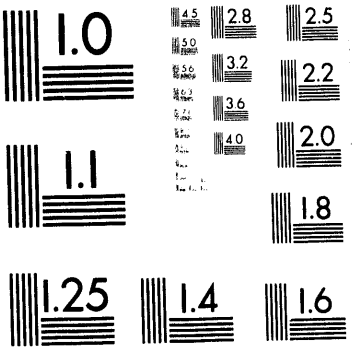
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ADVANCED COMBUSTION SYSTEM FOR INDUSTRIAL BOILERS PHASE II

Quarterly Technical Progress Report

JANUARY-MARCH 1991

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1.0 INTRODUCTION

The contract start date (for Phase I) was June 11, 1987. Contract completion date is November 30, 1991.

This is the sixth quarterly report covering work on Phase II of the project. The period covered is January through March 1991.

The purpose of this project is to develop an advanced coal combustion system for industrial boilers. With the new combustion system, coal could be used to replace oil and gas as fuels for many industrial boilers.

The advanced coal combustion system concept includes the following components:

- a new burner for ultra fine coal fuels which could replace existing oil and/or gas burners
- a coal injector that could replace the oil gun in existing burners, as an alternative to complete replacement of the burner assembly
- a coal storage and dense phase coal feed system
- an automatic control system, based on computer control with feedback from low-cost combustion-quality transducers
- ash removal and particulate cleanup equipment.

1.1 Phase I, Summary of Results

During Phase I of the project, a coal injector was designed, fabricated, and tested. It is a direct replacement for the oil gun in the original equipment of a 200 hp Cleaver-Brooks fire-tube boiler. The system was tested at coal-firing rates in the range of 2 to 6 million Btu's per hour, firing Upper Elkhorn No. 3 (eastern bituminous, "UE3")

coal supplied by Energy International, Incorporated. For these tests, propane was used to preheat the boiler before initiation of coal firing. The propane flow was turned off after coal combustion was established. No combustion air preheat was used. During these tests, boiler efficiency was typically about 85 to 86 percent, while carbon conversion efficiency was approximately 94 percent. Concentrations of CO were less than 150 ppm. The NO_x emissions were less than 0.6 pounds per million Btu's.

Following a series of laser-illuminated cold-flow-visualization tests, a new burner also was designed, fabricated, and tested during Phase I. It is a two-stage, swirl burner which fits in the space previously occupied by the original Cleaver-Brooks burner, and uses the existing section of refractory. Air flow can be regulated independently into each of the two stages. Additionally, the angle is adjustable for individual swirl blades.

Upper Elkhorn No. 3 ultra fine coal was used as the standard fuel for most UTSI-burner tests. Firing rates were in the range of 2 to 6 million Btu's per hour. Upper Elkhorn No. 3 coals were tested with three levels of ash. These were approximately 1.4%, 2.7%, and 4.8%, on an as-fired basis. The 2.7%-ash UE3 coal was used for most tests because it exhibited a good balance between ash content and ash-fusion characteristics. The 2.7%-ash UE3 coal also served as a reference and established a baseline for performance. Additionally, a 1.3 float fraction of a western Eagle Butte subbituminous coal was used as the fourth ultra-fine test fuel. It contained 4.4% ash on an as-fired basis.

All four test coals were supplied by Energy International, Inc. with a mean particle size of about 10 μm and a top size of 44 μm. The coals were delivered to UTSI in plastic-lined, 55-gallon steel drums.

Following the same approach as previous tests, propane was used to preheat the boiler before initiation of coal firing. The propane flow was turned off after coal combustion was established. No combustion air preheat was used with the UTSI burner. Boiler efficiency was approximately three percent higher with UE3 coal than in the previous test series, and typically was about 88 to 89 percent. Carbon conversion efficiency was approximately 97 to 99 percent for UE3 coals. A very high value of 99.9 percent carbon conversion was attained with the 4.4%-ash Eagle Butte coal. These results are about 3 to 6 percent higher than those measured when the UTSI coal injector was used in the Cleaver-Brooks burner.

