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MHD COAL-FIRED FLOW FACILITY

Quarterly Technical Progress Report for July–September 1979

By

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November 14, 1979

Date Submitted

Work Performed Under Contract No. AC02-79ET10815

The University of Tennessee Space Institute
Energy Conversion Division
Tullahoma, Tennessee

U. S. DEPARTMENT OF ENERGY

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PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Under Contract No. DE-AC01-79ET10815
Under Contract No. EX-76-C-01-1760
(Task 1 Only)

ABSTRACT

In this third quarterly report of 1979 submitted under Department of Energy (DOE) Contract Number DE-AC01-79ET10815, the University of Tennessee Space Institute (UTSI) reports on significant activity, project and task status, planned research, testing, and development, and conclusions with respect to the Magnetohydrodynamics (MHD) Coal-Fired Flow Facility (CFFF) and the Research and Development Laboratory.

This Quarter, work on the CFFF progressed with only minor problems. The weather was generally favorable to most outside work. The extent toward completion for all work presently scheduled is now about 93%. In the chemistry laboratory, experiments with pulverized coal and potassium carbonate (K_2CO_3) continued. Data indicated that the pulverizing operation unit could be improved by operating at a slightly higher temperature. Doing this, however, should not be a problem. Continued testing of platinum and iridium cladding on anode caps has shown that these materials seem to perform well. The degradation experienced is acceptable and should not pose any problem. This information will be used in developing more oxidant resistant electrodes. Despite initial promise, the Direct Reduction Seed Regeneration process does not seem to be a viable means of seed regeneration. Detailed evaluation of the Tomlinson-Tampella and Formate processes will begin next Quarter.

INTRODUCTION

In approaching the following report, the reader should be aware of some notable format and content changes from previous reports. Because the Quarterly (Annual) reports are now in essence summary reports, there is no longer a separate summary for the entire report. In keeping with the agreement made under the new, current contract, we are now reporting by task numbers in conformance with the Work Breakdown Structure. Per DOE specification, these reports will also now contain a status listing of Design and Component Specification reports and a listing of prospective Topical Reports for the next Quarter.

UTSI is now reporting concurrently under two contract numbers. Task 1, nearing completion, is reported under the initial contract, No. EX-76-C-01-1760. Tasks 2 through 9 are now reported under the new contract, No. DE-AC01-79ET10815.

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SECTION I
OBJECTIVE AND SCOPE OF WORK

A. Contract No. EX-76-C-01-1760

Under Contract EX-76-C-01-1760, The University of Tennessee Space Institute Energy Conversion Division is to achieve the following goal for Task 1:

- Complete and activate the Coal-Fired Flow Facility.

B. Contract No. DE-AC01-79ET10815

Under Contract No. DE-AC01-79ET10815, the overall objective is to advance the technology of direct coal-fired MHD components and systems required for MHD power systems operating under conditions simulating those of central power stations.

The specific objectives of the UTSI R&D MHD Facility and the MHD Coal-Fired Flow Facility are to resolve experimentally and analytically the key technical problems which have been identified or which may be found to occur in direct coal-fired MHD systems with moderate to high ash carryover. The problem areas involve (1) combustor performance, (2) seed separation efficiency from both the exhaust gas stream and from slag, (3) MHD generator performance and design requirements using slag deposition on the channel walls to protect these walls from the intense thermal environment, (4) effects of plugging by solid or high-viscosity slag particles during normal operation, (5) response of candidate materials to direct coal-fired MHD environment and (6) procedure and equipment to meet pollution requirements.

The overall scope of work contains eight tasks basically defined under each of the following task headings.

1. Task 2 - Design and Fabrication of the 8 lb/sec Total Gas Flow, High Slag Throughput Test Equipment

Design, procure, fabricate and install the 8 lb/sec (3.63 kg/sec) total gas flow test equipment in the Coal-Fired Flow Facility, providing DOE with a schedule and cost estimate for each activity. The design goal for all components is the demonstration of predicted system characteristics required of an MHD system (e.g., life, performance, reliability, failure mode, etc.) and applicability of design for base level operations.

2. Task 3 - Base Operations for the CFFF and the R&D Facility

Perform all operations and maintenance required to maintain the CFFF facility and the R&D Facility in a standby condition. Items included are a) materials and components handling equipment, b) required equipment for installation of components, coal/seed handlings, etc., c) emissions monitoring, and d) instrumentation and sampling devices for continuous monitoring of O₂, CO₂, NO_x, CO, SO₂, H₂S, etc. This Task covers such major services as:

- 1) General Administration and support
- 2) Operations planning
- 3) Crew and staff maintenance
- 4) Grounds and building maintenance
- 5) DOE vendor occupancy
- 6) Facility design maintenance

3. Task 4 - 8 lb/sec Total Gas Flow High Slag Throughput Test

Use the Coal-Fired Flow Facility to progressively test and demonstrate that equipment and subsystem requirements for UTSI-designed components (Task 2) are met via Operation Performance Demonstration Acceptance Tests. Based on acceptance test results, engineering data are to be obtained toward the development of scale-up MHD systems.

