PROCEEDINGS

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"Energy and the Environment: A Continuing Partnership"

VOLUME 3

Conversion Technologies

Electrochemical Conversion

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PROCEEDINGS OF THE 26th INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE

VOLUME 3

Conversion Technologies (Continued)
- Magnetohydrodynamics
- Thermionics
- Thermoelectrics

Electrochemical Conversion
- Aerospace Batteries
- Batteries for Secondary Applications
- Batteries for Terrestrial Applications
- Fuel Cells for Space Applications
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COAL-FIRED MHD TEST PROGRESS AT THE COMPONENT DEVELOPMENT AND INTEGRATION FACILITY

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ABSTRACT

The Component Development and Integration Facility (CDIF) is a Department of Energy test facility operated by MSE, Inc. MSE personnel are responsible for the integration of topping cycle components for the national coal-fired magnetohydrodynamics (MHD) development program. Initial facility checkout and baseline data generation testing at the CDIF utilized a 50-MW_t, oil-fired combustor (with ash injection to simulate coal slag carryover) coupled to the 1A supersonic channel. In the fall of 1984, a 50-MW_t, pressurized, slag rejecting coal-fired combustor (CFC) replaced the oil-fired combustor in the test train. In the spring of 1989, a coal-fired precombustor was added to the test hardware, and current controls were installed in the spring of 1990. In the fall of 1990, Phase I of the slag rejector was installed. In addition, significant progress and developments were made by MSE in the areas of solid suspension injection, stack gas analysis, and current control installation.

Testing during the last year emphasized baseline testing including materials, duration, and current control checkout testing. This testing will be discussed.

MSE test hardware activities included incorporating test coupons into the channel walls and installing various combustor components to test prototypic hardware designs. This paper discusses the involvement of this hardware in the test progress during the past year.

Facility modification and installation of system upgrades for improved operation and duration testing will be addressed. Future projects such as activation of the slag rejection/ removal system and testing to address preparations for the prototypic hardware will be discussed. In addition, this paper will also address long-term plans for new installations.

INTRODUCTION

The CDIF is operated for the Department of Energy by MSE, Inc. MSE is chartered with integrated testing of coal-fired MHD topping cycle components. Currently under evaluation are a 50-MW_t coal-fired combustor (CFC), developed by TRW, and a linear generator, diffuser, and a full complement of current control units, all supplied by Avco Research Laboratory, Inc. Previous CDIF papers have detailed the initial oil-fired, ash-injected power tests, as well as the CFC and coal-fired precombustor (CFPC) checkout and initial power generation testing at the CDIF. This paper provides the status of CDIF coal-fired power generation testing during the past year. Test activities have concentrated on technical issues of coal-fired MHD--the cathode wall shorting phenomena, proof-of-concept (POC) channel electrode materials and design, low stress operating conditions, current control operations, and duration testing--all with the goal of additional data to support POC hardware decisions.

TEST SYSTEM DESCRIPTION

Since August 1985 when the first electrical power tests with the CFC were conducted, CDIF test activities have focused on coal-fired MHD power generation. The oil-fired vitiator (OFV), sometimes referred to as the air preheater, receives the incoming air from a high-volume compressor and heats this air to 1,200 °F after oxygen is added to obtain the desired enrichment. The CFPC uses a portion of the preheated air from the OFV to combust coal and produce air heated to 2,900 °F that is then introduced to the first-stage combustor. Preheated air enters the cylindrical first stage tangentially and entrains pulverized coal particles injected from the head end plate. Operating substoichiometrically, coal is gasified, and slag particles are driven to the combustor wall. A concentric baffle separates the slagging stage from the deswirl section and assists in guiding the molten slag into a water-filled slag collection tank below. The gas stream continues through the deswirl section of the combustor (where dry potassium carbonate is generally added) and enters the second stage. Additional oxygen and sometimes nitrogen (to simulate a prototypical oxidizer product) are injected in the second stage to bring the plasma to near-stoichiometric conditions.

Baseline operating conditions used for the majority of the testing during the last year are:

Thermal Throughput	50 MW
Mass Throughput	17.4 lb/s
OFV Preheat	1,200 °F
CFPC Preheat	2,900 °F
Oxidizer Enrichment	39.2%
CFPC Equivalence	1.09
First-Stage Equivalence	0.55
Second-Stage Equivalence	0.90
Global N/O	0.70-0.76

The channels that provided almost all of the test service during the past year were primarily comprised of workhorse elements [1]. In addition to the workhorse elements, various prototypic material test elements were also installed in these channels.

A full complement of Avco-supplied current controls was installed. The aft power-take-off (PTO) region was resistively configured, and the forward PTO region was consolidated with an Avco-supplied current control portable unit.

