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MHD COAL-FIRED FLOW FACILITY

Quarterly Technical Progress Report for Period January-March 1980

May 30, 1980
Date Submitted

Work Performed Under Contract No. AC02-79ET10815

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

U. S. DEPARTMENT OF ENERGY

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MHD COAL-FIRED FLOW FACILITY
QUARTERLY TECHNICAL
PROGRESS REPORT

JANUARY - MARCH 1980

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Date Submitted - May 30, 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)

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ABSTRACT

In this first 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 Research and Development Laboratory.

Although slowed by incessant rain during several days, work on the CFFF Bid Packages progressed to nearly 100 percent completion, excluding later punchlist items. On the quench system, the cyclone separator was delivered to UTSI, and under Downstream Components, the secondary combustor was received and the radiant slagging furnace was emplaced at the CFFF.

Water quality analysis of Woods Reservoir provided the expected, favorable results, quite similar to last year's. Generator experiments describing local current distribution are reported along with behavior under conditions of imposed leakage. Also, during the Quarter, the shelter for the cold flow modeling facility was constructed and circuits installation begun. A jet turbine combustor was tested for use as a vitiation burner. Samples taken from the exhaust duct, besides other applications, show that the refractories used are performing well in alleviating heat loss while exhibiting acceptable degradation. Last, a new resistive power take-off network was designed and implemented in testing conducted during the Quarter.

CONTENTS

Abstract	11
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>	5
2.1 Primary Combustor	5
2.2 MHD Generator	7
2.3 Downstream Components	8
C. <u>TASK 3 - BASE OPERATIONS FOR THE CFFF AND R&D FACILITY.</u>	16
D. <u>TASK 4 - 8PPS HIGH SLAG THROUGHPUT TESTING</u>	17
E. <u>TASK 5 - TESTING OF DOE SUPPLIED COMPONENTS</u>	17
F. <u>TASK 6 - MODIFICATIONS TO THE CFFF</u>	17
G. <u>TASK 7 - TECHNOLOGY DEVELOPMENT PROGRAM</u>	17
7.1 Primary Combustor	17
7.2 MHD Power Generator	21
7.3 Downstream Components	39
7.4 Seed Regeneration	40
7.5 Pollution Control	40
7.6 Materials	40
7.7 Diagnostics	46
7.8 Generator Loading	50

7.9 Process Control	50
IV. Conclusions	52
References	53
Topical Report Status	54

FIGURES

1. Completed Cryogenic Piping System	4
2. Cyclone Separator	6
3. Drum Module	9
4. Conceptual Design for Special Refractory Test Support	13
5. Secondary Combustor	15
6. Effect of Slag Build-up on System Heat Transfer	19
7. Flow Train Schematic	23
8. Typical Electrode Frame	24
9. Cap Detail	24
10. Typical Capped Electrode Schematic and Current Instrumentation . .	25
11. Pressure, Heat Flux and Voltage Distribution for Test 7, TP40, Data Block 3470	26
12. Experimental Frame Current and Differential Voltage During Test TP40-06	28
13. Frame Currents for Electrodes, Frames 41, 42, and 43 During Test TP39-03	30
14. Frame Currents for Electrodes, Frames 41 and 42 During Test TP40-07	32
15. Average Differential Voltage Versus Average Frame Current	33
16. Voltage-Current Characteristic Between Electrodes 41 and 42 . . .	34
17. Currents on Electrode Frames 41 and 42 with Variable Resistor Between Frames, TP40-07	35
18. Frame Currents for Electrode Frames 41 and 42 Using a Voltage Source Between Frames During Test TP40-08	37
19. Reducing Probe Area Weight Change Versus Time	41
20. Oxidizing Probe Area Weight Change Versus Time	42

21.	Photomicrograph of Corrosive Pitting of Carbon Steel Simulated Boiler Tube, 62.5X	43
22.	Photomicrograph of Surface Scale, Chopped Away at Lower Edge on Carbon Steel Simulated Superheater Tube	44
23.	Photomicrograph of Discontinuous Surface Scale on Type 310 Stainless Steel Simulated Superheater Tube, 62.5X	44
24.	Coal Combustor Refractory Repair - Cell III, TP-40A	48
25.	Exhaust Duct Refractory Test - Cell III, TP-40A	48

TABLES

I.	Recommended Refractories for Initial Installation in the Radiant Furnace/Secondary Combustor	10
II.	Description of the Assembly of Module Channel TP-40-A	45
III.	List of Refractories & Locations	47

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

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

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

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

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

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

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

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

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

4. Task 5 - Testing of DOE Supplied Components

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

5. Task 6 - Modifications to the CFFF

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

6. Task 7 - Technology Development Program

Develop quantitative performance data pertinent to basic thermal, electrical and 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 Control Room and Test Buildings (Bid Package 2) in this project have been turned over to the University. Only the final details for project closeout remain to be completed. For the Coal Processing Area (Bid Package 3), project closeout was completed in this Quarter. This was also true for the oxidizer system, as installation of the cryogenic system was complete with initial checkout scheduled for April. Figure 1 shows the system in its completed state.

Figure 1. Completed Cryogenic Piping System

For the Support Systems and Shelters (Bid Package 5), all the piping was satisfactorily hydrostatically tested. Cooling water pumps were activated and checked out. Fire protection pumps were activated and checked out. Makeup cooling water system was activated and checked out. The fuel oil system was activated and checked out. The foundation for the Inverter Shelter was completed. Design work is continuing prior to placing orders for the remaining installation.

On the quench system the cyclone separator was completed and delivered to UTSI (see Figure 2). Concrete work was behind schedule due to the excessive rainfall occurring during the reporting period. As a result, we were prevented from installing the cyclone. 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. Next Quarter, the installation of the equipment will continue.

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

2.1 Primary Combustor

The vitiation heater purchase order was awarded early in this Quarter after review of the bids and the quality assurance inspection report of the vendors' facilities and capabilities. The combustor bids were opened in January and only one quotation was received, even though more than 25 ASME Code approved fabrication shops had been contacted earlier to determine interest in fabricating a combustor. It was decided that awarding the contract to the only bidder would be the best approach, considering the time available and the effort which went into selecting potential vendors. Furthermore, the vendor is competent and has done other work for UTSI.

Instrumentation specified for the vitiation heater and combustor included a flame detector, heat flux probes, ignitor and a combustor shell temperature monitoring device. A purchase order was written for all instrumentation noted except for the flame detector, which has already been procured.

Support stand designs and cooling water manifolds for both the vitiation heater and combustor were started and the concepts for the oxidizer plate and coal disperser tube were submitted to UTSI Design Engineering for detail design.

Investigation of electrical isolation of the coal tube was initiated. Tests were conducted to measure the potential across a dielectric union and a mixture of packed coal and potassium carbonate, using a 5,000 volt source.

Figure 2. Cyclone Separator

These results are being evaluated to assess the need for additional testing. Tests are presently being prepared to investigate isolation at the vitiation heater and combustor flange interface, by plasma spraying ceramic coatings on the flanges. These tests will be conducted in the next Quarter.

