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OXY-FUEL BURNER AND INTEGRATED POLLUTANT REMOVAL RESEARCH AND DEVELOPMENT TEST FACILITY

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JUPITER OXYGEN ENERGY TECHNOLOGY

- Development and Application of Oxy-fuel Technology
- Patents and Licensing
- Consulting Service

Fossil Fuel: coal, natural gas, oil, and biomass

Project Funding

Project revision	Start date	Government cost share	Recipient cost share	Total estimate
0	10/1/2006	$ 2,051,670	$ 517,455	$ 2,569,125
1	4/1/2008	$ 972,674	$ 243,162	$ 1,215,836
2	4/1/2009	$ 669,784	$ 173,492	$ 843,276
2010-11	4/1/2010	$ 2,825,387	$ 705,560	$ 3,530,947
Project total	Completion date 9/30/2011	$ 6,519,515	$ 1,639,669	$ 8,159,184
		79.9%	20.1%	100%

Project Participants

- Jupiter Oxygen Corporation
- NETL
- Industry and academic partners

SNC Lavalin America, Inc	Purdue University
Consortium for Clean Coal Utilization	Coalteck
Peabody Energy	Professor Stamps, Evansville University
Reaction Engineering International	EPRI

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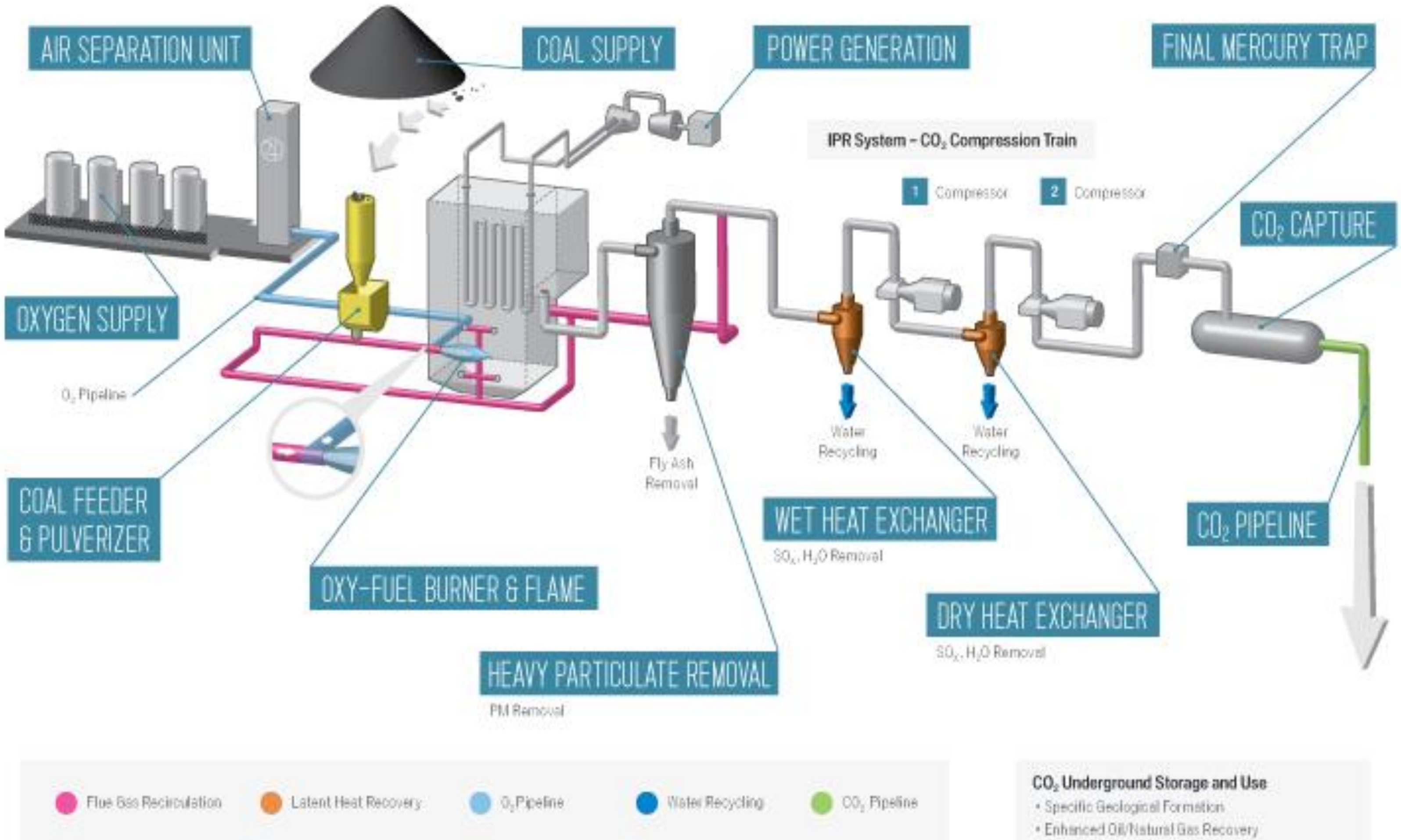

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Project Objectives

- Design, construct, and operate a 5 MWe equivalent test boiler facility
- Design, construction, and operate a 20 KWe equivalent IPR® facility
- Operate the test facility at steady state optimum oxy-coal combustion and perform parametric studies.
- Demonstrate oxy-coal combustion NOX levels no higher than 0.15 LB/MMBTU
- Demonstrate that $C0_2$ from the boiler/ IPR® meets the specifications for deep saline aquifer sequestration and/or enhanced oil recovery
- Evaluate the retrofit impact of oxy-coal combustion and the IPR® process on power plant design issues
- Generate the necessary technical data required to demonstrate the technologies are viable for technical and economic scale-up and conform to DOE's Carbon Sequestration Program goals

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Technology Background

JOC High Flame Temperature Oxy-Combustion

- Development of oxy-combustion technology for Jupiter Aluminum facility in Hammond, IN
  - Oxy-combustion process in use since 1997 in the aluminum furnace
- Jupiter Oxygen as a CRADA partner with the NETL (2003)
  - Successful retrofit of 0.5MWe equivalent boiler with JOC high flame temperature oxy-combustion
  - Produced saturated steam while maintaining boiler interior temperature profile the same as with air firing
  - Boiler efficiency gains resulted
- Jupiter Oxygen/NETL project funded by DOE (2006)

Technology Background

JOC High Flame Temperature Oxy-combustion

- Key characteristics
  - Eliminate air from the combustion system
  - Fuel and oxygen mixed at the burner undiluted with flue gas recycle except to motivate coal (unlike low temperature oxy-combustion which dilutes oxygen with flue gas recycle prior to combustion)
  - Results in a high flame temperature to enhance heat transfer in the radiant zone
  - Flue gas produced is primarily carbon dioxide and water
  - Flue gas recycle introduced around the flame/combustion zone to adjust the total flue gas volume flow and transfer heat duty to the convective zone as required
  - Additional FGR does not lower flame temperature

Technology Background

JOC High Flame Temperature

- Benefits
  - Significantly reduce NO_x emissions at combustion
  - Enhanced radiant heat transfer increases boiler efficiency which results in boiler fuel savings
  - Less fuel results in lower carbon generation, reduced capture costs, and lower oxygen demand
  - Reduced volume of flue gas and concentrated carbon dioxide in flue gas also reduces the cost of carbon capture
- Challenges
  - Burner stability and performance
  - Balancing heat duty in radiant and convective zones for retrofit projects or conventional new build projects
  - Minimizing air in-leakage to boiler

Technology Background
NETL Integrated Pollutant Removal (IPR®) System

- Key Characteristics
  - Flue gas is cooled and scrubbed via a direct contact wet heat exchanger for coal firing
  - Condensed water from the flue gas is separated and recovered for power plant use
  - Balance of flue gas is compressed in multiple stages to required pressure for CO_2 processing or sequestration
  - Heat of compression is recovered for power plant use
- Advantages
  - Integration of IPR® with the power plant thermal cycle minimizes parasitic load for the work required to remove pollutants and capture/process CO_2
  - Condensed water captured from the combustion flue gas is sufficient supply 100% of the boiler feed water makeup and up to 7% of the cooling water makeup for the plant
  - IPR® uses "off the shelf" technology
- Challenges
  - Optimizing material selection costs while minimizing corrosion concerns
  - Treatment of captured water for release and/or use in the plant water supply

