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MHD COAL-FIRED FLOW FACILITY

Annual Technical Progress Report for the Period October 1979–
September 1980

March 1981
Date Submitted

Work Performed Under Contract Nos. AC01-76ET10757
AC02-79ET10815

The University of Tennessee Space Institute
Tullahoma, Tennessee

U. S. DEPARTMENT OF ENERGY

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MHD COAL-FIRED FLOW FACILITY

ANNUAL TECHNICAL PROGRESS REPORT

OCTOBER 1979 ← SEPTEMBER 1980

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Under Contract No. DE-AC01-76ET10757
(Task 1 Only)

ABSTRACT

In this Annual report for DOE FY 1980 submitted under DOE contracts DE-AC01-76ET10757 (Task 1 only) and DE-AC02-79ET10815, The University of Tennessee Space Institute (UTSI) reports on significant activity, task status, planned research, testing, development, and conclusions for the Magnetohydrodynamics (MHD) Coal-Fired Flow Facility (CFFF) and the Energy Conversion Facility (ECF). Because this is a summary report no extended abstract is given.

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SECTION I

OBJECTIVE AND SCOPE OF WORK

A. Contract No. DE-AC01-76ET10757

Under Contract DE-AC01-76ET10757, 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 (CFFF)

B. Contract No. DE-AC02-79ET10815

Under Contract No. DE-AC02-79ET10815, 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 Energy Conversion Facility (ECF), previously referred to as the R&D Facility, and the MHD Coal-Fired Flow Facility (CFFF) 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 (ECF)

Perform all operations and maintenance required to maintain the CFFF and the ECF 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 modification 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 gasdynamic 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 depends 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

SUMMARY OF TECHNICAL PROGRESS

A. TASK 1—COMPLETION OF DESIGN OF CFFF & FACILITY ACTIVATION

1.1 Design and Construction

During the first Quarter of FY 1980, the Laboratory/Office Building (Bid Package No. 1) and Site Electrical Transmission and Distribution (Bid Package No. 6) were completed. The Control Room and Test Buildings (Bid Package No. 2) were almost completed, as was the Coal Processing Area (Bid Package No. 3). Bid Package No. 5 (Support Systems and Shelters) was 85% complete with hydrostatic testing remaining. Total construction work on the CFFF under the current contract was nearly 98 percent complete. By the end of the last Quarter all the construction bid packages were completed. Several small, finish-up construction type projects were completed during the period such as the inverter and coal preparation shelters. Major facility support systems were completed, activated, and checked out, including the cooling water system, the fire protection system, the fuel oil system and the cryogenic oxidizer system.

On the quench system, the design of the low mass flow portion was brought to 80 percent completion during the year with the ducts, venturi, and cyclone released to vendors for fabrication. Work was initiated on the primary quench and the secondary combustor for use with the high mass flow system located in Bay 2.

During the second Quarter the cyclone separator was completed and delivered to UTSI. Concrete work was behind schedule due to the excessive rainfall occurring during the reporting period. As a result, the cyclone could not be installed. However, rebar was placed for the quench system foundation. The support steel design was completed and released for bidding. The transition ducting connecting the low mass flow (LMF) test train to the quench system and the venturi was released to fabricators and was under construction at the end of the Quarter. All major equipment items were out for bidding by the end of the report period.

Work on the quench system continued during the third quarter and the concrete pad was completed. The cyclone was erected on schedule. The venturi was delayed by the fabricator and was not received as planned during the report period. Support steel work was bid and awarded for a scheduled delivery during the early part of the fourth quarter. Work was begun on the primary quench.

In the last Quarter of the fiscal year, the first phase of the quench system was completed with the venturi, cyclone, and transition duct installed in Bay 2. All connection ducting to the induced draft fan was installed as planned. Late delivery of the hydroclones and associated piping prevented system completion by the end of the report period.

B. TASK 2—DESIGN AND FABRICATION OF THE 8 LB/SEC₁ TEST EQUIPMENT

2.1 Primary Combustor

During the first Quarter, vitiation heater and primary combustor drawings for fabrication were completed and approved by DOE. Bid packages were sent to the vendors. In addition, the air heater test module was designed during FY80 with construction now in progress. This module will allow corrosion rate evaluation as well as observation of fouling factors with testing to be accomplished in the low mass flow train of the CFFF.

During the year combustor bids were evaluated, the purchase order was issued and the combustor was fabricated. The combustor consists of two cylindrical sections, a conical section, a disperser plate, and a coal tube. These items have been delivered and installed as discussed in the fourth quarterly report. Also included in this project is all of the support equipment, instrumentation, controls and operating procedures necessary to interface these components with the CFFF. Support stands have been fabricated and the instrumentation for the test train components has been purchased. Instrumentation for the vitiation heater and combustor were also purchased during this time.

A gas turbine combustor was tested in the ECF to see if it could be used as a burner in the vitiation heater. However, after a successful run at low oil flow rates, problems with the fuel oil system resulted in destruction of the turbine combustor. The combustor was replaced and further testing is expected.