4. Task 5 - Testing of DOE Supplied Components

Utilize the Coal-Fired Flow Facility for purposes beyond the demonstration of the 8 lb/sec flow train and superconducting magnet flow train. Specifically, UTSI is to be the initial operations contractor in performing feasibility studies for testing components in the CFFF, the components being supplied by other Department of Energy contractors via DOE.

5. Task 6 - Modifications to the CFFF

Provide modifications to the CFFF as required to test and to provide development assistance for DOE-supplied components, equipment and subsystems.

6. Task 7 - Technology Development Program

Develop quantitative performance data pertinent to basic thermal, electrical and gas dynamic design effects in MHD power generation. UTSI is to investigate the contractually specified components and provide recommendations for design, including materials selection and fabrication techniques of advanced components for CFFF verification. This task comprises a continuing effort to improve the technical basis upon which MHD commercialization rests throughout

the entire plant. The experiments are tracked not only from a standpoint of performance during testing, but also from how these results relate to the fundamental underlying technology. Conceptual designs will be produced, test results evaluated, plans formulated for retesting, and projected work replanned on a basis of data obtained. Theoretical work will be utilized to aid the design as well as predicting and interpreting experimental results. This task will support the technology needs of the 8 lb/sec facility.

7. Task 8 - Test Integration and Interface

Provide technical and management expertise to DOE upon request to attend meetings and conferences and serve on panels relating to MHD power generation. Also, at DOE request, UTSI is to perform MHD related studies for outside contractors, and to aid component vendors in their development of components to be tested in the Coal-Fired Flow Facility.

8. Task 9 - Program Management

Provide for effective project management by utilizing and updating the presently available PERT and MIS system activities for the total program. These systems identify firmly established baselines for each task. Project management is to be effected by close alignment of the UTSI reporting systems with the DOE Uniform Contract Reporting System (DOE/CR-0001/1) and the proposed MHD Division Work Breakdown Structure (WBS).

SECTION II QUARTERLY TECHNICAL PROGRESS

A. Task 1 - Completion of Design and Construction of the Coal Fired Flow Facility (CFFF) and Facility Activation

1.1 Design and Construction

1.1.1 Control Room and Test Buildings (Bid Package No. 2)

This Quarter the mechanical (equipment) room fireproof ceiling was completed. Work began on DC bus duct installation in the Test Building. The sprinkler system neared completion. Major piping and pipe support work continued in the test building and the cryogenics area (see Figures 1 and 2). The steel shielding on the east and west partitions was completed (see Figure 3). The control room dry wall installation was completed (see Figure 4). Electrical and mechanical work in both buildings neared completion. Also a change order was issued for the contractor to install control wiring to the three compressors and air dryers.

1.1.3 Coal and Seed Processing and Handling Area (Bid Package No. 3)

Work was concentrated on completing punch list items for this construction package. Hydrostatic testing of the high pressure piping was also completed.

1.1.4 Oxidizer Supply System

Foundations for the oxygen and nitrogen tanks and vaporizers were completed. Liaison with equipment suppliers continued in preparation for installation in October.

1.1.6 Exhaust/Quench System

The initial function of the quench is to provide gas cooling and particulate removal for the low mass flow system. The final phase of the quench will include the design and fabrication of the primary quench and secondary combustor capable of handling the anticipated exhaust gas flows of the high mass flow system. The final step in the integrated quench system will include a venturi scrubber that will be sized to handle the flow from the 30 lb/sec test leg in addition to the 8 lb/sec test leg. Experience from Kraft pulp and paper industry with this type of system makes us believe that the overall efficiency for removal of particulate matter will be approximately 90 percent.

Figure 1. Installing Insulation on Piping

Figure 2. Construction of Cryogenics Piping Bridge

Figure 3. Steel (Magnetic) Shielding Installation

Figure 4. Drywall Installation in Progress

This Quarter, work continued as planned on the fabrication of the connecting duct work for the venturi/cyclone system. Purchase requisitions were prepared and issued covering the venturi scrubber, cyclone, slurry pumps and the duplex strainer. No bids have been received to date. Design efforts covering Phase I of this project are essentially complete with the exception of support steel and concrete pad design.

Because Cell III was not operational this Quarter, we did not continue work on testing of the solubility and filterability of the ash collected in the heat exchanger downstream of the prototype secondary combustor nor on the evaluation of flocculants to determine if the mean particle settling rate can be increased to permit the use of gravity thickeners. This work will be accomplished next Quarter.

1.1.10 Ancillary Equipment

This Quarter the Cardox fire prevention system was received (see Figure 5).

1.1.16, 17 Sample Preparation and Inverter Shelters

Design work has begun on these two projects. It is planned that at least the foundation work will be completed before winter.

1.2.5 Support System and Shelters (Bid Package No. 5)

Most of the construction work at the Coal-Fired Flow Facility (CFFF) is now concentrated on this Bid Package. Its completion is necessary for the operation of the facility. This Quarter the Coal Shelter was erected (see Figure 6 showing work in progress), and fire loop piping made progress (see Figure 7). Concrete foundations for both the Lake Pump House and the Cooling Water Pump House were completed (see Figure 8), and the cooling towers and the cooling water pumps were installed. The fuel oil piping and pump have also been installed, and the fuel oil tank was set in place.

