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MHD COAL-FIRED FLOW FACILITY

Quarterly/Annual Technical Progress Report, October—December 1979

February 1980
Date Submitted

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

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/ANNUAL TECHNICAL
PROGRESS REPORT

OCTOBER-DECEMBER 1979

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Date Submitted - February 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)

UTSI
Energy Conversion Division

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ABSTRACT

In this Fourth Quarterly/Annual Report submitted under DOE contracts EX-76-C-01-1760 and ~~DE-AC02-79ET10815~~, the University of Tennessee Space Institute (UTSI) reports on significant activity, task status, planned research, testing, and development, and conclusions for the Magnetohydrodynamics (MHD) Coal-Fired Flow Facility (CFFF) and the Research and Development Laboratory.

Work on the CFFF progressed with only minor problems. Total construction activity for all site work presently awarded is nearly 98 percent complete. Water analysis shows that Woods Reservoir baseline conditions are within EPA or Tennessee drinking water standards. For the primary combustor, the vitiation heater and primary combustor fabrication drawings were completed and the nozzle design was completed. The drum module for the radiant slagging furnace was awarded. On the MHD Power Generator, development continued in several areas of advanced analysis including development of time-dependent models for use with the one-dimensional code. For seed regeneration, the tentative determination is that the Tomlinson Tampella is the most economically viable method.

With regard to capped electrode erosion, investigations have shown that the major degradation of the cladding still present is at the leading edge of the capped anode. To alleviate this, plans are to hot work the noble metal in the bending operation. In resolving another problem, a system employing the modified line-reversal method has been assembled and successfully tested to measure absolute plasma temperatures.

CONTENTS

Abstract	11
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Sections

I. OBJECTIVE AND SCOPE OF WORK	1
II. SUMMARY OF TECHNICAL PROGRESS-FIRST THREE QUARTERS	4
III. QUARTERLY TECHNICAL PROGRESS	24
A. <u>TASK 1 - COMPLETION OF DESIGN AND CONSTRUCTION OF THE CFFF AND FACILITY ACTIVATION</u>	24
1.1 Design and Construction	24
B. <u>TASK 2 - DESIGN AND FABRICATION OF THE 8 PPS TOTAL GAS FLOW HIGH SLAG THROUGHPUT TEST EQUIPMENT</u>	34
2.1 Primary Combustor	34
2.2 MHD Generator	34
2.3 Downstream Components	34
C. <u>TASK 3 - BASE OPERATIONS FOR THE CFFF AND R&D FACILITY</u>	41
D. <u>TASK 4 - 8 PPS HIGH SLAG THROUGHPUT TESTING</u>	42
E. <u>TASK 5 - TESTING OF DOE SUPPLIED COMPONENTS</u>	43
F. <u>TASK 6 - MAJOR MODIFICATIONS TO THE CFFF</u>	43
G. <u>TASK 7 - TECHNOLOGY DEVELOPMENT PROGRAM</u>	43
7.1 Primary Combustor	43
7.2 MHD Power Generator	44
7.3 Downstream Components	44
7.4 Seed Regeneration	45
7.5 Pollution Control	45
7.6 Materials	45

7.7 Diagnostics	52
7.8 Generator Loading	54
7.9 Process Control	54
IV. CONCLUSIONS	59
Publications	60

FIGURES

1. Ash/Seed Hopper	8
2. Secondary Combustor	9
3. Monthly Averages of Water Analysis During 1979	13
4. Workman Installing Piping on Cryogenic Bridge	25
5. Workmen Installing Conduit on Cryogenic Piping Bridge	26
6. Pipefitters Installing Fuel Oil Lines to Coal Processing Tower	27
7. Diesel Fire Pumps Being Unloaded on the Lake Pump House Slab	28
8. Completing Work on Fire Line Loop	29
9. Cooling Water Tower Piping Nearly Completed	30
10. Equipment in Place on the Lake Pump House Slab	31
11. Erection of Lake Pump House Building	32
12. Checkout of the Pulverizer Unit	33
13. Vitiation Heater	35
14. Primary Combustor	36
15. Primary Furnace Module Under Construction in Vendor's Shop	37
16. Top Portion of the Slag Receiver Under Construction	38
17. Structural Steel for Support of the Radiant Furnace and Secondary Combustor	40
18. High Temperature Probe Showing Potassium Compounds and Ash Deposition	47
19. Photomicrograph of Carbon Steel Pitting	48
20. Photomicrograph of High Temperature Corrosion	48
21. High Temperature Corrosion Probe	49

22.	Line Reversal System	53
23.	Plasma Emission Spectrum	56
24.	Time Plot of Plasma Temperature for TP 41-13	57
25.	Correlation of Plasma Temperature, Oxygen Flow and Optical Luminosity Probe Signals	58

TABLES

I.	Average Monthly Values for Each Parameter Measured at Station 1 During 1979	10
II.	Average Monthly Values for Each Parameter Measured at Station 2 During 1979	11
III.	Average Monthly Values for Each Parameter Measured at Station 3 During 1979	12

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 O_2 , CO_2 , NO_x , CO , SO_2 , H_2S , 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 TO OCTOBER

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

1.1 Design and Construction

The Laboratory Office Building (Bid Package 1) was completed and occupancy was successfully achieved. Personnel of the Chemistry R&D Laboratory and Materials R&D Laboratory moved in. Laboratory operations people also moved into their office space. However, a few minor points remained uncleared before the Bid Package could be closed out.

Approximately 90% of the work in Bid Package 2 (Control Room and Test Buildings) was completed by the end of the period. Mechanical and electrical work was completed successfully. Fire protection systems were installed, and change orders for steel shielding for the control room were issued and awarded. Some piping installation work remains to be completed.

The Coal Processing Area (Bid Package 3) structure was essentially completed. Hydrostatic testing of the piping was the principal activity, as well as verifying checkout equipment and startup procedures. Several change orders and custom installations were also included, such as insulation of the pulverizer air piping and air heater. Painting of piping and tanks was completed. At the end of the period this project was 98% complete.

Substation (Bid Package 4) work has been essentially completed. The substation was energized early in 1979.

The Support Systems and Shelters (Bid Package 5) is the last major construction package of the CFFF. The award was initiated during the second quarter of 1979. However, a major change order was issued immediately, which involved upgrading the fire protection loop. These changes were based on comments from the DOE review, which came after the job was bid. Otherwise the construction has proceeded on a reasonable schedule and according to plan. There have been fewer change orders with this particular bid package than with any of the others.

During this report period the Lake Pump House was completed and installed. The pumps and piping for the fire protection loop and the coolant loop were also installed. The Seed Shelter and the Coal Storage

Shelter were completed and installed as was the fuel oil tank and fuel oil system. In addition, the Cooling Towers were installed at the Cooling Water Pump House. At the end of September, the work on this particular bid package was approximately 58% complete.

Site Electrical Transmission and Distribution (Bid Package 6) was completed in the third quarter of 1979, and the system was tested and energized.

The Oxidizer Supply System award was made to the subcontractor for the system. Some changes to the oxidizer supply system occurred as a result of coordination meetings. In particular, a steam system replaced the hot water system originally specified. There was no increase in cost but some increase in capacity. Installation drawings for the equipment were released by Linde, and foundation drawings and bid documents were prepared. Foundations for the oxidizers and vaporizers were completed as liaison with the equipment manufacturer was continued.