Project Accomplishments

- Retrofitted and operated a 5 MWe equivalent test boiler facility
  - No major boiler modifications required
  - No increased fouling and slagging indicated (study continues)
  - No damage to boiler materials indicated (study continues)
  - Operated the test facility with air-natural gas and oxy-natural gas combustion
  - Performed parametric studies with natural gas combustion
  - Designed, constructed, and operated a pulverized coal feed system with a scaled up oxy-coal burner from the CRADA work
  - Performed a series of oxy-coal burner development tests which resulted in a modified first generation burner
  - Performed parametric studies with the modified first generation oxy-coal burner
  - Developed a CFD model of the modified first generation burner
  - Based on test results and CFD modeling a second generation burner is under development

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Project Accomplishments

- Designed, constructed, and operated a 20 KWe equivalent IPR® facility
  - Test IPR® system has yielded gas composition and liquid composition process results
  - Demonstrated CO_2 capture at 95% to 100%
  - Pollutant removal from captured CO_2
    - 95% NOx , SOx, particulate
    - 60% to 90% mercury
  - Water treatment tests (on flue gas condensate) point to $FeCl_3$ as an effective flocculent especially when paired with polymeric flocculent
  - Full-scale parametric model of a power plant retrofitted with high temperature oxy-combustion and an IPR® system has been developed and is ready for economic evaluation.

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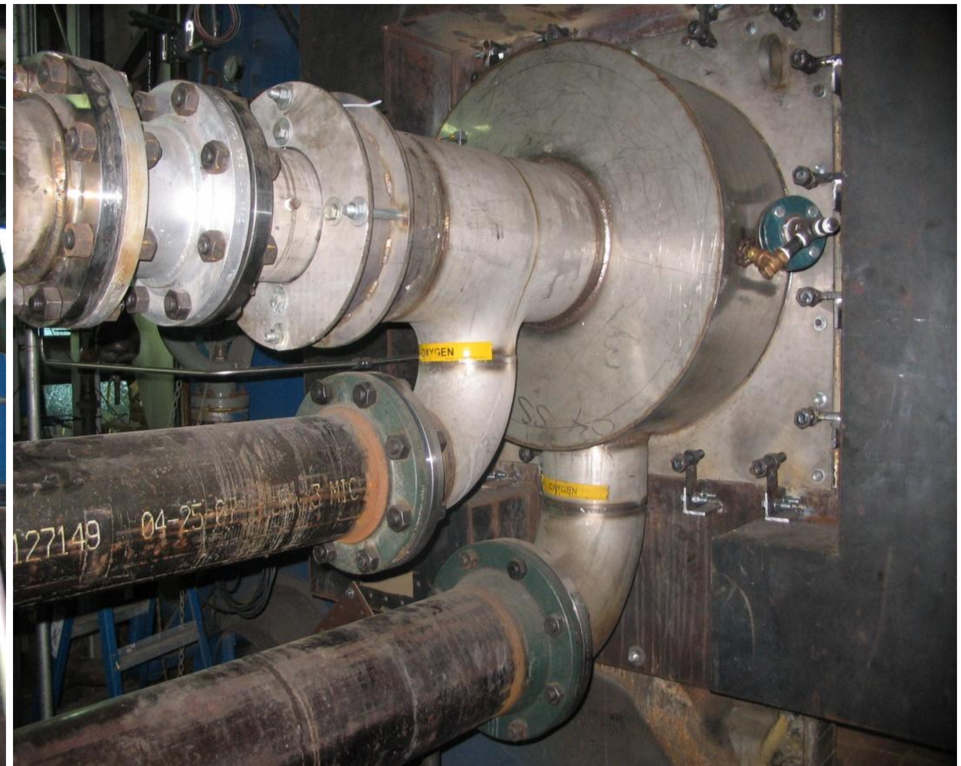
5 MWe Equivalent Test Boiler

50 MMBTU/hr OXY-COAL BURNER



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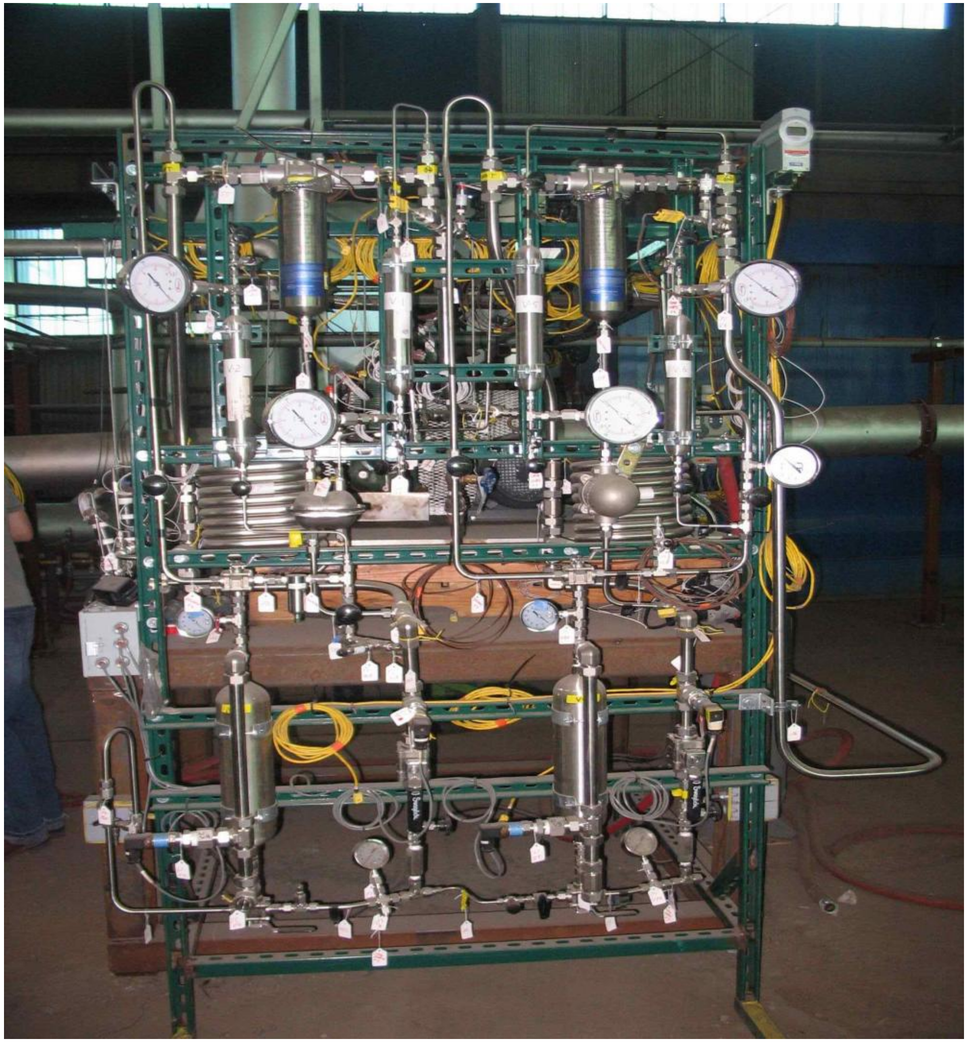
20 KWe
equivalent
IPR System



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Coal Pulverizer and Flue Gas Recycle Loop