Meetings were initiated during this Quarter to monitor, identify and resolve potential problems related to the status of the upstream components and their related interfacing facility equipment in the CFFF.

Responses were also prepared to questions raised at the vitiation heater and combustor design review.

A test of a gas turbine combustor used as a burner for the vitiation heater was conducted in the R&D Laboratory. Final evaluation of the test is not yet available but preliminary results indicate good exit temperature and temperature distributions. Inspection of the unit after the test showed no coking. The results of the test were encouraging. Additional tests are required at higher chamber operating pressures and oil flows after a higher pressure oil pump has been obtained.

Design of the nozzle for the 8 pps flow train has been completed. The bid package for the downstream plates of the nozzle has been released and the contract has been assigned. The throat plate will be fabricated by UTSI. Fabrication is projected to be completed on schedule. Activity for the next Quarter includes fabrication of the throat plate and preparation of assembly and installation plans.

Fabrication of the diagnostic conductivity channel is on schedule. The first two modules, made at UTSI, have been completed and tested. The remaining modules are in fabrication at Electric Materials Company, North-East, Pennsylvania. Plans for assembly and installation of the channel are complete. The design concept of the support stand is complete, and detailing for UTSI fabrication is in process. The conductivity channel and supporting equipment are projected to be completed on schedule. Final design and fabrication of the support stand, and continuation of module fabrication will occupy the next Quarter.

2.2 MHD Generator

A resistive power take-off (PTO) scheme was designed and scheduled for testing at the R&D facility. The outcome of testing may indicate revisions needed or will affirm the suitability of this configuration for the LMF generator uncontrolled PTO.

Design of a hardware simulator of an MHD channel was completed and the required parts ordered. At present this will be a steady state device, but methods of adding the characteristic noise to electrode outputs is being investigated. This simulator is to be used in investigations of filter system, PTO's and inverters in the bench scale model set-ups.

An extensive effort was made to break the 2.2 tasks down into the particular sub-tasks and investigations required. Next Quarter the design resistive PTO for the LMF generator should be completed. Initial investigation of controllable PTO schemes will begin.

Design of the CFFF generator is nearing completion. Computer-drawing of the electrode frames is 75 percent complete, and final-stage manual detailing and checking of the drawings is under way. The bid package will be released in April, and fabrication can be completed on schedule. Plans for assembly and installation are presently in draft form. Next Quarter's activities include completion of design and contracting for fabrication of the generator, and design and fabrication of the support stand. At the present time, design completion and bid request for the generator are scheduled for April 15, 1980.

The CFFF diffuser design was completed, the bid package released, and the contract assigned for diffuser fabrication during the past Quarter. Fabrication is projected to be completed on schedule. Activity for the next Quarter will include work by the fabricator on the diffuser, and preparation of installation plans, including detailed plans for welding of refractory support studs and application and curing of the refractory material.

2.3 Downstream Components

Fabrication of the radiant slagging furnace modules continued with all major units including the drum module being delivered to UTSI (Figure 3). The units were found to have excessive leakage due to improper welding at several of the stiffener pins. The vendor sent a representative to witness UTSI hydrostatic testing of the modules. UTSI Facilities' personnel will correct the leaks.

Refractory blends and qualities were specified for the various modules of the furnace based on the following criteria; materials were chosen:

- 1 That had the best combination of chemical and physical properties which are existing commercial products available on a tonnage scale.
- 2 That were based on our prior qualitative test experience at UTSI.
- 3 That were based on their performance in the few analogous industrial operations to our components.

The types of refractories chosen are given on Table I. The quantities are only approximate and will be verified prior to establishing a bill of materials. However, it must be noted that there will be trimming, slop, and rebound losses during application.

Chrome-alumina phosphate bonded materials were chosen for the primary furnace based on their slag resistance and high temperature strength properties. The traditional silicate bonded chromite materials such as "plastic chrome ore" tend to deform rapidly above 1865°K (2900°F) with consequent accelerated slag erosion. Therefore, the more modern technology chrome-alumina materials offer a better chance of survival giving the required metal protection until a quasi-equilibrium layer of slag can be formed. The thickness of this lining will be approximately 5/8" with some selected areas extended to 1" thick to cushion the effect of thermal shock when the device is initially operated. The primary slag screen will be lined with the chrome-alumina material.

Figure 3. Drum Module

TABLE I

Recommended Refractories for Initial Installation in the Radiant Furnace/Secondary Combustor

<u>Location</u>	<u>Refractory Generic</u>	<u>Commercial Names</u>	<u>Density As Applied (PCF)</u>	<u>Approximate Quantity For Initial Installation</u>
Primary Furnace	Chrome-alumina ram (90% Al ₂ O ₃ Class-Phosphate Bonded)	Ruby Plastic (Harbison-Walker)* Jade Pak-88-P (A. P. Green)*	196 198	18 ft ³ , 2.0 tons (1)
Primary Slag Screen	Same as primary furnace	--	-	12 ft ³ , 1.5 tons (2)
Secondary Furnace (up to secondary slag screen)	Chrome Gunning Mix	Kromight Gun (B&W)* Greencrete ARC (A. P. Green)* Kromespray A (General)	200 172 -	40 ft ³ , 5.3 tons (3)
Secondary Slag Screen	Same as secondary furnace	--	-	2.5 ft ³ , 0.4 tons (4)
Drum Module	70 PCF Insulating Castable	Kaolite 2500LI (B&W) Kast-O-Lite 25 (A. P. Green) Litecast 75-28G (General)	68	75 ft ³ , 3.5 tons (5)
Secondary Combustor	Same as secondary furnace	--	-	10 ft ³ , 1.4 tons (6)

NOTES:

- (1) Calculated at 1" initial rammed thickness trimmed to 5/8" (approximately) with an additional - 15% slop.
 (2) Calculated at 1" initial thickness on target baffle with 5/8" thickness on screen tubes and including - 25% slop.
 (3) Calculated at 25% rebound loss.
 (4) Calculated at 5/8" thickness on screen tubes and including 25% rebound and handling loss.
 (5) Calculated at 25% rebound loss.
 (6) Calculated at 25% rebound loss.
 (7) Recommended Accessory Installation Materials.

<u>Generic</u>	<u>Commercial Name</u>	<u>Quantity</u>
90% Alumina Morar/Mastic	Ruby Mastic (Harbison-Walker) No. 36 Refractory Cement (A. P. Green)	500 lb.
Chrome Mortar	Green Chrome Mortar (A. P. Green)	500 lb.

*The Materials Group has prior experience with these materials.

Industrial analogies for the use of chrome-alumina materials in this most severe area are limited. However, Dravo operates a pilot ore roaster with a tangentially fired slagging coal combustor with now successful use of chrome-alumina refractory. Inland Steel operates the only commercial Dravo device with similar results with regard to the refractories. This class of material has also been quite successful in foundry applications where acid slag resistance has been necessary. Laboratory or pilot plant scale testing has also been accomplished on this material at ANL, Fluidyne, and in coal gasification experiments.