The magnet movement platform itself is completed, but not checked out. It awaits compressed air to the test building. Also under consideration on this project are the various installation requirements for the magnet. Some design work took place during this period toward the goal of energizing the magnet early in 1980.

Design of the quench system was delayed during the early part of the report period pending approval of the conceptual design by DOE. The system was finally defined as a facilities item. Design continued throughout the middle of the report period, essentially on schedule.

Work on estimating the gas compositions of the quench system was under-taken based on the revised optimum feed streams required by the MHD channel. Equilibrium gas compositions were calculated using a computer program which calculates chemical and thermodynamic equilibrium values. Baseline calculations were completed and have undergone preliminary analysis. Work was initiated during the report period to generate a computer model of the quench system for use on-line in establishing cooling water flow rates and heat functions.

Testing of the solubility and filterability of the ash collected in the heat exchanger downstream of the prototype secondary combustor of Cell III was conducted. This material is expected to simulate material collected by the venturi scrubber and cyclone. Efficient collection and removal of the solids from the quench liquid will be required for continuous operation of the system. Sedimentation tests conducted on the samples indicate that an excessive area would be required to remove the solids via gravity settling equipment. Tests were conducted to evaluate various flocculants to determine if the mean particle settling rate can be increased to permit the use of gravity thickeners. The results of these tests were negative. Filtration tests have not been promising due to the high cake densities and associated low porosities exhibited by the ash. Investigation of alternate separation techniques and methods for improving the filterability of the ash slurries is continuing.

Because Cell III was not operational during the third quarter, no additional work was conducted on testing of the solubility and filterability of the ash collected in the heat exchanger downstream of the prototype secondary combustor nor on the evaluation of flocculants to determine if the mean particle settling rate can be increased to permit the use of gravity thickeners.

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

2.1 Primary Combustor

During the reporting period, vitiation heater and primary combustor efforts were concentrated on developing design criteria from previous tests in the UTSI R&D laboratory and on preparing component specifications and design reports. Detail drawings were also prepared. After completion of the reports and drawings, a design review was held. Both designs stressed flexibility. The vitiation heater has provisions for removing the burner assembly. Thus three different burners are being considered for use in this heater. A gas turbine combustor was acquired and is presently being prepared for testing in the existing R&D facility. This combustor, the UTSI and commercial burner designs will serve as the three alternatives for the vitiation heater in the low mass flow (LMF) test train.

2.2 MHD Power Generator

During the first three quarters of 1979, component specifications for the nozzle, the MHD generator, the diagnostic conductivity channel, and the diffuser were prepared and submitted to DOE. Design reports were also prepared and the preliminary design review of these components was held in July. Responses were prepared for the action items raised during this review. By the end of the third quarter, detailed drawings were completed and a bid package issued for the diagnostic conductivity channel. Detailed design of the nozzle, diffuser, and MHD generator continued.

2.3 Downstream Components

Design of the radiant furnace proceeded behind schedule following the approval to proceed with detailing granted as a result of the DOE Preliminary Design Review (PDR). Three addendums to the original design report were prepared in response to questions raised at the PDR. Permission to proceed with the procurement of long-lead-time components was granted subject to meeting the criterion that these items did not conflict with outstanding action items that the PDR committee considered to be incomplete. A test train component specification was prepared covering the radiant furnace to satisfy a portion of the action items requested as a result of the PDR.

The steel support structure for the downstream systems was released for bids and the contract awarded to Mingle and Elrod, Inc., of Murfreesboro. This bid package was expedited in order to minimize delays and permit timely installation of the structure. Bid packages covering the

furnace modules; support equipment, and control valves were prepared and held pending critical approval to purchase. These packages were released as approval was received. All furnace modules, with the exception of the drum module, were to the vendor before October 1979.

During the first three quarters of 1979, efforts were concentrated on development of design criteria from Cell III tests in the R&D Laboratory and preparation of the component specification and design report for the secondary combustor. Detail drawings were also prepared and a design review was conducted with DOE and other selected panel members. Responses to the review committees' action items were prepared and approval of the secondary combustor design was obtained from DOE. Final drawings were completed (see Figures 1 and 2). Bids for fabrication were requested, received, and a purchase order was processed.

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

The microscopic and materials preparation laboratories were moved to their new location in the laboratory/office building. These facilities include preparation equipment necessary for both metallic and ceramic samples. Examination and analysis of samples is accomplished with the use of scanning electron microscopy with energy dispersive X-ray analysis, and a research grade light microscope.

The microscopy and materials preparation laboratories have been used to examine problems associated with the generator electrode cap surfaces. The mechanism of surface metal removal due to erosion and corrosion during power generation under MHD conditions has received major emphasis.

Various ceramics, including spinels, chrome-aluminas, machinable glass ceramics, and calcium aluminate bonded refractories, were examined to study seed-slag interaction and to determine degradation mechanisms.

As reported previously, water analysis of Rollins Creek, a tributary of Woods Reservoir, was begun early in the year 1979 to establish baseline conditions for the stream. Attached are Tables I, II, and III and graphs (Figure 3) of monthly averages for the year 1979. Physical and chemical analyses were conducted on samples collected from three different sites during the period. The average values for each parameter tested were fairly constant and usually within the EPA or Tennessee drinking water standard. On some occasions results were above or below these standards because of conditions, not UTSI CFFF operations.

The first three quarters of 1979 were spent trying to get contract funding approved for all CFFF related projects, from Engineering Services to Superconducting Magnet Installation and Operation (Projects 3.1.2, 3.1.5, 3.1.6, 3.1.14, and 3.1.17). Most of the work involved planning and trying to determine the needs of the future. These are all level of effort projects, and no problems have been identified at this point; however, there is not much visibility as to what is required for Task 3.

Figure 1. Ash/Seed Hopper

Figure 2. Secondary Combustor

PH	PH	EPA STD >6.5	<9.0
CONDUCTIVITY	MICROMHO	NONE	
HARDNESS	PPM	TENN STD	<150 PPM
ALKALINITY (TOTAL)	PPM	EPA STD >20. PPM	
ALKALINITY (MO)	PPM	NONE	
CALCIUM	PPM	NONE	
IRON	PPM	TENN STD	<.3 PPM
POTASSIUM	PPM	NONE	
MAGNESIUM	PPM	NONE	
SODIUM	PPM	NONE	
SILICON	PPM	NONE	
CHLORIDE	PPM	TENN STD	<250 PPM
PHOSPHATE (TOTAL)	PPM	NONE	
SULFATE	PPM	TENN STD	<250 PPM
TOTAL SOLIDS	PPM	TENN STD	<500 PPM
DISSOLVED O2	PPM	EPA STD >5. PPM	
AMMONIA	PPM	STD *	
TEMPERATURE	DEG	TENN STD	<30.5 C
DATA TAKEN AT STATION 1			