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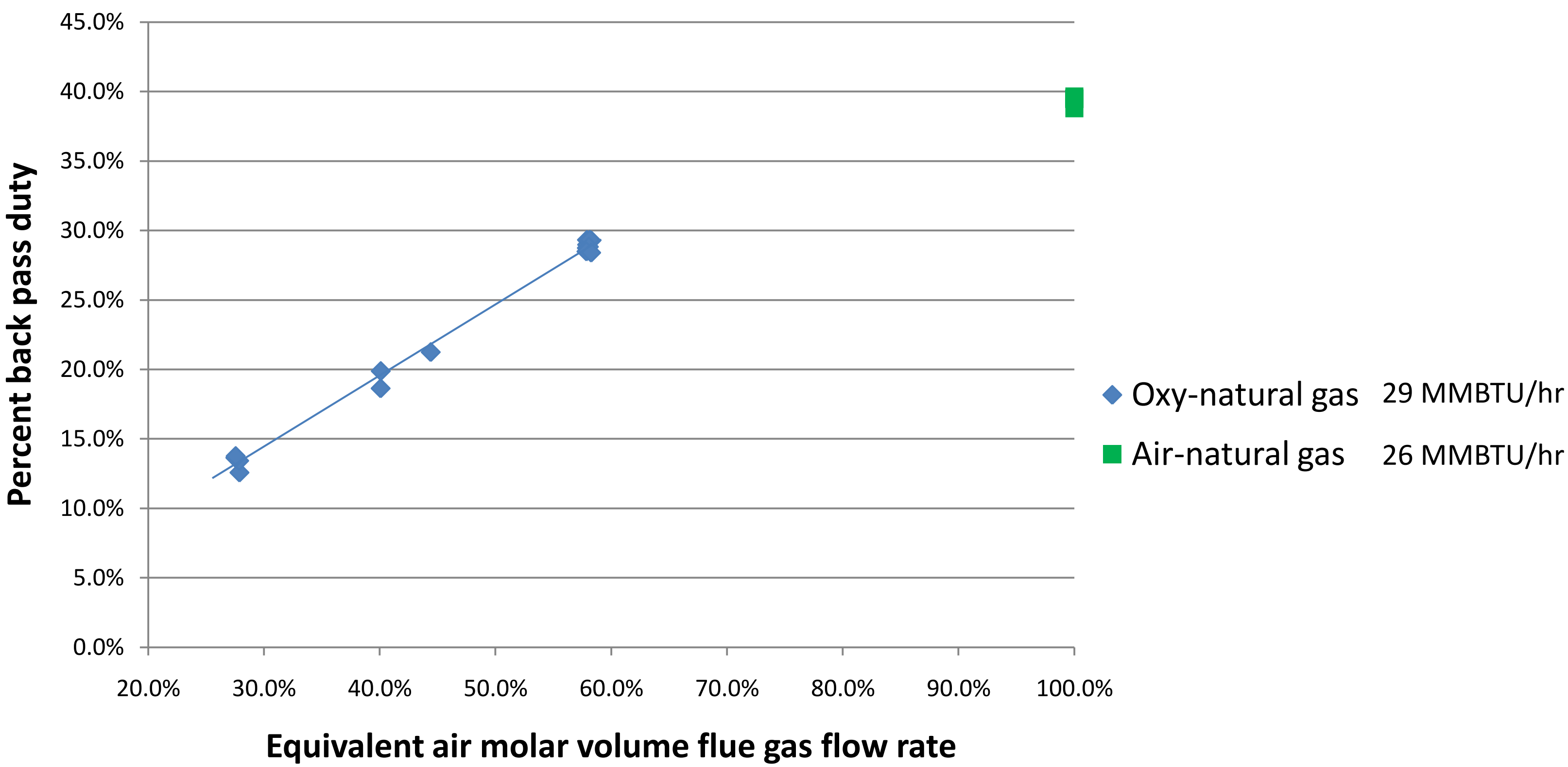
Radiant/back pass duty balancing – natural gas tests



Note that equivalent air molar volume flue gas flow rate was limited due to the capacity of the test recycle blower. The recycle blower capacity has since been increased.

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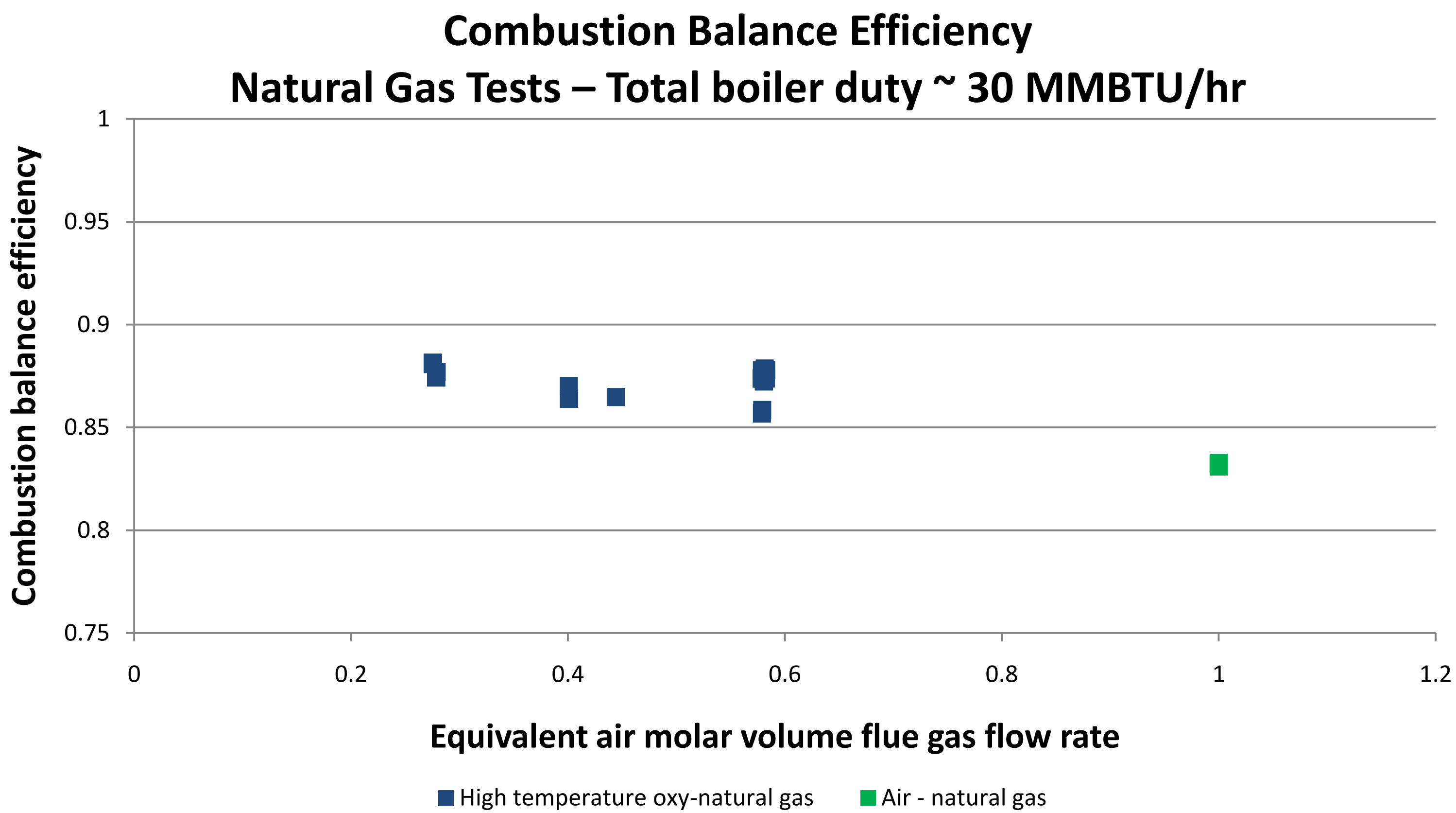

Combustion balance efficiency is the change in enthalpy of combustion gases across the boiler divided by the higher heating value of the natural gas.
Data indicates an average boiler efficiency increase of 4.6% for oxy-combustion over air-combustion, which translates to a 4.6% fuel savings at fixed boiler duty.

