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DEVELOPMENT OF AN ADVANCED HIGH EFFICIENCY
COAL COMBUSTOR FOR BOILER RETROFIT

DOE CONTRACT NO. DE-AC 22-86PC90275

C-E CONTRACT NO. 28486

QUARTERLY REPORT FOR THE PERIOD MAY 1987 TO JULY 1987

Prepared For:

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Pittsburgh Energy Technology Center

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ACKNOWLEDGEMENT

Contributors to this report include: M.J. Rini and R.C. LaFlesh of Combustion Engineering, Inc.; and J.M. Beer, M.A. Toqan and T. Yu of MIT.

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PATENT STATUS

This technical report is being transmitted in advance of DOE patent clearance and no further dissemination or publication shall be made of the report without prior approval of the DOE Patent Counsel.

TECHNICAL STATUS

This technical report is being transmitted in advance of DOE review and no further dissemination or publication shall be made of the report without prior approval of the DOE Project/Program Manager.

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.

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Task 1 Cold Flow Burner Development

During the previous quarter, a Swirler Test Facility (STF) was constructed to evaluate candidate swirler designs for incorporation into the HEACC. A baseline test, using an existing design tangential inlet swirler was conducted to provide a point of comparison for the new swirlers designed under this program. A total of six (6) advanced design axial flow swirlers were fabricated and characterized in the Swirler Test Facility during this quarter. The objective of this phase of the project was to develop a swirler that produces a swirl strength comparable to the baseline tangential inlet swirler but at an improved energy conversion efficiency (i.e., lower pressure drop). The baseline tangential swirler is from C-E's successful High Swirl Wall-Fired (HSWF) burner utilized in a previous DOE program.

Beyond swirler efficiency considerations, it should also be noted that most burner swirlers generate one of three distinct tangential velocity profiles in the near-field; these profiles also influence recirculation zone properties and are typically described as Free Vortex, Forced Vortex and Rankine Vortex profiles (Figure 1). Of the three, the Free Vortex design is most common in industrial boiler burners, however, the Forced Vortex design has demonstrated potential in the literature. The swirlers designed and tested under Task 1 have been configured so that comparative evaluations of the influence of free and forced vortex flow fields on total swirler angular momentum can be made with respect to swirler pressure losses.

The STF evaluation of seven swirlers was completed during this quarter. Swirlers tested were:

- o Tangential Inlet "Baseline" Swirler - Figure 2
- o Swirler "A" - Forced Vortex, Swirl Number = 2.0 - Figure 3
- o Swirler "B" - Forced Vortex, Swirl Number = 1.0 - Figure 4
- o Swirler "C" - Free Vortex, Swirl Number = 2.0 - Figure 5
- o Swirler "D" - Free Vortex, Swirl Number = 1.0 - Figure 6
- o Swirler "E" - Forced Vortex, Flat Blade Array - Figure 7

o Swirler "F" - Free Vortex, Flat Blade Array - Figure 8

The results of this testing showed that the Free Vortex - Swirler "D" generated equivalent torque to the Tangential Inlet Baseline Swirler with a 25% reduction in pressure drop. At equivalent pressure drops, Swirler "D" generated greater torque than the Baseline Swirler. The Forced Vortex - Swirler "B" generated substantially greater torque at a lower pressure loss than any other configuration. The Flat Blade Array Swirlers (Free and Forced Vortex) generated lower torque values than any other swirler configurations.

Based on these results, Swirlers "B" and "D" were chosen for further testing in the HEACC Burner Cold Flow Model.

A design for the prototype HEACC cold flow model was developed based on the design methodology outlined in Figure 9. This is an evolutionary design based on C-E's significant experience with CWF and coal combustion, direct input from Professor Beer of MIT and the findings available in the open literature. The design is tailored toward retrofitability to industrial oil-fired boilers.

One feature of the cold flow model, Figures 10 and 11 is the adjustable geometry of the combustion air zones. This will allow burner geometry and resulting aerodynamic flow field to be studied in a systematic manner, resulting in a final optimized design for pilot scale testing at MIT. The pilot-scale testing will further refine the design to be tested in an industrially significant scale (50×10^6 Btu/hr) at CE/KDL.

Cold flow burner modeling completed in this quarter included documentation of the baseline High Swirl Wall-Fired (HSWF) burner flow field for comparative purposes and construction of the HEACC prototype cold flow burner model to be tested in August.

In summary, Task 1 has succeeded in developing innovative swirler designs which operate at improved mechanical efficiency and promise to decrease operating costs when applied to an industrial boiler. The prototype HEACC has been designed and incorporates this swirler along with other innovative, flexible and efficiency-oriented features.

