315
5-28-81
jue

(2)

LB. 2691

MASTER

DOE/ET/10815-50

MHD COAL-FIRED FLOW FACILITY

Quarterly Technical Progress Report for the Period April-June 1980

By

M. C. Altstatt
R. C. Attig
W. E. Baucum
D. A. Brosnan
J. N. Chapman
T. A. Click
J. A. Cooper
L. W. Crawford
J. B. Dicks
T. E. Dowdy
K. D. Drescher
J. W. Frazier
F. L. Galanga

T. V. Giel
J. H. Hansen
R. L. Harlan
J. H. Hicks
W. L. Holt
R. D. Joseph
P. R. Kulesza
J. H. Lanier
W. C. Long
J. F. Martin
G. H. Masapati
G. E. Materi

W. T. McMinn
J. W. Muehlhauser
S. Owens
J. P. Rhudy
G. D. Roy
R. J. Schulz
M. H. Scott
S. P. Sharma
G. D. Smith
S. S. Strom
H. H. Wang
Y. C. L. Wu

Bind-224
NTIS-25
SP-3

July 31, 1980
Date Submitted

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

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

U. S. DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A03
Microfiche A01

MHD COAL-FIRED FLOW FACILITY
QUARTERLY TECHNICAL
PROGRESS REPORT

APRIL — JUNE 1980

Prepared by:

M. C. Altstatt	F. L. Galanga	G. E. Materi
R. C. Attig	T. V. Giel	W. T. McMinn
W. E. Baucum	J. H. Hansen	J. W. Muehlhauser
D. A. Brosnan	R. L. Harlan	S. Owens
J. N. Chapman	J. H. Hicks	J. P. Rhudy
T. A. Click	W. L. Holt	G. D. Roy
J. A. Cooper	R. D. Joseph	R. J. Schulz
L. W. Crawford	P. R. Kulesza	M. H. Scott
J. B. Dicks	J. H. Lanier	S. P. Sharma
T. E. Dowdy	W. C. Long	G. D. Smith
K. D. Drescher	J. F. Martin	S. S. Strom
J. W. Frazier	G. H. Masapati	H. H. Wang
		Y. C. L. Wu

The University of Tennessee Space Institute
Energy Conversion Division
Tullahoma, Tennessee 37388

Date Submitted - July 31, 1980

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Under Contract No. DE-AC02-79ET10815
Under Contract No. EX-76-C-01-1760
(Task 1 Only)

ABSTRACT

In this second Quarterly report of 1980 submitted under DOE contracts EX-76-C-01-1760 (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), formerly the Research and Development Laboratory.

CFFF Bid Package construction is now virtually complete. The remaining construction effort is being conducted by UTSI. On the quench system, another Task 1 effort, the cyclone was erected on schedule.

On Tasks 2 through 6, vitiation heater and nozzle fabrication were completed, an investigation of a fish kill (in no way attributable to CFFF operations) in Woods Reservoir was conducted, major preparation for ambient air quality monitoring was made, a broadband data acquisition system for enabling broadband data to be correlated with all general performance data was selected, a Coriolis effect coal flow meter was installed at the CFFF.

On Task 7, an analytical model of the coal flow combustor configuration was prepared; MHD generator testing which, in part, involved continued materials evaluation and the heat transfer characteristics of capped and uncapped electrodes was conducted, agglomerator utilization was studied, and development of a laser velocimeter system was nearly completed.

CONTENTS

Abstract	ii

Sections

I. OBJECTIVE AND SCOPE OF WORK	1
II. SUMMARY OF TECHNICAL PROGRESS	4
A. <u>TASK 1 - COMPLETION OF DESIGN AND CONSTRUCTION OF THE CFFF AND FACILITY ACTIVATION</u>	4
1.1 Design and Construction	4
B. <u>TASK 2 - DESIGN AND FABRICATION OF THE 8PPS TOTAL GAS FLOW HIGH SLAG THROUGHPUT TEST EQUIPMENT</u>	6
2.1 Primary Combustor	6
2.2 MHD Generator	7
2.3 Downstream Components	7
C. <u>TASK 3 - BASE OPERATIONS FOR THE CFFF AND EC FACILITY</u>	9
D. <u>TASK 4 - 8PPS HIGH SLAG THROUGHPUT TESTING</u>	13
E. <u>TASK 5 - TESTING OF DOE SUPPLIED COMPONENTS</u>	15
F. <u>TASK 6 - MODIFICATIONS TO THE CFFF</u>	15
G. <u>TASK 7 - TECHNOLOGY DEVELOPMENT PROGRAM</u>	16
7.1 Primary Combustor	16
7.2 MHD Power Generator	17
7.3 Downstream Components	22
7.4 Seed Regeneration	23
7.5 Pollution Control	23
7.6 Materials	23
7.7 Diagnostics	33
7.9 Process Control	36

IV. Conclusions	37
References	38
Topical Report Status	39

FIGURES

1. Checkout of CFFF Control Room Monitoring Equipment	4
2. Aerial View of CFFF	5
3. Vitiation Heater	6
4. Radiant Furnace Installation	8
5. Spores of <u>Myxsoma sp.</u> from Gills of <u>Minytrema melanops</u>	11
6. Gas Chromatograph-Mass Spectrometer	14
7. Temperature Profiles in the Cathode Cross-Section	17
8. Temperature Profile in 45 Degree Electrode	18
9. Comparison of Experimental Heat Flux with the DESIGN 3 Prediction. .	20
10. TP40B, Cap 7, Platinum Clad Anode	24
11. Typical Anode Cap Surface, Module 1	25
12. Typical Oxide Scale on Anode Surface	26
13. Cross Section of Slag Layer on Anode Surface	28
14. Arc Track on Anode Surface with Layers of CuO/Cu ₂ O	28
15. Particle Abrasion on Anode Surface	29
16. Arc Bore on Anode Surface	30
17. Leading Edge of Platinum Clad Anode Cap	30
18. Surface Abrasion on Platinum Clad Anode Cap	31
19. Plasma Temperature Plot for Test TP40A-16	34
20. Plasma Emission Spectrum Taken During TP40A-17 Test	35

TABLES

I. ITAH Tube Materials	8

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-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 ECF and the 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 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 results 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

The final two construction bid packages were completed this Quarter. The Control Room, Test Buildings and Support Systems and Shelters were accepted by the University. However, interior activity is in progress. For example, see Figure 1 which shows monitoring equipment checkout in progress. Bid Package completion is now virtually 100 percent. However, there are other construction type efforts which are proceeding in order to get the CFFF operational before the end of calendar year 1980. The sample preparation and the inverter shelters are on order and should be completed

Figure 1. Checkout of CFFF Control Room Monitoring Equipment

Figure 2. Aerial View of CFFF

in the next Quarter. The holding ponds design is almost completed and procurement should be completed in the next Quarter. An aerial photograph showing the current, nearly completed status of the CFFF is shown by Figure 2.