Major CDIF plant support systems are shown in Figure 1. Compressed air, gaseous oxygen and nitrogen, fuel oil, pulverized coal, iron oxide/oil slurry, and dry seed are the process flow delivery systems. Medium pressure, deionized cooling water maintains the desired test train component temperature. The magnetic field is provided by a 2.9 tesla iron core magnet. Conversion of the dc to ac power, transmission to the commercial power grid, and variable generator loading are provided by an EPRI-supplied inverter.

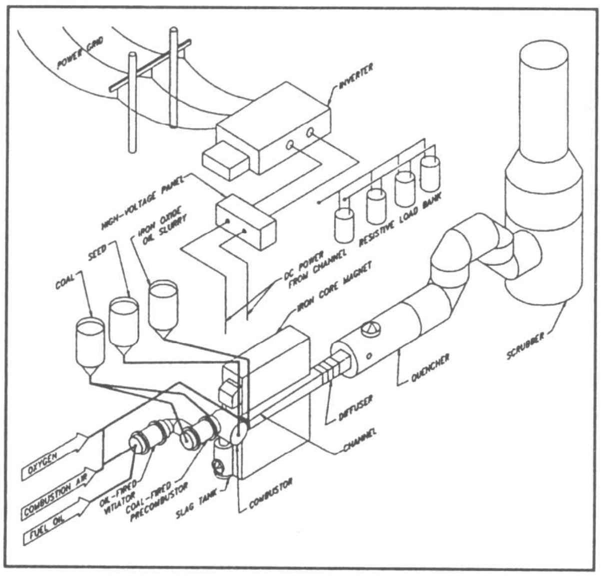

FIGURE 1 -- CDIF TEST TRAIN SUPPORT SYSTEMS

Channel electrical configurations and measurements are achieved in the high voltage room, which contains the required numerous termination blocks and voltage/current transducers. A data acquisition system (DAS) records and stores over 2,000 measurements and calculated values each second (over 1,500 of these are electrical parameters). Since the combustor operates at a voltage potential of up to 10,000 volts, all process flows, cooling water, and instrumentation attachments must be electrically isolated to this level.

TEST RESULTS

Programmatic and technical objectives have been met in the last year. From July 1990 through March 1991, 39 test starts occurred with a coal burn time of 93 hours 35 minutes and electrical power generation of 48 hours 53 minutes. Major test accomplishments are highlighted in Table 1.

Over the past year, the CDIF test program was designed to support the overall effort to acquire more and longer duration data to aid vendors responsible for designing the POC hardware. Major technical accomplishments during the year were:

- completed testing of several designs and materials for POC channel design--testing of the final candidates continues;
- completed a duration thermal test to address long-term slagging effects in the combustor--21 hours 12 minutes in length; and
- completed current control checkout testing.

Materials Testing

Potential prototypical materials, designs, and fabrication methods have been tested at the CDIF during the past year. These prototypic test elements have been installed in the nozzle and the combustor, but primarily in the channel. Various test elements have been installed in the anode, sidewalls, and cathode. The most notable test elements include a 0.7 pitch area of electrodes and sidewall elements. The anodes and cathodes in this region are of proposed prototypic design, and the sidewall is of prototypic Z-bar design (see Figures 2 and 3).

Duration Testing

One of the goals for the FY90-91 test program was to accomplish steady state combustor testing and long duration power testing. Efforts were made to test for a 24-hour duration. Although a 24-hour test was not accomplished, a record continuous thermal test duration length was achieved. This record, 21 hours and 12 minutes, surpassed the previous continuous thermal operation of 12 hours and 50 minutes. This new record allowed assessment of long-term slagging effects in the combustor--primarily in the CFPC filler section. A post-test examination found the slag coverage to be heavy, with some buildup in the filler section.