The nozzle design was completed and the nozzle was built at UTSI. UTSI fabricated the throat plate, and Lucey Boiler Company made the remaining four plates. Quality Assurance inspections and supervision of hydrostatic testing preceded acceptance of the completed nozzle, which was delivered to UTSI in the third Quarter of FY80.

2.2 MHD Generator

The generator design, including computer generated drawings, was completed. In March, a design review was conducted for DOE by the Energy Conversion Division (ECD). Several Action Items were responded to including thermal stress analysis of the capped frame design. Upon receipt of DOE approval, the contract to fabricate the four central modules was let to Schmiede Machine Tool Company. UTSI began fabrication of the upstream and downstream transition section modules.

Bench model testing was carried out on cooling water flow to check suitability of the 45° and 135° cooling water fittings necessary to connect the tubing to the slanted frames. These tests led to modification of the fitting design to minimize pressure drop through the fitting.

Laboratory testing was also initiated on an assembled cap/frame model to investigate heat transfer properties of various cap-to-frame gap filler materials. Continued thermal and stress analysis was performed along with the laboratory tests, particularly to evaluate the effects of relaxing the assumption that the inter-frame electrical insulation is thermally non-conducting also.

The diffuser design was completed and Tennessee Metal Fabrication was awarded the contract to build it. While the diffuser was under construction a procedure for installing the insulation in the last section was developed and support stand design was completed. The diffuser had been nearly completed at the end of the first three Quarters of the year with the first three sections finished and awaiting Quality Assurance inspection and hydrostatic testing.

The Cold Flow Facility was completed and the diffuser and radiant furnace models fabricated and installed, together with the required instrumentation and flow visualization apparatus during the first three Quarters.

2.3 Downstream Components.

All modules of the radiant furnace were under fabrication during the first Quarter with all major units including the drum module being delivered to UTSI during the second quarter. Work continued during the third and fourth quarters on installation of the radiant furnace. All sectional joints and the various access ports, doors, thermowells and other penetrations were completed.

Fabrication of the secondary combustor was underway early in the year. During fabrication, a new stud pattern and different size studs were recommended and installed in the secondary combustor. An air plenum was extended to the fourth side of the secondary combustor, as recommended by the Design Review Panel. The secondary combustor and ash seed hopper were completed and installed during the second Quarter. The equipment was leak tested and leaks were repaired.

The Intermediate Temperature Air Heater (ITAH) test module preliminary design drawings have been completed and a bid package for the module fabrication is being prepared. It is anticipated that a purchase order for the fabrication will be issued by early FY81.

Heat flux probes, thermocouples, an orifice plate for secondary air and pressure transducers were ordered and delivered. A paper entitled "Development of a Steam Plant for a Coal-Fired MHD Power Plant" describing the secondary combustor and radiant furnace design was prepared. This paper was presented at the Seventh International Conference on MHD Electric Power Generation in June.

C. TASK 3—BASE OPERATIONS FOR CFFF & E C FACILITY

1. Laboratory Services

In the microscopic and materials laboratories, refractories for intermediate to low heat duty were examined for confirmation of elemental content and morphology. Plastic chrome ore (TP41-07) was taken from the radiant furnace and examined to note the existence of a reaction product, resulting from its reaction with the constituents of slag. Spinel type structures were evident in the refractory-slag interphase and were found to be composed of aluminum, silicon, and potassium. Slag attack of the aggregate was evident. Electrodes from Module V (TP40) were examined for the effectiveness of the silver brazing alloy. Areas along the downstream edge of the anode cap showed signs of heat stress evident by the crystalline pattern of the grain structure and the sloughing off of platinum about 3000 μm from the downstream edge. There was also intragranular erosion in the sidewall cap at areas of failure. Interelectrode insulators of TP40 were examined for slag attack on various areas of each insulator. Energy dispersive analysis showed the presence of slag on the Refrasil insulator, but no gross damage was evident. Slag samples from various locations in the MHD power generation system were examined for basic constituents and crystalline phases evident in the composite. Boron nitride unused was examined from two different angles to determine which surface had less pores. Analysis was also made to determine if any impurities existed, but none were found.

The microscope and materials preparation laboratories began the second Quarter of 1980 by examining metallic and ceramic specimens for refractory development in such MHD sections as the primary combustor/vitiation heater. Materials studied included Kaotab 95, Ruby, and Greencrete-ARC. During the next Quarter a Unitron metallograph was received. Refractory investigation continued. In addition, considerable effort was devoted to the microscopy of electrode caps from Test Plan (TP) 40A to determine wear mechanisms.

In engineering and laboratory services, the main effort began during the last Quarter with primary activity devoted to planning. A standard laboratory procedures manual was completed, and an Elemental Analyzer and Atomic Absorption Spectrophotometer/Graphite Furnace were received. A gas chromatograph/mass spectrometer was also received and made operational.

2. Aquatic Monitoring and Terrestrial Monitoring

Environmental analyses results showed similar trends of previous months except for parameters affected by seasonal changes and higher values reported for iron. Since there was no apparent correlation of increased values for any parameter with scheduled test runs during the Quarter, runoff from the terrain above was determined to be the main source of iron. Overall, water quality data for the year compares favorably with that furnished by the State of Tennessee Department of Public Health. Application was made to the Division of Water Quality Control for a point source discharge permit. Also, a holding pond system was designed for the CFFF.