B. Task 2 - Design and Fabrication of the 8 lb/sec Total Gas Flow, High Slag Throughput Test Equipment

2.1 Primary Combustor Design and Fabrication

Fabrication of the gas turbine combustor adaptor for the 4 lb/sec Vitiation Heater was completed during this Quarter. Testing will take place next Quarter in preparation for possible use of this gas turbine combustor in the Low Mass Flow (LMF) Vitiation Heater.

The Combustor Design Report (DR-2.1.2-79-02) was completed during the Quarter. The report included extensive background information on combustor testing in the R&D Facility. A revised Vitiation Heater Design Report (DR-2.1.1-79-02) was submitted as a result of comments from Dynatrend.

Figure 5. Arrival of Cardox Fire Prevention System

Figure 6. Coal Shelter Being Erected

Figure 7. Piping Assembly

Figure 8. Lake Pump House Foundation

Other comments were discussed in the Design Review Presentation which was held at the end of the Quarter for both the Low Mass Flow Vitiator Heater and Combustor. A schedule to startup the vitiation heater and combustor in the CFFF by April 1, 1980, was prepared and also discussed at the Design Review. Instrumentation requirements were also specified during the last Quarter.

Action items from the Design Review Committee will be answered early next month and detail drawings will be completed. The bid package for the vitiation heater and combustor will be distributed to fabricators early next month and approval from DOE for fabrication should be obtained by the end of October.

2.1.3 Nozzle

The low mass flow (LMF) flow train in the CFFF requires the nozzle to accelerate the flow into the low supersonic regime and to serve to transform the cross-sectional area from circular to rectangular prior to entering the MHD generator. To meet these requirements, the nozzle design is based on experimental and analytical work conducted in the R&D Facility. The same basic flanged design tested in the R&D Facility is being utilized. Drawings for the nozzle are completed with the exception of the upstream flange. This drawing is being held pending completion of fabrication tests.

Additional information on the status of this flow train component is discussed in Section 2.2.

2.1.4 Diagnostic Conductivity Channel

The initial shakedown of the LMF flow train of the CFFF requires assessment of the quality of the plasma flow. A diagnostic channel of the Hall design (window-frame electrodes perpendicular to the flow direction) is being designed and fabricated in order to meet this goal by incorporating within the design the utilization of all existing diagnostic capabilities. The design is also flexible in accepting planned diagnostic developments.

The detailed electrode drawings are complete and the bid package has been released. Copper for the electrode frames and miscellaneous channel fittings have been ordered.

Additional information on the status of this flow train component is discussed in Section 2.2.

2.2 MHD Power Train

In the first continuous coal-fired MHD facility, the low mass flow test train of the CFFF is to contain an MHD generator of the same basic design as that tested for a number of years in the R&D Facility with design improvements incorporated based on experimental and analytical work conducted there. The DCW generator will be of the window-frame type construction with replaceable caps for anode, cathode and sidewalls.

A preliminary Design Review for the power train components, the nozzle, the diagnostic conductivity channel, the MHD generator, and the diffuser, was conducted on July 19. As a result of this review, a number of Action Items were defined by the Design Review Committee. Approval to proceed with the nozzle, diagnostic channel, and diffuser was granted pending satisfactory resolution of the Action Items. A Critical Design Review was called for the MHD generator, which should occur next Quarter.

Based upon the computer program generated for drafting the details of the diagnostic conductivity electrode frames, a similar program is being implemented to produce detailed generator electrode frames. Modifications of the computer software are complete and test frame drawings have been prepared. Production of the entire set of detailed electrode frames is in process.

2.2.2 Diffuser

Plasma flow entering the test components downstream of the MHD generator must be acceptably conditioned. Transition between supersonic and subsonic flow must be accomplished with sufficient pressure recovery and decrease in flow velocity prior to entering the first downstream component, the Radiant Slagging Furnace. The diffuser being prepared to accomplish this objective is based on experimental and analytical work conducted in the R&D Facility. The drawings for this diffuser are nearing completion. The analysis of the diffuser design has been extended during the past Quarter by the use of a recently acquired Argonne diffuser program (ANL/MHD-77-1).

Additional information on the status of this flow train component was discussed in the preceding paragraphs. Next Quarter, pending DOE approval, purchase orders will be let for the nozzle and diagnostic channel, as well as for the diffuser.

2.3 Downstream Components

2.3.1 Radiant Slagging Furnace

A radiant slagging furnace is required to effectively cool the hot MHD exhaust gases from a temperature of approximately 2,455°K to 1365°K prior to secondary combustion. Acquisition of engineering data necessary for subsequent scale-up to larger size MHD facilities requires the furnace to meet several criteria already reported.