Forty to sixty percent of the ASTM coal ash remained in the boiler. However, the deposits were powdery and easy to remove by increasing the fan speed after the conclusion of each combustion test. The increased air velocity quickly re-entrained and removed most of the previously-deposited ash.

Concentrations of CO were below 100 ppm. The NO_x emissions ranged from 1.2 to 1.3 pounds per million Btu's with the UE3 coals. With the Eagle Butte coal, a lower level of 0.86 pounds of NO_x per million Btu's was measured.

In addition to the burner-development activities, a system was designed, fabricated, tested, and used routinely for data acquisition and manual boiler/burner control. The system is based upon a dedicated micro-computer based on the Intel

"286" cpu chip architecture using UTSI-developed software. **In Phase II this system will provide automation of system control and data acquisition.**

1.2 Initiation of Phase II

Phase II started on October 1, 1989.

The main objective of the current work is to move ahead from the primarily R&D oriented approach of Phase I toward commercialization of a complete coal-retrofit system.

In order to accomplish this, our plans include the following goals and activities.

Goals

- Decrease NO_x emissions to less than 0.7 lb/MBtu

  Although the UTSI commercial fire-tube boiler is fired at 6 MBtu/hour and, therefore, is much smaller than steam generators usually subjected to strict NO_x regulations, we have based our goal upon the value specified in *Performance Standards for Commercial/Industrial/Institutional Steam Generation* for coal-fired boilers in the 100 MBtu/h to 200 MBtu/h range. A level of 0.6 lb NO_x/MBtu is specified for coal-fired electric utility steam generators larger than 250 MBtu/hour by the *Performance Standards for Electric Utility Steam Generating Units Commencing After September 18, 1978.* As a supplemental goal, we will attempt to obtain this lower level of emissions with NO_x less than 0.6 lb/MBtu.

- Decrease particulate emissions to less than 0.6 lb/MBtu

  This is based upon the current *UTSI site permit* issued by the state of Tennessee; otherwise, Tennessee particulate limit is 0.8 lb/MBtu for a 6 MBtu/h boiler such as the UTSI unit.

- Increase carbon burnout so all test coals exceed 99% efficiency at a firing rate of approximately 6 MBtu/h

  This is based upon a *stated DOE goal*.

- Increase the turn-down ratio from the present 3:1 capability

  This is based upon *extension of previous achievement* of the stated DOE goal of 3:1.

Planned Activities

- Investigate the effects on reducing NO_x emissions by deep-staging combustion air or reburning
- Add on-line cleaning capabilities for removal of powdery fireside deposits
- Add particulate-removal equipment to reduce stack emissions
- Develop higher efficiency three-stage burner
- Add air pre-heater and evaluate effects
- Add low-cost combustion-quality transducer for automated control of boiler efficiency
- Develop simple, reliable, and inexpensive on-line dense-phase flow-control capability with storage hopper operating at atmospheric pressure

and suitable for reloading with coal at any time during extended periods of operation

- Automate the boiler control system
- Evaluate potential of bulk bags for receiving, storing, and unloading ultra fine coal
- Develop a commercially acceptable ultra-fine coal storage and dense-phase feed system
- Demonstrate performance of new three-stage burner
- Make an economic evaluation and develop a commercialization plan
- Demonstrate commercial feasibility of the integrated system with a 100-hour test operation

1.3 Phase II, Summary of Previous Results

Work in Phase II has concentrated on: a.) adapting a commercially available automotive oxygen sensor for use in the boiler control system; b.) developing a commercially oriented dense-phase coal transport system; c.) designing, fabricating, testing, and fine tuning an improved burner for better combustion efficiency; and d.) adding deep-air-staging capabilities to the new burner to decrease NO_x emissions to slightly above 0.4 lb-NOx/MBtu with ultra fine coal. This performance is considerably better than the DOE goal for Phase II work.