Water quality analysis of Woods Reservoir, adjacent the CFFF, yielded expected seasonal results and showed similar trends as determined for the second Quarter of the previous year. Further, the epilimnial content of the reservoir displayed characteristic seasonal trends. Baseline conditions of stream quality were established for Rollins Creek, a tributary of Woods Reservoir.

During the third Quarter an investigation was made of a fish kill which occurred in Woods Reservoir during the Quarter. Since only a single species, Minytrema melanops, was involved, it appeared that death was caused by disease rather than by pollution. This view was substantiated by an examination of the water quality data during the period. Specimens were examined macroscopically and microscopically for external and internal pathogens. Heavy infestation of the myxosporidian spore Myxosoma sp. was found localized in the gills of the fish. Scanning electron photomicrographs revealed a heavy infection by the spores and this coupled with the stress of spring spawning was concluded to be a contributing factor in the death of M. melanops. Thus death was attributable solely to natural causes.

During the last Quarter, arrival of a boat and requisite field equipment made site monitoring possible. Preliminary phytoplankton analysis began. Collection sites for biological samples were correlated with previous existing sampling stations. Also, a quality control program was begun for water analysis. Outside analyses were to be conducted to ensure accuracy.

In the second Quarter, a radial line was run at a bearing of N15°W from the CFFF stack to the air monitoring station and past the station into a pine plantation. Twenty terrestrial plots were located along this radial line according to a plan designed to minimize pollutant concentration differences between plots within each impact area. A radial line was run at a bearing of S5°W from the CFFF stack through the secondary impact area. Eight plots measuring 20 x 25 meters each were established. A reconnaissance of the control area was made prior to the establishment of plots.

The terrestrial environmental monitoring program accomplished the sampling of foliage and soil from all study plots. Separate foliage samples were taken for red oaks, white oaks, dogwoods and hickories. Foliage was obtained from all forty-eight study plots. Soil samples were obtained from forty-eight study plots at three depths to sample the A, B and C soil horizons. A total of 288 soil samples were combined to make 72 samples.

For growth analysis, eight .05 hectare plots were established in each of the six main study areas. Trees were tagged and post markers were set. Poles were also set to enable the collection of rainwater.

The Franklin County Landfill Authority formally agreed to dispose of flyash and slag generated by Energy Conversion Division facilities.

3. Air Quality Monitoring

Major preparation for ambient air quality monitoring was accomplished beginning the second Quarter. This included the securing of station siting approval and the detailing of locations compatible with air quality models. Also, active implementation of the design and procurement of a computerized system to simulate atmospheric dispersion processes in order to calculate ambient air concentrations of atmospheric contaminants through modeling and to compare this with measured values proceeded in May and June. It was decided that a Cromemco Z2H system and some outside computer support would be the best combination.

During the third Quarter, the sites were prepared for the installation and operation of two air monitoring stations, one at the major impact site and the other at a site for gathering baseline data. The units for use at both sites were set up, calibrated and are at present fully operational.

Negotiations with the Tennessee Air Pollution Control Division (TAPCD) concerning air pollution permits for ECF test cells number 1 and 3 were started. A baghouse air pollution control device may have to be added to meet the State emission requirement. The need for and design of the baghouse are under investigation.

4. Engineering Design

Microfilm equipment was procured and installed. All of the drawing files are now on microfilm. Design Engineering moved from the main building to a location in the Industrial Park.

D. TASK 4—EIGHT LB/SEC HIGH SLAG THROUGHPUT TEST

4.1 Combustors

During the first Quarter component test plans were initiated for the vitiation heater/combustor and for the secondary combustor. Both component plans were later approved and distributed to DOE. The component test plans are general in nature and do not provide the specific detail required for operation of the component in the CFFF. Therefore, a detailed test plan preparation was initiated to provide a document containing the specific detail required for operation in the CFFF. The test plan covers operation during the initial CFFF operation (designated test LMF-0) and during the LMF-1 test series. The detailed test plan contains test schedules, flow conditions, hardware configuration, instrumentation and control details, and flow train operation procedure.

Design was initiated of an optical flange to provide optical diagnostic access to the flow field in the coal-fired combustor during LMF-1. The flange will provide access for making line reversal and luminosity temperature measurements as well as laser velocimeter and other optical diagnostic techniques, if available.

4.2 MHD Power Train

Information was provided during the first Quarter for preparation of the overall system test plan. In subsequent Quarters, detailed component test plans were prepared and published and work continued on use of generator computer codes for prediction of generator performance during the LMF-2 and subsequent test series.

Instrumentation requirements were outlined and sent to the Facilities Laboratory for implementation.

4.6 Diagnostics

In the first Quarter, basic instrumentation requirements for the CFFF LMF system tests were established and specifications for a broadband data acquisition system were finalized. Also, preparation of component test plans for the power train and diagnostic conductivity channel began. This activity continued in the second Quarter.

