DEVELOPMENT OF A VALIDATED MODEL FOR USE IN MINIMIZING NO_X EMISSIONS AND MAXIMIZING CARBON UTILIZATION WHEN CO-FIRING BIOMASS WITH COAL

Quarterly Report

Reporting Period Start Date: 10/1/2002
Reporting Period End Date: 12/31/2002

Larry G. Felix
P. Vann Bush

January 29, 2003

DOE Cooperative Agreement No. DE-FC26-00NT40895

Southern Research Institute
2000 Ninth Avenue South
P. O. Box 55305
Birmingham, AL 35255-5305

DISCLAIMER

ABSTRACT

This is the ninth Quarterly Technical Report for DOE Cooperative Agreement No. DE-FC26-00NT40895. A statement of the project objectives is included in the Introduction of this report. The pilot-scale testing phase of the project has been completed. Calculations are essentially completed for implementing a modeling approach to combine reaction times and temperature distributions from computational fluid dynamic models of the pilot-scale combustion furnace with char burnout and chemical reaction kinetics to predict NO_X emissions and unburned carbon levels in the furnace exhaust. The REI Configurable Fireside Simulator (CFS) has proven to be an essential component to provide input for these calculations. Niksa Energy Associates expects to deliver their final report in February 2003. Work has continued on the project final report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The work conducted in this project received funding from the Department of Energy under Cooperative Agreement No. DE-FC26-00NT40895. This project has a period of performance that commenced September 20, 2000 and, with an approved time extension, continues through March 31, 2003. A project Work Plan was submitted to DOE on October 18, 2000 as the first deliverable under the cooperative agreement. The Work Plan is not included in this report, but the objectives of the project are restated from the Work Plan in the following paragraphs.

Objectives

The project is designed to balance the development of a systematic and expansive database detailing the effects of co-firing parameters on nitrogen oxides (NO_X) formation with the complementary modeling effort that will yield a capability to predict, and therefore optimize, NO_X reductions by the selection of those parameters.

The database of biomass co-firing results are being developed through an extensive set of pilot-scale tests at the Southern Company/Southern Research Institute Combustion Research Facility. The testing in this program has monitored NO_X, unburned carbon (UBC), and other emissions over a broad domain of biomass composition, coal quality, and co-firing injection configurations to quantify the dependence of NO_X formation and LOI on these parameters. This database of co-firing cases characterizes an extensive suite of emissions and combustion properties for each of the combinations of fuel and injection configuration tested.

The complementary process modeling expands the value of the raw test data by identifying the determining factors on NO_X emissions and UBC. Niksa Energy Associates (NEA) is developing and validating a detailed process model for predicting NO_X emissions and LOI from biomass co-firing that builds on a foundation of existing and proven fluid dynamics, reaction kinetics, and combustion products models. The fluid dynamics data is being produced from computer models developed by Reaction Engineering International (REI). The modeling process will resolve all major independent influences, including biomass composition, coal quality, chemical interactions among biomass-and coal-derived intermediate species, competitive O_2 consumption by biomass- and coal-derived intermediate species and chars, extent of biomass/coal mixing prior to combustion, and mixing intensity during biomass injection.

The overall goal of the project is to produce a validated tool or methodology to accurately and confidently design and optimize biomass co-firing systems for full-scale utility boilers to produce the lowest NO_X emissions and the least unburned carbon. Specific program objectives are:

- Develop an extensive data set under controlled test conditions that quantifies the relationships between NO_X emissions and biomass co-firing parameters.

- Provide a data set of the effects of biomass co-firing over a broad range of fuels and co-firing conditions on flame stability, carbon burnout, slagging and fouling, and particulate and gaseous emissions.

- Develop and validate a broadly applicable computer model that can be used to optimize NO_X reductions and minimize unburned carbon from biomass co-firing.

Once validated, the model will provide a relatively inexpensive means to either (1) identify the most effective co-firing injection configuration for specified compositions of biomass and coal within a particular furnace environment, or (2) to forecast the emissions for a specified pair of fuels fired under an existing configuration. As such an important cost-saving tool, the modeling has the potential to accelerate widespread adoption of biomass co-firing as a NO_X control strategy in the electric utility industry.

RESULTS

Model Development

The three independent aspects of modeling for this project are (1) the mechanisms for fuel devolatilization and char burnout, and (2) the detailed chemical mechanism for combustion and fuel-N conversion in the gas phase, and (3) the equivalent reactor network. Niksa Energy Associates (NEA) has integrated these three aspects into a working version of the NO_X – unburned carbon predictive model and has been testing the model over the range of coal types, biomasses, and fuel injection configurations tested.