All segments of the radiant furnace, with the exception of the drum module, have been released to the fabricator. The drum module design has been approved for release for bidding. The shop drawings covering the steel support structure have been approved and the fabricator, Mingle and Elrod, Inc., has begun fabrication. The initial work on pouring the footers was bid and work initiated late in the report period. Requisitions were released covering the soot blowers, high pressure pump and the control valves.

Due to the effort required to release and evaluate bid specifications, we have not been able to complete the final design report. This report should be released by early November.

2.3.3 Secondary Combustor Design and Fabrication 8 PPS

A response to action items from the Design Review Committee was completed and approval to award the contract was acquired. Instrumentation and valves have been specified. The secondary combustor has been fabricated and is scheduled for shipment in the first Quarter of FY 1980.

C. Task 3 - Base Operations for the CFFF, R&D Facility

3.1 General Administration and Support

3.1.7 Chemical Laboratory Services

Activity during the Third Quarter of 1979 included work in three areas: support of testing in the R&D Facility, experiments with potassium carbonate and coal under simulated grinding conditions, and analytical support in quench design.

Testing support of the R&D Facility included fuel analysis of the coal tested in the facility, analysis of seed concentrations in the fuel to the MHD combustor, slag and ash analysis, and on-line gas analysis. A surplus hydrogen sulfide analyzer was received, and is being checked out for possible use in the R&D Facility. A moisture oven was purchased for use in the chemistry laboratory. An additional person was hired in the position of laboratory technician.

Experiments with coal and pulverized potassium carbonate continued in controlled humidity chambers. Data obtained indicates that operation of the CFFF coal grinding unit will be improved at 345°K. The current design temperature is 340°K, but modification does not appear to be a problem.

Additional analytical work was performed on the ash products obtained from operation in the R&D Facility. Tests were performed to provide physical and chemical data necessary for the quench design.

Next Quarter, additional laboratory furniture for the chemistry laboratory will be purchased. Also, a laboratory microcomputer to assist in logging and reporting chemical analyses is scheduled for procurement in the Fourth Quarter of 1979. Investigation will begin on procurement of a rapid carbon analyzer for coals and coke. Also, testing scheduled for Cell III in the R&D Facility will increase the work load in the area of slag and ash analysis.

3.1.9 Microscopic Laboratory Materials Testing

This Quarter, refractories and various other materials from various locations inside the MHD power generation system were evaluated for their resistance to destructive elements connected with MHD power generation. Slag from the nozzle, after the installation of Ruby Plastic, was analyzed for elemental content and the degree of reaction between the Ruby Plastic and the slag.

Copper anode, cathode, and sidewall caps from electrode number one were analyzed to determine the mechanism of erosion. Plasma abrasion was partially responsible for the eroded conditions of the sidewall caps. An electro-chemical reaction on the anode half of the MHD channel was responsible for proportionally more destruction than that observed due to plasma abrasion. The electro-chemical reaction on the anode portion of the MHD channel was accompanied by increases in sulfur and potassium, in contrast to the less affected cathode portion of the MHD channel. There was also more iron associated with those areas examined within the cathode portion of the MHD channel compared to the anode portion.

Carbon steel heat exchanger tubes, downstream from the secondary combustor in Cell III, were examined and found to be corroded. The corrosion attack began externally where traces of sulfur, potassium and chlorine were found. Corrosion probe samples were evaluated before actual exposure to test conditions for reference purposes.

Reactants from the O₂ return line were analyzed and found to be copper and sulfur combined.

Next Quarter, materials analysis support will continue as the need arises.

D. Task 4 - 8 lb/sec Total Gas Flow High Slag Throughput Test

There is no activity to report.

E. Task 5 - Testing of DOE Supplied Components

There is no activity to report.

F. Task 6 - Modification to the CFFF

The statement of work for the Heat Recovery and Seed Recovery (HRSR) System was received. Since this equipment is the first to be installed in Bay 3, it was reviewed to establish requirements for any modification. Air compressor and air heater system cost estimates were completed and a recommendation was proposed. Cost data were received to establish estimates for modification to operate on western coal and to separately inject seed. Plans for these projects will be completed and submitted to DOE.

G. Task 7 - Technology Development Program

7.1 Primary Combustor

During this period we participated to a limited extent in the generator tests in Cell I of the R&D Facility. Details of those tests are covered elsewhere. Support was also provided for the preparation of the design report of the Low Flow Mass Combustor in the areas of modeling, aerodynamics and heat transfer, as well as providing background on previous combustor test results. A jet turbine combustor was adapted for testing as a vitiation heater with our coal-fired combustor.

Special reference junctions required for the thermocouple/heat flux probe assemblies were purchased. These probes with their water cooled holders were installed at three different locations in the cyclone of Cell III. Readings from these probes will be recorded and monitored in the cathode ray tube (CRT) displays during the forthcoming Cell III tests.

We provided assistance to the Generator Design Review by answering action items related to temperature distribution in electrodes and started detailed analysis of heat balance in the downstream components. Moreover, a topical report on "Pressure and Heat Flux Distribution in MHD Channel-Diffuser System" is under preparation.

