane systems. First-generation OTM modules will be developed and tested in a developmental-scale, fully integrated, multi-module syngas system producing 160,000 standard cubic feet per day (scfd) of syngas and incorporating all components of a commercial system. Second-generation OTM modules will be developed incorporating improvements identified through module testing. The performance of the OTM modules will then be assessed in a development-scale fully integrated 1 megawatt thermal (MWth) oxy-combustion system. Evaluation of the results from all testing and modeling will be used to develop preliminary cost estimates for a demonstration-scale syngas system and a pilot-scale oxy-combustion system.

Primary Project Goals

The project goal is to achieve optimization of OTM performance, materials, and process configurations leading to the subsequent field testing of OTM technology for both syngas production and oxy-combustion applications, providing valuable experience needed to develop commercial OTM technology in industrial applications and, ultimately, future utility-scale power generation applications.

Objectives

Phase I Objectives:

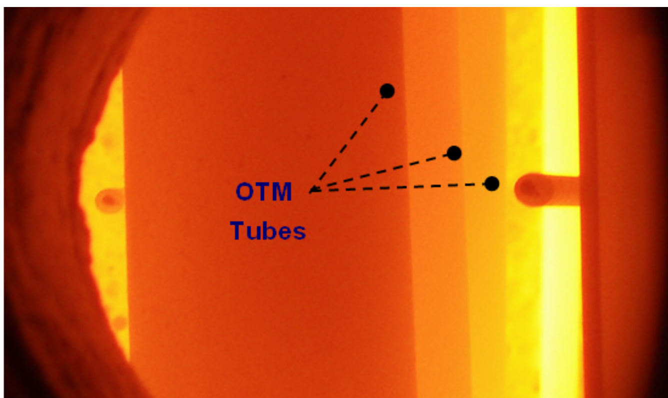
- Increase oxygen flux of OTMs to commercial targets while maintaining the current levels of strength and reliability.
- Develop and down-select an optimal process integration cycle for an OTM coal-based power system with CO_2 capture.
- Test the effects of coal and flue gas impurities on the performance of OTMs.

Phase II Objectives:

- Demonstrate ability to produce OTM tubes with the appropriate dimensions and manufacturing yield required to proceed with pilot demonstration.
- Deliver preliminary engineering design for OTM pilot plant system.

Phase III Objectives:

- Demonstrate conversion of natural gas to 160,000 scfd of synthesis gas in a skidded OTM integrated pilot-scale system.
- Demonstrate OTM oxy-combustion and heat transfer at high rates of fuel utilization in a developmental-scale system.



Oxy-combustion on OTM surface.

Planned Activities

- Evaluate OTM performance improvements in single- and multi-tube OTM reactors at Praxair research facilities in Tonawanda, NY.
- Design, construct, and operate a bench-scale OTM-coal reactor at the University of Utah for the evaluation of OTM performance in a coal-based power system.
- Conduct OTM manufacturing process development at Saint Gobain manufacturing facility.
- Develop detailed process models of an OTM Syngas unit and an OTM Combustion unit that, once validated, will be used for development of functional equipment specifications for techno-economic analysis, as well as to create a detailed process and instrumentation diagram (P&ID) for identification of unit operations to be designed.
- Design, optimize, and test first generation OTM modules, the building blocks for the multi-module OTM systems.
- Design the unit operation process equipment identified in the P&IDs, including the reactors housing the OTM modules, for both the syngas and oxy-combustion units.
- Perform testing on the development-scale syngas system (160,000 scfd), which will validate all required startup and shutdown processes as well as the overall performance of a fully integrated system.
- Develop a development-scale oxy-combustion system to test the performance of the OTM modules operating in a combustion mode and validate all required startup and shutdown processes as well as the overall performance and design guidelines for larger scale systems.

Accomplishments

- Demonstrated stable OTM performance with sulfur impurities in simulated coal-derived fuel gas.
- Developed pilot plant specifications for OTM oxygen flux and fuel utilization.
- Continued OTM performance improvement through characterization and manufacture of OTM tubes, and preparations for scale-up.
- Demonstrated achievement of flux and performance targets with advanced OTM materials.
- Developed manufacturing protocol for pilot-sized OTM tubes.
- Completed design and construction of the OTM multi-tube reactor at the University of Utah.
- Designed a hot oxygen burner (HOB) coal gasifier to achieve required testing parameters for the OTM system. The HOB was tested at Praxair's facilities and then sent to the OTM reactor at the University of Utah for integration. Testing on coal-derived syngas has been initiated.
- Developed conceptual design of prototype OTM module.
- Completed a Technology Evaluation Study of the Praxair OTM technology and all its potential uses/benefits. The study will contain projections on the amount of cost savings, CO_2 reduction potential, CCS capabilities, and other positive environmental and cost factors from application of the technology to both industrial and utility sectors.
- Selected Saint Gobain as the ceramics development and manufacturing company.

COST

Total Project Value
$65,128,206

DOE/Non-DOE Share
$41,188,249/$23,939,957

DOE Base/ARRA
$6,188,249/35,000,000

Government funding for this project is provided in whole or in part through the American Recovery and Reinvestment Act (ARRA).

AWARD NUMBER

DE-FC26-07NT43088

Benefits

The development of an OTM-based coal-fired power generation process will aid in attaining the EPEC program goals of advanced power generation that can achieve 90 percent CO_2 capture with less than a 35 percent increase in the cost of electricity. The OTM oxy-combustion system can provide a highly concentrated, sequestration-ready stream of CO_2 without costly cryogenic oxygen production or CO_2 separation processes. This reduction in cost can enable a variety of oxy-combustion technologies, as well as other combustion applications, where CO_2 capture may be required. The development of OTMs will also benefit industrial processes used to produce syngas for subsequent processing into a variety of chemical and/or petrochemical end products by dramatically reducing the power requirements.

The optimization and testing of OTM systems for both syngas and combustion is a critical step toward the commercialization of OTM technology. The development and commercialization of reactively driven OTM devices in a number of industrial applications will result in a fleet of operating sites that will serve as testimonials for the robustness and reliability of the core components of the OTM technology, thereby reducing the risk associated with a first-of-a-kind utility-scale demonstration of the technology.