Integrated Testing of a Membrane CO$_2$ Capture Process with a Coal-Fired Boiler

DE-FE0026414

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NETL CO$_2$ Capture Technology Review Meeting
August 22, 2017
Project Overview

**Award name:** Integrated Testing of a Membrane CO$_2$ Capture Process with a Coal-Fired Boiler

**Project period:** 7/1/15 to 3/31/18

**Funding:** $3.6 million DOE; $0.9 million cost share ($4.5 million total)

**DOE program manager:** José Figueroa

**Participants:** MTR and Babcock & Wilcox

**Project scope:** Demonstrate integrated operation of the MTR small pilot capture system with B&W’s SBS-II pilot coal boiler.

**Project plan:** The project is organized in three phases:

- **Phase 1** – Site preparation and system modification/installation
- **Phase 2** – Commissioning, testing, and data analysis
- **Phase 3** – Decommissioning and reporting
Benefits of selective recycle:

- Increases CO₂ concentration going to the capture step, and
- Reduces the fractional CO₂ removal required by the capture step
MTR CO₂ Capture Development Timeline

Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived

APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO₂ used for algae farm

APS Cholla Demo (DE-NT5312)
- First Polaris coal flue gas test
- 1 TPD CO₂ captured (50 kWₑ)

NCCC 1 MWₑ Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1,500 hours of 20 TPD system operation

Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m² optimized module

Hybrid Capture (DE-FE13118)
- Membrane-solvent hybrids with UT, Austin

B&W Integrated Test (DE-FE26414)
Prior Testing of 20 TPD System at NCCC

- Membranes are simple and compact compared to competing technologies.
- In previous 1 TPD testing, Polaris modules completed ~11,000 hours of operation at NCCC.

- In June 2015, MTR pilot system completed 1,500 hours of successful operation at NCCC.
- System was then moved to B&W in Spring 2016 for integrated boiler testing.
20 TPD System Shows Stable Performance

- System operated in slipstream mode (no recycle to boiler)
- Stable performance, reaching up to 90% capture
- System goes from cold start to steady state in ~15 minutes

Figure data from NCCC campaign PO3 (May to July 2015)
Prior B&W Studies of CO$_2$ Recycle Impact on Boiler Performance

Phase I – CFD modeling
- B&W modeled 2 boiler configurations (radiant boiler firing bituminous coal and SWUP firing PRB coal) and 2 sweep recycle cases (constant secondary air flow and constant stoichiometry)
- **Main conclusion of modeling study**: secondary air laden with CO$_2$ appears feasible as a retrofit in either of the boiler configurations examined if oxygen mass flow to boiler is fixed

Phase II – Pilot testing
- B&W’s SBS-II 1.8 MW$_{th}$ pilot boiler operated with CO$_2$-laden combustion air
- Two coals evaluated: a western sub-bituminous coal and a highly volatile bituminous coal
- O$_2$ content of windbox air varied from 21% to 16% through CO$_2$ dilution
- Monitored flame stability, length, and shape; unburned combustibles in fly ash, and furnace exit gas temperature
- Radiant furnace and convective pass heat absorptions were measured
- Boiler efficiencies for air and sweep firing were determined
Highlights from Testing with CO₂-laden Air on B&W Boiler

- Stable and attached flames with air (21% O₂) and CO₂-enriched air (16-18% O₂)
- CO₂-enriched flame was less luminous than air-fired case
- Lower furnace heat absorption but higher convection pass/air heater heat transfer for CO₂-enriched operation relative to air
- For bituminous coal, 30% lower NOₓ emissions with CO₂-enriched air
- No burner modifications necessary
- Net reduction in plant efficiency of ~0.75% at 18% O₂
Boiler Efficiency Versus Windbox O$_2$