Overall, predicted NO_X emissions agree with the experimental data within experimental uncertainties for all biomass fuel types, excess O_2 levels, and extents of air staging. The predicted unburned carbon (UBC) levels are less accurate, but are generally consistent with the qualitative tendencies in the data. *This level of performance was achieved without any adjustments to the model parameters for any of the biomass cofiring cases*. Instead, calibration factors were specified to match the predicted and observed emissions for the coal-only tests for all excess O_2 levels, and extents of air staging. These same calibration factors were then applied to the operating conditions for the co-fired flames. *In this way, these Test series were simulated with the detailed chemical reaction mechanisms, based on CFD simulations from REI and CFD simulations carried out with the REI's Configurable Fireside Simulator.*

NEA has completed calculations for model comparisons with tests involving Powder River Basin (PRB) coal and low-volatility bituminous coal and is completing its final project report.

CFD Simulations

REI's Configurable Fireside Simulator for the Pilot-Scale Combustion Research Facility has been used to complete CFD simulations for PRB coals and low volatility coal. Results of these calculations have been forwarded to NEA. CFD calculations are complete.

Pilot-Scale Combustor Testing

Furnace Testing Fourteen furnace tests have been completed through the end of December, 2002. These tests have been reviewed in previous quarterly progress reports. Table 1 summarizes the tests that have been completed to date. Figure 1 shows the various locations used for biomass injection.

DISCUSSION

The Configurable Fireside Simulator (CFS) has been used to complete the CFD simulations required by NEA to model all fourteen tests.

NEA has continued to refine the development of an innovative approach for the construction of the process model that will yield predictions of NO_X emission rates and carbon burnout efficiency. Results suggest that NO_X emissions can be predicted within experimental uncertainty and that UBC emissions trends are well characterized but are presently less accurate than are predicted NO_X emissions.

No further pilot-scale furnace tests are planned. To date four coals and two biomasses have been tested with up to three modes of biomass injection. Combustion of a third biomass (chicken litter) was simulated by adding ammonia to the primary air/fuel feed line. Most testing was conducted with a single-register burner, since budgetary constraints precluded developing CFD simulations (and model validations) for a dual register burner. However, one test was conducted with a dual-register (low-NO_X) burner so that the database of information generated for this project will include NO_X emissions

Table 1. Pilot-Scale Furnace Tests Completed

Test 1: Pratt Seam Coal – Comilled Biomass, single register burner (Location 1), 15%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15%, 30% overfire air. 1/28-2/3/01

Test 2: Pratt Seam Coal – Biomass through center of burner (Location 2), single register burner, 10% Sawdust. 0%, 15% overfire air. Problems with biomass injection scheme and flame stability. 2/25-3/2/01

Test 3: Pratt Seam Coal – Biomass through center of burner (Location 2), single register burner, 10%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15% overfire air. Continued problems with flame stability. 4/8-14/01

Test 4: Pratt Seam Coal – no biomass, single register burner (Location 1), extensive characterization of coal-only firing at 0% and 15% overfire air. Corrected flame stability problem. 5/14-17/01

Test 5: Pratt Seam Coal – Biomass injection toward quarl (Location 3), single register burner, 10%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15% overfire air. 6/10-15/01

Test 6: Galatia Coal – Comilled Biomass, single register burner (Location 1), 10%, 20% Sawdust. 0%, 15%, overfire air. 7/8-7/13/01 (switchgrass not delivered in time)

Test 7: Galatia Coal – Comilled Biomass, single register burner (Location 1), 10%, 20% Switchgrass. 0%, 15%, overfire air. Pratt Seam Coal comilled with 20% sawdust. 8/5-10/01

Test 8: Jacobs Ranch Coal – Comilled Biomass, single register burner (Location 1), 10%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15% overfire air. 9/16-21/01

Test 9: Jacobs Ranch Coal – Biomass through center of burner (Location 2), single register burner, 10%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15% overfire air. 10/21-26/01

Test 10: Galatia Coal – Comilled Biomass, dual register burner (Location 1), 10%, 20% Switchgrass, 10%, 20% Sawdust. 0%, 15%, overfire air. 1/6-11/02

Test 11: Pratt Seam Coal – no biomass, single register burner (Location 1), regular (~70%<200 mesh) and finely ground (~90%<200 mesh) coal at 0% and 15% overfire air. 2/10-13/02

Test 12: Galatia Coal – Comilled Biomass, single register burner (Location 1), 5%, 10%, 20% Sawdust. 0%, 15%, overfire air. Liquid NH_3 injected into primary air line to increase fuel-bound nitrogen. 4/7-13/02

Test 13: Galatia Coal (only) and Jim Walters #7 coal – Comilled Biomass, single register burner (Location 1), 5%, 10%, 20% Sawdust. 0%, 15%, overfire air. Char sampling below overfire air ports. 5/19-24/02