TABLE I

AVERAGE MONTHLY VALUES FOR EACH PARAMETER MEASURED
AT STATION 1 DURING 1979

	PH	CONDUCTIVITY	HARDNESS	ALKALINITY (total)	ALKALINITY (M. O.)	CALCIUM	IRON	POTASSIUM	MAGNESIUM	SODIUM
May	8.26	124.7	70.83	68.28	67.48	22.20	0.28	0.87	2.82	1.26
June	8.66	119.0	77.00	73.00	68.16	25.00	0.18	0.87	3.20	2.30
July	8.14	120.7	80.25	79.62	77.50	22.97	0.13	0.95	3.07	1.48
August	8.40	121.0	92.66	96.00	90.66	22.51	0.11	0.94	3.28	1.74
September	8.04	162.0	82.57	94.28	90.85	26.21	0.06	1.05	3.46	1.91
October	7.67	150.5	61.81	89.70	89.70	24.92	0.47	1.15	3.80	1.43
November	7.14	129.2	66.00	80.00	80.00	22.36	1.04	1.17	3.40	1.31
December	7.03	120.0	63.20	83.50	83.50	25.30	1.16	1.05	2.89	1.51

	SILICON	CHLORIDE	PHOSPHATE	SULFATE	TOTAL SOLIDS	DISSOLVED O2	AMMONIA	TEMPERATURE
May	****	4.30	0.028	7.35	125.7	6.7	****	****
June	****	4.75	0.020	7.85	135.8	7.0	****	****
July	****	3.67	0.027	8.35	109.6	7.8	****	****
August	****	4.67	0.035	8.04	139.0	7.9	0.191	26.80
September	****	4.46	0.012	8.10	122.2	7.7	0.300	24.04
October	****	4.41	0.021	9.91	143.1	7.7	0.516	18.36
November	****	5.91	0.054	11.94	132.6	8.2	0.366	13.73
December	****	4.96	0.000	10.59	136.4	11.2	0.060	7.85

PH	PH	EPA STD	>6.5	<9.0
CONDUCTIVITY	MICROMHO	NONE		
HARDNESS	PPM	TENN STD		<150 PPM
ALKALINITY (TOTAL)	PPM	EPA STD	>20. PPM	
ALKALINITY (MO)	PPM	NONE		
CALCIUM	PPM	NONE		
IRON	PPM	TENN STD		<.3 PPM
POTASSIUM	PPM	NONE		
MAGNESIUM	PPM	NONE		
SODIUM	PPM	NONE		
SILICON	PPM	NONE		
CHLORIDE	PPM	TENN STD		<250 PPM
PHOSPHATE (TOTAL)	PPM	NONE		
SULFATE	PPM	TENN STD		<250 PPM
TOTAL SOLIDS	PPM	TENN STD		<500 PPM
DISSOLVED O2	PPM	EPA STD	>5. PPM	
AMMONIA	PPM	STD *		
TEMPERATURE	DEG	TENN STD		<30.5 C
DATA TAKEN AT STATION 2				

TABLE II

AVERAGE MONTHLY VALUES FOR EACH PARAMETER MEASURED
AT STATION 2 DURING 1979

	PH	CONDUCTIVITY	HARDNESS	ALKALINITY (total)	ALKALINITY (M. O.)	CALCIUM	IRON	POTASSIUM	MAGNESIUM	SODIUM
May	8.20	132.0	71.51	63.44	62.79	21.38	0.19	0.96	2.74	1.41
June	8.49	125.3	77.90	72.80	69.36	23.70	0.12	0.89	3.40	1.90
July	7.97	125.0	84.55	81.55	80.66	23.61	0.09	1.01	3.23	1.74
August	8.11	146.0	101.75	95.55	93.77	23.47	0.13	1.01	3.55	1.98
September	7.80	160.06	86.25	98.12	97.62	26.15	0.07	1.07	3.47	1.99
October	7.84	147.47	58.44	79.11	79.11	23.96	0.14	1.10	3.85	1.82
November	7.69	133.50	69.25	78.75	78.75	21.98	0.28	1.10	3.58	1.46
December	7.80	129.50	54.56	85.00	85.00	26.73	0.43	1.12	3.03	1.78

	SILICON	CHLORIDE	PHOSPHATE	SULFATE	TOTAL SOLIDS	DISSOLVED O2	AMMONIA	TEMPERATURE
May	****	5.32	0.029	7.01	112.8	6.44	****	****
June	****	5.80	0.020	8.40	126.0	6.70	****	****
July	****	4.37	0.028	8.44	110.6	7.87	****	****
August	****	5.08	0.035	8.22	152.0	7.33	0.069	27.30
September	****	4.91	0.022	8.51	119.4	7.32	0.270	24.33
October	****	5.37	0.032	8.77	104.5	8.18	0.106	19.13
November	****	5.00	0.053	9.16	119.3	9.33	0.216	13.92
December	****	5.22	0.042	7.90	121.6	10.83	0.130	9.36

PH	PH	EPA STD >6.5	<9.0
CONDUCTIVITY	MICROMHO	NONE	
HARDNESS	PPM	TENN STD	<150 PPM
ALKALINITY (TOTAL)	PPM	EPA STD >20. PPM	
ALKALINITY (MO)	PPM	NONE	
CALCIUM	PPM	NONE	
IRON	PPM	TENN STD	<.3 PPM
POTASSIUM	PPM	NONE	
MAGNESIUM	PPM	NONE	
SODIUM	PPM	NONE	
SILICON	PPM	NONE	
CHLORIDE	PPM	TENN STD	<250 PPM
PHOSPHATE (TOTAL)	PPM	NONE	
SULFATE	PPM	TENN STD	<250 PPM
TOTAL SOLIDS	PPM	TENN STD	<500 PPM
DISSOLVED O2	PPM	EPA STD >5. PPM	
AMMONIA	PPM	STD *	
TEMPERATURE	DEG	TENN STD	<30.5 C

DATA TAKEN AT STATION 3

TABLE III

AVERAGE MONTHLY VALUES FOR EACH PARAMETER MEASURED
AT STATION 3 DURING 1979

	PH	CONDUCTIVITY	HARDNESS	ALKALINITY (total)	ALKALINITY (M. O.)	CALCIUM	IRON	POTASSIUM	MAGNESIUM	SODIUM
May	****	****	****	****	****	****	****	****	****	****
June	8.30	95.3	76.00	71.00	71.00	24.60	0.28	0.96	4.00	2.40
July	7.82	130.7	86.25	75.00	75.00	24.16	0.12	0.91	3.26	1.67
August	7.94	122.0	104.95	90.00	90.00	22.93	0.43	1.03	3.55	1.85
September	7.91	168.4	73.00	82.50	82.50	26.24	0.10	1.08	3.52	1.99
October	8.01	158.1	72.40	83.00	81.33	24.28	0.08	1.13	4.08	1.70
November	7.68	135.5	60.75	84.25	84.25	25.44	0.21	1.17	3.95	1.41
December	7.93	120.6	50.33	89.66	89.66	30.00	0.24	1.06	3.09	1.89

	SILICON	CHLORIDE	PHOSPHATE	SULFATE	TOTAL SOLIDS	DISSOLVED O2	AMMONIA	TEMPERATURE
May	****	****	****	****	****	****	****	****
June	****	4.88	0.08	9.50	119.6	6.80	****	****
July	****	4.25	0.04	8.43	101.0	7.32	****	****
August	****	4.63	0.02	9.35	152.6	7.01	0.108	28.52
September	****	4.82	0.01	9.13	123.5	7.30	0.280	26.57
October	****	4.96	0.03	8.67	108.3	8.42	0.076	22.13
November	****	4.31	0.07	8.81	143.0	9.05	0.1667	16.17
December	****	5.05	0.06	7.89	164.3	10.60	0.207	12.33

MONTHLY AVERAGES OF WATER ANALYSIS DURING 1979.