On the quench system, installation work continued with the concrete pad 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 next Quarter. Work was begun on the primary quench but the drawing package was not complete at the end of this Quarter.

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

2.1 Primary Combustor

Fabrication of the vitiation heater was completed during this quarter and the unit was delivered in June (see Figure 3). An inspection to determine the progress of fabrication on the combustor was made with quality assurance (QA) personnel at the vendor's shop in early June.

Figure 3. Vitiation Heater

Eighty-five percent of the parts were fabricated, and assembly of one of the cylindrical sections was started. Later in the month a QA representative witnessed ASME Code hydrotesting of the cooling tubes in that cylindrical section.

Instrumentation received during the Quarter included the ignitor, heat flux probes, and the combustor shell temperature detecting device.

Support stand drawings and cooling water header drawings were completed. In-house fabrication is continuing on the headers. In-house fabrication of the support stands will be initiated early next Quarter.

The oxidizer plate design was modified to incorporate a more versatile hole pattern by increasing the number of oxidizer holes and threading these holes so they can be plugged. This will enable us to vary the oxidizer flow pattern with little downtime. Difficulties in obtaining the copper for this plate were experienced because of the requirements for an ultrasonic test necessary to assure some degree of material integrity. This requirement has delayed delivery which will now be mid-July. Also,

it was determined that this plate could not be machined in-house because of the size. Thus, bids for the machining were obtained and a purchase order was awarded.

The coal disperser tube design was completed, and fabrication will be accomplished in-house. Fabrication is now 25 percent complete.

The gasket material and ceramic material for plasma spraying of the vitiation heater flanges for electrical isolation were specified. Instrumentation and cooling water schematics have also been completed.

Fabrication of the nozzle was completed during this Quarter. The nozzle was assembled at the fabricators, checked for compliance with the specifications by Quality Assurance, hydrostatically tested, and delivered to UTSI. During the next Quarter, assembly of the nozzle to the conductivity channel is anticipated.

Four modules of the diagnostics conductivity channel have been completed, test-assembled, hydrostatically tested, and delivered to UTSI. The remaining two modules will be delivered to UTSI within the first two or three weeks of the coming Quarter. The bid package for the conductivity channel assembly table has been released, and during the next Quarter the assembly table will be completed and the conductivity channel assembled.

2.2 MHD Generator

The bid package for the LMF Generator Channel was prepared during the last Quarter and let out for fabrication response. The resulting bids are now being considered. During the coming Quarter, pending DOE design approval, fabrication of the channel will begin.

The design resistive PTO for the LMF generator is still in the conceptual stage. However an improved technique involving 2-D electric field computation (Task 7.2.c, Advanced Analysis) is now being applied to the problem. Combining this with results from ECF testing will result in improved PTO design.

The diffuser is in fabrication. Sections will be delivered as each is completed.

2.3 Downstream Components

All of the radiant slagging furnace modules were installed in the steel support structure and all connecting welds completed. Work was initiated on installing the access doors, ports and thermocouple wells during the last third of the report period. The radiant furnace installed is shown in Figure 4.

The intermediate temperature air heater test section design has been delayed during this Quarter but will be available for initial LMF-1 testing. The component specification and the design report are

Figure 4. Radiant Furnace Installation

TABLE I
ITAH TUBE MATERIALS

<u>Alloy Steel</u>	<u>Cobalt-Base Alloys</u>
9 Cr-1 Mo	Haynes 188
	Haynes 25
<u>Stainless Steels (s.s.)</u>	<u>Alloy Cladding</u>
304	310 clad Croloy (Cr-Mo)
310	Inco clad 671/800H
316	
347	<u>Clamp-On Tube Shielding</u>
446	Inconel 671 on 316 s.s.
<u>Nickel-Base Alloys</u>	<u>Ceramic Coatings</u>
Inconel 601	Nickel-Aluminide plasma sprayed 316 s.s.
Hastelloy X	Chromic Oxide plasma sprayed 316 s.s.
<u>Iron/Nickel-Base Alloy</u>	Magnesium Aluminate plasma sprayed 316 s.s.
Incoloy 800	

essentially complete and will be sent to DOE during the next Quarter. Tube materials to be tested in the air heater are shown in Table I. Suppliers of these materials are currently being sought.

The ash/seed hopper was installed and all finish welding of the secondary combustor to the radiant furnace was completed. The entire secondary combustor unit installation is now complete except for installation and curing of the refractory, connecting the quench duct and air duct, and installing and calibrating instrumentation.

A paper "Development of a Steam Plant for a Coal-Fired MHD Power Plant" was presented at the Seventh International Conference on MHD Electrical Power Generation. This paper described the radiant furnace and secondary combustor design.

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

The microscope laboratory continued to provide materials analysis services using optical and scanning electron microscopy techniques. In addition, a Unitron metallograph was received during the reporting period, and it is now being installed in the microscope laboratory. This microscope is equipped with a high temperature, platinum-wound hot stage. Automatic polishing equipment has also been added.

Much time has been devoted to microscopy of electrode caps from Test Plan (TP) 40A after service to determine wear mechanisms. In related activities to this test plan, chrome plated sidewall caps were examined prior to service to verify the quality of the plating operation.

Refractories have been analyzed in support of combustor and downstream component development. Silicon carbide bricks from previous combustor trials are currently under examination. Various refractories from quantitative testing in Cell I of the ECF have been examined including chrome-alumina plastic, spinel castable, magnesia ram, and chrome base ram.

Major activities for the aquatic environmental monitoring program for this Quarter included:

- 1 Acquisition of equipment for field analyses.
- 2 Continuation of water analyses in Woods Reservoir.
- 3 Receipt of the final NPDES discharge permit for the CFFF issued by the Division of Water Quality Control.