The results from the heat flux probe installations will be studied. If found satisfactory, similar probes will be installed in the CFFF system. More detailed plans will be developed for combustor development. We anticipate that these plans will place greater emphasis on cold flow modeling. We are also preparing to test the jet turbine combustor in the R&D Facility.

7.2 MHD Generator Testing

During the past Quarter a series of generator tests, referenced as TP-40, was initiated. The 60° DCW generator was assembled with insulator materials for further evaluation and a modified set of electrodes designed to obtain current distributions within these electrodes. The test objective included obtaining current distribution in the generator as a function of load as well as overall plasma conditions.

Eight generator tests have been conducted under TP-40. Using a vitiation air heater, coal was burned with oxygen and nitrogen at a thermal input of near 12 MW at a nominal oxygen equivalence ratio of 0.85. One percent potassium seeding was utilized. For these nominal test conditions, a maximum power level of near 50 KW was observed at an external load of 12 ohms. The experimental load line obtained during this testing corresponds well with projected behavior. The evaluation of results obtained during these tests has been initiated. Dynamic data, insulator material condition and platinum cladding on the anode caps are being examined. This work will continue in the next Quarter.

Further discussion of the materials-related aspects of the testing conducted this Quarter is found in Section 7.6.

7.2.4 Advanced Analysis

Program development continued during the past Quarter with the addition of two new computer codes from outside sources. The STAN 5 boundary layer code was obtained and test cases were successfully executed. The Argonne Diffuser Code (ANL/MHD-77-1) has been checked out and is currently being applied to the LMF diffuser design.

An account has been established with Argonne National Laboratory for remote execution of the two-dimensional generator code. The remote link has been checked out and a test case is in preparation.

A recently obtained one-dimensional nozzle program is currently being tested. Utility programs for plotting and data reduction are under further development.

7.3 Downstream Components

7.3.1 Secondary Combustor

During the Quarter a topical report draft was forwarded to DOE and a paper was completed for presentation at the Winter Annual ASME Meeting in December.

The hardware and operating conditions for the upcoming Cell III tests were prepared. The conductivity channel was installed in the system, marking the first time this equipment will be used in Cell III. The heat flux probes were procured and installed in the cyclone. A refractory probe has been installed in the diffuser refractory furnace to test materials for possible future use in the system. Also, probes were prepared for material corrosion, ash deposition, and pollution monitoring. Ports for these probes were installed in the Cell III test duct. The tests will provide additional information on dust loading and particle size, NO_x and SO_2 . We also plan

to attempt to answer questions raised in the Low Mass Flow Secondary Combustor Design Review concerning alternate methods of air injection. The first phase of these test runs will be conducted next Quarter.

7.4 Seed Regeneration

7.4.1 Seed Regeneration

Test data from coal-fired MHD experiments conducted at the University of Tennessee Space Institute have shown that the potassium carbonate seed (K_2CO_3) has a significant impact on the environmental aspects and economics of the overall MHD process. Further, the relatively high cost of potassium carbonate dictates the need for recovery and recycling of the seed to the MHD system.

Recommendations presented in a topical report released January 4, 1979, (FE-1760-36, An Evaluation of the Direct Reduction Seed Regeneration Process) stated that bench scale investigation of the direct reduction process should be undertaken. This recommendation was made based on the high economic and technical potential of this process as compared to other seed regeneration processes. Bench scale investigation of this process has subsequently been accomplished. Experimental results utilizing potassium, as well as sodium salts, have shown that the direct reduction process does not appear to be a viable means of seed regeneration.

A final evaluation of the bench scale experiments utilizing the direct reduction reactor will be presented in a topical report scheduled for completion in November. Further testing utilizing this apparatus has been terminated. Within the objectives of this project, analysis of other potential seed regeneration systems is continuing. A basic economic analysis of the Tomlinson-Tampella Process has been undertaken. Bench scale experiments, presently planned for next Quarter, are anticipated to provide the data necessary for a detailed design and economic analysis. Evaluation of the Formate Process and bench scale tests of the Tomlinson-Tampella Process will be the major thrust of our efforts over the next Quarter.

7.5 Pollution Control

Aquatic environmental monitoring continued during this Quarter. Base-line data for the following parameters was collected during these months: pH, conductivity, hardness, alkalinity, calcium, iron, potassium, magnesium, sodium, chloride, phosphate, sulfate, total solids, dissolved O_2 , ammonia, and temperature. Presently three sampling stations exist near the shore line on Woods Reservoir. Water quality analysis from the MHD discharge site is compared with observation and findings from an upstream control station and a station within the reservoir that is unaffected by the MHD effluent. The values of the physiochemical data for each parameter tested have been fairly constant and have been consistent with the data of previous months during the entire Quarter.

Projected plans for water chemistry include depth sampling, and future reports should include vertical profiles of water quality. Also, in the near future a biological study of the lake should begin as soon as the necessary equipment has been purchased. Initially this study will consist of a quantitative and a qualitative phytoplankton analysis. Water quality will be characterized by trophic indices which will be formulated from this analysis. In addition, the phytoplankton population will be monitored for a shift in algal species, for species indicators of industrial or organic pollution, and for an anomalous algal growth. Physicochemical data will be combined with biological data and should result in a thorough analysis of the water quality around the testing facility.

