

Advanced Prediction of Unburned Carbon Levels in Two Utility Boilers Retrofitted for In-Furnace NO_x Reduction

Kevin A. Davis, James R. Valentine, Eric G. Eddings, Jacob Brouwer, and Michael P. Heap

davis@reaction-eng.com

ph: 801-364-6925

fax: 801-364-6977

Reaction Engineering International

77 West 200 South, Suite 210

Salt Lake City, UT, 84101

Robert H. Hurt, Brown University

Robert Hardman, Southern Company Services

Nick Grigas, Genco

Tony Facchiano, Electric Power Research Institute

In-furnace NO_x reduction techniques have been under development for more than two decades and second and third generation systems have been implemented. However, the difficulties encountered in obtaining satisfactory NO_x and LOI levels simultaneously have pointed out the complex relationship between the two-phase fluid mechanics, heat transfer, and chemistry that occurs in a coal-fired boiler. Computational simulations are a logical approach to understanding these interactions if all relevant physical and chemical mechanisms can be correctly implemented. The current effort involves the use of a state-of-the-art reacting, two-phase, computational fluid dynamics code to achieve an improved understanding of this problem by simulating two common, but distinctly different, types of boilers. Particular attention is given to the physical and chemical parameters that affect unburned carbon in flyash.

The computational tools used by Reaction Engineering International (REI) have been developed over the last fifteen years with the goal of addressing a wide range of problems encompassing utility boilers, pyrolysis furnaces, gas turbine combustors, rotary kilns, waste incinerators, smelting cyclones and others. Current software simulates reacting and nonreacting flow of gases and particles, including gaseous diffusion flames, pulverized-coal flames, liquid sprays, coal slurries, isothermal and reacting two-phase flows, injected sorbents, and other oxidation/reduction systems. Emphasis has been placed on simulating coal combustion and pollutant formation. REI codes, particularly *GLACIER*, include several capabilities necessary for accurate simulation of coal-fired boilers. These capabilities include turbulent particle transport with full coupling of particle and gas-phase mass and momentum; coal reaction processes such as devolatilization, char oxidation and gas-particle interchange; NO_x formation/reduction chemistry; particle convection and radiation with absorption, emission and anisotropic scattering; full coupling of gas-particle energy exchange; and ash deposition. In addition, boiler-side water wall and radiant panel surface temperatures can be predicted as part of the computation, given a back-side (i.e., steam) temperature and surface resistance (from the deposit thickness and thermal conductivity, for example).

Through several years of industrial case studies, this simulation capability has been established as a useful tool for problem solving and design development. In addition, application of this tool to the

specific issue of unburned carbon in flyash has been successfully performed. However, the effectiveness of the model across a wide range of boiler types, operating conditions, and coal types has not been evaluated. Recent advances in the understanding of char oxidation that are unlikely to affect heat release and pollutant formation, could play an important role in predicting both quantitative information and trends relating to unburned carbon in flyash. Therefore efforts have been made to integrate these advances with/into *GLACIER*.

Since char oxidation is the slowest step in the coal combustion process, the rate at which heterogeneous reactions occur can have an important effect on carbon levels in flyash. The combustion of char particles has been examined extensively and applicable reaction rate information is available for specific coals and for classes of coals. This information however, focuses on the early and intermediate stages of char oxidation. While these data have proven useful for evaluating heat release and pollutant formation, recent evidence shows that the oxidation rates during the latter stages of char combustion can be much slower. Therefore, simulations relying on these rate parameters can significantly underpredict unburned carbon levels in flyash. This work has been corroborated by analyses of residual carbon in flyash that show extremely low reactivities and nearly graphitic structures. Three mechanisms leading to this reactivity loss have been identified:

1. Thermal annealing of the carbonaceous material.
2. Statistical variations of single particle reactivity and density.
3. Other changes in physical properties related to diameter/density changes and ash inhibition.

Work performed at Sandia and Brown University has been completed to accurately model the impact of each of these mechanisms on char oxidation reactivity. More recently REI has begun to integrate these mechanisms into *GLACIER*. Initial efforts have been focused on interfacing the two codes (*GLACIER* and Carbon Burnout Kinetic Model) such that the statistical description of reacting flowfields and particle clouds available in *GLACIER* can be input to CBK in a useable and consistent manner. Case studies have been performed by simulating two utility boilers recently retrofitted with low NO_x burners/firing systems and overfire air. Useful observations and test data are available for these two boilers, one wall-fired and one tangentially fired, allowing for valuable comparisons and interpretation of the relative importance of the physics included in the model and of the technologies being applied for NO_x reduction. These two facilities are examples of units that have been significantly (wall-fired) and minimally (T-fired) impacted by the increases in unburned carbon loss resulting from their respective retrofits.