FIGURE 3

MONTHLY AVERAGES OF WATER ANALYSES DURING 1979.

FIGURE 3 (continued)

1979 ROLLINS CREEK COVE TOT. PHOSPHATE CONTENT WOODS RESERVOIR

1979 ROLLINS CREEK COVE CHLORIDE CONTENT OF WOODS RESERVOIR

1979 ROLLINS CREEK COVE SODIUM CONTENT OF WOODS RESERVOIR

1979 ROLLINS CREEK COVE MAGNESIUM CONTENT OF WOODS RESERVOIR

MONTHLY AVERAGES OF WATER ANALYSES DURING 1979.

FIGURE 3 (continued)

1979 ROLLINS CREEK COVE POTASSIUM CONTENT OF WOODS RESERVOIR

1979 ROLLINS CREEK COVE IRON CONTENT OF WOODS RESERVOIR

1979 ROLLINS CREEK COVE CALCIUM CONTENT OF WOODS RESERVOIR

1979 ROLLINS CREEK COVE ALKALINITY (MG) OF WOODS RESERVOIR

MONTHLY AVERAGES OF WATER ANALYSES DURING 1979.

FIGURE 3 (continued)

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

There has been no activity to report.

E. TASK 5—TESTING OF DOE SUPPLIED COMPONENTS

As a part of the joint US-USSR scientific exchange, two USSR diagnostic devices were made available for testing at the UTSI R&D Facility. These devices consisted of a conductivity probe and a modified line-reversal system for measuring plasma temperature. Testing of these devices began during the first quarter and ended during the second quarter. The primary result of this joint testing was a demonstration of the applicability of the Soviet conductivity probe and temperature device to a coal-fired environment. Express report ER-5.2.2-79-01 was published on this activity.

F. TASK 6—MODIFICATIONS TO THE CFFF

Thus far only one project has been funded under Task 6, a study to make preliminary estimates of proposed modifications. Five modifications were identified in the statement of work and have been addressed in a preliminary way to establish planning documents. Project plans and rough estimated costs on the work necessary to accomplish the modification were requested by DOE. The modifications were as follows:

- 1 Replacing the cryogenic oxidizer flow with an air compressor system.
- 2 Changing the coal system to handle western coals.
- 3 Looking at replacing the vitiation heater with a tubular, separately fired air heater.
- 4 Making Bay 3 operational.
- 5 Devising a separate seed injection.

Inputs for the statement of work for the Heat and Seed Recovery (HRSR) system were received. Other modifications to the facility were listed and a brief report supplied. Preliminary reports were written and recommendations made to DOE by the end of the third quarter, 1979.

G. TASK 7-TECHNOLOGY DEVELOPMENT PROGRAM

7.1 Primary Combustor

The UTSI coal-fired, high-slag carryover combustor is a two stage apparatus consisting of an upstream vitiation heater and a downstream coal combustion chamber that are separated by a perforated fuel/oxidizer injector plate. Areas of research in FY 79 concerning this combustor included:

- 1 vitiation heater performance
- 2 coal-combustor performance
- 3 heat transfer and thermal protection
- 4 fuel/oxidizer supply and injection

The research performed to investigate these areas included both hot and cold flow experimental investigations. In the operation of the research combustors in both Cells I and III, basic heat transfer data were acquired and analyzed, and techniques for gas diagnostic sampling were improved. Different refractory materials for protecting combustor components were installed and evaluated in the combustor and on the disperser or injector plate. Cold flow experimental research was performed to evaluate the mixing between the pulverized coal jet and the oxidizer jets that is created by the perforated disperser or injector plate. This research led to a plate design that improved combustor performance as measured by heat release, heat flux distributions, and channel voltage distributions during reactive testing. An analytical method for gauging coal-fired combustor performance was obtained and made operational. This consisted of the Argonne Coal Burn Program developed by P. Chung and his associates. With this program, estimates were made of the rates of pyrolysis and combustion of coal particles, thus providing insight into required residence times necessary for acceptable heat release and slag vaporization. Finally, alternate designs for vitiation heaters were considered and a configuration based on a turbo jet engine combustor can was selected for testing in the R&D Facility.

The heat losses were compared with a zone heat transfer model developed at UTSI and found to be in good agreement. The heat flux values obtained at various operating conditions in the R&D facility were used to extrapolate design values for the 8 lb/sec CFFF low mass flow combustor. Off-design operation was analyzed. The heat transfer results were contributed to the CFFF-LMF Combustor Design Report. A topical report entitled "Development and Heat Transfer Analysis of Direct Coal-Fired MHD Combustors" was initiated.

The heat flux measured from the generator was compared with a quasi one dimensional analysis with friction, heat transfer and chemical reaction for the various runs and found to have good agreement. The analysis was extended to the CFFF-LMF generator and calculations were made for design and off-design conditions. The effect of off-design combustor operation on

generator performance was investigated and described in a letter report. Contributions were made for the nozzle, generator, and diffuser design report for the CFFF-LMF system, with responses to action items.

Temperature distributions on electrodes with and without caps were studied. The program was modified to handle different frame materials, cap materials, and bonding/filling materials between caps and electrodes. Temperature distribution in stainless steel electrodes with copper caps was analyzed for various heat flux conditions to evaluate suitability for future applications.

7.2 MHD Power Generator

Tests were conducted in the R&D facility under two test series. Objectives included for these tests were to determine current distribution in electrodes, map generator performance for a range of conditions, evaluate insulator materials, determine generator electrical characteristics and test electrode designs and cladding materials. Considerable information has been obtained which will be published and used in future design work.

Analytic work has been continued including data analysis and development of analytic models. Programs have been obtained from Argonne National Labs, Stanford University and other sources for comparison with programs in use at UTSI and with test data. This comparison will lead to choices among the analytic models available for those most appropriate to the problems.

7.3 Downstream Components

During the first three quarters a topical report draft on the secondary combustor was forwarded to DOE ("Secondary Combustor Evaluation Cell III Tests at UTSI," FE-1760-41) and a paper was completed for the winter Annual ASME Meeting in December. The hardware and operating conditions for the Cell III tests were prepared. The conductivity channel was installed in Cell III for the first time. Heat flux probes were installed in the cyclone and a refractory probe was installed in the diffuser refractory, furnace. Also, probes were prepared for material corrosion, ash deposition and pollution monitoring.

During this time preliminary analysis of refractories for possible use in the slagging radiant furnace was also performed. A refractory test probe was fabricated and installed in the Cell III radiant furnace.