During the third Quarter, a broadband data acquisition system was selected with a tape search system to allow broadband data to be correlated with general performance data obtained in the various CFFF tests. Also, equipment to digitize the broadband data was specified so that digital stochastic time series data analysis and modelling techniques could be routinely employed. The luminosity relative-temperature systems were being built for the 8 lb/sec CFFF testing. A coriolis effect coal flow meter was installed at the CFFF. Finally, the component test plan for the CFFF 8 lbs/sec Hall conductivity channel was completed.

Programming was completed which enables engineers to interpret relationships between points and to quickly obtain a broad view of the experiment behavior. The preliminary layouts of the required plots were prepared for the LMF-1 Instrumentation and Data Manual. Also, the equipment required for CFFF broadband data acquisition and analyses was received and installation was initiated.

E. TASK 5—TESTING OF DOE SUPPLIED COMPONENTS

There is no activity to report.

F. TASK 6—MODIFICATIONS TO THE CFFF

No significant activity occurred in this task.

G. TASK 7—TECHNOLOGY DEVELOPMENT PROGRAM

7.1 Primary Combustor

In the first Quarter, a program of flow visualization and non-intrusive velocity field surveying was formulated to enable a variety of vitiation heater, coal combustor, and disperser plate concepts to be experimentally evaluated quickly and at relatively low cost. A program was initiated to develop a three-dimensional elliptic flow computer program for predicting the flow in the various UTSI combustor designs. Research into the design and performance of multiport coal combustors of the UTSI high slag carryover type was initiated by the formulation of a new research project. This project is to culminate in a demonstration combustor for development testing in the CFFF. Also, local heat flux measurements were made in Cell III. The heat flux distribution and the total heat lost in all components were analyzed for various runs. There was very good agreement between the heat flux measured by the commercial probe and the specially designed probes. Radiation measurements indicated about 12 percent of heat transfer by radiation. A preliminary letter report on Cell III heat transfer was released.

An experimental research capability was developed for investigating both the aerodynamic environment of the UTSI combustors and the performance of pulverized coal injectors. A test shelter has been constructed for each of these purposes. In both shelters, flow circuits exist that permitted both flow visualization and detailed flow field measurements to be made. The data from the experimental research in these facilities will be used to modify and upgrade the performance of existing ECD combustors, and to provide design inputs for new combustors.

A mathematical model of isothermal flow in the ECD combustor has been formulated and flow field predictions were made. The model is being extended to reacting flows with large heat release. Also, a bid for additional mathematical models of combustor systems from CHAM of North America, Inc., was selected. However, the contract award has not yet been approved by the DOE, so to date, no work has been done in advanced combustor math-modeling.

Conceptual designs for disperser plates and containment shells for both single and multiport combustors have been prepared. For single port coal injection, the disperser plate designs were used in the ECF and CFFF combustors. In the ECF combustor, this disperser plate has been used to burn nearly 50-50 coal-fuel oil mixtures, which creates a much different environment or test condition than has been previously achieved in testing with coal only. Thus, the new disperser plate design is a significant change from past configurations.

A survey was initiated to review potential candidate techniques for making diagnostic measurements in hostile combustor environments and to provide the capability of evaluating combustor performance. Candidate measurement systems include, but are not limited to, laser velocimetry (LV), laser holography (LH), line reversal (LR), laser-Raman spectroscopy (LARS) and coherent Anti-Stokes Raman Spectroscopy (CARS). The LV system can potentially provide information on flow velocity, turbulent and transport phenomena in the combustor flow. The line reversal technique

will provide relative temperature profile information while the LARS and CARS systems can potentially provide specie concentration information in addition to absolute static temperature data. The survey will include an in-depth review of the diagnostic development currently in progress at Mississippi State University as well as various DOD, DOE and NASA installations. When completed, the survey will provide a basis for selecting the diagnostic approach to be used in combustor development.

A heat transfer study of the entire test train was performed. Average heat fluxes were obtained for the entire length (in most cases) of downstream components in Cell III in the ECF. In the upstream components, which have cooling circuits manifolded over short axial distances, more detailed local heat flux distributions were determined. For test purposes, commercial total radiation heat flux probes together with heat flux probes designed and fabricated at UTSI were used in selected downstream locations. A total system heat balance was evaluated for the entire test train in Cell III to study the effects of slag and oxygen/nitrogen ratio on system heat transfer. Based on test results, it was decided to use commercial heat flux probes in the CFFF; this and the other heat transfer instrumentation were specified and purchased. Auxiliary hardware to install the probes was fabricated.

A program was continued to analyze channel frame electrode temperature distributions. A computer model developed and reported earlier was modified to account the UTSI electrode configurations by including cap/frame gaps and insulators. The model is based on a finite element analysis. A channel frame electrode was instrumented for measuring temperature distribution (anode, cathode and side wall) and was used in the tests conducted to generate power. The experimental temperature measurements and the analytical predictions of the model were compared. The gap conductivity was determined by numerical experimentation to achieve good agreement. The model was extended and applied to predict the performance of the 45° DCW electrodes of the CFFF generator channel.