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Peak Flame Temperature
Natural gas tests

	Purdue Calculation from Spectraline data	**NETL Wien displacement**	**Calculated adiabatic temp**
HT oxy-fuel No FGR	3275 K	2991 K	3130 K
HT oxy fuel w/FGR	3200 K	2994 K	3121 K
Air firing	2343 K		2168 K

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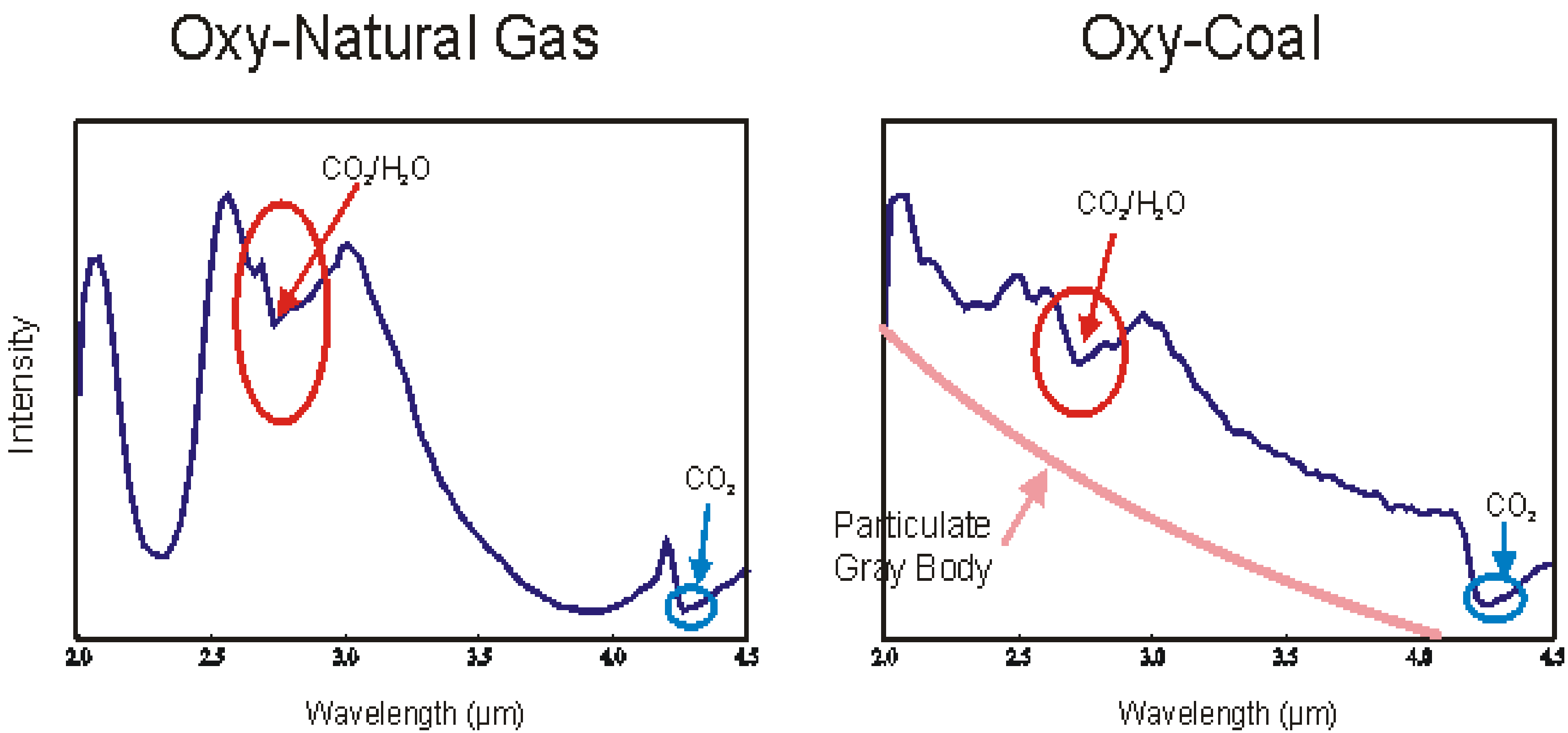
Flame intensity of natural gas and coal in oxy-combustion



Note that particle radiation during oxy-coal combustion results in wider wavelength band of high intensity.

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Oxy-coal burner development and testing

- •First generation modified oxy-coal burner
- •Scaled up from earlier burner on 1.5 MW_{th} test boiler
- •Utilized for the several days of testing

Although the modified first generation oxy-coal burner showed significant improvements from the first operation, further improvement in design performance and turndown is required to meet project objectives. Study of the results from this burner have led to further improvements.

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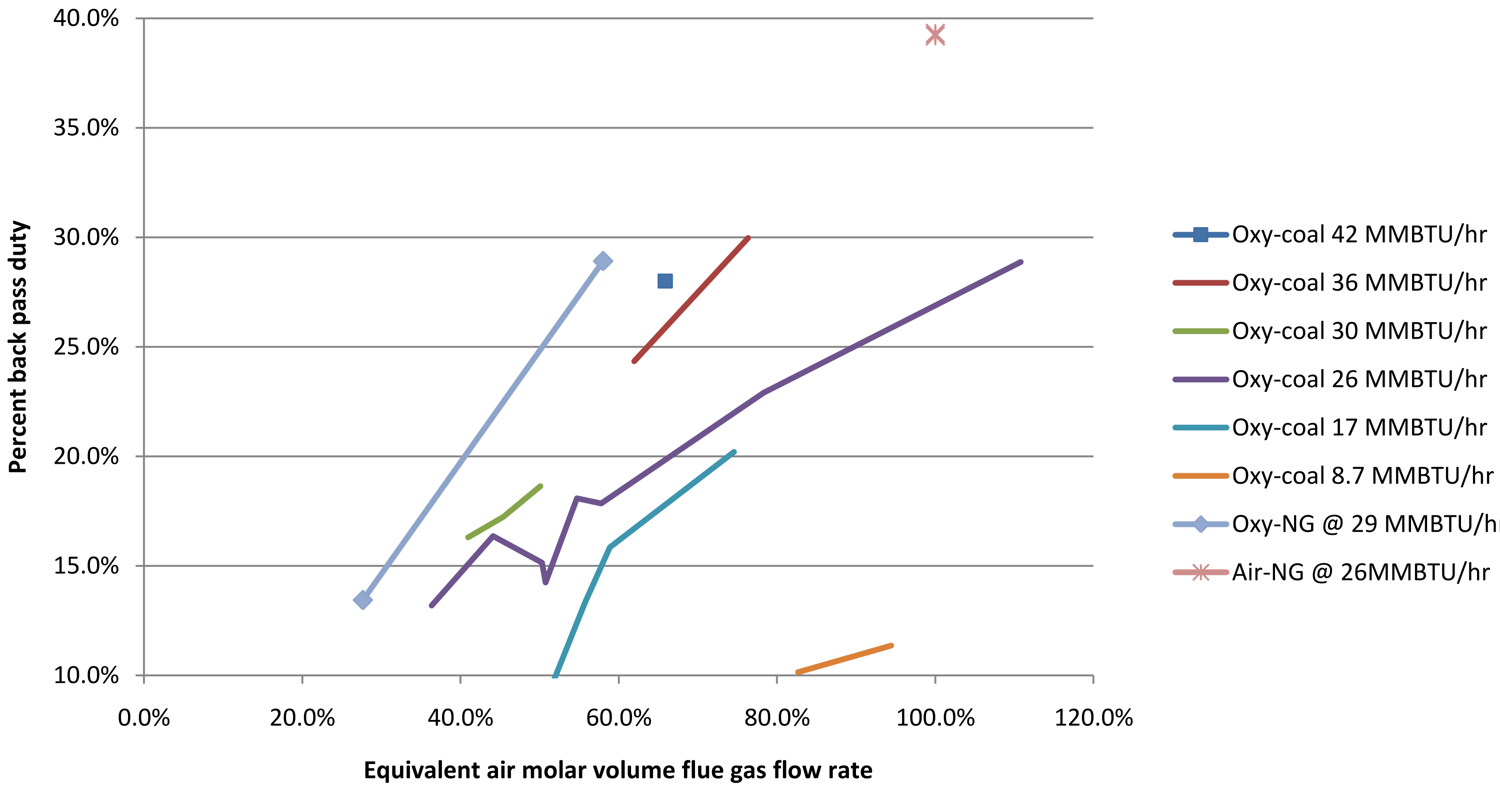
Radiant/Back pass duty balancing – coal combustion tests



Note that the above plot does not include an air-coal combustion reference point. Development of an air-coal base line is planned in the future work for this project.