4 Investigation of a fish kill in Woods Reservoir (not attributed to the CFFF).

5 Review of the literature relating to trace elements which may be significant pollutants from coal combustion.

The aquatic environmental program will be expanded to include field analyses with the arrival of the pontoon boat. The boat has been field tested and the vendor has made the necessary corrections. The boat will be equipped as an aquatic laboratory with field instruments for in-situ measurements of temperature, pH, conductivity and dissolved oxygen at depth intervals. Measurements of these parameters require field determination.

Water analysis of Woods Reservoir continued for the Quarter yielding expected seasonal results. Fluctuations in the values for potassium, sulfate, total solids iron and phosphate reported last Quarter have stabilized during this sampling period. Again occasional high values were reported for ammonia, but as indicated previously, this seems to be a stream condition. Water analyses for the reporting period are within expected results and depict similar trends for the same period of the previous year. Preparation of a topical report on a one-year baseline study of water quality in Woods Reservoir is underway.

An investigation was made of a fish kill which occurred in Woods Reservoir during the Quarter. A single species of fish Minytrema melanops (spotted suckers) was involved. Occasionally seasonal fish kills have occurred in Woods Reservoir during the past several years with minimal documentation of causative factors. During the early spring (April 1980) approximately one hundred fish of a single species Minytrema melanops (spotted sucker) died near the embayment of Rollins Creek. An investigation was conducted to determine the cause of death. Inasmuch as only a single species was involved it was assumed that the kill resulted from an infectious or parasitic disease rather than from 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 (see Figure 5) 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. A topical report on the fish mortality in Woods Reservoir will be forthcoming.

A study was made of the trace elements from coal combustion which may be environmentally hazardous. A preliminary list was compiled with emphasis on those trace elements which have been documented to have profound effects on aquatic ecosystems.

Activities within specific phases of the air pollution and solid waste environmental program included:

Figure 5. Spores of Myxsoma sp. from Gills of Minytrema melanops (Note Heavy Infestation)

- 1 Requesting air pollution operating permits for UTSI emission sources.
- 2 Initiating negotiations with Franklin County for CFFF solid waste disposal.
- 3 Pursuing certification credentials for the chemical laboratory.
- 4 Preparing for the air quality monitoring program.
- 5 Procuring a computer system to handle environmental data handling and modeling needs.

Three air pollution source operating permits for cells number 1 and 3 at the Energy Conversion Facility (ECF) and for the small oil-fired boiler at the CFFF were applied for through the Tennessee Air Pollution Control Division (TAPCD). Even though the actual permits have not yet been issued, present negotiations with the state indicate that, after agency review,

permits will be forthcoming. So far, the only restriction will be an operating time limitation for ECF cells 1 and 3. This is expected to be about ten hours per week, which should not be a problem. A report of the construction status of the CFFF was issued to TAPCD to keep the current air pollution source construction permit in effect.

Negotiations are underway with the Franklin County Board of Commissioners to use their landfill to dispose of ash and slag from the CFFF. This route looks promising, and a meeting with a committee of commissioners has been scheduled for July.

Major preparation for ambient air quality monitoring was accomplished during May and June. Included in the preparation was:

- 1 Securing station siting approval from AEDC.
- 2 Detailing locations compatible with air quality models.
- 3 Assuring electrical service to monitoring stations.
- 4 Interviewing air quality monitoring technologists who will operate the stations.
- 5 Aligning trace analyses of cations and anions on collected, particulate air pollution (coordinated with MERDI).

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 Cromemo Z2H system, the U.S. EPA's series of air quality models (including CRSTER), and some outside computer support, would be the best combination. The Cromemco System will be linked with UTSI's VAX-11 and also will be used for most environmental data handling needs.

Analysis performed in the CFFF Laboratory was as follows. Coal pulverized by the CFFF pulverizer has been analyzed and has met the requirement of coal being used in the test facility. Procedures and guidelines have been written for the analysis of boiler water in the CFFF. Analyses of coal and slag are being performed by summer students in the CFFF Laboratory. A new instrument has been ordered to perform thermal analysis and should arrive in a few weeks.

For the Quarter, a description of the progress on the terrestrial impact portion of the Environmental Monitoring program for the CFFF follows:

- 1 Several people have been interviewed for the position of environmental engineer-terrestrial systems.
- 2 A senior student from the Department of Forestry, Wildlife and Fisheries, UT-Knoxville, was hired for summer employment as a temporary research assistant to the terrestrial impact program.

3 A radial line has been 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 will be located along this radial line according to a plan designed to minimize pollutant concentration differences between plots within each impact area. A radial line has been run at a bearing of S5°W from the CFFF stack through the secondary impact area. Eight plots measuring 20 x 25 meters each have been established.

4 A reconnaissance of the control area has been made prior to the establishment of plots in this area.

5 In consultation with Mr. Jay Cornish, MERDI, we have agreed that chemical analyses be run on plant tissue, soil, rain, rain drip, and overland flow waters for the following elements:

Anions - F, NO₄, SO₄, Cl, PO₄
Cations - Hg, K, Cd, Pb, As, Cr

6 A comprehensive literature search has begun.

Procedures are being written and tested in the CFFF Laboratory in the analysis of water and waste water. A new instrument (Atomic Absorption Spectrophotometer/Graphite Furnace) has been ordered to perform trace analysis on coal, slag, water, wastewater, etc., and should arrive in a few weeks.

The gas chromatograph-mass spectrometer (Figure 6) has been received, installed, and put into good working order. Laboratory equipment and supplies have been ordered and analytical methods are being written for the analyses of gases and polynuclear aromatic hydrocarbons.

In this Quarter Design Engineering moved to its new location in the Industrial Park. The microfilm equipment was installed, checked out, and is now operational. As-built drawings for the facility are progressing well and should be completed in the next Quarter. The oxidizer system was installed and checked out. Its lease agreement was initiated.

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

Work continued on the data analysis programs to be used when testing of the slagging furnace commences. Efforts were concentrated on developing the data acquisition hardware necessary to obtain the desired operating data. Instrument lists were delivered and cross checked against the existing data acquisition system.

Figure 6. Gas Chromatograph-Mass Spectrometer

A component test plan for the vitiation heater-combustor was completed, circulated for review, and revised to incorporate comments during this Quarter. The final draft is now being prepared for distribution to DOE.

The secondary combustor test plan was initiated, and it is expected to be distributed for comments at UTSI early in the next Quarter. These component test plans are general in nature. Thus more specific detail is being prepared to supplement these general plans. The details will include additional information on instrumentation and control requirements.