Task 2 Pilot Scale Testing at MIT

In the previous quarter a brief series of cold flow atomization tests were conducted at MIT with OXCE MCWF for a two-fold purpose: 1) to evaluate two different C-E CWF candidate nozzle designs, 2) to assess the heatability and thermal atomization quality of a specific anionicfuel formulation prior to OXCE's production of a large batch of fuel for the MIT Combustion Tests.

The two nozzle types tested were the C-E "swirl-jet" (Figure 12) and the C-E "Y"-jet (Figure 13). Both nozzle types have been previously used with success in CWF test programs. The atomization test results are shown in Figure 14. It can be seen that the "swirl-jet" atomizer produced a finer spray at a lower air-to-fuel mass ratio. Because of this, the swirl-jet atomizer was chosen for the pilot-scale combustion tests.

During this quarter, further testing was conducted with the swirl-jet atomizer to assess the effect of MCWF heating. These results are shown in Figure 15. As can be seen, the spray quality steadily improved with increasing temperature over the range of 25°C (77°F) to 100°C (212°F). This is due to a steady reduction in fuel viscosity as demonstrated in Figure 16. From 100°C to 138°C (280°F) only a minor decrease in MMD is noted, but more significantly, a further decrease in SMD can be seen. This means that fewer large droplets were produced at the elevated fuel temperatures. This will have a positive effect on improved combustion and yield higher carbon burn-out.

Other work at MIT has involved the preparation of the Combustion Research Facility (CRF) for the pilot-scale combustion tests to be conducted under this task. C-E and MIT has been working together to integrate the HEACC into the CRF for testing. This work continues. The pilot-scale combustion tests are scheduled for the next reporting quarter.

Task 5 Project Management

In addition to the regular responsibilities under this task, two additional efforts were expended during this quarter. A detailed presentation of project results to date was prepared and delivered by the Program Manager at the Third Annual Coal Utilization and Environmental Control Contractor's review meeting in July. This meeting was a very effective vehicle for providing an exchange of ideas and viewpoints, and creates a synergistic atmosphere for DOE contractors.

The second effort involved preparation and presentation of a detailed technical response to a list of questions developed by the PETC Project Management group to assess the viability of the project and to determine whether to fund the Phase II work "Demonstration Scale Testing at Combustion Engineering." The presentation was made at PETC to a panel of DOE staff on July 10, by the CE Program Manager. Indication was later given by PETC that the Phase II work will be funded.

FREE VORTEX

$$W = \frac{C_1}{r}$$

FORCED VORTEX

$$W = C_2 r$$

RANKINE VORTEX

$$W = \frac{C_3}{r} \left[1 - \exp \left(- \frac{r^2}{r_0^2} \right) \right]$$

WHERE:

W=TANGENTIAL VELOCITY
COMPONENT

C_1, C_2, C_3 =CONSTANTS

r=RADIAL COORDINATE

r_0 =INITIAL r

Figure 1

**TYPICAL SWIRLER TANGENTIAL
VELOCITY PROFILES (NEAR FIELD)**

Figure 2

BASELINE TANGENTIAL INLET SWIRLER

SWIRLER "A"

Figure 3

Figure 4

SWIRLER "B"

Figure 5

SWIRLER "C"

Figure 6

SWIRLER "D"

Figure 7

SWIRLER "E"

Figure 8

SWIRLER "F"

Figure 9

Design Methodology for HEACC

- o Utilize most efficient swirler design for primary air stream
- o Incorporate a unique low pressure loss staged air distribution system for secondary air stream(s)
- o HEACC physical envelope (diameter, length) similar to conventional oil burner envelope to facilitate retrofit
- o Primary air stoichiometry (n_p) targeted for 0.3 - 0.4 to minimize NO_x

PROTOTYPE HIGH EFFICIENCY ADVANCED COAL COMBUSTOR COLD FLOW MODEL

Figure 10

PROTOTYPE HIGH EFFICIENCY ADVANCED COAL COMBUSTOR COLD FLOW MODEL

ADJUSTABLE LENGTH BURNER

RETRACTED POSITION

EXTENDED POSITION

Figure 11

Figure 12

"SWIRL-JET" CWF ATOMIZER

Figure 13

"COMMERCIAL STYLE" Y-JET CWF ATOMIZER

Figure 14
COMPARISON OF SWIRL-JET AND Y-JET ATOMIZATION TEST RESULTS

Figure 15

AVERAGE DROPLET SIZE OF CWF SPRAYS AS A FUNCTION OF CWF TEMPERATURE

Figure 16

EFFECT OF TEMPERATURE ON APPARENT VISCOSITY AT HIGH SHEAR RATES

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