Test 14 Jim Walters #7 coal – Comilled Biomass, single register burner (Location 1), 5%, 10%, 20% Switchgrass. 0%, 15%, overfire air. Char sampling below overfire air ports. 7/14-19/02

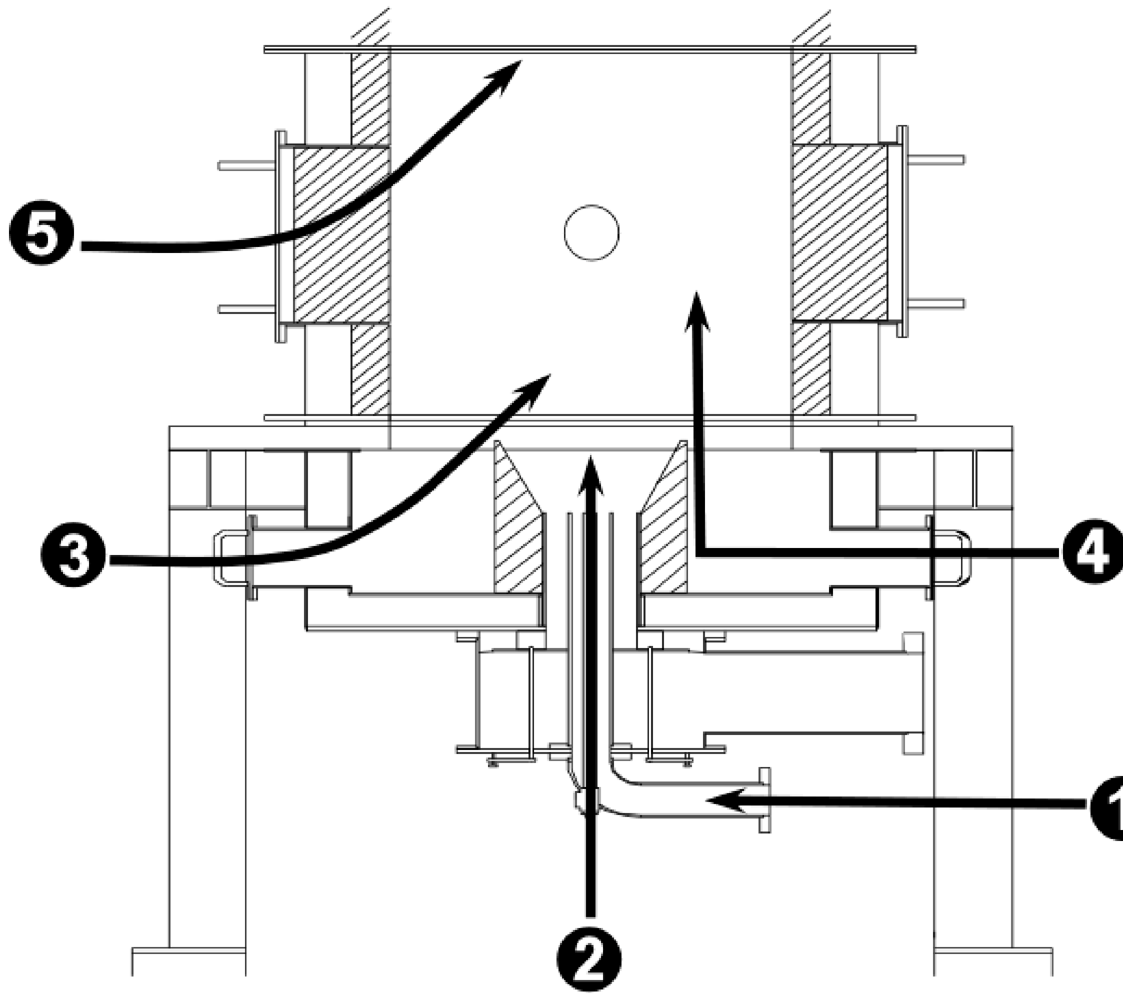

Figure 1. Locations for biomass injection in the SRI/SCS furnace equipped with the single-register burner.

data from a dual-register burner. After initial tests with comilling, center-burner biomass injection, and side injection of biomass into the burner, subsequent tests concentrated on comilling biomass with coal when results from the modeling effort indicated that the model was most stringently tested with emissions data from cofiring tests with comilled biomass.

CONCLUSIONS

Software development for the modeling effort incorporating an innovative approach toward defining reaction zones in a combustion system has proven to be successful. The result is a generally applicable algorithm that should benefit other process modeling efforts in which carbon consumption or conversion is a major component.

Plans for the next quarter include receipt of NEA's final report, incorporation of that report into the project final report, and completion of the project final report.