Reburning tests were conducted using ultra fine coal and propane in the external, water-cooled 15-foot long test duct. When propane supplied approximately 14% of the heat input, NO_x levels were as low as 0.295 lb-NOx/MBtu. Initial testing of the UTSI boiler control and automation system was successful. Normally-pulverized

coal (PC) with approximately 70% passing through a number 200 sieve was burned in the external test duct. Initial flame-visualization tests with PC were successful, and the burner was able to handle coal without being micronized to the ultra fine level.

An improved combustor second-stage assembly was fabricated and installed inside the 200 hp fire-tube boiler.

2.0 TECHNICAL PROGRESS IN PHASE II DURING JANUARY-MARCH 1991

QUARTERLY SUMMARY:

During this quarter, work continued with testing, developing and improving the new low-NO_x coal combustor and associated boiler system. Significant progress was made toward completion of the overall system. The new coal-feed sub-system was completed. With the on-line refillable coal hopper operating in air at atmospheric pressure, long-duration operation is feasible with coal being loaded periodically into the hopper from bulk bags. This technique will be used during the upcoming 100-hour demonstration test.

Carbon burnout of 99.1 percent was achieved in the Cleaver-Brooks fire-tube boiler with NOx emission of 0.44 lb/MBtu during testing with micronized Upper Elkhorn #3 coal with 2.4% ash, as fired.

Normally-pulverized coal (≈70% passing through a number 200 sieve) also was burned in the Cleaver-Brooks boiler. Although the coal feed rate was less consistent than desired during this initial test using PC with the new coal feed system, carbon burnout was very promising using this economical fuel.

2.1 Task 3: Integrated Combustion System Development

Quarterly activity details follow.

2.1.1 Coal Feed System

Electricians completed their work on the atmospheric-pressure coal hopper, including wiring the bin-discharger motor and connecting load cells. The external test duct was set up and used for shakedown of the new coal feed system.

During February, we modified the coal discharge tank weighing assembly to improve the signal-to-noise ratio. A screen was added to remove oversized material from the coal as it is loaded. (Although ultra fine coal nominally has a top size of approximately 44 µm, the coal supplied to UTSI by Energy International has some top-end coal chunks that exceed one inch!) Initial performance of the coal-feed system during combustion testing in the external duct indicated that we had achieved controlled ultra-fine coal flow rates in the range from 2.0 to 6.5 pounds per minute (approximately 1.8 to 5.8 MBtu/h) with burner-eductor air pressures in the range from 20 to 80 psig. Concurrent burner performance (turndown ratio) exceeds the fuel range of 3.25 to 1. This performance also exceeds the DOE goal, which is ≥3 to 1 for turndown. For example, the following table shows a 3.29 turndown ratio measured with 3 scfh of fluidizing nitrogen:

lb/min.	*Coal Flow with 3 SCFH Fluidizing Nitrogen*	*Btu/hour*
6.52	Measured high rate	5,868,000
1.98	Measured low rate	1,782,000

2.1.2 Low-NO_x Burner Modification and Testing

During January, we completed installation of the new six-foot combustor in the Cleaver-Brooks 200 hp fire-tube boiler, and cured the refractory. Subsequently we burned micronized coal to test the new configuration. and conducted an in-depth micronized-coal combustion test. Inspection of the interior of the boiler after testing revealed that the third stage was in good condition, and no significant slagging was noted after approximately 9 hours total of operating with coal. No downstream ash-fouling problems were observed.

Carbon burnout of 99.1 percent was achieved with a NOx emission of 0.44 lb/MBtu during the test using micronized Upper Elkhorn #3 coal with 2.4% ash, as fired. This performance exceeded the goals of >99% carbon burnout and <0.7 or <0.6 lb NOx/MBtu.

Measurements of the particle size of the fly ash from the micronized Upper Elkhorn coal (see Figure 2.1) indicate a cyclone would not be suitable for separating these particulates from stack gases. Therefore, a baghouse will be used. (In Figure 2.1, DUC indicates dry, ultra-fine coal.)