The component test plans for the nozzle, generator and diffuser were prepared during the past Quarter and are being reviewed internally. Instrumentation requirements are being coordinated with personnel in both the Design and Facilities Laboratory. Work in defining data acquisition and analysis requirements will accelerate during the coming Quarter.

In Diagnostics Support the following was achieved.

a. Analysis of Unsteady Phenomenon

A broadband data acquisition system has been selected with a tape search system to allow broadband data to be correlated with all general performance data obtained in the various CFFF tests. Also, equipment to digitize the broadband data has been specified so that digital stochastic time series data analysis and modelling techniques can be routinely

employed. Additional equipment required to avoid potential problems, such as data aliasing, is being examined.

The luminosity relative-temperature systems, as tested in the ECF, are being built for the 8 lb/sec CFFF testing. These systems include optical ports, purge systems, and photodiode detector circuitry.

A Coriolis effect coal flow meter has been installed at the CFFF. It will be calibrated as soon as possible. In addition, a volume fraction meter has been ordered from Auburn Instruments, Inc. It will be evaluated in the ECF for use in conjunction with the Coriolis meter, and will be installed in the CFFF if it proves to be satisfactory.

The objective of analysis of unsteady phenomena is the elimination or control of unsteady flow effects which can adversely affect generator performance. Work under this project is related to other work through adherence to the goal of maximizing generator output and lifetime.

b) Diagnostic Channel

The component test plan for the CFFF 8 lb/sec Hall conductivity channel is complete and is being reviewed internally. Instrumentation requirements contained in the test plan have been coordinated with CFFF instrument and controls personnel. Data acquisition and analysis requirements are being specified. Specified instrumentation includes all successful ECF instrumentation as well as some instruments which are still being tested, such as the AC conductivity monitor and the alumina insulated electrode thermocouples. Preparation of the detailed installation plan will be initiated in the coming Quarter.

E. TASK 5—TESTING OF DOE SUPPLIED COMPONENTS.

There is no activity to report.

F. TASK 6—MODIFICATIONS TO THE CFFF

There was no significant activity under this task. We are awaiting direction from DOE on facility modifications. In the interim it was decided to proceed with the preliminary design for the substation upgrade and the air compressor system.

G. TASK 7-TECHNOLOGY DEVELOPMENT PROGRAM

7.1 Primary Combustor

The water tunnel for flow visualization and flow field survey mapping of the combustor has been completed. The circuits for the water flow have been installed. A system for filtering the water supply has been obtained and installed, along with appropriate drainage and re-filling ports.

The laser velocimeter, the data acquisition microprocessor, and the laser test bed are complete in design and 75 percent complete in assembly. Some necessary components have been back-ordered.

An analytical model of the cold flow combustor configuration has been prepared. This model will be used to make predictions of the cold flow model aerodynamics which will be compared to the experimental data. A bid for computational consulting services from commercial firms has been prepared and released. From the successful bidder, we expect to obtain calculations of our reactive combustor system. If the quality of these calculations appears satisfactory, ECD may then purchase a copy of the computer codes for use by ECD engineers. Finally, work has begun on the long range goal of developing a code or math-model of the complete UTSI MHD duct flow system, from combustor inlet to the diffuser outlet.

Work on the multiport coal injector combustor has not progressed beyond ordering supplies necessary for cold flow testing of model configurations. An engineer was hired (who reported June 2, 1980) to supervise this project, but, as yet, the project remains behind schedule. This engineer has also begun reviewing potential analytical techniques for improving our capability to evaluate combustor performance. We will continue this effort, reviewing advanced insitu methods for measuring combustion temperature, gas species concentration flow velocities, and coal and slag particle behavior. Over the next few months, we plan to review other investigators' experience with advanced techniques, hold discussions with selected investigators, evaluate our needs and select the approach or approaches required at UTSI.

Numerical analysis was carried out, with various gap thermal conductivities, in an attempt to match measured temperatures. A layer of insulator was added adjacent to the electrode in the modified model. Figure 7 shows the calculated isotherms and measured temperatures in the cathode. Similar computation was done for the anode.

The numerical analysis was extended to the CFFF channel electrode where the electrodes have an inclination of 45° to the channel axis. Figure 8 shows the isotherm plotted for a heat flux value of 328 watts/cm^2 .

Figure 7. Temperature Profiles in the Cathode Cross-Section.
(Gap Conductivity = 0.346 watts/m°C, Conductivity of Copper Frame and Cap = 363 watt/m°C, and Avg. Heat Flux = 161 watts/cm²)

7.2 MHD Power Generator

The wind tunnel for diffuser research is slightly behind schedule for two major reasons. First, the air supply system has taken longer to fabricate than expected because of system safety requirements. Second, the diffuser model has been expanded to include a model of the downstream radiant boiler section. This will permit a study to be conducted of the interaction of the aerodynamics of the diffuser and the radiant boiler. Flow profiles in both components will be studied.

Extensive work was done on electrode temperature distribution to improve our prediction capabilities and to respond to the action items in the Generator Design Review. Thermocouple installation in the test electrode was completed and temperatures at these locations were measured during several runs.

MHD generator research reported herein covers several areas. First, progress in continued generator test series (TP40A) is reported. Secondly, plans for further local current/voltage distribution experiments are described. Finally, progress in analytical modeling of the MHD system is discussed.

Figure 8. Temperature Profile in 45 Degree Electrode
(Heat Flux = 328 watts/cm² and k_{gap} = 0.346 watts/m °C)

a. Continuing MHD Generator Testing

During this Quarter the TP40A test series was concluded. A total of seven tests were conducted. The objectives were as follows:

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

The following changes to the flow train were made:

- 1 A new oxidizer disperser plate was installed immediately downstream of the vitiation heater.
- 2 Module 5, which contained platinum clad copper anode caps on stainless steel electrode frames, was replaced with a copper-on-copper module.
- 3 The load dump device was boosted to a 16 ohm level.

The two power take-off (PTO) schemes employed diodes and ballast resistors in series with the current collecting electrodes and in parallel with the primary load.

The first of these schemes was designed to distribute the current evenly among the current collecting electrodes. An analysis by Pan and Doss¹ at Argonne National Laboratory was used as a basis for sizing the individual electrode resistors. Preliminary analysis indicates that, although the flow conditions did not reach the design point to achieve an equal current distribution, off-design performance was as predicted.

The second of these schemes employed (during the last test) equal resistors in the PTO regions. Upstream resistors were fixed at one value (5.25 ohms) while the downstream resistors were set at 1.0 ohm. Analysis of this data has just begun.