The plastic chrome class of materials was determined to be adequate for the secondary furnace and secondary combustor. This material has excellent alkali resistance below 1865K (2900°F) and has been extensively used in boiler applications for years. A gunnited application was recommended for this material for convenience and more uniform application. The chromite gunnited composition is essentially similar to the plastic chrome which must be applied by ramming. The gunnited chromite will be extended upward to the position of the secondary slag screen. Lining thicknesses are 5/8" in all cases in these areas. Further, the secondary slag screen itself will be lined with the gunnited chromite material.

The drum module will be lined with 3" of 70 PCF alumina insulating castable applied over BW-737-1 310 S/S anchors on 3" staggered centers with alternating angles. This material will be applied by gunniting. This material will start "beyond" the secondary slag screen. Support ledges are based on its acceptable thermal conductivity and alkali/slag resistance as compared to board or ceramic fiber insulating refractory.

Discussions of the available UTSI manpower and the level of expertise required to successfully apply the specified refractory materials indicated that the services of a commercial refractory construction company will be necessary. The furnace structure and the refractory materials specified for installation were discussed with A. P. Green Construction (Birmingham), Rust Engineering (Birmingham), and Furnco (Pittsburgh). With an unshaped refractory (as opposed to brick products), the quality of the installation is at least as important as the refractory composition with respect to refractory life. This is particularly true with gunnited material. Therefore, the need for experienced application personnel is self evident.

Similarly, the proper curing of refractory may require the services of a commercial contractor. Such companies have portable burners which are brought to the job site with specially experienced personnel. The slag screens will not be installed until after the curing operation as these access ports are necessary for the burner and exhaust in curing. The slag screens will be cured in a temporary, refractory fiber lined furnace using the contractor's portable burners to allow closer temperature control as compared to in-situ curing in the radiant furnace.

A special test support will be designed for testing of either bricks or brick shapes of monolithic specimens in the access door of the primary furnace just above the primary slag screen. The rationale for this testing is 1) to line our materials test data to former and concurrent work at Argonne and other MHD test programs, 2) to extend the scope of our testing such that the "hot wall" versus "cold wall" concepts can be at least

qualitatively examined, and 3) to allow testing of new state-of-the-art refractories such as magnesia/carbon compositions which have never been included in tests in other MHD programs.

A conceptual design for this test support is shown in Figure 4a and 4b. The design incorporates a standard brick shape with a defined cold face temperature using a water cooling block somewhat analogous to the system in Argonne's slag testing furnace. The support allows testing of half thickness (4.5 x 6 x 3") or thinner bricks to allow investigation of the effect of the temperature gradient on the wear rate. Each whole brick could weigh up to 25 pounds so the structure must incorporate a ledge (probably water cooled) to support 200 pounds of brick. A retainer shelf will be included to hold brick columns in place yet allowing for thermal expansion of the brick.

The stud size, type and pattern were revised to more adequately support the refractory in the secondary combustor. Another change to the design involved the extension of the air bustle to provide increased flexibility in oxidizer injection schemes, as recommended by the Design Review Panel. These changes were incorporated into the unit before it was shipped by the manufacturer. The secondary combustor (see Figure 5) was delivered in February and inspected by Quality Assurance shortly after arrival. A few water leaks were detected and arrangements made with the fabricator to deduct the cost of repairing these leaks in the field. Heat flux probes, high temperature thermocouples and an orifice to measure air flow were ordered. After discussions with refractory manufacturers, a gunnited chromite was selected for the secondary combustor lining. Next Quarter the secondary combustor is to be installed and instrumented in the CFFF.

A paper entitled "Development of a Steam Plant for a Coal-Fired MHD Power Plant" describing the secondary combustor and the radiant furnace designs was prepared. This paper will be presented at the Seventh International Conference on MHD Electrical Power Generation in June.

The intermediate temperature air heater test section is currently under design. The component specification has been completed and the design report is nearing completion. These will be submitted to DOE in the near future for review. The proposed design consists of 2.29 m (7.5 feet) long duct flanged at each end to mate between the bypass outlet of the ash/seed hopper and the first quench system bellows. The initial part of the duct is of rectangular cross section with water cooled walls and an area of 2.04 m² (22 feet²) to contain the tubular air heater bank. The downstream portion of the duct is of single wall cylindrical pipe construction. This section will contain the heated air exhaust inlet and the flue gas quench nozzles. The tube bank will consist of 34 tubes, 25.4 mm (one inch) O.D. and 3.05 m (ten feet) long, in the form of single U-bends and flowing air in parallel. Seventeen types of tube materials are planned ranging from low alloy steels to nickel and cobalt base super-alloys.

Figure 4 a. Conceptual Design for Special Refractory Test Support

Figure 4 b. Conceptual Design for Special Refractory Test Support

Figure 5. Secondary Combustor

During the next Quarter, after obtaining design approval by DOE, the final design will be completed and sent out for bids. Also, the tube materials, some of which may be long lead-time items or required special processing, will be ordered.

C. TASK 3—BASE OPERATIONS FOR CFF & R&D FACILITY

The microscope and materials preparation laboratories for examination of metallic and ceramic specimens were operated during the Quarter in support of metals and ceramic testing programs. This was accomplished with either optical or scanning electron microscopy (with energy dispersive X-ray analysis).

During this Quarter much time was spent examining ceramic materials after tests in various locations from TP-40 or TP-40A. For the combustor, an experimental chrome-alumina plastic with silicon carbide was examined in addition to the commercial materials Kaotab 95 and Greencrete ARC. Materials examined after service in the vitiation heater included Kaotab 95, Ruby, and Narphos 90P.

Materials were installed in the exhaust duct of Cell III TP-40A to allow refractory investigations of longer duration exposure. The following specimens from this location are currently under study: Spinel X-3337E (Didier Taylor), Ruby, H-W 10-61, and Greencrete ARC.

Water quality analysis of Woods Reservoir during the first Quarter of 1980 yielded expected seasonal results and showed similar trends depicted during the same sampling period of the previous year.

During January and February the epilimnial content of the reservoir displayed characteristic seasonal trends. For example, there was a steady increase in the total alkalinity during the winter months with the bicarbonates at peak levels and carbonates essentially nil during this period. Occasionally the pH approached the lower limits of the standard; however, the monthly means were above the minimum for the sensitive biota during the sampling period. Again, this is an expected seasonal condition due to a decline in the removal of carbon dioxide during decreased photosynthesis in the winter (Brown 1971).¹

Analyses during March indicate that vernal mixing of the lake has begun. Values for the month were similar to these values for March, 1979 (Water Quality Analysis of Woods Reservoir 1979).² Again, there were large increases in the values of potassium, sulfate, solids, iron and phosphate during periods of heavy rainfall. Total solids reached a high during this period due to runoff from the rains. Consequently, there was a considerable amount of nonfilterable solids in the samples as indicated from the sharp differences in the values for conductivity and total solids.

Our data parallels that reported by Reid and Wood of seasonal pulses in sulfates. Sulfates reach a peak in spring followed by a decreasing content to a low in autumn (Reid and Wood 1976).³

Occasional high values were reported for ammonia during the Quarter, but the values are within the reported range and seem to be a stream condition (Storet 1973).⁴ Domestic discharge from UTSI and AEDC sanitary facilities are probably the main source of this condition.