7.4 Seed Regeneration

Progress in seed regeneration during the first three quarters is highlighted by the following accomplishments:

- 1 The release of a topical report entitled "An Evaluation of the Direct Reduction Seed Regeneration Process," FE-1760-36. This report contained a preliminary analysis of potential seed regeneration processes. As stated in the recommendations section of the report, it was our opinion that the direct reduction process had the highest potential for MHD seed regeneration but was the

least developed process. Experimentation based on this conclusion was subsequently initiated.

2 "An Evaluation of the Direct Reduction Process," a second topical report, was released by DOE for publication during May. This report covered preliminary test sequences of fluidized bed reduction of potassium sulfate. During these test sequences, little reduction of potassium sulfate to potassium sulfide or potassium carbonate was observed. This result was unexpected based on our experience that sodium sulfate reduction is plausible under the test conditions. Hence, further testing utilizing sodium sulfate in the direct reduction reactor was recommended so that the basis for more conclusive findings with regard to the future of direct reduction could be developed.

3 Sodium sulfate tests in the bench scale fluidized bed were completed. Preliminary analysis of the results from this test sequence has indicated that fluidized bed reduction of potassium and sodium sulfates is not a viable means of seed regeneration. A report detailing the sodium sulfate test sequence is forthcoming. Further experimentation utilizing this direct reduction reactor has been terminated.

7.6 Materials

During the reporting period, no metals corrosion testing was performed. However, an intrusive probe was prepared for use, and the probe cooling system was designed and constructed in the R&D facility. Two series of corrosion tests were planned to begin upon resumption of testing in Cell III in October 1979. These consisted of boiler tube simulation using carbon steel samples and superheater tube simulation using eight different iron-base alloys.

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

a. Capped Electrodes

The use of noble metal clad anodes for increased oxidation resistance is being investigated. Studies during the first three quarters have shown that the most desirable cladding is of a wrought metal foil on the order of 0.005 inch or greater to offer the best diffusion barrier to ion penetration and greatest assurance of a uniform coating. Of the materials tested, platinum and iridium have performed the best.

Attachment to the copper anode cap with silver brazing alloys has proven unacceptable due to sulfur attack on exposed brazing alloy

containing silver. Incomplete metal-to-metal bonds are also common with the use of fluxes due to the difficulty of removing them from between the planar surfaces to be joined. Fluxless brazing in a hydrogen (reducing) atmosphere using a copper-gold eutectic brazing alloy (20 percent Cu, 80 percent Au) has proven to be most acceptable due to the alloying effect of the gold to platinum, iridium and copper.

To assure a good fit of noble metal cladding to the cap and allow the use of a eutectic brazing alloy, a bending and brazing jig has been fabricated for forming the noble metal to the copper cap and holding the two surfaces together under compression during the brazing operation.

b. Interelectrode Insulation

A topical report entitled "Interelectrode Insulator Development for the UTSI MHD Generator," FE-10815-44, has been released for DOE review. It outlines insulator material development at UTSI during 1977-1979.

Hot pressed boron nitride (BN) underwent testing in the form of monolithic insulators, unbonded strips, strips bonded with a silicate bonded alumina adhesive, strips exposed to the gas stream, and strips recessed from the gas stream. An elastomer matrix asbestos sheet was used as a locator and gas seal backup for each insulator.

Exposed faces of the BN strips showed abrasion, apparently suffered during the early stages of startup. At unbonded joints of the BN and at fractures which existed prior to firing, seed penetration through the cracks was noted. Recessing of the BN strips behind the electrode faces for the unbonded strip insulator appears to have aided in that slag was tightly adhered to the ceramic adhesive. Electrochemical slag attack appears superficial. A recessed boron nitride insulator still showed the original machining marks at a location where the slag had chipped off.

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

c. Refractory Tests

The Kao-Tab 95 castable refractory insulation on the oxidizer injector plate was replaced with a Ruby Plastic ramming mix. In addition, the high density alumina tubing used to line the ports was replaced with thin-walled mullite to improve thermal shock resistance. This combination has performed well except for some degradation of the mullite tubes attributed to a temperature excursion in the inlet oxidizer temperature.

Experimentation with combustor refractories at UTSI has borne out that in specifying refractories for use in a combustor (i.e., located in a high heat flux zone) great importance must be placed on the refractory thermal conductivity. Because of this, silicon carbide has emerged as the most

likely candidate for this application. At present, various types of matrix constituents and binders are being investigated for use in holding the silicon carbide grains in place.

The calcium-aluminate bonded matrix containing silicon carbide does not appear as susceptible to leaching as the high alumina refractories. This may be due to the lesser temperature gradients seen in silicon carbide refractories.

Samples of refractories to be tested for use in the radiant furnace were obtained and several preliminary tests were performed. It was noted that in those refractories utilizing a calcium-aluminate bond, the slag in contact with the refractory tends to leach out the calcium leaving unbound grains. Clay bonded refractories show significant slag penetration and reactions along grain boundaries. Chrome-containing refractories have shown slag resistance that increases as the chrome content increases. The chemically bonded high aluminas appear to be good candidates because the chemical bond (such as alumino-phosphates) has low temperature strength which is maintained until a heat set is obtained.

7.7 Diagnostics

A Coriolis Mass flow meter was evaluated and deemed acceptable for the on-line, continuous measurement of coal flow for testing in the R&D facility. A topical report is in final stages of preparation describing this work.

Improvements were made to the relative temperature system and, based on the success of the joint US-USSR testing discussed under Task 5, plans were implemented to set up a line reversal system at the R&D facility.

7.8 Generator Loading

Work to date has been limited because of the difficulty in obtaining qualified personnel to work on this Task.

7.9 Process Control

During the reporting period, effort was concentrated on the development of:

- 1 A steady-state model for a commercial scale MHD generator using the Continuous System Modeling Program (CSMP) simulation language. This was completed and was able to account for friction, electrode voltage drops, and heat transfer. It was used to provide basic input/output characteristics such as load lines.
- 2 A simple model of an inverter feeding a stiff AC grid.
- 3 A scheme for analyzing the frequency characteristics of an inverter.

Using the models for the MHD plant and the inverter, along with known models for a steam plant, an incremental model for an MHD/steam plant was devised. This model was used to study the power-frequency control of such a plant, using both classical and modern control theory techniques.

SECTION III

LAST QUARTER TECHNICAL PROGRESS

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

1.1 Design and Construction

Bid Package 1 (Laboratory/Office Building) was completed this quarter, as was Bid Package 6 (Site Electrical Transmission and Distribution). Figures 4 and 5 show cryogenic work being performed in completing Bid Package 1.

The Control Room and Test Buildings (Bid Package 2) piping and electrical work has been completed. This includes painting, touchup work, and final piping details. At the end of 1979 the building complex was essentially complete and was prepared for turnover to the University. Total work is now approximately 98 percent complete.

Work progressed in the Coal Processing Area (Bid Package 3) as indicated by Figure 6. Further, work has reached the point that both closeout items and punchlist items were worked on. This total Bid Package is now almost 98 percent complete.

On bid Package 5 (Support Systems and Shelters), the fire pumps were installed (see Figure 7) and checked out. Fire loop piping (see Figure 8) was completed and flushed, with only hydrostatic testing remaining. The Cooling Water Shelter was energized electrically and pumps checked out. Piping was essentially installed (Figure 9) with only hydrostatic testing remaining. Equipment was emplaced on the Lake Pump House slab (Figure 10) and the building is now nearly erected (Figure 11). This bid package is approximately 85 percent complete.

