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# Assessment of full-scale boiler oxy-combustion retrofit using CFD modeling

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**1. Abstract**

The future use of coal in the U.S. depends on technologies being made available to capture and store $CO_2$ emissions from power plants. A key candidate $CO_2$ capture technology for coal-fired power plants is oxy-firing. In this process, the air typically used for combustion is replaced with a combination of oxygen and recycled flue gas. Application of oxy-firing to existing power plants presents unquantified challenges as the characteristics of oxy-firing compared to air-firing have not been fully determined. Key elements to be characterized include:

- Appropriate coal feed, oxygen feed, and flue gas recycle (FGR) design for oxy-fired burners or systems;
- Impacts of oxy-firing system design on boiler flame characteristics (burnout, emissions, heat transfer), fouling, slagging and steam tube corrosion relative to the expected behavior in existing air-fired systems.

Characterization of the differences between air and oxy-firing and the impacts of different oxygen feed and FGR designs is challenging due to the cost of experimental testing, particularly at large scale, and due to the variability in different potential firing configurations. A useful approach to conduct this characterization is to combine experimental testing with validated computer models. Experiments can provide fundamental data of different aspects of combustion impacts such as flame temperature, sooting, heat transfer and ash properties. With sufficient time and funding, this can be done for several coals, oxygen feed and FGR configurations. Practically however, not all designs and operating conditions of interest can be evaluated experimentally. Computer modeling using computational fluid dynamics (CFD) software can provide less expensive alternatives to testing and can evaluate numerous designs, including designs of full-scale systems. Advanced CFD models can provide accurate representation of the combustion, mixing, heat transfer, surface deposition and pollutant formation in coal-fired power plants. An accurate CFD tool for predicting boiler flame characteristics, fouling, slagging and corrosion is critical to the design and scale-up of oxy-firing systems, because critical aspects for the oxy-firing system, like the recycle of flue gas, will have a pronounced effect on these processes.

Reaction Engineering International, under funding from the U.S. Department of Energy National Energy Technology Laboratory (NETL), has performed a series of multi-scale experiments to characterize potential changes to boiler flame characteristics and surface impacts when converting from air to oxy-firing. These experiments

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ranged from bench-scale to 1.2 MW pilot-scale furnaces. The results of these tests were used to update and/or validate established mechanisms describing flame behavior, steam tube corrosion, slagging and fouling in coal-fired boilers. The validated mechanisms were then cast into a form amenable for inclusion into computational fluid dynamics (CFD) software.

For the purposes of this study, REI's *GLACIER* code was used for CFD modeling based on the extent of sub-models already in the code, access to source code, and previous experience using *GLACIER* to predict coal combustion behaviour in utility boilers. Note that other CFD codes, such as the commercial code Fluent, could also make use of the developed mechanisms. Development of *GLACIER* began over two decades ago primarily for the computational evaluation of coal-fired combustion. Physical and chemical models describing mechanisms for heterogeneous and homogeneous reaction, radiative heat transfer, particulate deposition on walls, pollutant emissions, etc. were initially targeted for describing coal combustion. Subsequent commercialization of *GLACIER* by REI as a tool for evaluating turbulent reacting flows has not been limited to coal combustion but the majority of problems have involved simulation of air-coal combustion.

To date, REI has used *GLACIER* to simulate over 180 utility boilers representing over 70,000 MW of capacity on units ranging in size from 20 MW to 1300 MW. The majority of these units have been coal-fired. Focus has been on reduction of emissions including $NO_x$, $SO_x$, and Hg as well as impacts of various pollution control devices. As such, *GLACIER* has been used to provide qualitative and quantitative predictions of impacts of equipment modifications or reagent/sorbent injection processes on emissions as well as on combustion performance (e.g. LOI, CO, soot), slagging and fouling, heat balance, and waterwall corrosion. Model simulations have been followed up with equipment installation accompanied by testing, leading to a relatively high level of model validations over a range of gaseous and solid fuels, a range of boiler geometries and sizes, and boiler operating conditions. Much of the non-proprietary work has been documented [Valentine 2007, Cremer 2005a, Cremer 2005b, Cremer 2002)]. Given that *GLACIER* is a working code used for engineering problem solving and conceptual design over a range of applications, it remains in a form that allows relatively easy access for modifications, additions, and improvements. For this work, enhanced mechanisms for slagging, fouling, waterwall corrosion, char oxidation, soot formation and gaseous radiative heat transfer developed or evaluated as a product of the experimental testing were implemented into *GLACIER* with relative ease by engineers that had previous experience with similar code developments.