Generally, water quality analyses for the reporting period are within expected results, showing seasonal trends and depicting results similar to those of the previous year. The water quality program conducted by the Chemistry and Environmental Laboratory was enacted to establish baseline conditions of stream quality for Rollins Creek. A topical report of baseline water quality conditions covering the period March 1, 1979 - February 29, 1980 should be released in the near future.

Microfilm equipment was specified and procured. Design Engineering is in the process of moving to a new building. The equipment will be installed after that move which is now scheduled for the end of April. Personnel have now been added to work on as-built drawings.

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

For the primary combustor and downstream components, input was provided to aid in preparing the overall system test plan. Next Quarter, we shall begin work on the more detailed component test plans.

Basic instrumentation requirements for the CFFF facility 8 pps system tests have been established and build up of some non-conventional sensors, particularly luminosity probes, has been initiated. In addition, specifications for a broad band data acquisition system are being finalized. Possible routine broad band data analysis techniques, such as digital stochastic time series modelling techniques, are being considered together with instrumentation requirements to employ such techniques.

Preparation of component test plans for the power train (nozzle, generator and diffuser) began as well as for the diagnostic conductivity channel. These plans will be submitted during 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 is no activity to report.

G. TASK 7—TECHNOLOGY DEVELOPMENT PROGRAM

7.1 Primary Combustor

The shelter for the cold flow modeling experiments has been constructed, and flow visualization and gas diagnostic flow circuits are

being installed. Models of the combustor and diffuser are being fabricated for installation and testing. The fabrication of the instrumentation system, which includes the laser velocimeter, is about 30 percent complete.

An existing disperser plate was modified to operate without ceramic inserts in the oxygen injector holes. A test performed with this plate provided results as good as the best previous test, using the same O_2/N_2 mixture ratios. In addition, a new injector or disperser plate was designed and fabricated for application and verification testing in the R&D Facility. This plate was designed to improve mixing performance over any past design.

Analytical modeling of the combustor, nozzle and diffuser is progressing along three lines. First, existing computer programs are being applied to make parametric calculations of the qualitative nature of the flows in these components. Second, we are requesting proposals from Computational Fluid Dynamics (CFD) Companies providing CFD codes that would apply to our system. From these proposals, we can select, if desired, the best commercially available analytical models of our system. Third, under the guidance of an experienced Professor of Mathematics at UTSI, we are initiating a long range goal of creating a three-dimensional Navier-Stokes solution procedure that incorporates the best features of the current, successful codes, but which is designed specially to account for the flows in the coal-fired flow facility and the full-scale, demonstration baseline plants yet to be built.

Several multiport coal injector combustor designs have been sketched. The most favored design at this time features central, clustered coal injector ports with annular rings of oxidizer injector ports. This design is closest to the existing single coal injector design. Further, because of this similarity, the design would require a minimum of cold flow testing. However, each multiport coal combustor design will require coal transport, distribution, and injection testing and development.

Based on the evaluation of heat flux probes in Cell III tests, and comparison with specially designed thermocouple probes, it was decided to use commercial probes for the CFFF system. Heat transfer instrumentation requirements for the LMF secondary combustor and ash/seed separator were prepared and purchase orders were placed.

The final manuscript of a paper "Heat Transfer as a Diagnostic Tool in the Development of Direct Coal-Fired MHD Combustors" was forwarded to DOE and ASME and approved for presentation at the 19th ASME AIChE Heat Transfer Conference in Orlando, Florida, July, 1980. Final mats were prepared and forwarded after approval.

The final draft of Topical Report "Development and Heat Transfer Analysis of Direct Coal-Fired MHD Combustors," FE-10815-46, was reviewed at UTSI and is being prepared for DOE review.

Evaluation of a heat balance of MHD systems with downstream components was continued and the effect of slag build-up on heat flux distribution and heat losses was evaluated for various runs. Figure 6 (a) shows the system components used in the study (Cell III). In Figure 6(b) a typical plot of cumulative heat loss as a percentage of the total heat input is shown.

Figure 6(a). System Components (Cell III) used in Heat Balance Study

Figure 6(b). Effect of Slag Build-Up on System Heat Transfer

The system components are shown along the x-axis, refer to Figure 6 (a) and the axial distances are not to scale. As expected, maximum heat transfer through the walls occurs initially. As the slag builds up on the upstream component walls, the thermal conductivity decreases, resulting in a decreased heat flux. The heat loss up to diffuser exit drops from about 48% to 35%. Since most of the slag is removed at the cyclone, there is limited effect on the heat transfer in the downstream components (Figure 6).

In the next Quarter, the instrumentation will be completed and models of existing UTSI combustors will be fabricated, installed and tested in the cold flow test site. Calculations of the flow patterns in these combustors will be made and compared to experimental data. With the modified analysis for electrode temperature distribution (finite element analysis), isothermals will be obtained for various metal-cap materials combination. Instrumentation of the caps and frames in a test electrode is expected to be completed and measurements will be compared with the analysis. Heat transfer instrumentation in the CFFF secondary combustor and ash/seed hopper are expected to be installed.

7.2 MHD Power Generator

MHD generator research reported herein covers three areas. First, the initial data analyses of current distribution measurements from tests conducted during the last Quarter of FY 79 are presented. Secondly, the status of the modeling effort in support of generator work is described. Finally, a description of the ongoing generator testing in the R&D facility is given.

a. Current Distribution Test Results

Recent generator experiments at the R&D facility were aimed at increasing the understanding of some of the more fundamental aspects of diagonal conducting wall (DCW) generator behavior in a high slagging power train. Since wear mechanisms, loading and control of the channel are a strong function of the current conduction mechanisms in the channel, it is important to develop an increased understanding in this area. Special electrodes were designed, fabricated and installed in an existing channel to allow determination of local behavior in the channel as a function of loading, leakage and overall channel conditions.

The series of experiments reported was conducted to meet the following objectives:

- 1 Determine the current distribution in electrodes (segmented in six sections) in the 60° DCW generator under slagging conditions.
- 2 Assess the effect of increased leakage on the current distribution by inserting an external resistance between the electrodes.
- 3 Examine the current distribution under augmented voltage conditions.

The experiments reported were conducted at the UTSI R&D facility, operating under the following nominal conditions.

Total mass flow:	3.5 to 4.0 lb/sec (1.6 to 1.8 kg/sec)
O ₂ equivalence:	0.85
Nitrogen/oxygen ratio:	0.0 to 0.3

The seeding compound (K₂CO₃) pre-mixed with the pulverized coal provides a potassium concentration of between 1% and 2% of the total flow. Nominal power production is approximately 40 to 45 kW for a nitrogen flow of 0.4 lb/sec and a load of 8 ohms.

The flow train configuration used for this testing is shown in Figure 7. As shown, a kerosene-fired vitiation heater is used to simulate preheated oxidant (temperature up to 1100°C) supplied to the coal combustor. Under nominal conditions the adiabatic temperature for the combustion is between 3100 and 3200°K. The combustion products are expanded through a nozzle to a supersonic velocity (1200 m/sec).

