THE JUPITER OXYGEN BOILER TEST FACILITY: 3RD GENERATION

HISTORY CHART

	PHASE I 1995 – 1997	PHASE II 1997 – 2001	PHASE III Jun 2002 – Feb 2003	PHASE IV Jan 2003 – Jan 2004	PHASE V Sep 2004 – Dec 2004	PHASE VI Apr 2007 – Current
Project Title	Proof of concept oxy-fuel process	Commercialization of oxy-fuel melters for aluminum	Viability testing of JOC oxy-fuel concept for boilers	Computer modeling for boiler retrofit including IPR	IPR demonstration using JOC coal-fired test chamber as CO_2 source	Enhanced test facility and IPR demonstration phase
Summary	Fired NG and oxygen in test melt furnace at up to 10 MMbtu's	Applied system based on commercially available components for production aluminum melting	JOC coal firing of Keeler D boiler on coal and NG with high purity oxygen	GE GateCycle computer modeling JOC and NETL	JOC firing of test chamber to generate CO_2 for NETL IPR testing	Coal firing of 15MWth boiler on Illinois #6 coal with slip stream CO_2 capture using NETL IPR unit built of commercially available components
Project Objectives	Determine significant parameters for operating aluminum melting furnace using oxygen and fossil fuels. Test burners and controls.	Specify, test, operate commercial-scale burners and controls. Confirm component accuracy and precision, and operational economics	Prove application of coal-fired JOC oxy-fuel to a boiler	Balance boiler heat transfer using 100% oxy-fuel firing at high temperature with recycle gas. Model ≥ 95% CO_2 capture	Prove viability of NETL IPR system on pilot plant slip stream	Oxy-fire 15 MWth boiler on Illinois #6 coal. Build IPR with commercially available components and capture CO_2
Location	Jupiter Aluminum Corporation test facility	Jupiter Aluminum Corporation production melters	JOC test facility	With NETL modeling	JOC test facility	JOC test facility
Sponsorship	Jupiter Aluminum Corporation	Jupiter Aluminum Corporation	JOC	JOC	NETL and JOC	NETL and JOC
Thermal Capacity	10 MMbtu/hr	40 MMbtu/hr	1.5 MWth	400 MWe	75 KW/hr	15 MWth
Fuel	NG and oil	NG and oil	NG and coal	Coal	NG and low sulfur coal	NG and high sulfur coal
Flue Gas Recycle	Not applicable for aluminum	Not applicable for aluminum	Test 0 to theoretical air volume	Test 0 to theoretical air volume	Test 0 to theoretical air volume	Test 0 to theoretical air volume
Burner Technology	Jupiter, Maxon	Jupiter, Maxon	Maxon test burner and Jupiter	Maxon test burner and Jupiter	Maxon test burner	Maxon 25 MWe commercial size burner
Instrumentation	Non PLC based	Computer based data for production in plant	PLC based–minimal data	Complete integrated control	PLC based–minimal data	PLC and LabView–full instrumentation
Emission Controls	Baghouse	Baghouse	No	Full IPR system	Full IPR system	Baghouse and cyclone, IPR system
Key Results	Operated refractory-lined melter without degradation of material performance.	Achieved long-term commercial operation using 70% less fuel	Proved feasibility of retrofit concept; used 16% less natural gas	Modeled thermal balance of oxy-fuel boiler with recycled flue gas	Captured 80% of CO_2 at pressures indicating >95% capture is feasible	Prove feasibility of commercial burner and IPR scale-up

DETAILS

- Located in Hammond, Indiana
- 30,000 square foot site
- 60,000 pound per hour super heated steam boiler
- 105 ton per day cryogenic plant
- Data collection system
- Integrated Pollutant Removal System
- Equipment to supply and control a variety of fuel sources:
  - Pulverized coal
  - Natural gas

HYPOTHESES

Increased flame temperature will result in:

- Increased heat transfer in the radiant section
- No increase in damage to boiler materials
- An increase in the total heat transfer in the boiler
- A decrease in fuel usage

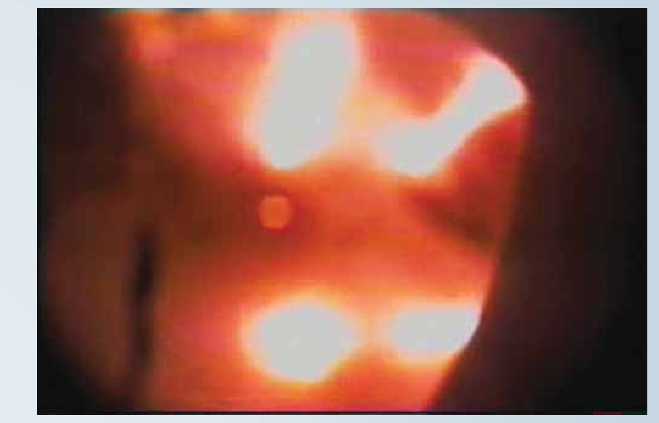
Heat transfer uniformity, corrosion, and erosion will be evaluated to answer concerns regarding the effect of higher temperature flames. This phase of testing also will establish the overall relative burner performance and monitor the geometry of the flame. The data collected will be analyzed with respect to the hypotheses as well as to data obtained from oxy-natural gas firing.

OUR UNIQUE APPROACH

- Undiluted high flame temperature
- Maximized heat transfer
- Improved efficiency of burner and boiler
- Advanced flame stability
- Achieved fuel & cost savings

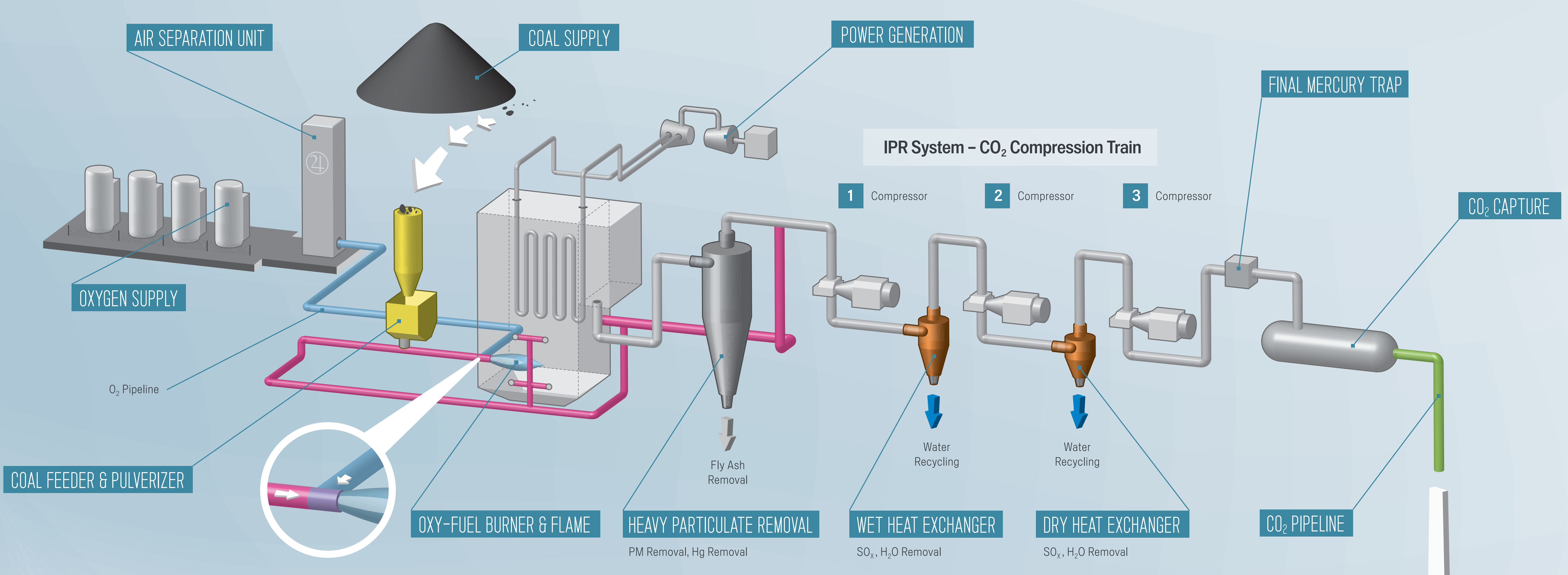
Jupiter Oxygen's approach avoids replication of an air-fired equivalency through the introduction of recycled flue gas into the oxygen stream to the burner, that:

- Reduces flame temperature, thus reducing radiation quality and quantity
- Results in less energy available for heat transfer in the boiler



The Jupiter approach of using low recycle at the burner results in a high oxygen concentration at the burner. That produces a high flame temperature and a very stable and controllable flame. The operation of recycle systems in boilers is well-known and existing engineering principles will be used for this study. Integration of the thermal cycles of heating and cooling of the cryogenic plant will also be investigated in the overall engineering study. Using oxygen preheaters to heat the oxygen will improve the combustion cycle thus reducing the power penalty of the overall power plant.

JOC OXY-FUEL IPR SYSTEM DETAIL: CLEAN COAL POWER GENERATION



CO_2 Underground Storage and Use

- Specific Geologoical Formation
- Enhanced Oil/Natural Gas Recovery

The figure above is a pictorial representation of IPR in the context of a complete oxy-combustion system. Various configurations are possible. In this version, bulk particulate removal is achieved in the first stage. Thus, the bulk of the ash is removed as a dry powder. Note that the bulk particulate removal operates on the full flue gas stream, which is split, after this bulk particulate removal, into a recycle stream and a product stream. The product stream is treated by IPR. Before the first stage of compression, a wet heat exchanger can be used with a caustic solution for SO_2 and fine particulate removal along with condensation of flue gas moisture. The water from this process is sent to water treatment, which will generate a waste stream including any contaminants removed, excess reagents and reaction products. Subsequent stages of compression and wet or dry heat exchange will remove remaining contaminants with the condensed water and, in the last stage, with condensed CO_2 as well. Mercury salts will be removed in the aqueous phase. Mercury vapor may require an activated carbon trap or other device. The final product stream is supercritical CO_2, which can be pumped to supercritical conditions and delivered via pipeline for enhanced oil recovery or sequestration.

RETROFIT STEPS

A Add oxygen plant or pipeline source

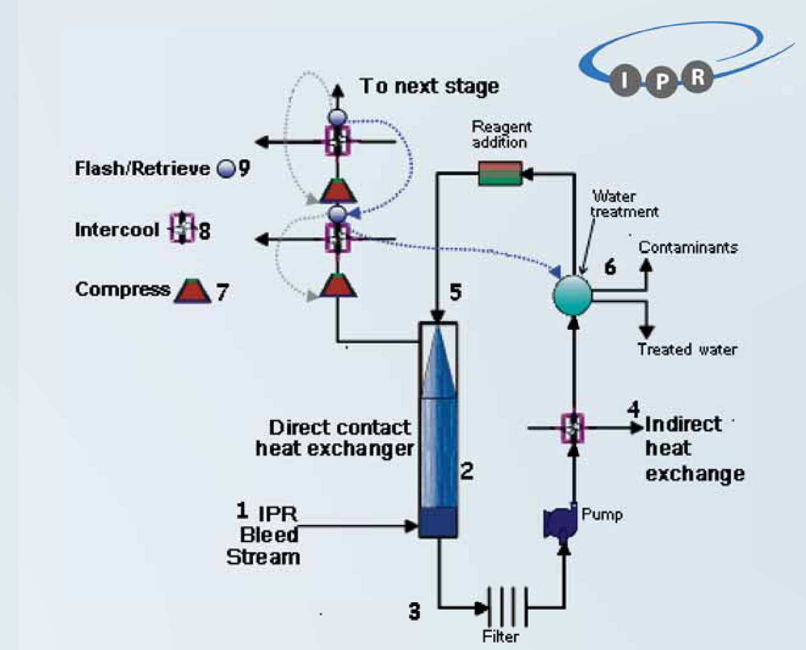
B Implement special oxy-fuel burners and oxy-fuel control system