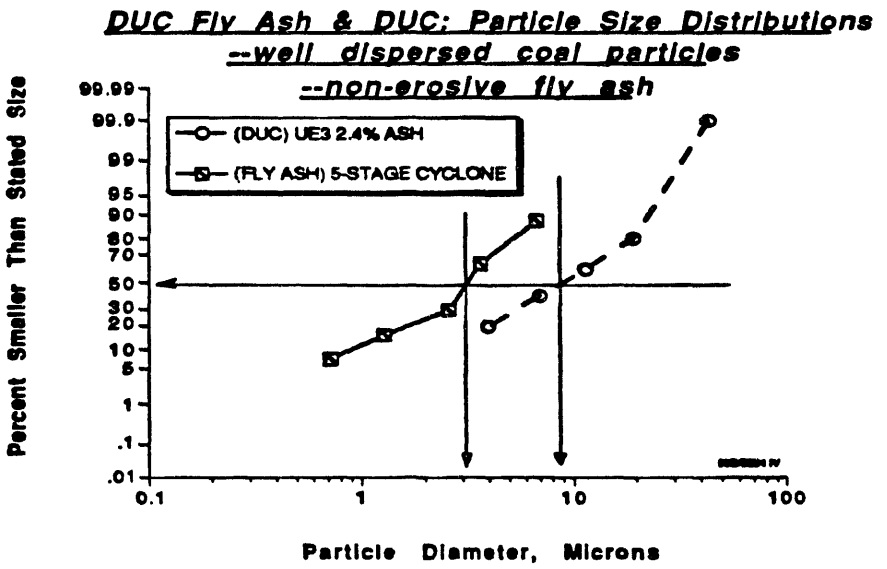

Figure 2.1. Particle Size Distribution Data

Calculations indicate that it will be necessary to remove fly ash from the stack gases in order to decrease particulate emissions to less than 0.6 lb/MBtu. Use of extremely low ash coal without additional flue-gas clean up does not appear to be a practical alternative. Assuming on-line soot blowing is used, unburned carbon associated with 99% combustion efficiency will produce nearly 0.6 lb-particulates/MBtu by itself (see Figure 2.2). Coal ash, based on ASTM "ash" analyses, would contribute to much larger, additional emissions. Conversely, a baghouse easily can reduce particulate

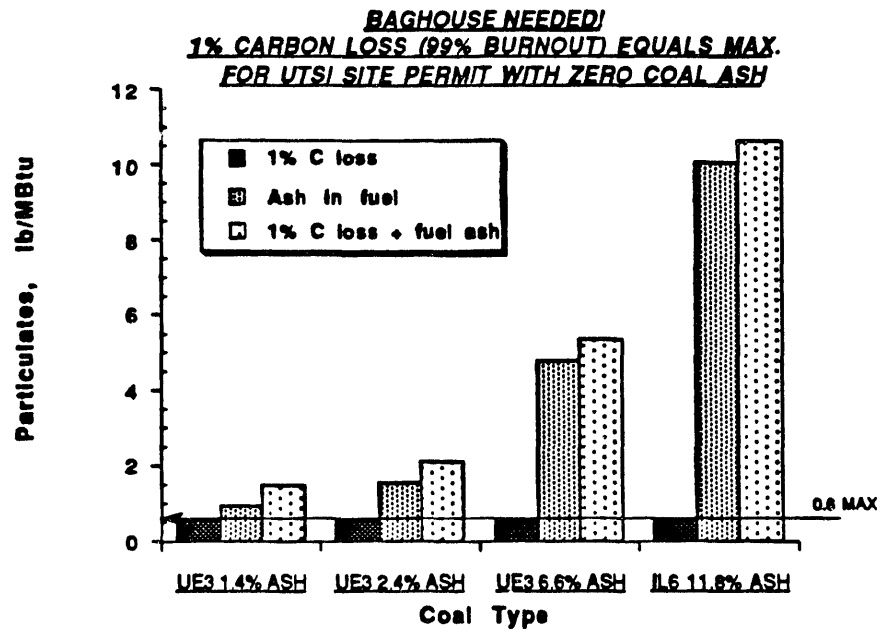

Figure 2.2 Calculated Particulate Emissions Without Baghouse

Following the ultra fine coal tests, we successfully burned Illinois No. 6 coal during a two-hour test. ***Carbon burnout of 93.7 percent was achieved with a NOx emission of 0.57 lb/MBtu using pulverized coal (PC) with 12.5% ash, as fired. The PC was obtained from the MHD CFFF facility at UTSI.*** Significantly better carbon burnout is expected in future tests with PC when coal flow variations associated mainly with the pulverized coal are minimized and air staging is optimized.