A typical frame is shown in Figure 8, while the cap detail is shown in Figure 9. To obtain current distribution data, five electrodes in the maximum Hall field region of the generator were segmented into six sections. Electrodes 40-44 were used for this purpose. Each electrode frame was fitted with a copper cap on the anode and cathode surfaces and two caps on each sidewalls which were electrically isolated from the electrode frame. The sidewall dimension was split equally between the anode and cathode sides. Instrumentation, in the form of a current shunt coupled with an isolation amplifier, monitored the total current flowing in each frame. The currents in each of the segments of three frames were also monitored as shown schematically in Figure 10.

Current distribution measurements were made at nominal operating conditions as well as for a range of external loading. Other measurements made during the test included standard plant operation parameters, and standard generator parameters. These include mass flow rates of fuels and oxidants, static pressure measurements, coolant temperatures for heat flux determination, component surface temperatures, absolute electrode voltages and current measurements in the power take-off region of the generator. All parameters were sampled at a 10 Hz or 1 Hz data rate (dependent on sensor bandwidth) by the data acquisition system. A small number of representative plant and generator parameters were also measured over a wide frequency band (to 5K Hertz) in order to study the dynamic effects in the system.

The generator was operated under nominal flow conditions. Representative test conditions, as listed below, were used as input conditions to the quasi-one-dimensional computer code for comparison.

$\dot{m}_T$	= 3.58 lb/sec (1.62 kg/sec)
O ₂ equivalence	= 0.9
N ₂ /O ₂	= 0.19
$\dot{m}_{\text{coal}}$	= 1.01 lb/sec (0.46 kg/sec)

The resulting axial pressure and heat flux in the channel are shown in Figure 11 along with the experimental measurements. The experimental

NOTES:

1. ALL WATER INLETS AND OUTLETS TO BE CONNECTED PARALLEL
2. ADD TAILPIPE EXTENSION

Figure 7. Flow Train Schematic

Side View

Front View

Figure 8. Typical Electrode Frame

Figure 9. Cap Detail

voltage distribution is also shown in Figure 11. This distribution was a part of the input to the computer code along with the load current. Through an iterative process, the experimental voltage is matched by determining the effective loss term, Δ , necessary to account for the experimental conditions. This voltage loss term, defined as $\Delta = V_d/uBd$, includes contributions from plasma non-uniformities, current leakage effects, shorting, sheath drop and emission losses. For the case shown, Δ varied from 0.32 to 0.4, dependent on channel location. The corresponding voltage drop ranged from 150 to 230 volts.

As discussed, the current distribution electrodes were installed in the maximum Hall field region of the channel. The approximate cross-

Figure 10. Typical Capped Electrode Schematic and Current Instrumentation

sectional area in this region is 2 inches x 10 inches (5.08 cm x 25.4 cm). The three phases of the current distribution experiments reported are as follows:

- 1 current distribution, external conditions unaltered,

A) VOLTAGE DISTRIBUTION TP 40 TEST 7

B) HEAT FLUX TP 40 TEST 7

C) TOTAL PRESSURE - PRESSURE TP 40 TEST 7

NOTE: THIS TITLING APPLIES TO A,B,C

○ EXPERIMENT DATA

— PREDICTION USING ENTRANCE
CONDITIONS AND VOLTAGES

Figure 11. Pressure, Heat Flux and
Voltage Distribution for Test 7, TP40,
Data Block 3470

2 current distribution for imposed external leakage,

3 current distribution for augmented voltage between electrodes.

For the first of these, five electrodes located in the maximum Hall voltage region of the channel were instrumented to give total current flowing in each of these frames. Two of these frames were also instrumented to give the current flowing in each of the six capped segments of each electrode frame.

The electrode frame current predicted by the quasi-one-dimensional code is shown in Figure 12a and 12b along with the typical measurements of a current over the range of conditions covered during the tests. Also shown in this figure are the measured voltage differentials between adjacent electrodes and the code predictions of these values for the same conditions. These measurements reflect not only the conditions of the plasma but also those imposed by surface effects and the inter-electrode impedance. The latter conditions are not adequately treated by the quasi-one-dimensional code. By a local averaging process (spatial), the individual measurements of both electrode current and voltage are brought into closer agreement to the predicted values. Values obtained by this averaging process are shown in Figure 12.

Typical current distributions obtained for two tests are illustrated in Figures 13 and 14a and 14b. In each case, positive current flow is plotted outward from the electrode cross-section. Following the test for which typical measurements are shown in Figure 15, the electrodes used for current distribution were disassembled, then reassembled for further testing. Experience gained from the first assembly produced a more reliable assembly the second time and a longer testing period was possible.

As seen in Figure 14, large sidewall currents flow in the anode portion of electrode 41. Further, unlike earlier tests,^{5,6} the cathode sidewalls carry significant current. The total current flowing in electrode 42, as seen here, was very low during the entire series of tests. Its value increased only when increased leakage was simulated by the addition of a series resistor between this electrode and its upstream neighbor.

The second phase of the current distribution experiment examined the effect of decreasing the effective resistance between electrodes by inserting a variable resistor between electrodes 41 and 42. The V/I characteristic obtained by varying the resistance is shown in Figure 16.

The total current in electrode 42 increased for the testing period during which the resistance was in the circuit, and an improved voltage distribution in the vicinity of these electrodes resulted. However, there was no improvement observed in the non-uniform current distribution in these electrodes. To the contrary, the absolute magnitude of negative current flowing in the anode cap region of the electrode 41 increased. Characteristic distributions are given in Figure 17.

The third phase of this experiment replaced the variable resistance with a voltage source. Electrodes 41 and 42 were again used. The

Figure 12a. Experimental Frame Current and Differential Voltage During Test TP40-06

Figure 12b. Experimental Frame Current and Differential Voltage
During Test TP39-03

N2 = .386 lb/sec

Power = 30.4 KW

O2 = 2.11 lb/sec

B Field = 1.9 T

Total Mass = ~3 lb/sec

Load Gen = 7 Ohm

Coal/Seed Flow = ~1 lb/sec

CURRENT ON ELECTRODE FRAMES 41, 42, AND 43

ARROW DENOTES DIRECTION OF POSITIVE CURRENT FLOW

Figure 13a. Frame Currents for Electrodes, Frames 41, 42, and 43 During Test
TP39-03 for Data Block 1500

N2 = .380 lb/sec
O2 = 2.11 lb/sec
Total Mass = ~3 lb/sec
Coal/Seed Flow = ~1 lb/sec

Power = 21.9 KW
B Field = 1.9 T
Load Gen = 4 Ohm

CURRENT ON ELECTRODE FRAMES 41, 42, AND 43

ARROW DENOTES DIRECTION OF POSITIVE CURRENT FLOW

Figure 13b. Frame Currents for Electrodes, Frames 41, 42, and 43 During ~~Test~~
TP39-03 for Data Block 1500

Figure 14. Frame Currents for Electrodes, Frames 41 and 42 During Test TP40-07

resultant alteration to the current distribution in these electrodes is illustrated in Figure 18. As the voltage increased, the frame current electrode 42 became negative. This reversal point was reached when the frame current of electrode 41 exceeded the maximum value ("short-circuit") condition shown in Figure 16. Correspondingly, current reversal occurred in the various caps of electrodes 42. Maximum voltage developed between frames was near sixty volts.

