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DEVELOPMENT OF AN ADVANCED HIGH EFFICIENCY

COAL COMBUSTOR FOR BOILER RETROFIT

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Prepared For:

Mr. Douglas Gyorke
U.S. Department of Energy
Pittsburgh Energy Technology Center

Prepared by:

Mr. M.J. Rini - Program Manager, C-E
Mr. R.C. LaFlesh - C-E
Dr. J.G. McGowan - UMass
Dr. J.M. Beer - MIT
Dr. M.A. Togan - MIT
Dr. T.U. Yu - MIT

Combustion Engineering
1000 Prospect Hill Road
Windsor, Connecticut 06095

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OBJECTIVE AND SCOPE

The objective of this two year project is to develop a High Efficiency Advanced Coal Combustor (HEACC) for retrofit to existing boilers currently firing oil or natural gas. The program will develop a retrofitable suspension firing system that is adaptable to the use of ultrafine coal-water fuel (with and/or without alkali sorbent) or dry ultrafine coal. The maximum potential of the ultrafine CWF will be realized by employment of the technique of "secondary atomization."

The project is divided into five technical tasks:

1. Cold Flow Burner Development
2. Pilot Scale (5×10^6 Btu/hr) Testing at the Massachusetts Institute of Technology (MIT)
3. Demonstration Scale (50×10^6 Btu/hr) Testing at Combustion Engineering (C-E)
4. Data Analysis and Final Report
5. Project Management

Tasks 1, 2 and 5 have been funded for Fiscal Year 1987.

SUMMARY

Work was initiated on the project during this reporting period. During the quarter from October 1986 to January 1987 the following technical progress was made:

- o A technical kick-off meeting was held at Combustion Engineering's Kreisinger Development Laboratory. The meeting was attended by DOE, MIT, and C-E, to review overall program and task plans.
- o Initiated a literature study focusing on optimized burner aerodynamics and design methodologies for high efficiency swirl generation devices.
- o Completed design of Swirler Test Facility (STF) to be used for comparative swirler evaluations.
- o Initiated facility preparation at MIT for thermal atomization studies and high shear viscosity measurements.

Task 1 Cold Flow Burner Development

Task 1.1 Project Planning

During the period covered by this report, work was formally initiated on the project.

A project kick off meeting was held at Combustion Engineering's Kreisinger Development Laboratory (C-E/KDL) on November 13, 1986. The meeting was attended by four representatives from DOE/PETC, three from the Massachusetts Institute of Technology (MIT) and several project-related C-E personnel. The meeting opened with a slide and movie presentation of C-E's extensive experience with coal water fuels and prepulverized, pneumatically conveyed pulverized coal. A project review followed, with a project overview and task plans for work at C-E and MIT. CWF supply was discussed extensively. C-E and DOE agreed that the fuel rheology and physical characteristics are of critical importance to the success of this project.

After consultation with PETC, requests for quotations for the fuel supply for the initial portion of this program were sent to three leading CWF suppliers (Atlantic Research Corporation, Advanced Fuels Technology, and OXCE Fuel Company). Based on the responses received, OXCE was chosen to supply a ultrafine CWF for the MIT testing.

On January 9, 1987, the C-E HEACC project team traveled to MIT for a project planning and technical meeting. Highlights of the meeting were:

- (1) MIT to conduct a brief atomization test matrix with OXCE ultrafine CWF in early March to assess the heatability and thermal atomization quality of the specific fuel formulation prior to OXCE's production of a large batch for the MIT combustion tests. The major atomization study will be conducted in early June with the large batch of fuel, just prior to combustion testing. C-E is to design and fabricate the CWF nozzle for MIT.
- (2) Combustion testing at MIT, which had been originally scheduled for May, cannot be conducted until June because of facility commitment to

an EPRI sponsored Pulverized Coal Ash Deposition program now scheduled for March 1 through May 30. This commitment pre-dates the C-E/DOE contract. This will require C-E to request a contract performance extension beyond current end date of July 26, 1987. (NOTE: C-E requested contract extension to September 30, 1987 on February 5, 1987.)

- (3) Fuels to be tested at MIT are: (a) heatable ultrafine grind CWF, (b) heatable regular grind CWF, and (c) heatable ultrafine CWF mixed with a separate sorbent slurry just prior to fuel pump.
- (4) A lengthy discussion was held concerning burner design. In the original proposal, C-E had stated that the new burner would be derived from C-E's successful High Swirl Wall-Fired (HSWF) CWF burner, and its predecessor, the Direct Ignition at Pulverized Coal (DIPC) burner. Professor Beer offered the use of his Multi Annular Swirl Burner (MASB) for evaluation on this project. The MASB has demonstrated low NOx production as a gas turbine combustor under a NASA program. The discussion centered around testing both burners at MIT. It was concluded that the program funding is sufficient to test only one burner and that (a) the HSWF is an existing boiler oriented design and (b) the aerodynamic principles (internal staging) which led to the low NOx levels produced with the MASB would be incorporated into the new burner design. All parties were satisfied with this decision, particularly in view of the program's budgetary and scheduling limitations.
- (5) Obtained some technical input on the analytical approach to axial swirler design.
- (6) MIT to finalize fuel quantities needed for testing and communicate to C-E.