7.6 Materials

7.6.1 Corrosion of Metals and Alloys

An intrusive probe, Figure 9, has been designed to conduct preliminary screening tests on candidate boiler, superheater and other downstream component materials. Eight alloys have been selected as candidates (Table I), and specimens of these alloys will be subjected to MHD gas-slag-seed environments in Cell III of the University of Tennessee Space Institute's R&D facility. Post-test analyses of the probe specimens will be conducted for corrosion, erosion and other degradation modes.

TABLE I

Corrosion Probe Samples

1. 1030 Carbon Steel
2. Croloy - 1/2
3. Croloy - 2 1/4
4. 304 SS
5. Croloy - 9
6. 310 SS
7. 316 SS
8. 446 SS

The first series of probe tests will be conducted in October 1979 using carbon steel samples at 645°K in a reducing environment to simulate boiler tube conditions. Subsequently, several candidate materials will be exposed to oxidizing conditions with metal temperatures of 810°K or higher to simulate superheater tube conditions. These tests will provide essential information for materials selection for downstream components.

Figure 9. Intrusive Probe

During the past Quarter, progress on this project has consisted of assembly of the probe with the first set of specimens and the design and construction of the probe cooling system. Probe testing has been delayed by the lack of testing in Cell III.

A topical report entitled "Interelectrode Insulator Development for the UTSI MHD Generator" has been released for internal review. It outlines insulator material development at UTSI during the period 1977-1979. Release to DOE should occur early in November.

Next Quarter, corrosion testing in Cell III will be conducted on a carbon steel sample in a reducing atmosphere to simulate boiler tube conditions. Post-test analysis of erosion and corrosion tests will be conducted.

7.6.2 Materials Testing for the MHD System

The thermal and chemical severity of the environment created by the extraction of energy from coal imposes stringent limitations on the selection of materials of construction for coal conversion facilities. The MHD process adds potassium compounds to coal ash and sulfur compounds which result from coal combustion. The aggressiveness of this environment requires careful selection of construction materials. To select materials best suited for use in commercial installation, programs to test the performance and durability of candidate materials are imperative. Toward this goal, UTSI has accomplished the following during the present Quarter.

Duct development testing has been performed per Test Plan 40. Materials testing included in these tests were 1) noble metal cladding on anode caps, 2) woven refractory interelectrode insulators, 3) a copper capped stainless steel frame electrode, and 4) refractory lining on oxidizer injector plate.

a. Capped Electrodes

Evidence indicates that increased run times in a Coal-Fired Cold Wall MHD system may result from the use of noble metal anodes for oxidation resistance. The adjoining problem of heat dissipation from arc roots requires a thin layer attached to a good thermal conductor to prevent material vaporization. To facilitate fabrication, testing, and replacement, UTSI's approach has been to use copper caps for the electrodes. These caps may then be given a noble metal face by using fabrication techniques independent of the electrode frame. This allows replacement of anode surfaces which are subject to electrochemical erosion during the generation of power with the MHD process. The caps also provide a means of testing various materials, including coatings and claddings, and of conducting experiments to quantify coulombic material transfer.

Continued testing of platinum and iridium cladding on anode caps has shown that both materials have performed well for cumulated run times of approximately one hour. These caps have not been disassembled for detailed analysis but visual observation indicates that all thicknesses of platinum sheets, except one, and the iridium sheet showed acceptable degradation (see Figure 10). The degradation that was present was greatest on the leading edge. The one platinum failure is believed to have resulted

Figure 10. Post-Run Status of Platinum and Iridium
Sheets Showing No Severe Degradation

from a brazing imperfection. Each sample was air brazed to the copper cap using a silver brazing alloy containing its own flux. Only superficial degradation was found on cathode caps. These caps were installed onto the copper electrode frames with a boron nitride paste to increase heat transfer away from the caps and allow for electrical isolation of the caps for testing purposes.

A bending and forming jig has been fabricated (see Figure 11) for bending the sheet noble metal cladding material to improve the fit between the cladding and cap. Successful hydrogen brazing tests have been performed using a sheet having 80% gold, 20% copper fluxless brazing alloy (see Figure 12). This alloy, with a melting point near that of the copper cap, will allow operation of the cap at a higher temperature. Preparations are underway to incorporate these methods in the next generator tests.

b. Interelectrode Insulators

TP 40 included tests of woven refractory interelectrode insulators. Refrasil and Irish Refrasil (chrome oxide diffusion coated for slag resistance) were impregnated with several coating mixtures containing boron nitride powder to improve its gas sealing and thermal conductivity properties. Disassembly of all the channel has not been made to allow for an accumulation of run time but test data showed acceptable results. The gas sealing quality of the cloth was improved by pulling a vacuum on the assembled channel and painting the exterior with an insulating varnish.

Several other commercially available materials are being compared to this combination's thermal conductivity and electrical insulation properties on a bench scale apparatus.