In summary, the experimental results reported show a strong influence of leakage effects on the local electrode behavior in the generator. In order to obtain more reasonable agreement between these results and performance predictions, leakage effects must be incorporated into

Figure 15. Average Differential Voltage Versus Average Frame Current

Figure 16. Voltage-Current Characteristic Between Electrodes 41 and 42

Figure 17. Currents on Electrode Frames 41 and 42 with Variable Resistor Between Frames, TP40-07

Figure 17. (Continued)

CURRENTS ON ELECTRODE FRAMES 41 AND 42 DATA BLOCK 3370

CURRENTS ON ELECTRODE FRAMES 41 AND 42 DATA BLOCK 8760

CURRENTS ON ELECTRODE FRAMES 41 AND 42 DATA BLOCK 7880

Figure 18. Frame Currents for Electrode Frames 41 and 42 Using a Voltage Source Between Frames During Test TP40-08

equations describing generator behavior. This work is continuing along with the further analysis of the data presented here and will be reported upon completion.

b. Modeling Support

The objective of advanced analysis development is to provide powerful and efficient computational support for generator design, test data analysis, and data display. Code development is keyed to, and paced by, MHD project and facility needs.

Improvement and documentation of versions of the one-dimensional generator program, used extensively in generator design and test data analysis, continued during this Quarter. Data display and analysis programs specifically for the UTSI R&D facility were also generated this Quarter. The latter programs are in use for data analysis and test reporting, as evidenced by the symposium paper of M. Scott, et. al.⁷

Other codes under development at UTSI include the VNAP program.⁸ This program is being run for channel flow studies and will be modified for MHD effects. The Argonne Two-Dimensional MHD Generator code and other Argonne codes are also being used in support of project activities with the assistance of Argonne personnel.

Development of a two-dimensional MHD code, with slagging boundary layer, is continuing. Activities for the next Quarter include completion of the two-dimensional MHD code, with results as applicable to UTSI MHD work, and further work on VNAP program modification for MHD effects.

The use of cold-flow modeling and studies in support of MHD channel diffuser development is the objective of the diffuser studies project, and the results will be brought to bear on the CFFF and other MHD diffuser designs. Work on the test model of the UTSI diffuser and its instrumentation proceeded on schedule during this Quarter. A computer code for modeling the three-dimensional flow (NASA CF-3157, 1979) is being implemented at UTSI for supportive flow analysis work.

Activities for next Quarter will include further progress toward initiation of cold-flow diffuser testing and completion and demonstration of three-dimensional flow code implementation.

c. On-Going MHD Generator Testing

A series of generator tests was initiated during this Quarter with the following objectives:

- 1 Continued evaluation of insulator materials and assembly techniques in the channel.
- 2 Test the durability of platinum and iridium cladding on anode caps.
- 3 Evaluate the overall performance of the generator as a function of slag throughput.

- 4 Evaluate the electrical performance of the generator with a power takeoff scheme designed to minimize Hall current.

Nominal operating conditions for the tests are:

Total flow rate	1.6 kg/sec
N ₂ /O ₂ ratio	0.22-0.3
O ₂ equivalence	0.85
Potassium seed content	1%-2% of total flow

Initial results after a continuous operation of coal for 50 minutes indicate that peak power production was 56KW at a load of 12 ohms (B-Field = 2 Tesla). At the nominal load of 8 ohms power, production ranged between 41 and 43 KW. There was no degradation in the power output during the run.

The power takeoff (PTO) scheme employed ballast resistors in series with the load and connected between electrodes instead of in parallel with the load. A quasi one-dimensional computer code was run in the Faraday mode ($J_x = 0$) to obtain the individual electrode currents in the PTO regions. The code was then employed to determine the load line of the generator operating in a two terminal mode. The present maximum load utilized with the load dump is 12 ohms. Individual electrode currents for two terminal operations were scaled from the Faraday case, and the value of the ballast resistors was chosen to match the interelectrode impedance. While the experimental data show that the individual electrode currents do not exactly match the analytical prediction, a fairly good agreement was evident. More studies will be undertaken to determine the optimum lengths of the PTO regions in order to minimize Hall current.

A new technique was employed to bond the platinum and iridium foils to the anode caps included in the current testing program. The method involved the use of hydrogen brazing with an 80% copper-20% gold fluxless alloy. This technique virtually eliminated air bubbles between the foil and the cap and created an improved bond compared to previous braze attempts. After more than 1 1/2 hours of operation with coal, the condition of the foils remains excellent. Some pitting of the upstream edge was evident in Module 5 (electrodes 40-44) but this was attributed to the thick boron nitride insulators used between electrodes which caused the frames to protrude into the flow in a stair-step fashion. No evidence of hot spots caused by brazing imperfections and air gaps has yet been found.

7.3 Downstream Components

During this Quarter, the chemical analysis has almost been completed on all the samples taken during the Test Plan (TP)-41 Phase I tests. Data reduction has begun and after the chemical analyses are completed, the data evaluation from these tests will be completed. Work has begun on preparing for the Phase II tests to begin next Quarter. Part of the run schedule and hardware components for Phase II has been established.

On the radiant furnace, several materials have been installed in Cell III for evaluation. Small samples of each of these have been taken and are now undergoing examination. Visually, all samples appeared to be performing satisfactorily. The main body of each material has been left in

place for analysis after longer term testing. A complete list of materials being tested is reported under Section 7.6.

7.4 Seed Regeneration

A preliminary economic analysis of the Tomlinson Tampella and Formate processes was completed during the last Quarter of 1979. On the basis of this analysis, we have concluded that the Tomlinson Tampella process is the most economically viable method of seed regeneration for MHD plants utilizing high sulfur coal. Review of these processes and those proposed by other organizations (e.g. Engel-Precht and Aqueous Carbonate processes) have supported these conclusions. As a consequence of the results of this analysis, we are continuing our analysis of the Tomlinson Tampella process such that a conceptual seed regeneration program for the CFFF will be available by July 1980. In addition, cognizance of the development efforts afforded other regeneration processes will be maintained.

7.5 Pollution Control

Information has been gathered and reviewed regarding the design of electrostatic precipitators and baghouses for use with MHD. This information is presently being summarized. The literature received to date does not have sufficient information to design an agglomerator to operate in this environment with a high probability of success.

7.6 Materials

During this period, analysis continued of the results of corrosion probe experiments conducted in Cell III of the R&D facility during the previous Quarter. Microscopic and EDX examinations of ash/seed deposits and the metal surfaces were performed in addition to gravimetric measurements. Figures 19 and 20 show the weight change per hour per unit area of outside sample surface for the reducing and oxidizing probes, respectively, as a function of sample temperature. Figure 21 shows the pitted upstream surface of the middle sample of the reducing probe after 295 minutes accumulated exposure time. For the high temperature (oxidizing) probe, the scale on the metal surface was not removed as it was desired to continue exposure. Figure 22 shows where the scale had chipped from an edge of the carbon steel sample exposed for a total of 86 minutes.