C Install flue gas recirculation ducting if necessary

D Install Integrated Pollutant Removal (IPR™) with CO_2 capture train

E Connect to pipeline for underground storage or EOR

IPR SYSTEM DETAIL

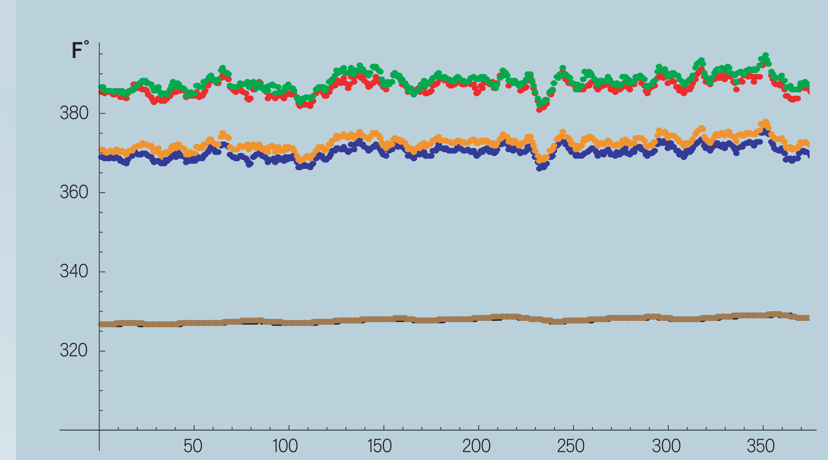


IPR process flows

1. Oxy-combustion flue gas enters IPR (~400°F)
2. Spray tower with countercurrent spray stream (± reagent for SO_x removal)
3. Condensed combustion product and spray water
4. Water cooling
5. Tower spray inlet for recirculated condensate
6. Water treatment for excess condensate
7. Two-stage, reciprocal "off-the-shelf" compressor
8. Water-cooled, counter-flow heat exchanger (internal to #7)
9. Water collection vessel for condensate from gas cooling. Periodically, gas is returned to the IPR gas stream and accumulated water to treatment (gray and blue arrows)

ONGOING RESEARCH

Current activities at the test facility include analysis of data generated during natural gas testing and shakedown for coal and oxygen operations. The 15 MWth boiler has been firing coal and oxygen since August of 2008. Operations are focusing on execution of a test matrix designed to gather the information required to test hypotheses regarding the effects of increased flame temperature.



Preliminary heat transfer results for the oxy-combustion boiler, measured by thermocouples embedded in the boiler tube wall (chordal thermocouples). Sample number is along the x-axis.

Results were obtained during shake-down oxy-natural-gas firing. Two thermocouples are located near the skin of the tube on the fireside (red and green lines). Two more thermocouples are located at a measured distance into the wall of the tube in line with the first two thermocouples (orange and blue), also on the fireside. The difference in temperature between the two thermocouples (one at the skin and one deeper in the tube wall) directly indicates heat transfer rate. A fifth thermocouple (brown line) is located on the back side of the tube (opposite the fireside); it measures the wall temperature on the non-illuminated side of the tube.

GHGT-9

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Results of Initial Operation of the Jupiter Oxygen Corporation Oxy-Fuel 15 MWth Burner Test Facility

JUPITER OXYGEN CORPORATION NETL

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