Task 1.2 Swirler Development

A survey of the open literature was initiated, concentrating on identifying methodologies for optimization of burner aerodynamics. The initial focus of the survey, in preparation for later task activities, centered on reviewing both analytically and empirically derived procedures for the design of high efficiency swirl generators. These computational procedures will provide a foundation for development of the HEACC combustion air swirl generator.

Key geometric variables which affect the performance of various swirl generation devices were identified. For tangential inlet and axial vane tube swirlers (the types most commonly used in turbulent diffusion flame burners for boilers), the geometric variables include:

Initial and Final Vane Angles

Vane Length (chord length if blade is curved)

Central Hub Diameter

Spacing Between Blades (Pitch)

Blade Aspect Ratio $\left(\frac{\text{Blade Height}}{\text{Chord Length}} \right)$

Blade Pitch to Chord Ratio

These variables are illustrated in Figure 1.

The performance of a specific swirler geometry is typically defined in terms of the characteristics of the aerodynamic flow field generated with respect to the observed static air pressure (energy) loss across the swirl generator. The literature review has identified theoretical relationships which can be used to estimate key properties of the flow field generated by specific swirler geometries. In addition, the literature has revealed several computational routines which can be used to estimate static air pressure loss across specific swirler geometries.

The above information will be referenced in selecting optimum combinations of swirler geometry, near-field aerodynamics, and pressure loss.

Experimental comparative swirler evaluations, planned under this task, will test the validity of the computational routines employed in the selection process.

Design of the Swirler Test Facility (STF) was completed. This facility is similar to a smaller scale facility used by the International Flame Research Foundation, IJmuiden, the Netherlands, to characterize the effectiveness of various swirler geometries. The STF is designed to quantify the total angular momentum of the aerodynamic flow field generated by a test swirler with respect to static air pressure loss. The total angular momentum of the flow field is a critical factor in establishing burner near-field aerodynamics which enhance fuel/air mixing, flame shape and stability, and combustion efficiency.

A plan of the facility is shown in Figure 2. A metered air stream, representing total primary combustion air mass flow, enters a cylindrical plenum which contains a test swirler (Figure 3). The swirler forces the entering axial air stream to rotate. The rotating air mass, which possesses both axial and angular velocity components, then enters an aluminum "honeycomb" flow straightening disc. The honeycomb disc is mounted on a counterbalanced shaft and tends to rotate when the angular momentum components of the air stream apply a torque to the disc. The total torque applied to the disc, measured by shaft rotational deflection, can then be directly related to the total angular momentum of the rotating air mass.

Various components of the test facility were placed on order with vendors, the longest lead item being the aluminum "honeycomb" flow straightener material. Delivery of these components was made in February. Initial testing of the Swirler Test Facility is scheduled for early March.

A baseline swirler geometry was identified, this geometry being identical to a tangential inlet design which is an integral part of C-E's 50×10^6 Btu/Hr Wall Fired CWF burner register. This swirler/register system has been successfully employed in several laboratory and field CWF combustion trials. As such its near-field aerodynamic properties are known to promote

good flame stability and combustion efficiency. The baseline swirler will be fabricated and tested in the STF under Task 1.2 and will serve as the performance "bench mark" against which the experimental swirler designs will be compared.

One of the experimental swirler designs which is being considered for fabrication is a specific axial vane cascade which is an integral part of Professor Beer's Multi Annular Swirl Burner (MASB).

Final selection of the experimental swirler designs to be evaluated under Task 1.2 is scheduled for March.

Task 2 Pilot Scale Testing at MIT

In the first phase of this task, atomization tests and high shear rate viscosity measurements will be made using both a spray rig test facility and a high shear rate viscometer built at MIT. In the experiments, the effect of heating upon both the coal water fuel droplet size distribution (p.s.d.) and viscosity will be evaluated. The preparations for these runs are nearly completed. A detailed description of the apparatus which will be used follows.

