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Technical Progress Report No. 1

ADVANCED VORTEXING COMBUSTOR
(VC) FOR SPACE/WATER HEATING APPLICATIONS
(PROOF-OF-CONCEPT MODEL DEVELOPMENT)

To

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SUMMARY

The Naval Civil Engineering Laboratory is developing a proof-of-concept Vortexing Combustor (VC) with 2-4 MMBtu/hr firing capacity to burn both coal-water fuel and ultrafine coal for boiler applications. This work is being done under Interagency Agreement No. DE-AI22-87PC79660 with the Department of Energy, Pittsburgh Energy Technology Center. This first technical progress report is for the period between 30 September 1987 and 31 January 1988.

Thermodynamic analysis was made to trade off design features of the combustor. Results indicated that for best thermal efficiency, consistent with the low temperature combustion requirements, a sub-adiabatic VC arrangement should be selected. In order to minimize the risk of uncertainties, a three-step approach was chosen by which two small size models (0.15 and 0.6 MMBtu/hr) will be designed, built, and tested. The full-scale, proof-of-concept model will then be designed based on the results of tests using the small-scale models. Extensive testing of the full-scale model will be conducted to prove the concept. All combustors will be designed based on the use of one type of coal-water fuel. Ultrafine coal will be tested and regarded as a variance. Although not discussed in our Management Plan submitted earlier, we do not anticipate any significant cost impact due to the sub-scale model tests.

The design and construction of the 0.15 MMBtu/hr model has been completed and it is being assembled for exploratory testing of the VC concept. Several major pieces of equipment, purchased with NCEL funds as a part of the cost sharing effort have arrived. The overall project has been progressing well and is on schedule. Hot testing of the 0.15 MMBtu/hr model will take place in the March - June time frame.

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INTRODUCTION

Commencing 30 September 1987, the Naval Civil Engineering Laboratory (NCEL), under Interagency Agreement DE-AI22-87PC79660 with the Department of Energy, Pittsburgh Energy Technology Center (PETC), was tasked to develop the vortexing combustion technology for coal. This project is for a period of 27 months beginning on 30 September 1987 and ending on 29 December 1989. At the conclusion of this work, a 2-4 MMBtu/hr proof-of-concept Vortexing Combustor (VC) capable of burning both coal-water fuel and ultrafine coal will have been designed, built, and tested to demonstrate the concept. This is the first of the quarterly technical progress report covering the period 30 September 1987 to 31 January 1988.

COMBUSTOR DESIGN

The Vortexing Combustion Concept

The vortexing combustion concept is schematically shown in Figure 1. Fuel and air are injected tangentially into the combustor. The tangential air is used for combustion and also to establish a stable suspension layer of particles to control the particle flow so that no unburned fuel will escape the combustor. The combustion products (hot gases and ash) leave the combustor through the center tube which may serve also as a radiator for flame stabilization.

For best control of pollutant emissions and good thermal efficiency, low temperature and low excess air combustion are essential. Our goal is to base our design on 1650°F (~900°C) exit gas temperature and 20% excess air. As a result, the ash will be dry and will be removed all from the center tube along with the flue gas.

Figure 1. Schematic of the VC Concept.

Basic Construction Features

A preliminary analysis has been made to examine a number of possible options of the construction features and identify the best choice based on heat and mass balances. A tabulation of the results is given in a separate report.* It shows clearly that in order to achieve the goal of 1650°F gas temperature and 20% excess air, a fair amount of heat must be removed from the combustion products in the combustor. To make this possible, from the standpoint of ignition and flame stabilization, a sub-adiabatic construction feature must be chosen for this development.

The sub-adiabatic construction is made of three major independent components as shown in Figure 2. Brief descriptions of these components follow:

* "Development of a Vortexing Combustor (VC) for Space/Water Heating Applications (Cold Flow Modeling)," Technical Progress Report No.1 submitted to Pittsburgh Energy Technology Center, by S. Nieh, The Catholic University of America, Washington, D.C., August 1987.

Figure 2. The 0.15 MMBtu/hr exploratory hot test model.

(1-LVD fuel igniter, 2-Adiabatic section, the primary combustion zone, 3-Water-cooled section, the secondary combustion zone, 4-Contraction, 5-Center tube, 6-Stabilizer)

1. An adiabatic section with a co-flow, large velocity difference (LVD) fuel ignition device to insure positive ignition. This is the primary combustion zone where fuel and the primary air are injected. Fuel is rich in this section.
2. A water cooled section to remove the excess heat for gas temperature control. Secondary air is tangentially injected into the section to:
 - a. Complete the combustion, and
 - b. Control the particle residence time.

A contraction at the inlet of this section and a cup-shaped top are incorporated in the design to help stabilize the flame.

3. A center tube for the exit of flue gas and the ash. The outside end of this tube may be connected to a heat absorbing device such as a boiler.