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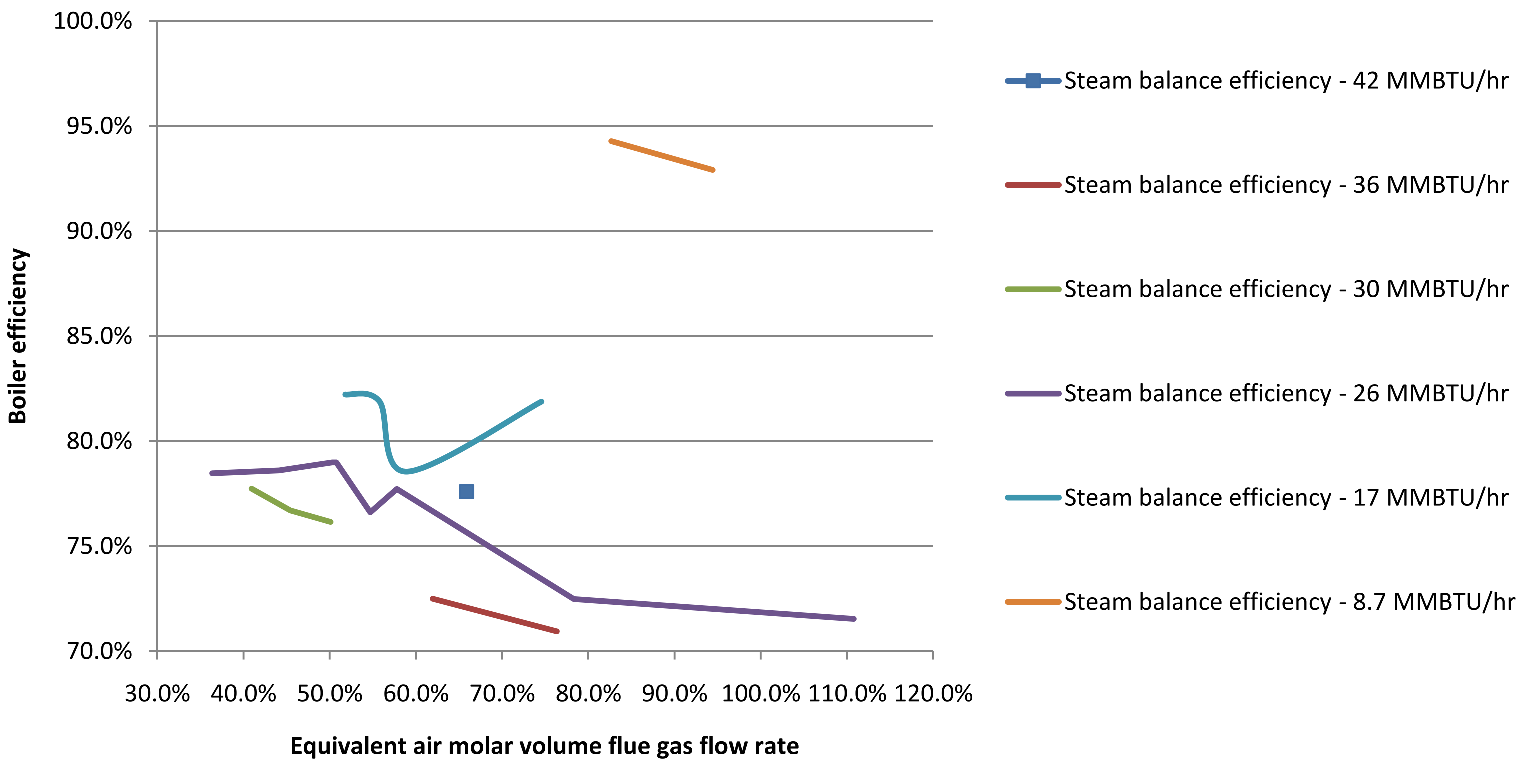
Boiler steam balance efficiency
Oxy-coal combustion tests



Boiler steam balance efficiency is defined as the enthalpy change across the steam side of the boiler (BFW to superheated steam) divided by the heat value of the coal.

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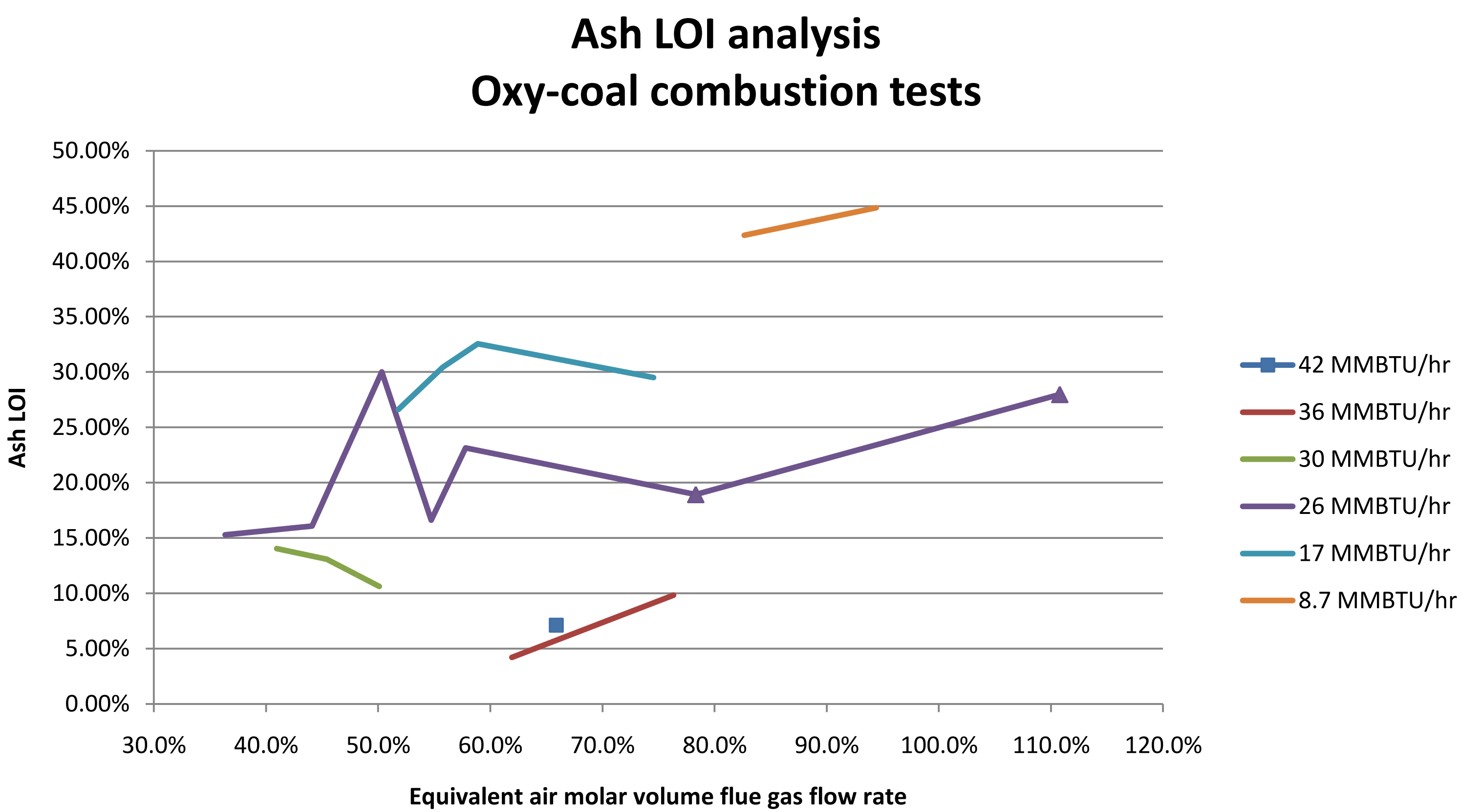
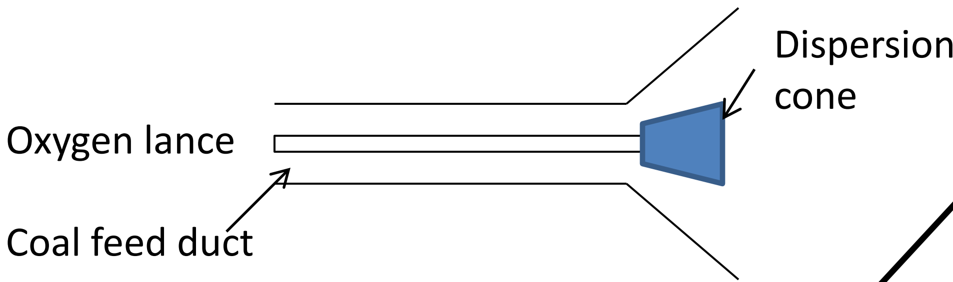
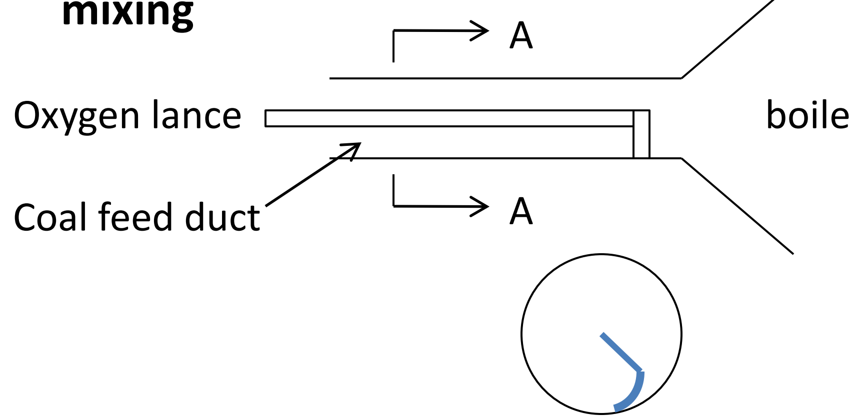