Once the mechanistic-based sub-models in *GLACIER* were updated, the code was used to carry out an assessment of a full-scale boiler oxy-combustion retrofit. The approach used to conduct the assessment included the following key steps:

1) Verify results from the updated CFD model against pilot-scale data for oxy-coal combustion.
2) Use the CFD model to simulate combustion with coal-air firing in a full-scale boiler. Use available operational data and observations to ensure air-fired model reflects current boiler characteristics.
3) Scale-up oxy-combustion firing system design (e.g., oxygen feed, recycle gas properties) to utility scale.
4) Simulate full-scale boiler under oxy-firing conditions to compare boiler characteristics under air-coal and oxy-coal firing conditions.
5) Optimize firing system under oxy-coal conditions to produce furnace behaviour similar to air-fired conditions.

With participation of utility Advisory Panel members, a suitable coal-fired boiler was selected simulation under both air and oxy-coal firing. The unit selected was a 460 $MW_e$ opposed wall-fired boiler firing U.S. western bituminous coal (low sulphur, HHV ~11,000 Btu/lb). A wall-fired unit was selected because the wall-fired burners were similar to the burner studied during pilot-scale testing. The unit has 40 low-NOx burners operating under staged conditions with overfire air ports. This unit was previously modeled by REI under air-fired conditions, but was adjusted to current operational conditions for the retrofit study.

The model results that were used to compare behavior under air and oxy-firing included: gas temperatures in the near burner region and at the inlet to the convective section, wall heat flux profiles, absorbed heat distribution in the boiler radiant and convective sections, NOx concentrations, $SO_2$ concentrations, soot concentrations, ash particle

LOI, ash deposition patterns and rates, fouling patterns and rates, slagging patterns and composition, and waterwall corrosion rates. Figure 1 shows gas temperature, wall heat flux, unburned carbon and ash deposition patterns for the Hunter 3 unit under air-fired conditions.

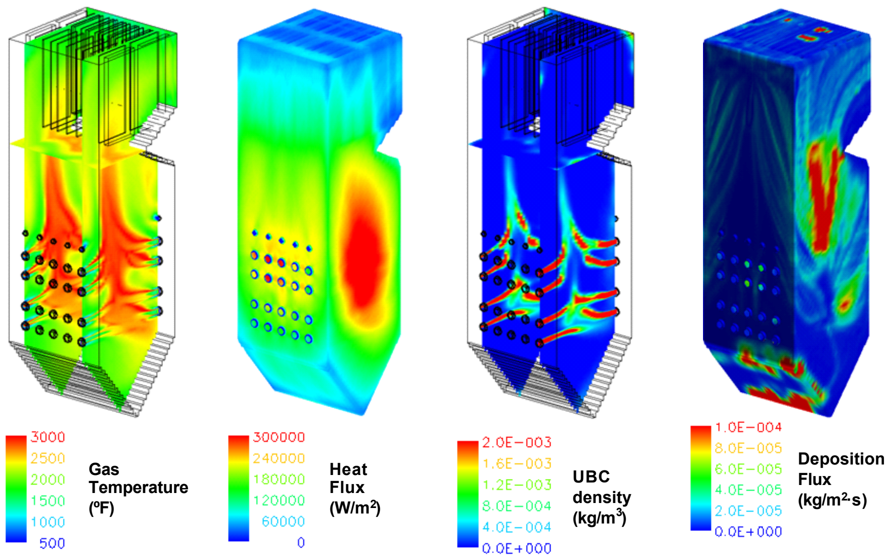


Figure 1. Hunter 3 simulation results under air-firing conditions.

Based on the simulation results for the first oxy-coal design, design and operational changes were made to optimize firing system performance. Changes included variations to burner oxygen and FGR injection, burner staging levels, and design, composition and temperature of the FGR. The intent was to closely approach the unit heat balance that was achieved during air-coal firing, and to improve upon slagging and fouling and waterwall corrosion rates as compared to that seen and predicted under air-coal conditions. *GLACIER* has been employed in this manner for performance optimization of full-scale air-coal boilers, so it is expected that the results obtained here can be viewed with confidence.

Initial simulation results suggest that gas temperatures and heat transfer characteristics under oxy-firing conditions can be made comparable to air-fired conditions. Temperatures can be controlled by the amount of oxygen and flue gas recycle used during firing. NOx concentrations appear similar under oxy-firing conditions, but overall emissions were lower due to lower flue gas volume emitted under oxy-firing. $SO_2$ concentrations increased with flue gas recycle; full assessment of the impact of the FGR on slagging, fouling and corrosion is still on-going.

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