Overall Approach

No technical data relevant to the design of the proof-of-concept model exists. In order to minimize the risk of uncertainties, some basic design data must be generated first. To achieve this, small-scale models of progressively larger size will be designed, built, and tested. The overall design effort will be carried out in three steps as follows:

1. 0.15 MMBtu/hr model. This model will be designed and built for exploratory testing in order to obtain operating experience and data for an improved design and scaling up. The level of tests will be qualitative and observational in nature. Instrumentation and quantitative measurements will be for diagnostic purposes only.
2. 0.6 MMBtu/hr model. The data and experience obtained from the exploratory model tests will be used as the basis for the design

of this intermediate model. Quantitative and detailed measurements will be made where appropriate for the design of and scaling up to the proof-of-concept model.

3. The 2-4 MMBtu/hr proof-of-concept model. This model is the prototype for demonstrating the VC concept. It will be designed based on experience gained and data generated during tests of the two prior smaller scale models. The prototype design will be submitted to the PETC project officer for review and approval. When finalized, a prototype will be built and tested according to a test plan to be developed and approved by PETC while it is being constructed. Extensive instrumentation and detailed measurements will be made.

All the above models will be designed based on the use of coal water fuel (CWF). Finely pulverized coal firing will be regarded as a variance.

The Exploratory Model Design (0.15 MMBtu/hr)

The overall arrangement of the exploratory model is shown in Figure 2, with details shown in Figures 3 and 4. A summary of the design parameters is given in Table 1. Some important features are built into the design in order to facilitate fuel ignition, flame stabilization, and temperature control as briefly described in the Basic Construction section. In the adiabatic section, in addition to the LVD igniter, the massive body and the flow contraction above it are intended for flame stabilization. Adjustments may be made by changing the height of this section. The water-cooled section is used to achieve effective temperature control. Since the exact heat transfer characteristics of this type of device is not known at the present, the heat removal rate must be adjustable. This design permits such adjustments by simply moving the positions of the center

Figure 3. Details of the Adiabetic section.

(1-LVD fuel igniter, 2-Adiabetic section, 3-Bottom, 4-Ash drain)

Figure 4. Details of the water-cooled section.

Table 1. Summary of Design Parameters.

Combustor:

Output capacity, MB/H	0.15
Overall thermal efficiency	0.83
Fuel consumption rate, lb/hr (Assuming 10,800 Btu/hr high volatile bituminous coal)	16.7
Excess air, %	20
Total air requirement, SCFM	34
Flue gas temperature in center tube, °F	1650
Flue gas velocity at center tube exit, ft/sec	49
Heat absorption by water cooled section, % of input	45

Flue Gas Tempering Facility:

Flue gas inlet rate, ACFM @ 1650°F	152
Ambient cooling air rate, SCFM	417
Exhaust gas rate from facility, ACFM @ 212°F	580

tube and/or the cup-shaped stabilizer. For safety and ease of construction, this water cooled section is open to the ambient atmosphere.

The construction of this model has been completed. Some photographs have been submitted to PETC separately. Assembling of the model and preparations for the tests are in progress. Hot testing is expected to begin in mid March.

INSTRUMENTATION

For the exploratory model, because of the nature of the work, only the gross performance of the combustor will be measured. Detailed instrumentation is not contemplated. In preparing for the testing of the larger models, basic instrumentation for energy and mass balance purposes are being procured. In addition to the NCEL continuous stack gas monitoring instrumentation package, an Orsat apparatus has been procured which is practical and most suitable for the small model tests. For CWF testing a Brooks' magnetic type slurry flowmeter has been received.

AUXILIARY SYSTEMS

Flue Gas Cleaning Facility

In order to comply with the local environmental requirements, a flue gas cleaning and tempering facility has been designed as shown in Figure 5. This facility consists primarily of a cyclone separator with a water spray wet scrubbing capability. It can also temper the hot flue gas by mixing it with the cold ambient air thus eliminating the need for any auxiliary heat sink. It is intended primarily for use in conjunction with the 0.6 MMBtu/hr model testing.

Figure 5. Schematic of flue gas cleaning facility.

Other Equipment Received

CWF storage tank - 210 ft³ with steam heating coil and agitator.

Blower - 670 SCFM, 50"H₂O discharge pressure, 15 Hp variable speed drive.

Air heater - 480v, 3-phase, up to 3,070 #/hr at 600°F.

Slurry pump - 1 gpm, 150 psig at 120°F, Moyno pump.

FUTURE PLANS

For the coming quarter, we plan to:

1. Obtain sufficient data to enable us to arrive at a definitive design of the 0.6 MMBtu/hr model.
2. Complete the design of the 0.6 MMBtu/hr model.
3. Complete installation of the flue gas cleaning facility.
4. Procure instrumentation and equipment as required for test support.
5. Coordinate with Dr. Nieh of The Catholic University of America on Cold Model Studies.

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