Ash LOI is defined as the percent of unburnt carbon in the ash.
Data indicates improvement in ash LOI with increasing burner duty, however further improvement on this modified first generation burner is required to meet objectives .
Results led to further modifications aimed at better coal-oxygen mixing.



Modified first generation burner arrangement

Oxygen swirl lance arrangement Designed for better coal-oxygen mixing



View A-A

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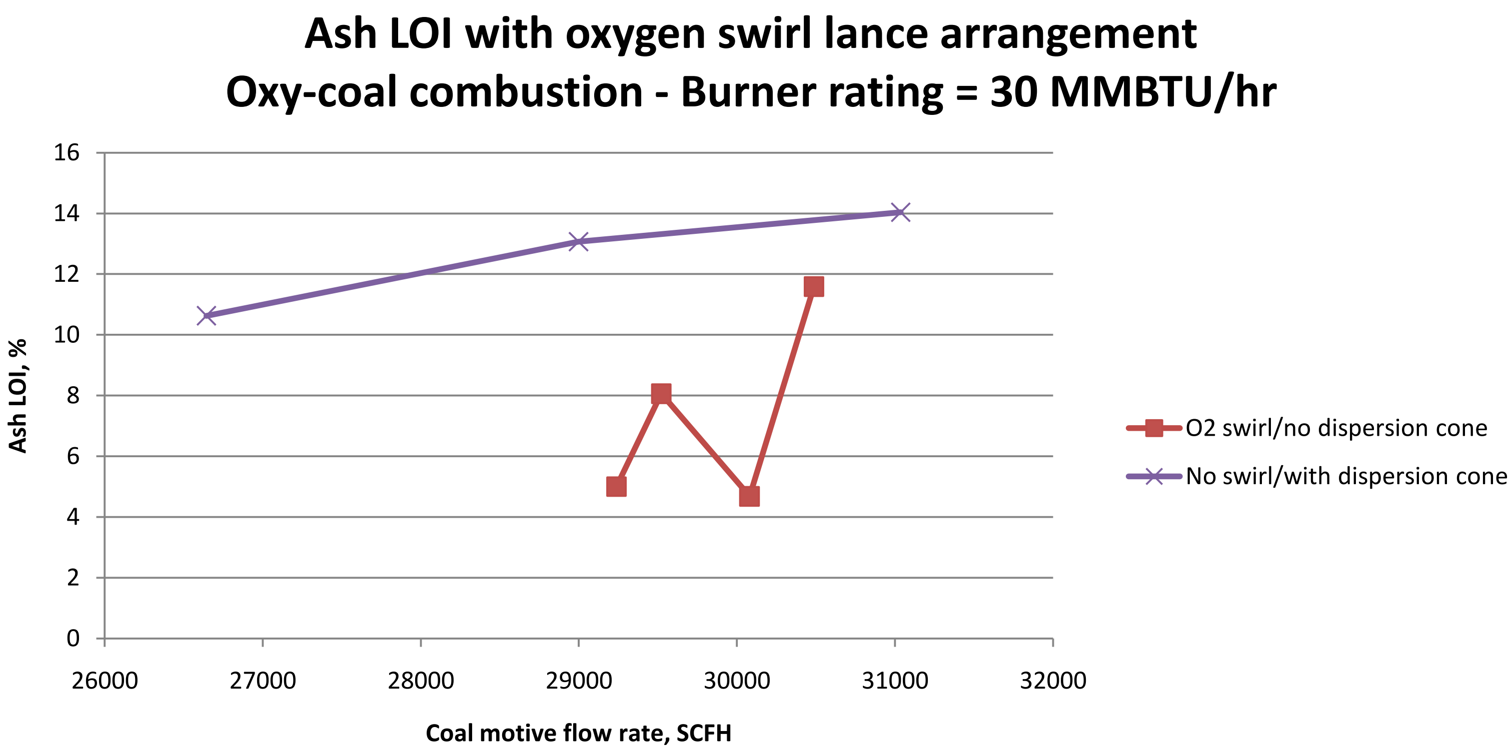
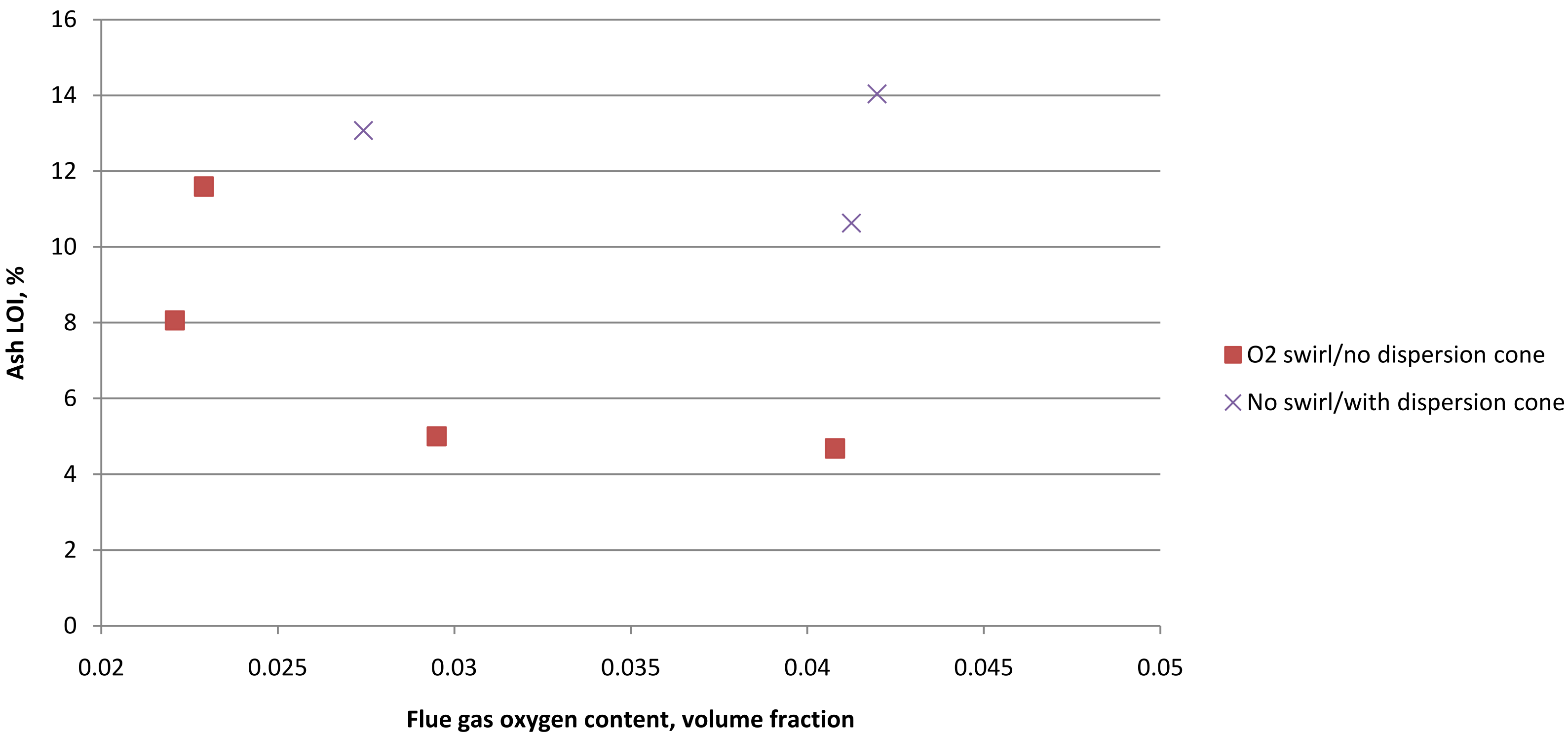
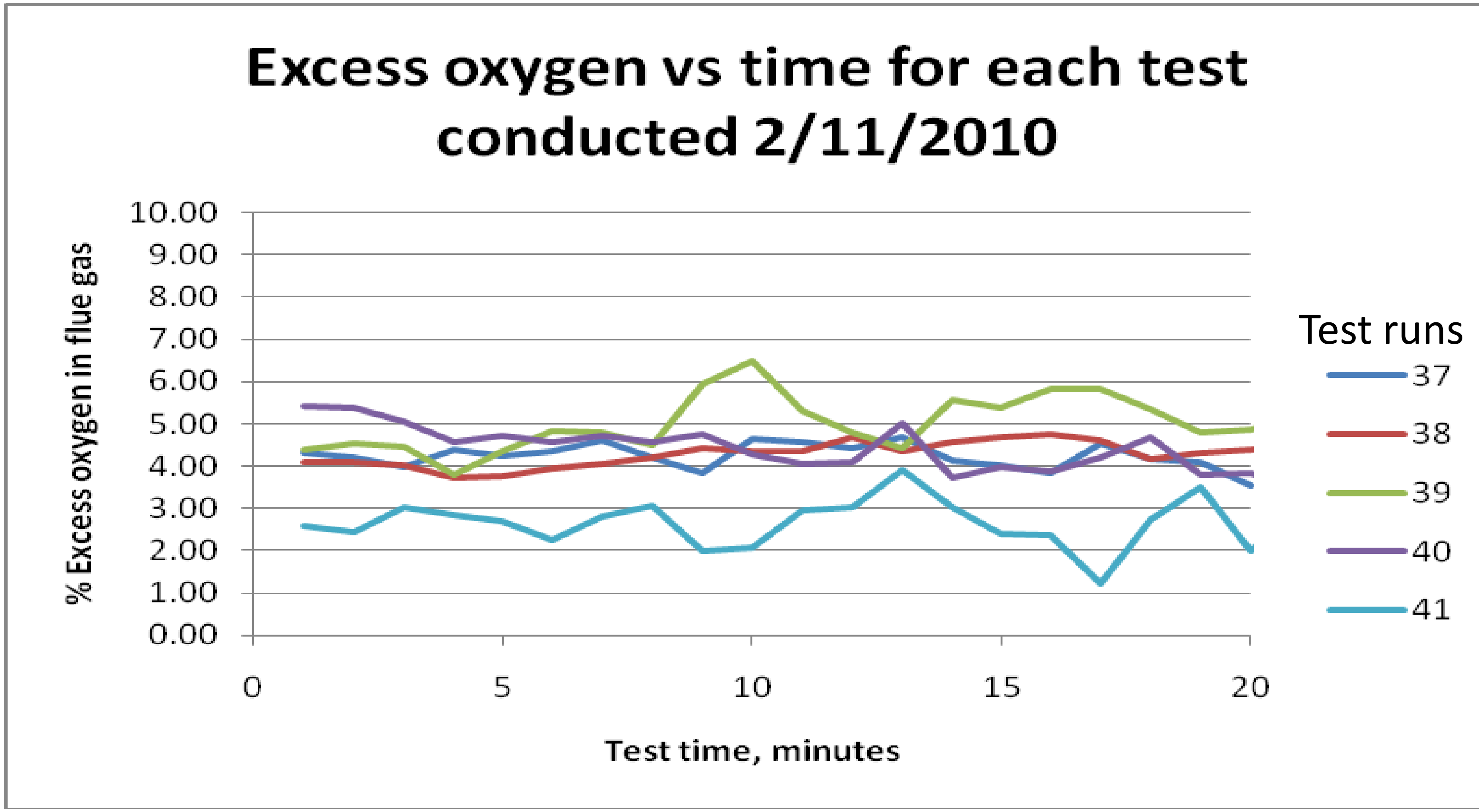