On the Oxidizer Supply System, Linde delivered the equipment to the site and installation began. At the end of 1979 the tank (three cryogenic storage dewars) and vaporizers and boiler were placed on site. Installation and piping will continue into 1980. Also, during the final quarter of 1979 design work began on the Sample Preparation and Inverter Shelters, in order to get the foundation drawings out before winter drawings were completed and bids received.

During the quarter the coal pulverizer unit was inspected by the Babcock and Wilcox technical representative and the air flow was calibrated (Figure 12). Total construction work on the CFFF under this contract (for all site work presently awarded) is estimated to be nearly 98 percent complete.

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

Figure 4. Workman Installing Piping On Cryogenic Bridge

Figure 5. Workmen Installing Conduit On Cryogenic Piping Bridge

Figure 6. Pipefitters Installing Fuel Oil Lines To Coal Processing Tower

Figure 7. Diesel Fire Pumps Being Unloaded On The Lake Pump House Slab

Figure 8. Completing Work On Fire Line Loop

Figure 9. Cooling Water Tower Piping Nearly Completed

Figure 10. Equipment In Place On The Lake Pump House Slab

Figure 11. Erection Of Lake Pump House Building

Figure 12. Checkout of the Pulverizer Unit

future testing. The high mass flow design presently stands as a short run test with a three hour run duration. Tests in excess of this three hour maximum will require upgrading the primary quench by inclusion of a continuous slag removal screw conveyor in the design.

Phase 1 of the quench system, involving vendor fabrication, will progress at UTSI in March. We are holding up Phase 2 until DOE notifies us of what will have to be done to accommodate the needs of the HRSR contractor.

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

2.1 Primary Combustor

During the last quarter the Design Review Committee's action items were answered and vitiation heater and primary combustor drawings for fabrication completed. (See attached drawings, Figures 13 and 14.) Approval for both components was received from DOE. Bid packages were sent to vendors. The vitiation heater bids were received just prior to the Christmas holidays and a UTSI quality assurance representative inspected one of the vendor facilities. Early in the next quarter, after review of the inspection report and evaluation of the bids, a purchase order will be processed for the vitiation heater. Bids on the primary combustor are due in mid-January. Efforts will also continue to finalize and order instrumentation and conclude the interface requirements between component and facility.

The nozzle design is now complete. The bid package is being assembled and will be released for bid on Quality Assurance (QA) approval. The conductivity channel is in fabrication with delivery scheduled for April 1980.

2.2 MHD Generator

Computer drawing of the generator electrode frames is progressing. The bid package will be assembled and a final design review will be scheduled in the coming quarter.

Based on testing of the aerodynamic channel in the R&D Facility, the diffuser design has been modified. This modification will delay release of the bid package, but should not impact the test schedule.

2.3 Downstream Components

The drum module for the radiant slagging furnace was awarded during early November 1979. All modules were therefore under fabrication at various stages of completion by the end of the year. Figure 15 is a photograph of the primary furnace module under fabrication at the vendor shop. Figure 16 is a similar photograph of the slag tap at the top of the slag receiver module.

Figure 13. Vitiation Heater

Figure 14. Primary Combustor

Figure 15. Primary Furnace Module Under Construction in Vendor's Shop

Figure 16. Top Portion Of The Slag Receiver Under Construction

Discussions with several refractory manufacturers and applicators about the optimum refractory type to use in the various zones of the furnace indicate that the use of chrome ore based ramming mixes was not the preferred material for application to vertical walls. The recommended material for both durability and installation economy is a chrome-ore based gunning mix. The spacing of the refractory support studs was also discussed at these meetings with the refractory vendors recommending a maximum stud spacing of no more than one and one half inches. Since the original design called for a stud spacing of three inches, a change order was issued to the fabricator of the furnace modules changing the spacing. All or a portion of the increased cost incurred will be recovered by the decreased installation cost of the gunned refractory as opposed to the rammed refractory.

Work was started in the installation of the steel support structure in December with the work approximately 40 percent complete by the end of the report period. Figure 17 is a photograph of the steel work under construction. Inclement weather during the month prevented completion of the structure during the report period.

Project time phasing was maintained during the early portion of the report period, but delays due to withholding bid packages and insufficient manpower during the middle of the year resulted in slippages in the overall project completion schedule. The major components and the support structure were expedited through the fabrication phase with a net result that essentially no slippage will occur in these components. A three-month project slippage is forecast, however, due to long term delivery of such items as electrical components and instrumentation and relief valves. Next quarter, efforts will continue to be made to expedite these items.

During the reporting period an air bustle to extend the existing bustle to four sides of the secondary combustor as suggested by the design review panel for greater oxidizer flexibility was designed, priced, and added to the secondary combustor purchase order. Refractory stud spacing was also investigated as noted above and a new pattern and type of refractory were recommended to conform to that being applied in the radiant furnace modules. The drawings were also updated to reflect these changes.

The secondary combustor module will be delivered early next quarter. Efforts will continue to finalize some minor instrumentation requirements and interfacing between the component and the facility.

Regarding the combustion air preheater, a project was initiated in November 1979 to design and construct a heat exchange unit for inclusion in the low mass flow CFFF flow train to simulate the direct heating of oxygen enriched air 866-925K (1100-1200°F) for primary combustion. Direct air heating is a desirable alternative to vitiation air heating in that the need for a secondary non-coal fuel is eliminated. However, many unknowns exist relative to optimum configuration, materials stability, seed/ash fouling and consequent heat transfer characteristics and deposits removal. The experimental unit in the CFFF will be designed to investigate these unknowns by simulating as closely as possible the conditions expected for an actual heater.

Figure 17. Structural Steel For Support of The Radiant Furnace and Secondary Combustor

Work during the reporting period has consisted of setting design specifications and reviewing alternative design concepts and materials requirements relative to corrosion stability in the severely aggressive environment. Work during the next quarter will consist of finalizing design specifications and developing a preliminary design.

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

In the microscopic and materials laboratories, refractories for intermediate to low heat duty were examined for confirmation of elemental content and morphology.

Plastic chrome ore (TP41-07) composed of aluminum, silicon, chrome, and iron was taken from the radiant furnace and examined to note the existence of a reaction product, resulting from its reaction with the constituents of slag. Spinel type structures were evident in the refractory-slag interphase and were found to be composed of aluminum, silicon, and potassium. Slag attack of the aggregate was evident.

This quarter, some visibility of the work required on maintaining the engineering effort for the CFFF was obtained. In 1980 the nature of these projects will be better defined.

Kemram (TP41-10) composed of chrome and iron from the radiant furnace probe (TP41-10) was analyzed for its interaction with slag. Reactant products composed of iron, potassium, and silicon were evident.

Electrodes from Module V (TP40) were examined for the effectiveness of the silver brazing alloy. Areas along the downstream edge of the anode cap did show signs of heat stress evident by the crystalline pattern of the grain structure and the slothing off of platinum about 3000 μ m from the downstream edge. There was intragranular erosion in the sidewall cap at areas of failure.