Interesting results were obtained with respect to the heat flux measurements made on the capped and uncapped electrodes. From the data presented in Figure 9, it is evident that there is a marked decrease in the heat flux to capped electrodes (~30%) resulting from higher electrode temperatures. The solid line represents the UTSI quasi-one dimensional computer code prediction based on an empirical model² for solid electrode frames. Historically the model has been able to predict the heat flux to solid electrode frames, as is also indicated in Figure 9. An analysis has been undertaken to account for the lowered heat flux to the capped electrodes. The influence of the thermal contact resistance at the cap-frame interface will be studied in an effort to account for the elevated electrode surface temperature.

Figure 9. Comparison of Experimental Heat Flux with the DESIGN 3 Prediction

During the next Quarter, a thorough analysis of all data obtained during the test series will be accomplished and reported on.

b. Electrode/Coolant Isolation

Experiments conducted earlier in the ECF initiated more detailed examination of local generator behavior by electrically isolating segments of the electrode surfaces from the main frame structure, thereby permitting current measurements. This work as reported last Quarter is being continued through an improved electrode design whose implementation was initiated during this Quarter. The importance of the work stems from the fact that it is necessary to understand more of the basic physics involved to provide quantitative data in order to design MHD generators for maximum lifetime and performance.

Current and voltage nonuniformity occurring in MHD generators degrades the performance of these devices and may lead to shortening of the electrodes' life and complete failure of the generator. Since these non-uniformities may grow in time, if unchecked, long-time operation of a commercial MHD generator requires understanding and control of these

processes. Three electrodes have been designed each having eight segments insulated from each other. Current flowing through each segment and inter-segment voltages will be monitored.

Design for supporting instrumentation for these tests has begun. These include high frequency (~ 100 kHz) current and voltage sensor systems, an acoustic pressure probe and a slag resistance metering system.

Since the core flow and conditions in the boundary and slag layers do affect the nonuniformities, experiments with various slag carry-over conditions will be considered in order to understand the phenomenon.

Other work during the Quarter focused on the complex nature of the collisional phenomenon in MHD generator plasmas. Any sudden change in basic plasma properties (e.g., ρ , u , e) may initiate a wave of a certain frequency (traveling or standing), which may grow (or damp) in the spatial or temporal domains.

A test plan was begun for measuring the fluctuations in plasma properties following a simulated sudden change in pressure (or other relevant properties). Plasma diagnostics and related data will be recorded and the spectrum analyzed.

c. Advanced Analysis

The generator program is supported by the development of methods for analysis and prediction of MHD generator flow train performance and testing of these methods against experimental data. This development consists of the adaptation of applicable computer codes developed elsewhere and original analysis and programming at this facility. These analytic methods are necessary for the design of larger generator flow trains and the scaling of MHD effects. Both long-term studies and modification of programs for immediate use are being conducted.

The first steps in producing a three-dimensional fluid and electrodynamic code have been initiated. A numerical method of solution applicable to the turbulent Navier-Stokes equations which can take advantage of the capabilities of a new vector processing machine has been chosen. Development of solution algorithms is in progress.

For immediate needs, the one-dimensional MHD generator program versions in use here are being improved and extended. A boundary layer model is being included in one version of the program to improve modeling and scaling of wall effects. This version is now being tested against other generator solutions and will then be used for analysis of experimental generator performance. The modification of the program described in NASA SP273 used for thermochemical input to this and other generator programs has been updated to include recently published chemical equilibrium data.

Other approaches are also being used to illuminate various aspects of MHD generator behavior. Work has been initiated on a cross-plane solution for a DCW generator to determine the potential distribution in the presence of a slag layer; the numerical solution is being programmed and will be coupled with a longitudinal generator solution in the next Quarter.

A two-dimensional electrodynamic model is being used to study the effects of resistance distribution in loading the R&D generator. The results of this analysis will be applied to loading the CFFF LMF generator. Also, this method will be expanded to a three dimensional electrical study (without gasdynamic interaction) of current distribution in the DCW generator.

One-dimensional electrodynamics for infinite segmentation has been added to a two-dimensional Navier-Stokes solution developed at Los Alamos Scientific Laboratory, and initial-coupled solutions have been obtained. After the addition of an appropriate turbulence model and additional electrochemical correlations, this program will be used for analysis of experimental results.

A program has been developed with two-dimensional fluid and electrodynamic representations and finite segmentation. With the addition of a slag model and diagonal electrode pattern, this program will be useful in examining the current flow in sections of the generator--particularly the current to the electrodes.

Utility programs are being developed for analysis and display of test data. These programs will be used to examine experimental results and provide data packages for analytic comparisons.

As indicated, work in all the areas discussed will be continued in the next Quarter.

d. Diffuser Development

The use of cold-flow modelling is planned to support diffuser development as well as combustor development, as discussed in an earlier section. Work on constructing the facility to support these studies is progressing satisfactorily.

During the past Quarter, the test shelter and the air and water flow test rigs were completed. The water tank support pad was poured and the water tank, with necessary strengthening, was installed. Hook-up of the air supply will be accomplished during the first week of the coming Quarter, and test runs will begin in the second week.

7.3 Downstream Components

The chemical analysis of the samples taken in the Phase I test series has been completed. The final review of the data from these tests is presently being made. An informal letter report of these findings should be circulated next Quarter for comments and additional information. This sub-task is presently under review for schedule changes. The present schedule is behind due to manpower shifts and delays in the present testing in the Energy Conversion Facility, but no impact is expected on the CFFF schedule.

Testing of several possible materials for use in the radiant furnace has continued. Results are reported separately in the materials development section.

Next Quarter materials testing will continue. Also, plans will be made for FY-81 activities.

7.4 Seed Regeneration

Researchers at UTSI have concluded that the modified Tampella process is the most viable means of regenerating spent potassium seed from MHD power plants utilizing high sulfur coal. 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 in seed regeneration (until comments are received from DOE concerning our program) will include maintaining cognizance of research efforts devoted to seed regeneration by other organizations.

7.5 Pollution Control

During this Quarter internal memorandums have been prepared on the use of electrostatic precipitators, fabric filters, and various types of agglomerators for use in a coal-fired MHD system. Literature reviews have been completed on each of these topics.

A significant quantity of information is available to design an electrostatic precipitator or a fabric filter. Extrapolation of this information to the MHD system is possible. However, accurate information on the particulate properties, especially size distribution and electrical resistivity, is not available. This will introduce significant uncertainties into the design of these facilities.