Spray Test Facility and Optical Spray Measurements

A schematic diagram of the spray facility (STF) which will be used to characterize CWF sprays is shown in Figure 4. CWF is delivered to the spray nozzle through a flow meter (Micro Motion Model C 25) by a Moyno pump which can provide injection pressure up to 4 MPa (600 psi). Fuel pressure and temperature are measured at the atomizing gun entrance. Atomizing air is supplied at pressures up to 7 MPa (1000 psi). It passes through a pressure regulator, flow meter and a flexible stainless steel hose, to a spray nozzle. Atomizing air pressure and temperature are measured at the entrance of the fuel gun. A spray gun transporting the CWF and the atomizing air can be adjusted vertically and horizontally to permit the traversing of different segments of the conical spray by the laser beam of the optical spray analyzer.

Two sides of the 1.26 m x 0.45 m x 1.0 m chamber have plexiglas walls for optical observation and measurement. About half of the other sides of the chamber have honeycomb sections through which air to be entrained by the spray can pass. The supply of outside air is necessary to suppress the recirculation of small particles into the path of the laser beam. Air at room temperature enters through the honeycomb sections when the exhaust fan is switched on. This entrained air flow and the atomizing air stream are separated from the CWF at the exit from the spray chamber and then flow through a filter and a flexible hose in route to the exhaust system of the CRF. The used CWF is collected in a storage tank through a pump.

The spray test facility is equipped with a laser diffraction size analyzer for droplet size measurements. The operational principle of the laser diffraction analyzer is based on the Fraunhofer diffraction pattern superimposed on the geometrical image, produced by droplets in the path of the monochromatic light beam. This analyzer, manufactured by Malvern Instruments, Inc., allows a laser light source to pass light through the two plexiglas plates perpendicular to the fuel spray flow. The instrument consists of a 31 annular-element photodetector that receives the light signal from the other side of the chamber, a minicomputer, and a control terminal that processes output signals from the photodetector to calculate droplet size distributions. A computer program of the analyzer is capable of deducing the corresponding particle size distribution responsible for producing the measured light energy distribution in various functional forms, such as Normal, Log Normal, Rosin Rammler, or Model Independent.

In the experiments, the laser beam will be aimed through the middle of the spray 30 cm away from the nozzle tip. The transmissivity of the spray will be monitored, and multiple scattering effects will be determined.

Capillary Tube Viscometer

A capillary tube viscometer will be used to measure viscosities of non-Newtonian fluids such as CWF at shear rates up to $2 \times 10^5 \text{ sec}^{-1}$. A schematic diagram is presented in Figure 5. A cylindrical pressure vessel, 0.62 m long and 0.15 m inside diameter, designed for the maximum working

pressure of 2000 psia is used to store CWF. When the cylindrical vessel is pressurized by compressed air, CWF in the vessel is forced to flow through a capillary tube to a Micro Motion flow meter. The applied pressure is measured by a pressure transducer and recorded as a function of the CWF mass flow rate. In order to obtain the pressure drop along the fully developed laminar tube flow region free from effects of inlet and exit losses, the measurements of applied pressure and volume flow rate are repeated with another tube of the same diameter but of different length. By subtracting the two pressures at the same flow rate, the pressure difference (ΔP) can be related to the apparent viscosity (μ_a) and shear rate (γ_w) as:

$$\mu_a = \frac{D \Delta P}{32LV} \left(\frac{4n}{3n+1} \right)$$

$$\text{and } \gamma_w = \frac{3n+1}{4n} \cdot \frac{8V}{D}$$

where D is the tube inside diameter, L is the length difference between the two tubes; V is the average velocity in the tube, and n is

the slope on the plot of $\text{Log } \frac{D \Delta P}{4L}$ v.s. $\text{Log } \frac{8V}{D}$.

The capillary tubes which will be used are 1.5 mm in diameter and 1.0-10.0 cm long.

Task 5 Project Management

During this reporting period, work on the DOE Project Management Post Contract Award Plans and Schedules was initiated. A pre-contract audit had been conducted by the Defense Contract Agency (DCAA) and had resulted in some cost adjustment. A copy of the audit report was requested from DOE to ascertain specifically where the cost adjustments had been made. This information was necessary to complete the DOE forms. A copy of the audit report was received by C-E in late January. The Plans and Schedules required in fulfillment of DOE's Reporting Requirements Checklist, form DOE 537, will be completed and forwarded to DOE early in the next quarter.

TYPICAL FLAT BLADE AXIAL VANE SWIRLER

s - Spacing between blades (pitch)

θ - Vane angle

$\frac{Z}{C}$ - Blade aspect ratio $\left(\frac{\text{blade height}}{\text{chord length}} \right)$

d - Central hub diameter

Figure 1

SWIRLER TEST FACILITY

PLAN VIEW

FIGURE 2

SWIRLER TEST FACILITY

FIGURE 3

FIGURE 4. SCHEMATIC OF THE MIT SPRAY TEST FACILITY

FIGURE 5. SCHEMATIC DIAGRAM OF A CAPILLARY
TUBE VISCOMETER

**DATE
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