Interelectrode insulators of TP40 were examined for slag attack on various areas of each insulator. Energy dispersive analysis showed the presence of slag on the Refrasil insulator, but no gross damage was evident. Slag samples from various locations in the MHD power generation system were examined for basic constituents and crystalline phases evident in the composite. Boron nitride unused was examined from two different angles to determine which surface had less pores. Analysis was also made to determine if any impurities existed, but none were found.

Observation of both upstream and downstream deposits on Spacer 1 of the high temperature probe TP41-14 was made to determine the elemental

content of deposits present. Silicon, potassium, sulfur and iron were found to exist there but in different amounts at each location.

The corrosion probe of TP41-07 at the crossover duct (simulating the drum module of the CFFF), Cell III carbon steel, showed signs of corrosion evident by the visibility of grain structures in the metal. Corrosion probe sample TP41-04 was analyzed for the ash-metal interphase.

Next quarter, services will continue to be provided as needed.

Environmental analyses continued during the final quarter and results showed similar trends of previous months except for parameters affected by seasonal changes and higher values reported for iron. Since there was no apparent correlation of increased values for any parameter with scheduled test runs during the quarter, runoff from the terrain above has been determined to be the main source of iron. Also, modification of sample preparation in mid-October could have affected the values for iron this quarter. Stored data from the state reveals that the iron content of Woods Reservoir had a range of .049-3.30 with a mean of 0.532 over a 15 year period. Overall, our water quality data for the year compares favorably with that furnished by the State of Tennessee Department of Public Health.

Initiative was taken during this reporting period to comply with environmental regulations regarding air, water, and solid waste disposal. The Tennessee Division of Air Pollution Control requires that application for an operating permit be made within 60 days after operation has begun. At the appropriate time, efforts to obtain this permit will be made. In the meantime we will continue to operate under the construction permit issued in 1976. Also during the quarter, application was made to the Division of Water Quality Control for a point source discharge permit. Approval from the State of Tennessee is expected during the second quarter 1980. In addition, the Division of Solid Waste Management authorized the disposal of waste from the CFFF into a registered sanitary landfill. Compliance with regulations regarding all permits for the CFFF is expected to be completed by the end of the second quarter 1980.

Other environmental activity during the quarter consisted of designing a holding pond system for the CFFF. A recommendation was made for a pond system consisting of two 50' x 100' x 4' concrete ponds with a total capacity of 300,000 gallons. This arrangement will enable treatment of the effluent, if necessary, before discharge. The holding ponds will be adequate for our operation and will enable us to meet State and Federal requirements for point source discharge.

Beginning next quarter we will continue water quality monitoring. Composite samples will be used to assess the value of some of the parameters.

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

There is no activity to report.

E. TASK 5—TESTING OF DOE SUPPLIED COMPONENTS

There is no activity to report.

F. TASK 6—MODIFICATIONS TO THE CFFF

No activity took place in the final quarter other than meeting with DOE to explain and justify the recommendations. We await official word as how to proceed. A problem area which has been identified is with the workload projected. There is not enough manpower in the Design Engineering Department to do an adequate job for these modifications.

G. TASK 7—TECHNOLOGY DEVELOPMENT PROGRAM

7.1 Primary Combustor

The beneficial results of cold flow modeling have provided the impetus to extend the primary combustor effort. A program of flow visualization and non-intrusive velocity field surveying was formulated to enable a variety of vitiation heater, coal combustor, and disperser plate concepts to be experimentally evaluated quickly and at relatively low cost. A site for extensive cold flow research was chosen and test models were selected. An instrumentation system, including a modern Laser velocimeter probe, was selected and purchase orders for the components were sent out for bids. The existing disperser plate in the combustor of Cell I was analyzed for heat loss and mixing by applying turbulent jet mixing theory. Suggested design modifications were incorporated into a modified plate which awaits hot flow research testing and validation.

A program was initiated to develop a three-dimensional elliptic flow computer program for predicting the flow in the various UTSI combustor designs. The program will be calibrated, based on the data obtained in cold flow model research, and then used to evaluate or predict designs acceptable for much larger scale, multiport coal combustors that will eventually be required for commercial sized MHD power plants. Research into the design and performance of multiport coal combustors of the UTSI high slag carryover type was initiated by the formulation of a new research project (Task 7.1.2, Multiple Coal Injectors) which has been approved. This project is intended to culminate in a demonstration combustor for development testing in the CFFF.

Local heat flux measurements were also made in Cell III. Both the commercial heat flux probes, housing a radiation flux probe and the special thermocouple probes designed by us, were located close to each other for comparison of measurements. Determination of the integrity of this instrumentation and evaluation of total heat balance of the system were included among the primary objectives of a test plan (TP 41).

The heat flux distribution and the total heat lost in all components were analyzed for various runs. There was very good agreement between the heat flux measured by the commercial probe and the specially designed probes. Radiation measurements indicated about 12 percent of heat transfer by radiation. Some problems such as thermocouple life and radiation heat flux window breakage were experienced. We are working on possible solutions to these problems. The probes will be used in the CFFF-LMF System. The variation of heat flux in the system with time (due to slag buildup) and the effect of secondary combustion and nitrogen/oxygen fraction were studied.

A preliminary letter report on Cell III heat transfer was released. A report "Supersonic and Subsonic Diffusers for MHD Generators" has been prepared. Another report based on testing in Cell III during this quarter is under preparation. Further, technical support was provided to the MHD Gasdynamics Section on heat transfer in the diffuser.

The work to be accomplished in the next quarter is to continue the fabrication of cold flow models and prepare the test site for their installation and testing. Alternate designs for multiport combustors will be selected and some travel to other MHD combustor research facilities will be done to review existing combustor designs. A first step will be taken to formulate the combustor analytical methodologies necessary for future combustor design and evaluation needs.

7.2 MHD Power Generator

No duct development testing was conducted this quarter. However, data reducing and analysis for TP40 continued. In addition to the Test Report, a paper is being submitted for the Seventh International Conference on MHD Power Generation. Preparation for continuing this test series is underway. After completion of a test of downstream components now in the R&D Facility, duct development testing will continue.

Program development continued in several areas of advanced analysis: (1) comparison of results of recently acquired programs (Argonne, Stanford, etc.) with results from programs in use at UTSI, (2) development of a slag model and incorporation into a two-dimensional MHD program, and (3) improvement of the quasi-one-dimensional code in use. This effort will continue next quarter.

7.3 Downstream Components

During this last quarter the first phase of testing in Cell III was completed, with a total of seventeen runs. The data are being evaluated and chemical laboratory analysis of the flyash and slag is being completed. After these are completed, decisions will be made about the phase two testing in Cell III. The data are being evaluated for information about dust loading, particle sizing, NO_x and SO_2 emissions reduction, material corrosion, refractories, and alternate methods of air injection in the secondary combustor. These tests took longer than anticipated because of delays caused chiefly by failure of hardware components. During this testing, failures occurred in the simulated aerodynamic channel and one of the constant area spacers. Internal water leaks also occurred in the

combustor, refractory probe, and water injection probe. We are evaluating what hardware is needed to increase reliability during the second phase of testing.

During the current quarter a paper was presented at the Winter Annual ASME Meeting in December. Next quarter we will continue evaluating what hardware is needed to increase reliability during the second phase of testing.