Much less information has been found on the design of an agglomerator. It appears, however, that it will not be feasible to use an agglomerator based on the design of any of the several types reviewed (i.e., acoustic, radiation, etc.) except to augment a fabric filter or electrostatic precipitator.

During the next Quarter, a topical report will be issued on the design of each of the three particulate removal systems for a coal-fired MHD power plant and specifically for the CFFF.

7.6 Materials

During the current reporting period, there has been great emphasis on studying electrode performance. Electrode wear has been monitored during TP40A, and specimens have been selected after various tests for further study including metallographic examination. An increased understanding of the wear mechanisms of copper electrodes has been gained and tests on other materials are strongly suggested in the upcoming generator experiments.

Other experiments are in progress relative to electrodes. Tests of materials to provide improved cap to frame gap thermal conductivity have been initiated. Equipment for larger scale brazing of noble or other corrosion resistant metals to electrode caps for the 8PPS generator have been recommended. A special fixture for uniformly producing boron nitride-refrasil insulator composites has been fabricated.

Metal corrosion probe specimens exposed to simulated downstream corrosive environments in Cell III of the EC Facility are now being prepared for metallographic examination. An interim topical report describing the phenomenological results of ash/seed deposition and surface corrosion on test coupons has been prepared. Tests on refractory specimens have continued during the reporting period.

a. Electrode Wear Phenomena

The generator channel is made of 72 electrode frames in eight (8) modules. Modules I and V are modified to capped design as shown in Figure 7. The caps offer a means for material evaluation and serve as replaceable electrodes.

Anode electrode caps were removed from Module I after test TP40A-12. These caps were subjected to approximately three hours cumulative testing under generator operation. Caps 2-6 were electrolytic tough pitch (ETP) (110) copper whereas cap 7 was clad with 0.010" Pt brazed with Cu-Au alloy over ETP copper. Cap 1 was alumina dispersed copper, "Glidcop.®" There was excessive copper loss on electrodes 1-6, whereas the Pt-clad electrode had only leading edge abrasion which was most likely exaggerated by immediate upstream electrode recession, see Figure 10. The high rate of corrosion probably resulted from the combination of high electrode temperatures (see Figure 9 of lowered heat flux) and high sulfur content (slightly over 1% sulfur by weight in total flow). The high projected temperatures for the UTSI caps result from the reduced thermal conduction at the gap between the cap and frame. While it is accepted that copper is unsuitable as an anode material for long term operation, experiments such as these are needed to study the basic corrosion processes and the effects of sulfur content.

Examination of caps using optical and SEM microscopy revealed the phenomena discussed in the following paragraphs.

Figure 10. TP40B, Cap 7, Platinum Clad Anode

The typical copper anode cap surface exhibits a fairly flat leading edge which seems much less affected by corrosion processes than the downstream portion of the same cap. This "unaffected" region is shown in Figure 11 and extends about 100 μ behind the leading edge. This "unaffected" region is a succession of "peaks and valleys" which become progressively deeper as progression is made away from the leading edge.

Figure 11. Typical Anode Cap Surface, Module 1

The leading edge shows particle abrasion damage. Further downstream in the areas of "peaks and valleys," the surface patterns suggest an aerodynamic influence or other influences on material recession rates. Other influences on this uneven material loss might include arc path and arc instability factors behind the leading edge.

The typical surface appearance of copper anode caps is shown in Figure 12 where a scale of black colored material seems to be separating from the electrode substrate. Upon sectioning several anode caps, this surface scale is found to be discontinuous in some areas and continuous in others with thicknesses up to 100 μ (Figure 12). X-ray diffraction analysis conducted at the National Bureau of Standards on May 15, 1980, confirmed that one component of the scale was copper oxide, Cu_2O . The tendency of the oxide layer to form scale which flakes away from the copper base was demonstrated in a subsequent experiment where a copper plate was held in a laboratory furnace at 980°C briefly until a black surface oxide layer formed followed by air quenching. The oxide layer spalled off violently as the base metal cooled, reflecting the difference in thermal expansion coefficients between copper oxide and metallic copper. These observations

TP40A-12

A = Oxide
Layer

B = Copper
Cap
(Etched)

TP40A-12

Figure 12. Typical Oxide Scale on Anode Surface

indicate that repeated short term electrode exposure to plasma with frequent shutdowns is a contributor to accelerated electrode wear as the oxide layers are disrupted on cooling exposing bare copper for subsequent corrosion.

The formation of copper oxides on exposure of copper electrodes to MHD plasma/coal slag has been recognized for some years as "electrochemical corrosion," i.e., the migration of oxygen in the electromagnetic field to the anode with subsequent reaction with the base metal electrode. What is less well recognized is that a coherent oxide scale over a copper anode is a desirable feature because of the following:

- 1 It limits further copper consumption to a relatively slow diffusion controlled reaction. (This assumes the solution of copper oxide in the local slag is fairly slow, which is indicated in this work.)
- 2 It provides some means of the slag reacting with and thereby adhering to the exposed electrode surface.

If the formation of a continuous oxide layer is advantageous over a copper electrode, the disruption of this layer is a contributing factor to excessive electrode wear rates. Loss by thermal spalling leads to the "flaking" of oxide which is rapidly washed away by flowing slag. The chances of detecting these relatively large copper oxide flakes is small, and since there is insufficient time for them to dissolve in the slag, investigators in the past have been unable to identify copper in the slag in sufficient average concentration to account for those copper loss rates actually observed. All of these arguments indicate that copper anode recession is exaggerated by short duration test runs so that under long duration testing, anode recession rates might be much more acceptable.

The typical appearance of a slag layer over a copper anode cap is shown in Figure 13. The slag cross section exhibits bubbles or gas pockets indicating a rather high viscosity at the electrode/slag interface. The slag, as shown in Figure 13, lays over and is attached to small oxide crystals on the cap surface. Sulfur was detected by EDAX evenly distributed over the slag cross section.

An area containing a suspected arc track is shown in Figure 14. These tracks typically exhibit a gold coloration perhaps reflecting a "fire polishing," i.e., alloying or other effect due to the arc traverse. These tracks are of some significance in that they usually are found at areas of maximum electrode recession, i.e., "valleys." Adjacent to the arc tracks are red colored surface scales (probably Cu_2O) as detected by NBS and black surface scales (probably CuO). The Cu_2O seems to form immediately over the copper metal substrate with black CuO overlying the Cu_2O .