Combustor development and investigation at UTSI were analyzed and reported in detail with emphasis on the system heat transfer. A paper based on this study, entitled "Heat Transfer as a Diagnostic Tool in the Development of Direct Coal-Fired MHD Combustors" was presented at the ASME/AICHE National Heat Transfer Conference, Orlando, Florida, July 1980. A topical report, "The Development and Heat Transfer Analysis of Direct Coal-Fired MHD Combustors," was also prepared and reviewed.

A test plan for the ECF was prepared to define the experiments necessary to study the performance of MHD combustors with constant mass flow rate but with varying combustor pressure, and with different L/D ratios. One test run was made and the data are being analyzed.

7.2 MHD Power Generator

Data reduction and analysis for TP40 continued during the first quarter. Also, program development in several areas of advanced analysis: 1) comparison of results of recently acquired programs (Argonne, Stanford, etc.) with results from programs in use at UTSI, 2) development of a slag model and incorporation into a two-dimensional MHD program, and 3) improvement of the quasi-one-dimensional code in use.

In the third Quarter, an extensive report of data analysis of segmented electrode current distribution tests was presented. The Energy Conversion Facility test series TP40A was concluded. TP40A included:

- 1 Testing of new power take-off schemes
- 2 Materials evaluation
- 3 Evaluation of heat transfer characteristics of capped and uncapped electrodes
- 4 Evaluation of generator performance at various N/O ratios.

Changes to the flow-train included:

- 1 A new oxidizer disperser plate
- 2 Replacement of Module 5, which had platinum clad copper anode caps on stainless steel frames, with a module having copper cap on copper frames
- 3 Reconfiguring the load dump device to operate also at the 16 ohm level.

Data analysis was performed during the third Quarter, and a final report is scheduled for completion during early FY81.

In connection with electrode system development a testing program concept was under development which would enable the investigation of electrode frame currents and surface conditions with a view to development of electrode control methods.

During the first three quarters of the year, advanced analysis work continued in the area of code development for generator performance prediction and design. One-dimensional codes were modified and evaluated, two-dimensional codes were in use (and a modification to include slagging was under development), and three-dimensional solutions were being prepared. Generator end effects were being investigated analytically, and an unsteady flow code was implemented and was being evaluated during the last Quarter of the year.

7.3 Downstream Components

During the year the first phase of testing in Cell III was completed. The data were being evaluated and chemical laboratory analysis of the flyash and slag was being completed. These tests took longer than anticipated because of delays caused chiefly by failure of hardware components. During this testing, failures occurred in the simulated aerodynamic channel and one of the constant area spacers. Internal water leaks also occurred in the combustor, refractory probe, and water injection probe. A study was initiated to evaluate ways of improving equipment reliability.

A letter report of the results from chemical analysis of samples taken in the Phase I test series was written and will be distributed internally early FY81.

Effort was expended to monitor the testing of potential refractory materials for the radiant furnace utilizing ECF combustors.

7.4 Seed Regeneration

Economic analysis of the Tomlinson Tampella (TT) and Formate processes led to the preliminary conclusion that the TT process is the most economically viable method of seed regeneration for high sulfur coal-fired MHD plants.

In line with this conclusion UTSI, in conjunction with the J. E. Sirrine Co., has prepared a program for a seed regeneration pilot plant to be located at the DOE CFFF. Future work will include maintaining cognizance of research efforts devoted to seed regeneration by other organizations.

7.5 Pollution Control

This project was activated by beginning to gather and analyze data concerning the physical and chemical properties of MHD "dust" and operating characteristics of various particulate control devices. The initial effort was to determine the most promising state-of-the-art control device. The effort will then be directed to ascertain if agglomeration can supplement or replace this device.

During the year a study was made on the use of electrostatic precipitators, fabric filters, and various types of agglomerators for use in a coal-fired MHD system. A recommendation was made to utilize the electrostatic precipitator Babcock and Wilcox heat recovery/seed recovery (HRSR) contract for the CFFF and to test a slip stream fabric filter.

7.6 Materials

The activities of the Materials Group during FY 1980 devolved about the following priorities:

- 1 Assist in refractories selection, construction, and curing activities for the LMF radiant furnace and secondary combustor components and establish a test program for refractory materials in downstream components consistent with requirements in the LMF train and with previous work in other MHD test programs.
- 2 Obtain knowledge of electrode metal wear mechanisms to provide input on the test configuration for the LMF-2 generator.
- 3 Assist in the design of the air heater test module and superheater components and establish a test program for metals testing in the air heater module.
- 4 Perform bench scale experimentation in generator related areas such as generator sealing, thermal conductivity sealing for electrodes, and interelectrode insulators.

To accomplish these tasks, a materials test shelter was constructed and equipped with various mixers, ovens, and furnaces, Table I. Some items of new equipment were obtained including electrolytic polishing equipment for analysis of electrode metals after service. Additionally, several meetings were held with suppliers of metals, refractories, and other materials to obtain information for experimental, design, and construction activities.