Addition of oxygen from lance to the coal/motive gas mixture with swirling action improves Ash LOI over the modified first generation burner with dispersion cone.

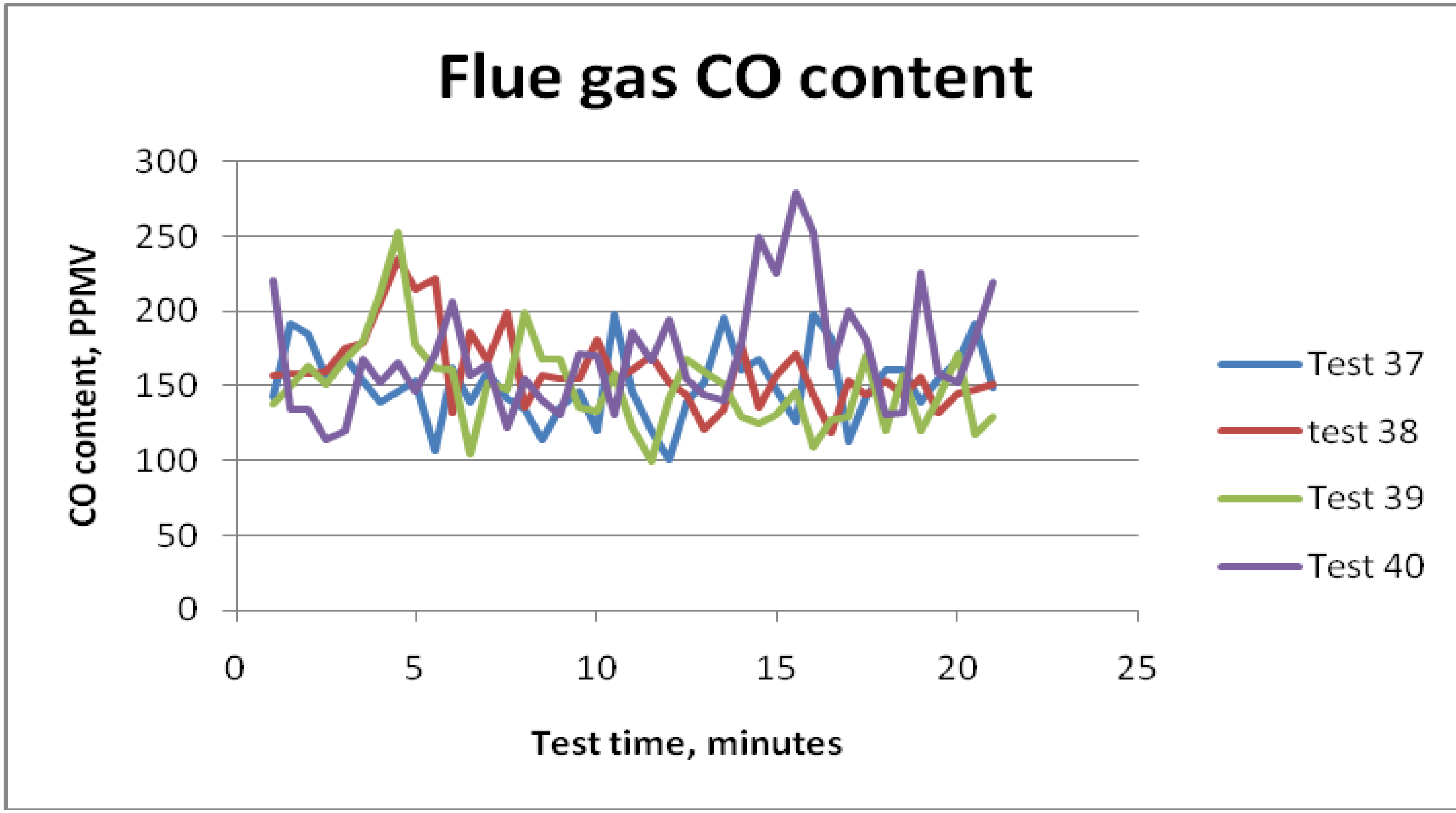
Ash LOI vs Flue gas oxygen content
Oxy-coal combustion - Burner rating = 30 MMBTU/hr



Note that at fixed excess oxygen content the oxygen swirl lance arrangement shows improved LOI performance over the modified first generation burner with dispersion cone.