- Increased CO$_2$ recycle reduces windbox O$_2$ content through dilution, which reduces plant efficiency almost linearly.
- However, increased CO$_2$ recycle reduces capture energy; net benefit.
- 18% O$_2$ appears to be optimum for retrofit; beyond this point tube erosion, abrasion, and slagging may become important.
- Because flame is stable to 16% O$_2$, this level of recycle should be further evaluated for new plants.
Objectives of Integrated Project (DE-FE0026414)

- Use an existing 20 TPD MTR small pilot membrane system to test integrated operation (with CO$_2$ recycle to boiler) on an appropriately-sized boiler (B&W SBS-II)
- Validate prior B&W modeling and testing showing modest effect of recycled CO$_2$ on boiler performance
- Understanding how the various membrane parameters impact performance of a dynamic boiler system
- Reduce risk prior to scaling up to larger demos
Schematic of Integrated Test
MTR Skid During Transport and Installation at B&W

Skid arriving at B&W

Installation of 2nd floor
MTR Skids at B&W’s SBS-II Research Facility

Main skid and smaller low-pressure drop sweep module anchored to foundation
Sample Results from B&W Integrated Tests

Membrane-Boiler Integrated Test Plan

- 5 weeks of testing on natural gas, Powder River Basin (PRB) Coal, and Eastern Bituminous Coal
- 90% capture achieved and a variety of partial capture conditions
- CO₂ content of flue gas increased as expected in simulations
- Boiler flame was stable allowing a full battery of stream conditions and boiler efficiency measurements to be conducted (analysis is ongoing)

Oxygen at Boiler Windbox: 17.0 – 21%

Air sweep + CO₂ recycle

Primary CO₂ capture step

Flue gas

Selective CO₂ recycle step

CO₂-depleted flue gas

Air sweep

Boiler

Coal feed

14.3 – 20.6%

7.3 – 17.4%

6.2 – 10.8%

2 – 6.7%

20%

10%

8%

65%

361-Pre062215
1 MW_e System Sweep Flow Rate Parametric Results from Integrated Tests

Influence on the Overall CO₂ Capture Rate

- CO₂ capture rate (%)
- Sweep flow rate (lb/h)
- Feed = 30 psia

Influence on Sweep Step CO₂ Capture Rate Efficiency

- Sweep-step CO₂ capture rate (%)
- Sweep flow rate (lb/h)
- Feed = 30 psia
Integrated Boiler/Membrane Systems Transition Response

Gas Flow Rates (lb/hr)

Gas Concentration (Vol. %, dry)

Fresh Air Intake Flow
Sweep Gas Flow
Convection Pass Flow
Windbox O2
Convection Pass O2
Convection Pass CO2

11/3/2016

11/16/2016
Integrated Boiler/Membrane Systems Transition Response to E-Stop

Graph showing gas flow rates and concentrations over time.
B&W’s Analysis of CO₂ Recycle Impact on Boiler Operation

- Furnace heat absorption is lower
- “Furnace” refers to the radiant heat transfer section of the boiler upstream of the tube banks in the convection pass.
- Convection pass heat absorption is higher
- Convection pass outlet heat flux is higher
- Air heater heat absorption is higher
- Air heater flue gas outlet heat flux is higher
- Total heat absorption is slightly reduced

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Decommissioning and Site Restoration Activities Have Been Completed

- All skids decommissioned and removed from site by June 2017

- Site clean-up and smooth-out of concrete foundation has been finished

- Final reporting and analysis is underway
Summary

- CO₂ capture membrane performance continues to improve and has been validated on the 0.05 MWₑ slipstream system with over 11,000 hours of runtime at NCCC

- 1 MWₑ small pilot operation at NCCC was completed in 2015. Testing successfully demonstrated optimized modules (low ∆p, low cost) with over 1,500 hours of runtime

- 1 MWₑ small pilot was successfully integrated with the B&W research boiler for five weeks of integrated testing with CO₂ recycle to the boiler in late 2016

- The integrated membrane-boiler field test experimentally validated simulated system performance

- Boiler flame was stable throughout parametric testing allowing a full battery of stream conditions and boiler efficiency measurements
Acknowledgements

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