Future plans are to include further testing of both monolithic and pieced, hot pressed boron nitride insulators in several thicknesses.

c. Stainless Steel Electrode

Because of the undesirability of having copper in any boiler feed-water circuits, an attempt is being made to utilize austenitic stainless steel for electrode frames. One stainless steel frame with copper electrode caps was installed during testing under TP 40. Data obtained from these tests are being analyzed. Testing planned for the coming Quarter will include five stainless frames installed in the generator at a lower heat flux, and lower electric stress region than for the initial testing location. Results from both test series will be analyzed and a recommendation made for further utilization of this design concept.

d. Refractories

The Kao-Tab 95 castable refractory insulation on the oxidizer injector plate was replaced with a Ruby Plastic ramming mix. This was accomplished by ramming around steel pins, then removing the pins. In addition, the high density alumina tubing used to line the ports was replaced with thin-walled

Figure 11. Bending and Forming Jig for Mating and
Brazing Platinum and Brazing Alloy to Copper
Anode Caps

Figure 12. Platinum Sheet Brazed to Copper Anode Cap

mullite to improve thermal shock resistance. This combination has performed well except for some degradation of the mullite tubes attributed to a temperature excursion in the inlet oxidizer temperature.

Future plans for refractory testing include the testing of plastic chrome ore with a refractory test probe recently installed in the radiant furnace of Cell III. Also planned is the further testing of refractories for use in the coal combustor.

7.7 Diagnostic Support

Diagnostic projects are included in order to develop experimental measurements and analysis techniques in support of the broad technology base required by the MHD system. During the past Quarter, wideband data for key parameters were included in the testing conducted in the R&D Facility under TP-40, generator testing. Support is also planned for upcoming tests during the next Quarter in Cell III through the implementation of the bulk conductivity measurement.

7.7.2 Temperature Sensors

Using data obtained during the USSR Diagnostic Evaluation Tests, where plasma luminosities were measured simultaneously with line-reversal measurements, data from the relative temperature measurement system is being transformed into approximate absolute temperature measurements under similar plasma conditions.

During generator testing, under TP-40, luminosity data were taken in the ports available in the nozzle. Examples of temperature profiles calculated from this data are illustrated in Figure 13. Between tests TP-40-06 and TP-40-07, the oxidizer distributor plate between the vitiation air heater and coal combustor was refurbished. The resultant effect of improved combustion is seen in the flatter temperature profile.

During the past two Quarters, a Beckman DU spectrometer has been modified for use in experimental examination of the spectral content of the coal-combustion plasma for use as a monochromator in the line-reversal temperature measurement system presently being assembled. The old detection electronics of the spectrometer were replaced with a modern wideband system, and a high resolution stepping motor has been interfaced to the wavelength drive to permit remote automatic control. A computer program to control the spectrometer during testing is partially complete.

The spectrometer will also be used in the line-reversal temperature measurement system. This system consists of a tungsten filament light source whose radiation is chopped and imaged into the plasma as shown in Figure 14. On the other side of the plasma, the plasma and light source radiation is imaged onto the spectrometer entrance slit. The spectrometer is used to select the appropriate emission line for the analysis. It is anticipated that the system will be ready for operation during the coming Quarter.

a) TEMPERATURE PROFILES FOR TP 40-06

Figure 13. Temperature Profiles Immediately Downstream of the Nozzle Throat for Three Tests During TP-40

b) TEMPERATURE PROFILES FOR TP40-07

AVERAGE BLOCKS : 3000-3100

AVERAGE BLOCKS: 6400-6500

AVERAGE BLOCKS: 9600-9700

TOP 0.71" 0 -0.46" -1.75" BOTTOM
c) TEMPERATURE PROFILES FOR TP 40 - 08

Figure 14. Line Reversal System

A paper entitled "Status of the Evaluation of a Coriolis Effect Mass Flow Meter for Dense Phase Coal Flows" was presented to the 1979 Symposium on Instrumentation and Control for Fossil Energy Processes in Denver, Colorado, during the past Quarter. A topical report on this subject is being prepared and should be completed during November 1979.

Plans are being formulated to modify the R&D Facility coal delivery system to facilitate further testing of the mass flow meter in the light phase flow regime. The proposed modification is shown in Figure 15. This system is similar to the previously described system but includes the addition of a fluidizing hopper to uniformly fluidize the coal and a coal/ N_2 mixer to uniformly mix the transport gas with the fluidized coal. It is planned that the coal/ N_2 ratio will be varied in several steps down to a 1:1 mixture to determine the response of the meter to light phase coal flows.

7.9 Process Control

7.9.1 Process Control Development

During the Quarter a number of models have been developed to assist in the control of the overall MHD/steam plant.

A simple model was developed for an inverter that feeds a stiff AC grid and is powered by a DC source with a linear voltage/current relationship. The resulting current and power relations involve the DC source characteristics, the firing angle of the inverter, and the voltage of the AC grid.

An incremental model of the MHD/steam plant was developed for the purpose of finding the control strategy necessary to follow fluctuation in the real imaginary power demand. Since the firing angle of the inverter can only change the division of real power between the MHD and steam sections, an auxiliary boiler has been proposed to take up the slack in the power demand while the power delivered to the common prime mover -- the combustor -- is changed and finally alters the power available at the inverter and alternator sections downstream. Because of this, it is expected that the inverter's firing angle will play only a small part in the control of the power flow.