Particle abrasion is also frequently seen on copper anode cap surfaces. One such abrasion, shown in Figure 15 has a width of about 1.25 mm. Abrasive tracks may vary in width but usually are more or less parallel to the plasma flow. The abrasion typically shows "ribs" of random spacing.

TP40A-16

Figure 13. Cross Section of Slag Layer on Anode Surface

100X

TP40A-16

Figure 14. Arc Track on Anode Surface with Layers of $\text{CuO}/\text{Cu}_2\text{O}$

40X

TP40A-16

Figure 15. Particle Abrasion on Anode Surface

On an infrequent basis, arc tracks may be found which terminate with a shallow hole on the copper anode surface (See Figure 16). This might be called "arc bore." The hole might be typically about 0.5 mm in diameter and up to 2 mm deep. In some cases, these holes tend to fill with slag or salt-like deposits.

As has been indicated earlier, the electrode cap with 0.010" Pt brazed to ETP copper included in TP40A has exhibited leading edge abrasion. This leading edge, after approximately five hours exposure, is shown in Figure 17 where a very uneven edge is due to particle collisions with resulting deformation. Behind the leading edge, surface abrasions are also readily apparent (Figure 18). There is no indication of any local arc damage or melting phenomena. The ultimate life of this anode configuration is yet to be determined.

Cathodes examined after service in UTSI's 4PPS generator show only very slow recession rates. In general, they are coated with a continuous slag layer which appears to have been highly fluid at the operating temperature. Copper oxide layers have been observed on cathodes; however, the extent of oxide formation is very limited and base material loss through flaking and spalling of oxide is probably not significant.

Following recent work at AVCO, various low-Ni stainless steels will be included in upcoming generator test programs. It is anticipated that initial efforts will involve brazed steel sheet over oxygen free high conductivity (OFHC) copper electrode caps. The choice of oxygen free copper at this point is from brazing considerations. Further tests with Pt cladding are necessary to establish its lifetime under UTSI conditions.

40X

TP40A-16

Figure 16. Arc Bore on Anode Surface

40X

TP40A-16

Figure 17. Leading Edge of Platinum Clad Anode Cap

40X

TP40A-16

Figure 18. Surface Abrasion on Platinum Clad Anode Cap

b. Brazing Operations With Electrode Caps

Because of the increased importance of anode cladding to generator life, much attention has been devoted to improving and qualifying the brazing technique and cladding material. A recommendation has been made for a furnace/retort system to expand and increase the reliability of the hydrogen brazing process now in use. Provision for a vacuum cycle and inert gas purge as well as the capability for retrofitting ultrasonic assist is included.

The cladding material which has shown the greatest resistance to degradation to date is platinum. One iridium sample tested showed very low corrosive action but had greater material loss than platinum. This is believed to be related to iridium's higher vapor pressure and lower oxidation resistance compared to platinum. The sample tested also suffered considerable microcracking due to cold working done in sample preparation. Plans call for the testing of a hot worked platinum/20% iridium alloy in an attempt to utilize platinum's workability and oxidation resistance along with iridium's corrosion and abrasion resistance.

c. Improved Cap-to-Frame Gap Conductivity Material

Increased emphasis on the role of lower electrode cap operating temperatures in increasing the lifetimes of materials has led to investigations aimed at rating thermally conducting compounds to be used to assure good electrode cap/electrode frame heat transfer. These materials

include thermally conducting epoxys, pastes, cements, adhesives, heat sink compounds, and copper based high temperature anti-sieze compounds. Samples of these materials have been recently obtained, and experiments are planned in the near future to rate the effectiveness of each compared to the current copper-glycerin gap filler material.

d. Metals Corrosion Experiments for Downstream Application

Analysis of deposits and surface scales obtained from corrosion probe experiments designed to simulate boiler and superheater tube environments has been delayed this Quarter due to a leave-of-absence taken by the project engineer. This problem, however, has been alleviated and extensive analysis of corrosion probe coupons and deposits will be undertaken in the next Quarter.

Due to the fact that there are no current plans to continue testing in Cell III in the EC facility, the decision has been made to section the corrosion coupons and begin metallographic analysis and scale characterization in order to better determine the prevailing corrosion mechanisms in the two environments. In addition to these activities, a materials list for corrosion coupon testing in the downstream sections of the CFFF is being drawn up and these tests will be further outlined in the next Quarter.

e. Refractories Test Program

Aremco's Ultra-Bond 552 has been found to be successful at effecting a high temperature gas seal between the copper oxidizer disperser plate and the coal injector feed line in the R&D vitiation heater. This seal was given a surface coating of Alchrome-85 for added protection but it was found upon later examination to be unnecessary.

An unsuccessful attempt has been made to increase the strength, thermal shock resistance and thermal conductivity of the SiC castable material (Carbofrax 1111) used in the coal combustor by an addition of ~15 wt % 446 stainless steel fibers 0.75" long and approximately 0.020" diameter supplied by Ribtec Corporation. A recommendation has been obtained from the manufacturer of Carbofrax 1111 for an optimum cure cycle for this refractory, which is installed in the CFFF 8PPS combustor. This recommendation is being reviewed internally.

Four refractories (Green Crete Arc, Ruby Plastic, X-3337E, and HW10-61) located in the exhaust duct of the EC facility are continuing testing for lifetime and investigation of long time degradation mechanisms. Visual observations indicate that the major loss mechanism to be surface spalling. The spinel composition X-3337E and the magnesia HW10-61 show the least penetration by slag but the lowest spall resistance. Green Crete Arc is extensively penetrated but shows good strength and appears to have become stabilized to further penetration. The Ruby Plastic has a thin (~3 mm) reaction layer with little further penetration evident.

7.7 Diagnostics

a. Dynamic Interactions

A feasibility study of employing a digital stochastic time series modelling technique has been initiated. Broadband data were recorded during several of the TP40A tests to provide an initial data set for this feasibility study. If these techniques provide satisfactory results they will be employed for routine examination of the broadband data. Furthermore, digital correlation and frequency domain data reduction techniques, to be developed in the initial phase of the feasibility study, will be subsequently used for routine data reduction of all ECF and CFFF broadband data.

b. Advanced Techniques

Development of a laser velocimeter system to measure the velocity field at various locations in the flow train is nearly complete. A Mie scattering computer code has been developed to define expected laser velocimeter signal quality and to evaluate the possibilities of using laser velocimeter visibility particle sizing techniques. Other laser based diagnostic techniques have also been examined. Specifications are being prepared for developing a holography system for particle sizing, particle dispersion, and fluid density variation studies. A laser scattering/transmission system as used at MIT is also being considered.