TABLE I

Partial Listing of Equipment in Materials Shelter

<u>Item/Purpose</u>	<u>Source</u>
Hobart Mixer/insulator fabrication	Federal Surplus (FS)
Littleford Mixer/insulator fabrication	FS
Pereny Furnace (15KVA)/refractory testing	FS
Pereny Furnace (35KVA)/refractory testing	FS
Lindberg Furnace/brazing electrode caps	New

a. Electrode Metals

Microscopic evaluation was made of numerous electrode caps after generator service in TP40A. These examinations led to the following conclusions regarding electrode wear mechanisms:

- 1 Copper anode caps appear to wear by electrochemical corrosion processes which seem to be accelerated by arcing phenomena which disrupt the local oxide layer on the electrode surface. A rough correlation was established between current carried and electrode cap weight loss. The slag layer does not appear to corrode copper oxide on the electrode surface at a sufficient rate to account for the majority of the copper loss. Therefore, the electrochemical phenomena control the overall rate of anode recession.
- 2 Platinum-clad anode caps wear at a much slower rate than copper caps with platinum loss primarily by abrasive wear. In the latter stage of the wear process, the cladding can be penetrated by abrasive scars resulting in accelerated material loss. These phenomena suggest that alloying elements such as iridium which impart greater hardness to the platinum would result in extended cladding life. Experiments with iridium cladding have been inconclusive due to fabrication difficulties.

With the increased understanding of electrode wear processes, a special test series entitled TP40B, "Electrode Metals Durability," will be held in early December 80. This test plan includes testing of stainless and alloy steel clad copper electrode caps to be tested in relation to copper and platinum clad "standards" in the ECF generator facility. Electrode cladding metals included in this test plan are given as follows:

446 SST	ASTM-A-268
EB 26-1	ASTM-A-268
310 SST	ASTM-A-312
309 SST	ASTM-A-312
Inconel 601	ASME-SB-167
Hastelloy X	SAE-5536G
Platinum	

Should problems develop testing should resume during the second Quarter of FY81. Results from this test will be used for selection of cladding metals for the LMF-2 generator in the CFFF.

Experiments were conducted during the year with materials and techniques for generator gas sealing and for interelectrode insulation. In TP40A, interelectrode insulation was successfully obtained using both single sheet or pieced hot pressed boron nitride (BN) plates or by using a composite insulator consisting of a silica fabric (Irish Refrasil) coated with a BN paste (Carborundum's BN Types). Sealing experiments included the incorporation of silicone base elastomer compounds in the interelectrode insulator composite composition as well as using the elastomer as a "cold face" external seal. Other experiments have employed epoxies and other materials as external sealants. Additional development work is planned during 1981.

Bench scale tests were conducted during the year to determine the effectiveness of various thermal conductivity sealing materials to be used between electrode caps and electrode frames to insure optimum heat transfer. It was found that a family of materials/techniques gave the best conduction results including:

- 1 Silver inks
- 2 Silver filled epoxy
- 3 Copper filled adhesive
- 4 Copper microspheres in glycerine vehicle
- 5 Cap-to-frame braze with silver alloy.

b. Refractories

Refractory specimens were subjected to microscopic examination after their testing in various upstream or near upstream locations in the various ECF test trains. The results of these investigations are summarized as follows:

- 1 Silicon carbide castable refractory currently used in the ECF combustor assembly wears by solution of the calcium aluminate binder phase in the coal slag coating. Silicon carbide brick exhibits lower wear rates with relatively slow corrosive attack by oxidation mechanisms. Plans to perform additional experiments to quantify these observations are now being made.

2 Chrome-alumina plastic refractory has performed quite well in all tests to date. Microscopic studies have shown that extremely low melting potassium alumina-silicates (feldsparic phases) are not formed as long as the Al_2O_3 content of the refractory is sufficiently high. For this reason, the chrome-alumina plastic was chosen for the CFFF primary furnace (designed for a thin-wall refractory configuration).

3 Chrome ore base materials, i.e. chrome castables, exhibit acceptable performance in downstream locations in regions where the surface temperature is relatively low, i.e. $< 1860\text{K}$. This material was chosen for the secondary furnace and secondary combustor components in the LMF train.

c. Downstream Metals Corrosion

Metals corrosion probes were installed in the ECF Cell III flow train during 1980 in order to obtain corrosion results simulating superheater and boiler conditions. In relatively short duration testing (< 4 hours total exposure), the probes were coated with deposits with very high contents of potassium overlaying corrosion products at the probe metal surface. Initial results of this program are as follows:

1 Corrosive attack on superheater probe specimens seemed to proceed by attack by potassium iron trisulfates. Corrosion resistance appears to be related to chromium content of the alloy with 310 SST (25% Cr) exhibiting the best corrosion resistance of the materials tested.

2 Corrosive attack on the boiler probe specimens appeared to proceed by hydrogen sulfide attack.

Longer duration tests using corrosion probes are planned in the CFFF.