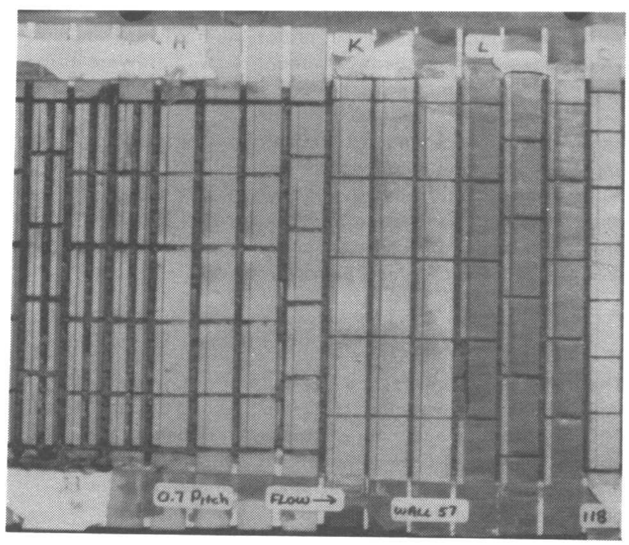

FIGURE 2 -- 0.7 PITCH ELECTRODES AND SIDEWALL ELEMENTS

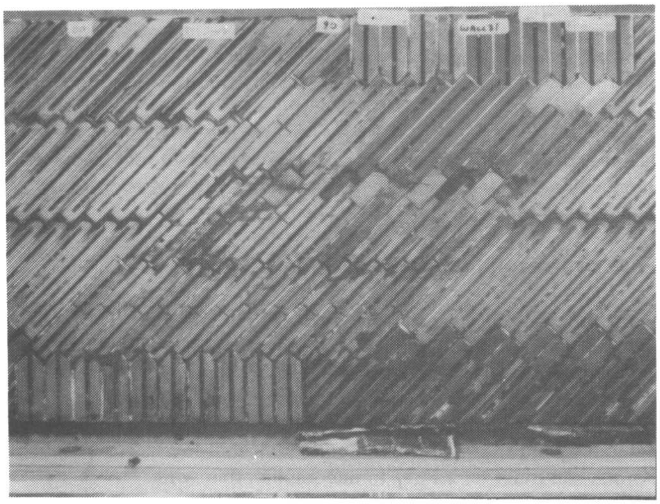

FIGURE 3 -- PROTOTYPIC Z-BAR COUPONS

Current Control Checkout Testing

Original testing of the Avco-supplied current controls (CCs) in May 1990 resulted in the units being removed from service for further investigation. In August, the units along with diagnostic instrumentation were reinstalled to complete checkout testing. Instrumentation revealed that the line voltage feeding the CC cabinets sagged when all the facility equipment was brought on line. This condition resulted in a supply voltage that was too low, which caused the CC clock boards to malfunction. During the testing, correct CC operation was verified with an alternate power source from an isolated feeder. The CCs continued to be operated with the alternate power source until November 1990, when new clock boards with updated power transformers were installed. Once this upgrade was complete, the CCs operated successfully with regular facility power.

TEST HARDWARE SUPPORT ACTIVITIES

During the last year, several test hardware activities in support of the test program have been accomplished. These activities, as agreed upon with the TRW and Avco vendor representatives, have included the following significant accomplishments.

- Completed the CFC modification as specified by TRW to enhance first stage reliability, test prototypic designs, and address the filler fouling potential.
- Continued a program of $1A_1$ channel refurbishment, fabrication, assembly, and materials test element installation necessary to support testing at the CDIF.
- Completed installation and initiated checkout of the TRW-supplied slag rejection system.
- Continued the design, fabrication, and installation of the replacement diffuser sections.

TRW Combustor Modifications

The smooth-wall air inlet filler section installed to reduce CFPC fouling was replaced with a hot-wall section to simulate the prototypic high pressure, high temperature cooling system (HPCS). Since the HPCS project was canceled and an alternate cooling method is being planned, the hot-wall section was replaced with a coupon filler section.

An Avco-supplied iron oxide injection frame to simulate prototypic iron oxide injection on the cathode wall of the channel was installed. Installation of a new head end plate and a replacement pintle were also completed.

Channel Refurbishment, Fabrication, Assembly and Material Test Element Installation

On May 11, 1990, the materials test channel was placed into service. The channel contained wall sections 33, 34, 19, 20, 37, 30, 31, and 32. Because of an internal water leak in the cathode wall, the materials test channel was removed from service on May 22, 1990. The leak was caused by restricted cooling water flow to a bar element. The channel was repaired and reinstalled on June 8. It was again removed from test service June 22 because an electrical arc had burned the G-9 frame material near the midjoint.

After the channel was removed and inspected, it was discovered that the workhorse bars in the anode wall had markedly deteriorated after only 19 hours 16 minutes of test service. It was decided to install the material coupons in new anode wall sections 41 and 42. On July 31, 1990, testing resumed with a materials test channel that consisted of wall sections: 41*, 42*, 19*, 20, 37, 30*, 31, and 32*.

During the October shutdown, the channel was dismantled, coupons were removed for evaluation, and repair/refurbishment activities on the channel were completed. Wall 63 (new) was installed during this shutdown as a replacement for wall 31. Some of the coupons previously used were reinstalled and some new ones were installed.

Following the November testing, the channel was removed because of a water leak on left forward sidewall 63. The channel was disassembled and inspected for wear. Refurbishment activities were started on wall sections 19, 20, 30, and 32. These wall sections were incorporated into the next channel, which was designated as Materials Test Channel II. In addition to the above mentioned wall sections, Materials Test Channel II also consisted of anode wall sections 57 and 50 and forward diagonal bar sidewalls 29 and 31. The anode wall sections contain many new prototypic designs, and the forward sidewalls contain elements of Z-bar wall prototypic design.