Oxy-coal combustion tests 37 – 40 (burner rating = 30 MMBTU/hr) showed improved excess oxygen control due to improvements in coal feed systems.



With improved excess oxygen control on these test oxy-coal combustion tests (burner rating = 30 MMBTU/hr), flue gas contaminants also tighten up particularly the CO content.

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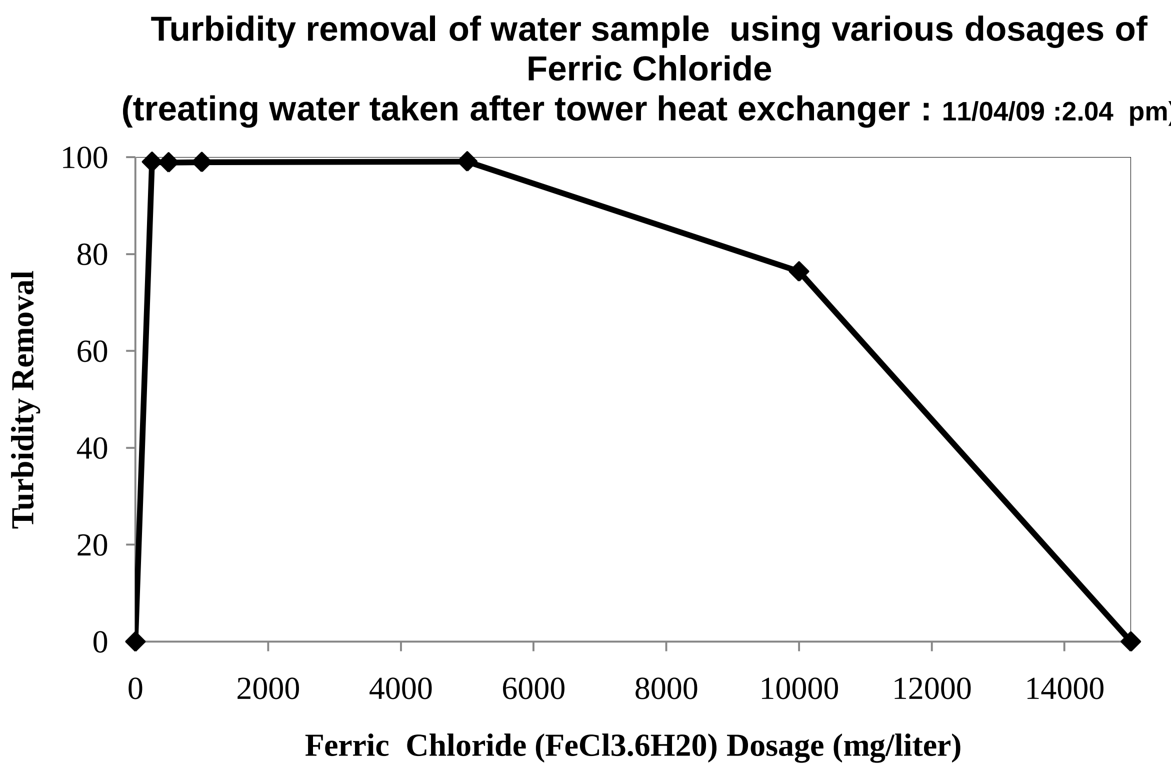
Flocculation/Coagulation tests show ferric chloride treatment as a promising first step to purifying recovered flue-gas water (effective at low dosage)



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IPR® **Gas Composition Summary**

Oxy-coal combustion tests 12/7/2009

Average Component composition over capture-time, volume %										
	CO_2	**H_2O**	**O_2**	**SO_2**	**NO_2**	**NO**	**N_2O**	**CO**	**HCl**	**N_2/Ar**
IPR inlet	56	32.7	3.24	0.990	0.0003	0.0560	0.009	0.03	0.0029	6.78
2nd Stage outlet	82	0.11	3.50	0.043	0.0007	0.0379	0.004	0.05	0.0000	14.55
Final stage outlet	89	0.06	4.34	0.003	-0.00001	0.0004	0.005	0.06	-0.0001	6.85

Notes:

1 Oxygen measured by zirconia probe. All other components measured by FTIR

2 Nitrogen and argon calculated by difference

3 High than desired nitrogen throughout system due to air in-leakage which will be addressed later

4 Final stage nitrogen is unexpected low due to sampling inconsistencies.

5 Inlet and 2nd stage are measured during testing. Final is measured post testing from final gas collected in a cylinder

Project work going forward

- Develop second generation oxy-coal burner
  - Burner design based on first generation tests and CFD modeling
  - Design for improved coal/oxygen mixing, shorter flame length, turndown capability
  - Increased steady state run length
  - Improve flame characterization and heat transfer measurement
  - Commission and operate burner to meet project objectives
  - Run final oxy-coal combustion tests with test instrument penetrations closed to reduce air in-leakage
- Doosan Babcock slagging and fouling study
  - Modeling work already completed
  - Slag samples collected from December 2009 testing
  - Slagging and fouling study to be completed
- Develop air-coal combustion base line
  - Purchase and install air-coal combustion burner assembly
  - Commission and operate to determine a base line performance for coal combustion in the JOC test boiler
  - Evaluate performance with respect to oxy-coal performance

Project work going forward

- IPR® evaluation
  - Optimization of the heat recovery via cycle modeling
  - Evaluate interactions between gas species which are expected to enhance the removal of SOx, NOx and Hg from the gas.
  - Analysis of gas compositions at inter-stage points in the IPR® process and at the final outlet CO_2 product
  - Further evaluation of corrosion via coupon testing on-site and in the laboratory to guide material selection
  - Further evaluation of water treatment requirements via modeling and laboratory tests with water samples collected from the site
- Generate additional technical data for the following
  - High flame temperature oxy-coal/ IPR® retrofits
  - Captured CO_2 meeting EOR/sequestration specifications
  - Commercial scale-up study with economics
  - Meeting DOE Existing Plants Program Goals

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Summary

Combined Jupiter Oxygen high flame temperature oxy-combustion technology and NETL IPR® pollution control and carbon capture system for coal fired power plants

- Technologies provide a means to retrofit existing power plants and build new ones.
- Boiler system fuel savings can be expected from high flame temperature oxy-combustion technology.
- 95-100% carbon capture is feasible.
- Technologies allow fully carbon capture ready power plants to exist today which can be completely compliant with clean air regulatory requirements.
- Water recovery will exceed boiler feed water makeup requirements and partial cooling water makeup requirements.
- Heat integration from cryogenic oxygen plant and IPR® compressors can lower fuel costs.

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Summary

- While high flame temperature oxy-combustion burner and IPR® scale-up and optimization will continue during the current project year, these technologies are ready for commencement of a demonstration pilot project.

- The 5 MWe equivalent boiler retrofit completed for this JOC-NETL project has demonstrated
  - High flame temperature oxy-combustion can make steam in a conventional, older boiler without changing boiler interior materials
  - The IPR system uses commercialized equipment, and scale-up also will use commercialized equipment.

- Total parasitic power requirements for both oxygen production and carbon capture currently are in the range of 20%.

- Preliminary economic projections indicate that new and retrofitted coal fired power plants can achieve 95-100% carbon capture with COE increase of not more than 35% provided a net CO_2 revenue of approximately $20 per ton.

Thank you