7.7 Diagnostics

Since it is desirable to measure absolute plasma temperatures, a system was assembled and tested to perform this function. The system employs the modified line-reversal method to measure the absolute plasma temperature. The basic plan of this method was to measure both the plasma emission and absorption simultaneously to calculate plasma temperature. The line-reversal system was applied to the measurement of plasma temperatures in recent TP41 test series in Cell III. The initial tests were used to debug the system and to measure the plasma emission spectrum. The major spectrum peaks corresponded to K emission (765 nm) and Na emission (589 nm). Several lesser intensity K peaks (405 nm, 579 nm, and 691 nm) and one small Na peak (554 nm) were also observed in the plasma spectrum as well as a possible singly-ionized K peak (624 nm). During the later tests of this series, after debugging was completed, the system indicated plasma temperatures in the range of ~ 2620 to 2750K for normal test conditions, which appeared reasonable. Correlation among luminosity probes, the line reversal system and the oxygen flow rate indicated that the line-reversal system was operating properly.

In the second Quarter additional broadband data were recorded in both test series TP-41 and TP-40A. Only limited data analysis, to resolve dynamic interactions, was accomplished due to the limited results obtained with the existing analog analysis techniques. During the TP-41 test series, where the line-reversal temperature measurement system was used, several spectral scans were made of the plasma emission. These scans, made with a Beckman DU spectrometer showed the atomic emission peaks of potassium and sodium at the wrong wavelengths. Faulty spectrometer performance was hypothesized as the cause of this problem. However, after moving the spectrometer to the diagnostic laboratory, scans of the emission from a sodium lamp showed the emission lines at the proper wavelengths. Further examination of the spectrometer showed that the entrance and exit slits were not closing as indicated, and also showed that the mirror position locking mechanisms were not functioning thus allowing the emission spectrum to shift from the indicated wavelengths with vibration or movement of the spectrometer. These problems were corrected and the plasma emission spectrum was scanned successfully.

Progress continued on development of a laser velocimeter system being built in conjunction with combustor development. Development of the optics system was completed, and the laser velocimeter processor electronics were partially assembled. A Mie scattering computer code was developed to define expected laser velocimeter signal quality and to evaluate the possibilities of using the laser velocimeter at different locations in the MHD flow train. The laser velocimeter is being built to simplify modifications into a visibility particle sizing velocimeter, but a visibility system is not being incorporated at this time pending further evaluation of the visibility particle sizing concept.

The feasibility study of using random data analysis methods for diagnostic broadband analysis of open cycle MHD power generation produced several digital data analysis codes. These codes have been validated using broadband data recorded during TP40A testing in the Energy Conversion Facility. Additional codes and code refinements are being developed. These codes will be validated and further refined when better broadband data is recorded in upcoming Energy Conversion Facility tests.

Existing diagnostic systems have also been refined. During test series TP40A it was discovered that the luminosity system photomultiplier detectors were being affected by the high magnet field present in the MHD environment. This problem was corrected by providing improved shielding but future use of photomultipliers in higher magnetic fields is unfeasible. As a result, an improved photodiode detector has been selected for use in the CFFF luminosity measurements.

7.9 Process Control

During the second Quarter a model for a commercial scale MHD/steam plant was developed that is sufficiently accurate for studying control problems. The model was taken from a 1000 MW_e plant derived by the Systems Studies Group. The resultant plant yields about 400 MW_e from MHD and 600 MW_e from steam under optimum constant load conditions. The model itself

includes primary combustor, channel, diffuser, radiative-convective section, air preheaters, gasifier, high temperature air heater, seed recovery and regeneration components and steam bottoming cycle.

By assuming only small changes in input conditions for the plant, a linearized incremental model is used to determine how the plant responds to changes in load demand. By using only proportional, integral and derivative control (PID), the simulated plant settles to a new steady-state point within 50-100 seconds. The large time lags in the steam section are overcome by the relatively fast response of the MHD section and results in a good transient response with no auxiliary boiler present. The control is accomplished by monitoring the change in frequency and using it to control the fuel input to the overall plant.

In the third Quarter the model was used to design optimal control algorithms and a direct digital algorithm. In all cases the system settled down well within 50 seconds. The direct digital algorithm appeared the simplest to implement.

SECTION III CONCLUSIONS

Construction of the Coal-Fired Flow Facility was virtually completed this year. This included all test train components from the vitiation heater to the stack, except for the generator.

Baseline data were obtained for monitoring Woods Reservoir and Rollins Creek, a tributary. Study of a fish kill, Minytrema melanops, revealed that death was solely attributable to natural causes. Terrestrial monitoring plots were determined and foliage and soil samples taken. For air quality monitoring, sites were prepared for the installation and operation of two stations. No problems are anticipated in any phase of environmental monitoring.

Under the Technology Development Task, techniques were determined for making diagnostic measurements in hostile combustor environments. Such is to provide information on flow velocity, turbulent and transport phenomena etc., in the combustor flow. For the MHD power generator, work continued with significant expansion in basic capabilities code development for generator performance prediction and design. Seed regeneration study has led to the conclusion that the Tomlinson Tampella process is best for UTSI MHD application. Materials study showed that platinum-clad anode caps wear much more slowly than do copper caps, and that chrome-alumina plastic refractory performs well in the radiant furnace.