The assembly of these new and refurbished channel walls was completed; the channel was assembled and again installed into the test train. This channel contained all of the new Avco test bars and A-bar sections in the right and left forward sidewall sections. The channel consisted of wall sections 57*, 50*, 19, 20, 29*, 30, 31*, and 32.

* Walls containing test coupons.

The channel was again removed when testing was shutdown because of a water leak in the magnet, after an accumulated 22 hours 30 minutes of electrical power generation. All anode and sidewall test bars were removed and shipped to Avco for evaluation and input into their Channel Design Review Update. All test bars shipped to Avco with the exception of several molybdenum Z-bars, were reinstalled into the materials test channel. This channel, which was installed for April-May 1991 testing, consisted of wall sections 49, 56, 19, 20, 29, 30, 31, and 32.

Slag Rejection System Installation and Checkout

The TRW slag rejector consists of a slag grinder assembly, a dense phase pneumatic transport vessel, and an atmospheric collection tank with interconnecting valves and piping. The slag rejector project has been separated from the CDIF slag removal system, which is discussed in the Plant Support section of this paper. The two systems together provide batch removal and slag weighing from the TRW 50-MW_t coal-fired combustor to support extended duration testing.

The hardware was installed in phases to minimize test interruption. During the past year, the slag grinder assembly, the dense phase pneumatic transport vessel, and the atmospheric collection tank with interconnecting valves and piping were installed. Between phases, the newly installed equipment was used as batch slag containers, in much the same as the previous equipment was used. This configuration was used during the November and January-February testing, without the electrical, instrumentation, and control portions. The electrical, instrumentation, and electrical portion of the slag rejection system was then installed during the March-April shutdown and checkout testing began in April 1991.

Replacement Diffuser Walls

Until recently, the diffuser was made up of the original Avco-supplied diffuser walls with a few special purpose walls (i.e., triple port wall) added. The original diffuser walls had become warped, and reassembly of the diffuser was difficult. Therefore, MSE began to design and fabricate new diffuser walls. The new walls are being installed as they are completed and when test shutdowns occur. The fabrication of the aft subsonic and forward horizontal subsonic diffuser wall sections was completed, and they were installed into the diffuser. Replacement sections for the aft subsonic section are in progress.

PLANT SUPPORT SYSTEM ACTIVITIES

Major improvements in plant system operation yielded longer duration tests and higher quality experimental data. Many plant activities improved system reliability while others satisfied changing requirements of the test program. For a more extensive overview of these activities, see Reference [2].

Coal System Improvements

As the result of an external task force coal system review, eight coal-related projects were budgeted and scheduled. It is believed that implementing these projects will enhance the overall performance of the coal system. These projects include reintroducing the coal fines into the system and replacing the scalping screen. An analysis and performance of a system mass balance are also planned. This analysis will quantify the performance of the coal system, especially through the pulverizer.

Designs for many of these modifications are in progress and are planned for installation on a noninterference basis with the test schedule.

Seed System Improvements

A task force assessment of this system was completed. Some of the suggested modifications to the system included items such as placing a vertical plate in the conical section of the seed storage silo and replacing the silo outlet spool. Design work for many of these modifications is near completion, and field work is planned during the May-September 1991 shutdown. The seed storage silo must be empty to accomplish this work.

Solid Suspension Injection System

The solid suspension injection system was designed to mix, store and inject slurry additives into the test train. The current slurry, a 50/50 by weight mixture of iron oxide and hydraulic oil is being added to mitigate the effects of erosion caused by interelectrode shorting.

Two new progressive cavity pumps have been installed as replacements/back up for existing diaphragm metering pumps. These pumps are being characterized. The iron oxide injectors, which have a concentric annulus nitrogen flow, still experience some plugging when configured with a single pump with split flow to two ports. The lower flow rates have been a difficult requirement to meet; therefore, new pumps for supplying lower flow rates have been ordered.

Stack Gas/Environmental Compliance Upgrade

A new stack gas analysis facility and a compressed gas storage facility were designed and constructed. The upgrade provides permanent facilities for analyzing off gases at the CDIF during on-line operation. It also includes a modification to comply with the required safety standards for storing and dispensing compressed gases and to comply with the Environmental Protection Agency's and the State of Montana's need-to-know the actual stack emissions of nitrogen oxides (NO_x), sulfur dioxides (SO_2), and carbon monoxide (CO).

Work continues on analyzing the off gases for CO, CO_2, and O_2 on a dry basis and SO_2, CO, and NO_x on a wet basis. A new H_2 analyzer is scheduled for installation.

New Data Acquisition System

A new data acquisition system (DAS) to replace the existing system is scheduled for delivery to the CDIF in July 1, 1991. The system will arrive at the CDIF ready for installation and will include both hardware and software commensurate with the original system. This turnkey DAS will be installed, checked, and prepared for immediate use during September checkout testing.