All of the carbon and low alloy steel samples were entirely covered with a fairly uniform scale layer. The stainless steels were much more scale resistant. Type 310 with highest chromium content, being the most resistant. Figure 23 shows the surface of that sample after the same amount of exposure. Iron oxide exists only in spots. Chemical analyses of the deposits from both probes were obtained. As expected, the low temperature (reducing) probe deposit contained a large percentage, 34% of K_2CO_3 , whereas the high temperature (oxidizing) probe contained only 5.5% carbonate, the remainder of the potassium being present mostly as K_2SO_4 .

A more extensive analysis of the deposits and surface scales will be done next Quarter. Additional exposure of the probes is expected in Cell III using the same samples previously tested.

Figure 19 . Reducing Probe Area Weight Change Versus Time

Figure 20. Oxidizing Probe Area Weight Change Versus Time

Figure 21. Photomicrograph of Corrosive Pitting of Carbon Steel Simulated Boiler Tube, 62.5X

In an effort to gain additional generator materials testing and evaluation through longer run times, the generator, as used in TP-40, was refitted with only a different Module 1 and 5 (see Table II). The "coal-on" run time for TP-40 was 1 hour 7 minutes with the generator producing power for 52 minutes. During TP-40A, to date the coal on run time is 1 hour 36 minutes with the generator producing power for the same time.

Visual observations indicated that one of the alumina dispersion strengthened copper "Glidcop AL-20" anode caps had developed a small pin hole near its centerline. Both the platinum and iridium caps show some degradation. The platinum clad cap has a sand blasted appearance, shows evidence of particle impingement, and may be undergoing a form of silica attack on the leading edge. The iridium clad cap still retains its metallic luster experiencing little chemical attack but is severely degraded along the leading edge. This is believed to be associated with microcracks formed in this area during the cold worked forming process or from possible volatilization of metal and iridium oxide at the higher localized temperatures at the leading edge.

The only visible difference internal to the channel seen from the use of stainless steel frames as opposed to copper frames is the slag layer which adheres to those caps on stainless frames. This implies that the phenomena is temperature related, but it is not known at this time what cap surface temperature for strong slag adhesion is required. External to the

**Figure 22. Photomicrograph of Surface Scale,
Chopped Away at Lower Edge on Carbon Steel
Simulated Superheater Tube**

**Figure 23. Photomicrograph of Discontinuous
Surface Scale on Type 310 Stainless Steel Simulated
Superheater Tube, 62.5X**

TABLE II

Description of the Assembly of Module Channel TP-40-A

	<u>Electrode</u>	<u>Insulation</u>	<u>Cap</u>
Module 1	Nozzle-1, 1-2,2-3	Irish Refrasil Impregnated with BN type S paste	#1 and #2 are Copper frames with GLIDCOP AL-20 caps on anode.
	3-4,4-5 5-6,6-7	1/16" thick x 5/16" wide Boron Nitride solid coated with AREMCO's Cermabond 503, adjacent to gas port. Outside BN to exterior electrode wall build up with 1/32" G-7 phenolic joined with DC 96-083 adhesive	110 Copper on electrodes #3, 4, 5, 6
	7-8	1/16" x 5/16" BN around gas port with 1/32" G-7 phenolic joined with DC 96-083 adhesive	Platinum Clad anodes with Copper Cathodes for electrodes #7, 8, 9
	8-9	Irish Refrasil coated with BN type S	
Modules 2-4,6-8		No change from previous TP 40-07	
Module 5		Gasket-insulator material com- posed of 1/8" x 5/16" BN solid coated with BN type S around gas port backed with RTV coated Garlock around perimeter	
	37,38,39,45		Copper frames with copper caps
	41,42,43,44		SST frames with Platinum Clad copper caps
	40		SST frame-Iridium cap

NOTE: All Noble Metal Anode Cladding foils were Hydrogen brazed with
fluxless brazing alloy (20% Cu - 80% Au)

channel, the stainless steel frames run visibly hotter evidenced by the condition of the Glyptol insulating varnish.

Data collected during the generator tests show no evidence of major interelectrode insulator material degradation. Visual observations have revealed only one area of a sidewall insulator which has apparently been dislodged. Because this area filled with slag the following run it is assumed the piece fell from position during shutdown of the previous run. Subsequent runs have shown no interelectrode shorting at this location. Detailed analysis awaits disassembly of the channel at the completion of the test series.

Some gas leaks were experienced upon pressure testing the channel after initial assembly. Most of these were along joints between caps and their frames. These were successfully sealed by pulling a light vacuum on the channel and coating with a combination of Dow Corning 96-083 adhesive and Glyptol.

Experiments are now under way to find an optimum insulator/seal material configuration to effect a gas seal as assembled. Additionally, materials are currently being investigated for use in electrically isolating electrode caps from their frames. Pending the results of these investigations, the most promising materials will be prepared for in-channel testing.

The refractory material as installed initially in Test Plan 40-A is given in Table III.

After the second run, the Greencrete ARC at the coal injector/disperser plate joint was found to have undergone excessive creep because of the 1873K (1600°C) temperatures and 3-4 atm pressure differential experienced. This material was replaced for the third run with Narphos-90P with similar results. Subsequently, a phosphate bonded chrome-alumina (Alchrome-85) was found to be successful in this area.

A patch of the coal combustor's Carbofrax IIII refractory liner was attempted unsuccessfully with a mixture of Ruby Plastic and 30% Carbofrax No. 9 SiC (see Figure 24). Although none of this material remained following the run, it is believed that this failure was due to excessive heat fluxes and low refractory thermal conductivity. Future plans for refractory include the use of 446 stainless steel fibers to improve the refractory's thermal conductivity and add some spalling resistance as well as thermal shock resistance.

Samples have been taken from the exhaust duct of TP-40A (see Figure 25) and are currently undergoing SEM analysis. In general, all the refractories placed in this area appear to be performing satisfactorily. In an effort to determine performance ratings among them, they have been left in place to acquire additional run time.

7.7 Diagnostics

Additional broadband data were recorded in both test series TP-41 and TP-40A. Only limited data analysis, to resolve dynamic interactions, has been accomplished due to the limited results thus far obtained with the

TABLE III

List of Refractories & Locations TP-40-A

		<u>MFG.</u>
1) Vitiation Heater		
a) On inner wall of heater:	KAOTAB 95	B&W
b) Covering Layer of Kaotab:	RUBY Plastic	H. W.
2) Coal Injector & Disperser Plate		
a) Filling gap between injector and Disperser Plate:	GREEN CRETE ARC	A. P. Green
3) Coal Combustor (CM2)		
a) On inner wall of combustor:*	CARBAFRAX 11LI Slag	Carborundum
b) Covering layer of CARBAFRAX & Slag:	RUBY Plastic	H. W.
4) Conical Section		
a) On inner wall of conical section:	CARBAFRAX 11LI	Carborundum
b) Covering layer of CARBAFRAX:	RUBY Plastic	H. W.
5) Exhaust Duct		
a) Four test samples in four quadrants located at exit of duct on the inner wall:	GREEN CRETE ARC RUBY Plastic Jade Set Super (TC tubes) X 3337E HW 10-61	A. P. Green H. W. Taylor H. W.