PUBLICATIONS

Articles and Papers

- Attig, R. C. et. al. "Air Pollution Control with a Coal-Fired Magnetohydrodynamic System," presented to the Second Conference on Air Quality Management in the Electric Power Industry, Austin, Texas, January 22-25.
- Chapman, J. N. and Hollis, J. R. "A Computer Based Model of the MHD Steam Power Plant," presented at the International Symposia on "Modelling, Policy, and Decision in Energy Systems" Conference, Montreal, Canada, May 28-30.
- Chapman, J. N., Strom, S. S., and Wu, Y. C. L. "MHD/Steam Electrical Power Production-Promise, Progress and Problems," ASME Potpourri Conference, San Francisco, CA, August.
- Joseph, R. D. "Frequency Characteristics of a System with Periodic Window," presented at Southeastern 80, Nashville, TN, April 13-16.
- Kulesa, P. R., et. al., "Development of a Steam Plant for a Coal-Fired MHD Power Plant," presented at the Seventh International Conference on MHD Electrical Power Generation, June.
- Martin, J. F., Muehlhauser, J. W., and Strom, S. S. "Description of the DOE MHD Coal-Fired Flow Facility (CFFF)," presented at the AIAA 15th Intersociety Energy Conversion Engineering Conference, New York, April 29.
- Roy, G. D. "Heat Transfer as a Diagnostic Tool in the Development of Direct Coal-Fired MHD Combustors," presented at ASME/AIChE National Heat Transfer Conference, Orlando, FL, July.
- Scott, M. H. et. al. "Recent Experimental Results from Tests of the UTSI Coal-Fired MHD Generator," presented at 7th International Conference on MHD Electrical Power Generation, MIT, Cambridge, MA, June.
- Smith, G. D. et. al. "Experimental Investigation of Reactive Turbulent Recirculating Jet Mixing in a Dump Combustor Flowfield," presented at 17th JANNAF Combustion Meeting, NASA Langley Research Center, Hampton, VA, September 22-26.
- Strom, S. S. "Material Design Requirements for MHD," DOE Newsletter Materials & Components in Fossil Energy Applications, No. 27, April 1.

Quarterly/Annual Reports

The following Quarterly Technical Progress Reports were issued:

- 1) October-December, 1979, FE-10815-46
- 2) January-March, 1980, FE-10815-47
- 3) April-June, 1980, FE-10815-50
- 4) July-September, 1980, FE-10815-54

(Also, monthly Project Status Reports were submitted during 1980.)

Contract Deliverable Milestone Log Reports*

- 1) Coal-Fired Flow Facility Acceptance Plan, CDML-10757-1B, distributed September 18, 1980.
- 2) Overall Test Plan for the Low Mass Flow Test Train at the CFFF, CDML-10815-4A, distributed September 23, 1980.
- 3) Operations Plan, CDML-10815-3A, distributed September 14, 1980.
- 4) Spill Prevention Control & Countermeasure Plan, AI-10815-2.

Letter Reports

- 1) G. D. Roy, "Heat Transfer Studies Cell III Tests, A Preliminary Summary of Typical Results," December, 1979.

Quarterly Travel Plans

- 1) QTP-ET-10815-2, January-March 1980, issued January 17, 1980.
- 2) QTP-ET-10815-3, April-June 1980, issued April 10, 1980.
- 3) QTP-ET-10815-4, July-September 1980, issued June 6, 1980.

* Only those issued in final approved form (though subject to revisions) are listed.

Topical Report Status

A. Reports Completed (distributed) in 1980

- 1) Evaluation of a Coriolis Mass Flow Meter, FE-10815-45, distributed August 18, 1980.
- 2) Interelectrode Insulator Development for the UTSI MHD Generator, FE-10815-44, distributed August 18, 1980.
- 3) Investigation of Minytrema Melanops Mortality in Woods Reservoir Near the CFFF, FE-10815-49, distributed September 19, 1980.

B. Reports Approved by DOE for Distribution*

- 1) An Investigation of Swirling Flow Mixing for Application in an MHD Pulverized Coal Combustor Using Isothermal Modeling (INTERIM REPORT), FE-10815-39, approved August 28, 1980.

C. Reports in Production Cycle

- 1) Pendleton, J. D., "Light Scattering Calculations for Evaluation of the Particle Sizing Techniques of Laser Interferometry."
- 2) Roy, G. D. and Attig, R. C., "The Development and Heat Transfer Analysis of Direct Coal-Fired MHD Combustors."
- 3) Schulz, R. J., Ghosh, A and Attig, R. C., "Cold Flow Modeling of Pulverized Coal Combustors for Magnetohydrodynamic Channel Applications."
- 4) Schulz, R. J., Lee, J. J. and Attig, R. C., "Mathematical Modeling and Predictions of Flow in Pulverized Coal Combustors for MHD Applications."
- 5) Tyle, N. "Control of a Commercial Scale MHD/Steam Power Plant," (Thesis).
- 6) Winkleman, B. C., "Application of a Modified Line Reversal Temperature Measurement System to Coal-Fired MHD Plasmas."
- 7) Wang, H. H., "A Study of Seed Recovery and Particulate Emissions Control of the Coal-Fired Open Cycle Magnetohydrodynamic Steam Power Plant (CFFF)."

* All of these will be distributed in January 1981.