Presently these models are being investigated to determine the constants necessary to bring the real power balance into equilibrium in the shortest time with the least overshoot. Both classical and modern (optimal) control theory techniques will be used to accomplish this. Further work on these models will be continued in an effort to improve the models and give a control strategy that will produce the desired results on a real system.

It is planned to prepare a topical report discussing this incremental model in detail during the next Quarter. The proposed title is "Control of MHD/Steam Plant Using Its Incremental Model." It will be prepared by Dr. R. D. Joseph and A. K. Agarwal and should be finished by the end of December 1979.

Figure 15. Proposed Modification to R&E Facility Coal Delivery System

III. CONCLUSIONS

Continued testing of platinum and iridium cladding on anode caps provides favorable results for cumulative run times near an hour. A special bending and forming jig has been made toward improving the cladding-to-cap fit. Because of continued success and improvements such as this, it is concluded that all of these improvements be incorporated in the next generator tests.

Although the Direct Reduction process was recommended last January as a leading potential method of seed regeneration, experimentation indicates that it is not, in fact, viable. Thus it is concluded that no further work be done on this process and that effort be concentrated on the Formate and Tomlinson-Tampella processes.

Generator testing conducted under Test Plan 40 confirmed the strong coupling of generator performance and combustion performance. Deterioration of the oxidizer distributor plate to the combustor reduced generator output at nominal test conditions. Refurbishment of the plate led to output power levels consistent with theoretical predictions for nominal test conditions.

Design and Component Specification Reports Status

Submitted to DOE (No approval required)

- 1) DR-1.1.6-79-01, Quench System Design Report, by Johanson and Owens, issued March 13, 1979.
- 2) DR-1.1.6-79-02, Test Train Specification Component, by Johanson and Owens, issued March 22, 1979.
- 3) DR-2.1.1-79-01, Test Train Component Specification for the Vitiation Heater, by Johanson and Kulesza, issued March 28, 1979. DOE comments received on July 23, 1979. Report distributed required no revisions.
- 4) DR-2.1.1-79-02, Vitiation Heater Design Report, by Johanson and Kulesza, issued May 8, 1979. Per DOE comments received July 23, 1979 a revised copy was distributed.
- 5) DR-2.1.2-79-01, Test Train Component Specification for the Low Mass Flow CFFF Primary Combustor, by P. Kulesza, issued May.
- 6) DR-2.1.2-79-02, Design Report, Primary Combustor for the Low Mass Flow CFFF, by D. Attig...M. Scott, issued August 28, 1979.
- 7) DR-2.1.3-79-01, Nozzle Test Train Component Specification, by Johanson and Roy, issued on May 30, 1979.
- 8) DR-2.1.3-79-02, et. al., Nozzle, etc., Design Report, by Alstatt...Xiques, issued on June 18, 1979.
- 9) DR-2.1.4-79-01, Diagnostic Conductivity Channel Test Train Component Specification for the Low Mass Flow CFFF, by Johanson and Scott, issued May 30, 1979.
- 10) DR-2.1.4-79-02, Diagnostic Conductivity Channel CFFF 81b/sec Test Bay Design Report, by Baucum, Suneson, McMinn, and Scott, issued on July 5, 1979.
- 11) DR-2.2.1-79-01, MHD Generator Channel for the Low Mass Flow CFFF, Component Test Train Specification, by Johanson and Roy, issued on May 30, 1979.
- 12) DR-2.2.1-79-01, et. al., Generator, etc., Design Report, by Alstatt ... Xiques, issued June 18, 1979.
- 13) DR-2.2.2-79-01, Test Train Component Specification for the Low Mass Flow CFFF Diffuser, by Johanson and Roy, issued on May 30, 1979.
- 14) DR-2.2.2-79-02, et. al., Design Report, etc., for the Low Mass Flow CFFF Diffuser, by Alstatt...Xiques, issued on June 18, 1979.

- 15) DR-2.3.1-78-01, Radiant Furnace System Design Report, by Owens, Johanson, and Kolbe, issued on November 15, 1978.
- 16) DR-2.3.1-79-02, Radiant Furnace Test Train Component Specification, by Johanson and Owens, issued on March 22, 1979.
- 17) DR-2.3.3-79-01, Secondary Combustor and Ash/Seed Hopper Design Report, by Attig...Power, issued on March 20, 1979. Review meeting held June 21, 1979. Design was approved with provision for backup hardware.

Topical Reports To Be Prepared in Fourth Quarter of 1979

1. Pressure and Heat Flux Distribution in MHD Channel-Diffuser System.
2. Final Evaluation of the Direct Reduction Seed Regeneration Process.
3. Status of the Evaluation of a Coriolis Effect Mass Flow Meter for Dense Phase Coal Flows.
4. Interelectrode Insulator Development for the UTSI Generator.
5. Control of MHD/Steam Plant Using Its Incremental Model.