*NOTE: On the two farthest downstream cooling tubes lining the combustor. There is no CARBAFRAX 11LI. Instead, this area has been repaired with a mixture of RUBY plastic and CARBAFRAX #9.

Figure 24. Coal Combustor Refractory Repair - Cell III,
TP-40A

Figure 25. Exhaust Duct Refractory Test - Cell III,
TP-40A

existing analog analysis techniques. Alternate analysis techniques are being considered in an attempt to obtain more useful results while reducing the manhour investment required for the analysis. A feasibility study of the promising digital stochastic time series modeling techniques is being considered. Analog-to-digital instrumentation requirements are being reviewed in case these modeling, or other digital techniques, prove adequate.

The objective of the present diagnostic temperature sensor study, conducted during this Quarter, was to provide temperature measurement in support of overall project and facility diagnostic requirements. The results were obtained from the TP-41 tests in the UTSI R&D facility.

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, indicated that the emission peaks of potassium and sodium were somewhat shifted from their normal wavelengths. For example, the sodium doublet at 589 nm was shifted so that the peak intensity occurred at 594 nm, as indicated by the spectrometer. There is the possibility that the peaks could shift a small amount due to the high electron concentration in the plasma, but 5 nm is an extremely large shift.

After the TP-41 test series was terminated, the DU spectrometer was subjected to a complete analysis to determine whether a malfunction might have caused the shift observed in the emission peaks. The spectrometer was exposed to three spectral calibration lamps containing Hg, K and Na, and the measured wavelength of each spectral peak was compared to that listed in the appropriate table for each lamp. It was found that the measured values corresponded to the table values to within the listed accuracy of the instrument. Thus it would appear that the spectrometer was functioning properly. However, the lamp spectrums did not contain the background variation that was present in the TP-41 test plasma spectrum as a result of the continuum emission by the particles of slag in the plasma. This continuum emission could cause an apparent shift in the atomic emission peaks if the spectrometer entrance and exit slits were open wider than was indicated by the instrument dial. Thus, an inspection of the spectrometer slits was required.

Since the spectrometer slits are located in positions which make them difficult to examine directly, it was decided to direct a He-Ne laser beam onto the entrance slit and observe the diffraction pattern obtained through the exit slit. The extent of the central maxima would be a measure of the slit width. After performing this experiment, it was determined that the slit widths were somewhat wider than indicated by the dial and also that the slits did not appear to close uniformly with the dial setting at a certain point.

A stereoscopic microscope with a graduated reticle and the proper focal length was obtained so that it became possible to view and measure the slit widths directly. It was discovered that the slits would not close to a width smaller than 0.8 nm, whereas the dial indicated 0.01 nm.

This slit problem would result in poor resolution by the spectrometer and may explain the apparent peak shifts. An effort is being made to repair the slits and re-scan the plasma.

Work for the coming Quarter will include repair of the slits and rescanning of the plasma.

In advanced diagnostic techniques, development of a laser velocimeter system to be used primarily in the cold flow modelling studies of the flow train continued. Most of the optics and electronics for the laser velocimeter and its associated data acquisition/analysis system and traversing system have been ordered. Other laser diagnostics techniques have been examined. Systems being considered for possible development include holography and laser-induced fluorescence technique.

Progress continued on schedule in developing other diagnostics techniques. The draft of the topical report on the Coriolis coal mass flow meter has been prepared for final review. In addition, circuit diagrams of the high frequency, low power plasma conductivity instrument have been reviewed and plans have been formulated to complete and test it. This effort will continue through the next Quarter.

7.8 Generator Loading

A new resistive power take-off network was designed with testing scheduled at the R&D facility. A zener type of electrode over-voltage protection device was designed and installed on one electrode pair for evaluation. Work continues on equipping the electrical section electronics laboratory. This effort is required before work begins on developing bench models of controllable power take-off schemes, inverter control systems, and filters. Next Quarter, design and testing of the resistive PTO for the R&D generator will begin.

7.9 Process Control

During the Quarter a model for a commercial scale MHD/steam plant has been 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 400MW_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 (to sense plant's ability to meet load demand) and using it to control the fuel input to the overall plant. With PID control a larger proportion of the load change

seems to shift to the MHD section during the transient period; the demand takes a long time to be met through the time lags in the steam section.

Next, optimal control will be tried in an effort to improve the transient response while at the same time reducing the necessary energy expended. It will also be of interest to monitor the load division during the transient period while the frequency deviation settles back to zero. It is hoped that some decision can be made as to the general type of control necessary to bring the system to a new steady-state point in a minimum length of time with minimum expenditure of energy -- above that necessary to satisfy just the change in demand.

SECTION IV CONCLUSIONS

Under Task 1, it is anticipated that all construction work on the CFFF is at the point that virtually all of this activity will be completed on the various Bid Packages next Quarter.

On the radiant slagging furnace investigation has led to the decision to use chrome-alumina phosphate bonded materials because of their slag resistance and high temperature strength properties. Traditional silicate bonded chromite materials tend to deform too rapidly for this application. Results of analysis of annual solids and chemicals in Woods Reservoir compare favorably with those for last year and reflect expected seasonal patterns.

Under Task 2, procurements were initiated for combustor, nozzle and diffuser. Fabrication of the diagnostic channel continued ahead of schedule. Detailed design of the MHD generator neared completion. The radiant furnace and secondary combustor arrived on site and erection began.

Under Task 7, Technology Development Program, an oxidant disperser plate was modified to operate without ceramic inserts, and was tested with good results. A new design was completed to improve mixing and cooling. This design will be tested in the R&D facility and, if successful, will be built for the LMF. Generator experimentation results have shown a strong influence of leakage effects on local electrode behavior. It thus follows that to obtain more reasonable agreement between these results and performance predictions, leakage effects must be incorporated into equations describing generator behavior. Current generator testing featured a new technique involving hydrogen brazing and a special gold alloy to bond platinum and iridium foils to the anode caps. This technique virtually eliminated air bubbles between the foil and the cap and created a very much improved bond. After more than 1 1/2 hours of operation with coal, the condition of the foils remained excellent. It appears that this application technique merits further evaluation.

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TOPICAL REPORT STATUS

Current Quarter (January-March, 1980)

- 1) "Evaluation of a Coriolis Mass Flow Meter," FE-10815-45 (Draft for DOE review).
- 2) "Secondary Combustor Evaluation Cell III Tests at UTSI," FE-10815-41 (Distributed in Final Form).

Next Quarter (April-June, 1980)

- 1) One-Year Baseline Study of Water Quality in Woods Reservoir
- 2) "Development and Heat Transfer Analysis of Direct Coal-Fired MHD Combustors," FE-10815-46.
- 3) Cell III Corrosion Probe Studies