Data were analyzed from previous propane-reburn experiments conducted to evaluate performance using this advanced NO_x-reduction technique. Propane/air injection nozzles were designed conceptually. These could be used for additional NOx-reduction experiments via reburning near the end of the first pass inside the 200 hp boiler.

During March, we conducted combustion tests in the external duct to try an increased angle for the primary swirl-blades (60 degrees). Results were good, but the normal 45-degree setting produces superior performance.

2.1.3 Controls

Work continued on modifications to improve operation of the flame and oxygen sensors which are part of the automatic control system.

A spectrometer was set up to measure spectra of coal and propane flames to find an optical filter combination which can optimize performance of the present automatic flame-detection system. A diaphragm isolation system is being designed/assembled for measuring vacuum in the dense-phase coal delivery line.

2.1.4 Refurbishing the Baghouse

Vendors were contacted to obtain prices for replacement parts for the existing UTSI Aeropulse baghouse which will be connected to the 200 hp boiler to assure control of particulate emissions at a level well below the current DOE contract goal.

Replacement parts were ordered for the baghouse. Design details were finalized for connecting the baghouse to the 200 hp Cleaver-Brooks boiler. Materials were specified and ordered.

2.1.5 Commercialization

As we approach finalized equipment design, the commercialization and economic evaluation activities can be addressed. Mr. James Oakley visited the UTSI test site on March 21, 1991 to review our progress. Mr. Oakley is Executive Vice President of Boiler Supply Company of Nashville, a major distributor of Cleaver Brooks boilers. He made very positive comments about the simplicity and

compactness of the coal conversion arrangement (almost as easy as burning number 2 oil), the simplicity of the coal delivery system, the usefulness of the air-flow control arrangement using a speed controller on Cleaver Brook's fan in lieu of the factory-supplied dampers, the use of an automotive oxygen sensor to set excess air automatically, the close control of excess air over the whole firing range, whether on clean fuel or coal, the fact that standard off-the-shelf refractory material is used, and the low-NOx burner performance demonstrated with propane. Also, he indicated that he was quite impressed with a number of features we have implemented with clean fuel (propane) and the fact that we have achieved low emissions of NOx and CO, with high carbon burnout on a wide range of fuels, combined with high boiler efficiency, over a range of boiler heat inputs without flue gas recirculation, increased excess air, etc.

2.2 Task 4: Project Management and Reporting

The December, 1990, and the January and February, 1991 monthly project status reports were issued. The July-September, 1990 quarterly report also was issued. Work continued on the October-December, 1990 quarterly report.

3.0 WORK PLANNED FOR APRIL-JUNE 1991

Additional experiments will be conducted using fluidizing nitrogen in the plenum located at the exit of the coal feed system. The goal is to further reduce the quantity of motive air used in the eductor stage, and improve uniformity of coal flow. Combustion testing will then be used to find operating conditions for optimum performance to maintain high carbon conversion efficiency, combined with low NOx emissions.

The advanced-combustor system will be completed with addition of the baghouse, soot blowers, and improved controls. Commercialization activities will continue, and preparation for the 100-hour test will be accelerated. Work will continue on quarterly and monthly reports.

Mr. Charles Ebbert, Senior Engineer, Cleaver Brooks plans to visit the UTSI test site early in May, 1991. The President of Cleaver Brooks Division of Aqua-Chem, Incorporated, Mr. John Plant, also has indicated an interest in visiting UTSI later in 1991 for a first-hand look at the coal retrofit.

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