the ENERGY lab

PROJECT FACTS

Advanced Research

Development of Computational Approaches for Simulation and Advanced Controls for Hybrid Combustion-Gasification Chemical Looping

Background

The United States Department of Energy (DOE) National Energy Technology Laboratory (NETL) develops affordable and clean energy from coal and other fossil fuels to secure a sustainable energy economy. To further this mission, NETL funds research and development of advanced control technologies, including chemical looping (CL) power plants.

Chemical looping is a recently developed process that can be used in power-generation plants that burn fuels such as coal, biomass, and other opportunity fuels. A typical CL system employs a high-temperature process whereby solids such as calcium- or metal-based compounds are "looped" between a first reactor, called an oxidizer, and a second reactor, called a reducer. In the oxidizer, oxygen from injected air is captured by the solids in an oxidation reaction. The captured oxygen is then carried by the oxidized solids to the reducer to be used for combustion and/or gasification of a fuel such as coal. After undergoing reduction in the reducer, the solids, no longer carrying the captured oxygen, are returned to the oxidizer to be re-oxidized, and the cycle repeats. The benefits of chemical looping, compared to traditional combustion processes, include reduced air pollutants and production of a carbon dioxide–rich flue gas for sequestration.

In alignment with DOE Fossil Energy (FE) program goals, NETL has partnered with ALSTOM Power and the University of Illinois to investigate the application of sensors and controls technology to enable and improve the performance and reliability of CL plants.

Project Description

In the next generation of power plants based on chemical looping, control requirements for the steam/water side will remain essentially the same as in current conventional plants. However, it is expected that improved controls that use both steam/water-side variables and combustion/gasification CL variables will be required to better handle inherent process-variable interactions. In addition, conventional power plant simulators are limited to steam/water-side process dynamics and only very simple combustion or furnace process dynamics are modeled; dynamic models of complex atmosphere control systems, such as those in the CL process, are not available.

This project investigated the application of sensors and controls technology to enable and improve the performance and reliability of CL plants. Teaming with the University of Illinois, Alstom Power used the experience and knowledge it gained

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PARTNERS

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PROJECT DURATION

Start Date
07/12/2007

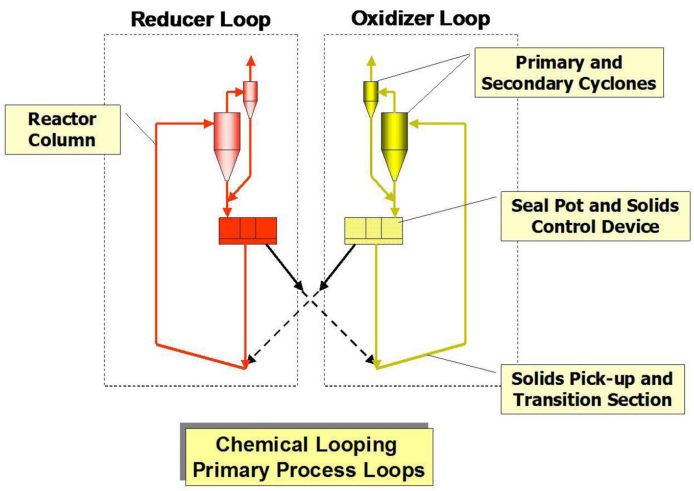
End Date
03/31/2011

COST

Total Project Value
$1,993,281

DOE/Non-DOE Share
$1,594,625 / $398,656

after several years of collaborative research and development with DOE to apply first principles and CL experimental data to derive the simplified process models needed for controls evaluations. The project used CL facilities to test and validate the models, which were linked to a dynamic control simulation for developing and testing advanced control algorithms. Researchers applied the modeling and control tools to the issue of solids/gas flow control. The project will lead to an overall control system concept with advanced methods that can be specified and built for use in a hybrid CL prototype and field demonstration units.



Conceptual schematic of the loops in the primary process chemical looping.

Goals and Objectives

The project goal was to develop advanced multivariable optimizing controls for early integration in the process development cycle to ensure a plant-level design that is controllable and reliable.

The specific objectives were to—

- Develop an understanding of the complex process dynamics and sensor and control needs of CL processes.
- Build simple process simulation models with dynamic capabilities suitable to evaluate control methods.
- Develop a method for proactive integration of advanced controls into the hybrid CL plant design process in order to optimize the process and controls.
- Investigate advanced (multi-variable/model-based) process control and analysis methods for chemical looping, their application to complex solids flow and gas pressure control in the interacting multiple-loops, and their implementation into a total plant integrated control concept.
- Develop an advanced process control system design concept that can be used as a starting point for design and implementation of the control system for a future hybrid CL prototype facility project.

Accomplishments

In 2007, Alstom derived one-dimensional and partial differential equation models for 11 pre-defined components of the single-loop cold-flow model. A proprietary steady-state lumped model was developed for the cyclone in the loop in terms of discrete algebraic equations. A proprietary differential pressure model for the seal pot control valve was identified for steady-state simulation. Solid flow models for the seal pot control valve were developed and revised.

In 2009, Alstom completed simplified process models simulating the CL process and verified the overall validity of these models against its bench-scale unit. The models were used to develop controls coded in MatLAB Simulink and to compare model-based process controls to standard PID controls. Alstom tested the linear model predictive controller in the CL experimental dual-loop facility to establish effective and stable solids transport control. In addition, Alstom tested a solids inventory sensor in the experimental facility and established its feasibility for future controls application.

In 2010, Alstom developed specifications for simulating a larger prototype of their CL system, which is being constructed under another agreement with DOE. The new prototype implements dual hot-reacting loops, and the new specifications allow for enhancements to the mass/energy models to be used in simulation and model-based controls. These models represent a process improvement and can, for the first time, be validated against the pilot-scale system under construction. Alstom also successfully developed effective computational reduced order models for use in real-time simulation and in a state-of-the-art nonlinear model predictive controller for further process control improvements.

Benefits

This project developed a multi-variable, non-linear control optimization system to provide integrated dynamic and steady-state performance and controls design optimization for a CL plant. Once optimized, the CL process can be implemented in power plants, promising improvements in terms of reduced plant size, reduced emissions, and increased plant operational efficiency.