Progress continued in developing non-laser based diagnostics, too. The AC plasma conductivity instruments/channel interface has been designed and built. The instrument is being installed for checkout during the final TP40A tests and the upcoming combustor isolation tests. If the interface and instrument function properly, comparison tests will be initiated using the Hall channel conductivity measurements as the data base. A specification has been established for a coal-flow volume fraction meter to compliment the Coriolis effect coal mass flow meter in measuring actual coal supplied to the combustor. Finally, the emission spectra acquisition program has been completed and emission spectra have been obtained using this program in recent TP40A tests. Specifications have been established for a quality spectrometer to be used for these emission measurements as well as for line reversal and possibly for laser-induced fluorescence, spontaneous Raman, on CARS diagnostics.

c. Temperature Sensors

During this Quarter, work has been done to support testing in the Energy Conversion Facility using both luminosity and spectrometric measurement equipment. For the initial TP40A tests, luminosity was measured using photomultiplier detectors until it was discovered that they could not be properly shielded against the high magnetic field present during testing. Photodiode detectors of improved design were substituted for the photomultipliers. The improvements were in the area of better insulation between the photodiode case and the nozzle plate due to the use of black Derim material for the photodiode holders and in the area of better mechanical attachment between photodiode holder and optical probe so that the holder can be removed from the optical probe without removing the photodiode from its holder.

A typical example of the relative temperature profiles obtained during the TP40A-16 test is shown in Figure 19. The upper left hand plot shows temperature profiles obtained from probes P2-P5 located in a vertical line at the center of the nozzle plate at five different times (T1-T5) during the test. The upper right hand plot shows the variation of temperature with time for the four probes. The bottom plot is a three-dimensional representation of the data shown in the upper two plots.

Figure 19. Plasma Temperature Plot for Test TP40A-16

The spectrometric data was obtained using a Beckman DU spectrometer. Plasma emission radiation was received through a standard optical probe (such as is used for the luminosity probes with the optical filter removed) and transmitted via optical fiber to the spectrometer. As was indicated in the previous quarterly report, the entrance and exit slits of this spectrometer were found to be operating improperly and an attempt was made during this Quarter to repair them; this attempt was partially successful but better improvement was obtained by substituting slits from another surplus spectrometer of the same type. Although the spectrometer wavelength calibration still changes slightly during the test, due to vibration, a method has been applied which allows the in-situ calibration of the spectrometer during the test using a standard Hg lamp source. To accomplish this, a bifurcated optical fiber bundle was used to mix light

from both the plasma and the Hg lamp at the spectrometer input. This permits continuous calibration of the spectrometer during the test.

A typical plasma spectrum obtained during TP40A-17 test is shown in Figure 20. The atomic species giving rise to each peak is marked above the peak except for the one at 671 nm which has not yet been identified. It can be noted that the high background continuum radiation is probably due to the presence of high concentration of slag particles in the plasma and that the main K line at ~ 768 nm suffers a self-reversal effect at its peak due to the high absorption of K in the cooler boundary layer.

The spectrometer is now automatically controlled by the Data General Computer which also acquires the spectrometer data and is capable of analyzing the data both during and after the test.

Figure 20. Plasma Emission Spectrum Taken During TP40A-17 Test

7.9 Process Control

During the Quarter the incremental model for a 1000 MW_e MHD/steam plant was used to design optimal control algorithms and a direct digital algorithm which forces the system to respond to a load demand in a fixed number of sampling intervals.

In all cases classical PID control, optimal control, and direct digital (deadbeat performance)-the system settles down well within 50 seconds. The direct digital algorithm seems to be the simplest to implement but must be chosen carefully in order that the maximum input fuel rate is not exceeded during the transient period. If the sampling rate is too high the fuel rate goes to extreme values in an attempt to force the plant to a new steady-state value within the required number of sampling intervals.

During the next Quarter the various control techniques will be compared. It is expected that a topical report will be prepared discussing the various algorithms and a suggested "best" algorithm will be proposed.

SECTION IV CONCLUSIONS

The construction contractor is finished with all major construction on the CFFF. The remaining construction is the installation of instrumentation and controls, test hardware and the Quench System, all of which are being installed in-house by UTSI.

Under Tasks 2 through 6, the vitiation heater arrived on site, the primary combustor is nearing completion, and QA checks have been performed at the manufacturer's plant. The nozzle is completed and the diagnostic channel electrodes have been completed and trial fitted. The MHD generator final design review was conducted and efforts are underway to resolve the action items resulting therefrom. An air pollution monitoring program was initiated with efforts concentrated on getting site preparation and power for the monitoring stations which were transferred to UTSI from MERDI. Water sampling and analysis of Woods Reservoir continued to establish the baseline conditions. During the period a fish kill was investigated and found to be due to natural causes.

Under Task 7, generator tests continued with emphasis on electrode wear, power take-off schemes, and heat transfer, particularly to the capped electrodes. Results show the resistive power take-off system performs satisfactorily for test conditions. The platinum clad electrodes exhibit the longest lives as expected. It was concluded that it was not feasible to use an agglomerator instead of a bag house or electrostatic precipitator; however, it may be used in combination with either.

REFERENCES

1. Pan, Y-C., and Doss, E. D., "Power Take-Off Analysis for Diagonally Connected MHD Channels," AIAA-80-0253, AIAA 18th Aerospace Sciences Meeting, Pasadena, California, January 14-16, 1980.
2. Wu, Y. C. L., Dicks, J. B., Crawford, L. W., Muehlhauser, J. W., Scott, M. A., and Sood, N., "Theoretical and Experimental Studies of Magneto-hydrodynamic Power Generation with Char," 12th Symposium on the Engineering Aspects of Magnetohydrodynamics, Argonne National Laboratory, Argonne, Illinois, p. II.1.1., March 27-29, 1972.

TOPICAL REPORTS PROJECTED FOR NEXT QUARTER

1. Experimental Results of the UTSI MHD Generator Test Series TP40A.
2. Light Scattering Calculations for Interferometric Particle Sizing Diagnostics Using the Laser Doppler Velocimeter.
3. Downstream Component Corrosion in Coal-Fired MHD Power Plants.
4. Comparison of Particulate Control Devices for Coal-Fired MHD.