This quarter, with regard to the radiant furnace, tests were performed on B&W's plastic chrome ore and C.E.'s Kemram in the Cell III refractory probe during TP 41. The results are included in the Materials section of this report under Refractories (Task 3.1).

Next quarter, effort will continue on monitoring test results.

7.4 Seed Regeneration

During the last two quarters of 1979, an economic analysis of the Tomlinson Tampella and Formate processes was undertaken in cooperation with a grant received from the NASA Lewis Research Center. The results obtained from this analysis are directly applicable to the seed regeneration project being supported under this contract. Although further analysis is required, we have preliminarily concluded that the Tomlinson Tampella process is the most economically viable method of seed regeneration for high sulfur coal MHD plants. On the basis of this conclusion, the Tomlinson Tampella process will undergo further evaluation such that a conceptual design for the CFFF will be available by July 1980.

7.5 Pollution Control

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

Next quarter, we will continue our study of the feasibility of using electrostatic precipitators or bag filters with or without an agglomerator.

7.6 Materials

Tests for metals corrosion under MHD gas-seed conditions in Cell III have been conducted for evaluation of candidate downstream component materials. Two series of tests were done using two intrusive probes.

In the first series designed to simulate boiler tube conditions, 3.81 cm (1.5 inch) O.D. tubular samples of 1030 carbon steel were tested in the crossover duct under reducing conditions with gas temperatures of about 1000-1100K. The metal temperatures ranged from about 573K to 693K with the temperature at the middle of the test section maintained at 644K (700°F) by

nitrogen or air cooling. Testing of these samples was conducted during seven runs of Test Plan 41 for a total of 295 minutes or about five hours.

Deposits of potassium compounds and ash were formed to a thickness of 3-4 mm on the upstream face, see Figure 18, and 1-2 mm on the downstream face. These ranged from very tightly adherent on the higher temperature portions of the upstream face to extremely fragile on all of the downstream face. While chemical analyses have not yet been performed, EDX analysis, pH tests in aqueous solution, and its hygroscopic nature indicate it to be largely potassium carbonate with a lesser amount of potassium sulfate.

Corrosion of the carbon steel was largely by pitting, as shown in Figure 19, although a transition to a more sheet form of corrosion was indicated on the upstream portion at temperatures above about 675K (750°F), as seen in Figure 20. The severity of the degradation increased substantially over the temperature range experienced. Gravimetric tests indicate less than 0.01 percent weight loss per hour for all samples. The mechanism of this corrosion has yet to be determined but may involve the reaction of either potassium sulfate or potassium pyrosulfate with the iron oxide to form a complex potassium iron trisulfate.

In the second series of tests, designed to simulate superheater tube conditions, tubular samples of eight different candidate alloys were exposed to oxidizing conditions using a probe inserted just downstream of the secondary combustor. These materials were 1030 carbon steel, Croloy-1/2, Croloy-2 1/4, 304 SS, Croloy-9, 310 SS, 316 SS, and 446 SS. The metal temperature at the center of the test section was controlled at 866K (1100°F) with a temperature variation of about 100K over the test length, i.e., from 815K to 912K. Testing was conducted during two runs of TP 41 for a total of 86 minutes.

Figure 21 shows the deposit on the upstream side of the high temperature probe. The nature of this deposit and the extent of corrosion on the individual alloys has yet to be ascertained. The thickness of the upstream deposit was about 3 mm, while that on the backside was about 1 mm thick. Neither deposit was well adhered to the metal surface.

Continued metals corrosion testing using the same samples is planned when testing is resumed in Cell III.

Because the MHD process adds potassium compounds to coal ash and sulfur compounds which result from coal combustion, the aggressiveness of this environment requires careful selection of construction materials. To select materials best suited for use in commercial installation, programs to test the performance and durability of candidate materials are imperative.

Figure 18. High Temperature Probe Showing Potassium Compounds and Ash Deposition

Figure 19. Photomicrograph of Carbon Steel Pitting

Figure 20. Photomicrograph of High Temperature Corrosion

Figure 21. High Temperature Corrosion Probe

A general review of the material requirements at UTSI was presented at the 4th Annual Conference on Materials for Coal Conversion and Utilization, October 9, 1979, at National Bureau of Standards (NBS). The paper was entitled "Material Design Requirements for MHD."

a. Capped Electrodes

Investigations during this quarter have shown that the major degradation of the cladding still present is at the leading edge of the capped anode. It is apparently encouraged by the microfractures caused at this location during the bending operation, particularly with the use of iridium. Minor degradations are in the form of particle impact tracks, especially for the platinum which is relatively ductile, presumably occurring during the early stages of startup before a full slag layer has developed. Future plans include attempts to hot work the noble metal in the bending operation to alleviate the problem of brittle fractures and to conduct investigations into the use of noble metal alloys.

Because of the high heat fluxes incurred in the upstream portion of the channel, unclad copper anodes are currently used. This heat flux along with the high velocity particle laden gases at this location provides a highly erosive environment. During this quarter, in an attempt to find a way of enhancing the ability of copper to withstand these conditions, two caps have been made from 20 percent aluminum oxide dispersion strengthened copper and will be tested in an upstream location in the upcoming Cell I tests, TP 40A.

b. Stainless Steel Electrodes

Tests have been conducted on the use of austenitic stainless steel for electrode frames in an effort to avoid copper in any future boiler feed-water circuitry and allow increased interelectrode bolting forces. Unclad copper caps were used with a copper powder and glycerine mixture underneath to help assure good heat transfer. Investigations during this quarter have shown that the failure of the anode cap after a short run is due to a combination of poor heat transfer and electrochemically enhanced oxidation. There is also some indication, although slight, of sulfur attack, indicating that sulfur attack of the copper may be a step in the oxidation of the copper cap.

In an effort to determine the effects of the high heat fluxes experienced by the electrode in the upstream position, this test will be rerun in TP 40A with several electrodes in a mid-channel location. The anode caps have also been given a noble metal cladding for oxidation protection. This assembly was made and checked during the fourth quarter and will be run in the upcoming test plan, TP 40A.

c. Interelectrode Insulation

During this quarter, the channel was assembled for testing in TP 40A. Of the electrode modules, only Modules 1 and 5 were replaced allowing a run

time accumulation on the rest of the modules. All caps were held in place with scroll pins and installed with a copper/glycerine mixture underneath. Module 1 consisted of all copper framed electrodes. The first two electrode anode caps were fabricated from an alumina dispersion strengthened copper, Glidcop AL-20. These frames were insulated with standard Refrasil impregnated with boron nitride paste. Electrodes 3 through 8 were insulated with 1/16 inch thick hot pressed boron nitride backed up with g-7 phenolic and Dow Corning's 96-083 adhesive to provide mechanical support and gas sealing capabilities. These insulators included both monolithic and pieced strips of boron nitride with several different joint configurations. All joints were bonded with Cermabond 503, silicate bonded alumina adhesive. Electrode 9 was insulated with "Irish" Refrasil and boron nitride paste. Electrodes 7, 8 and 9 had a .010 inch platinum cladding brazed to their anode caps with a .005 inch thick foil 20 percent copper/80 percent gold brazing alloy in a hydrogen atmosphere.

Module 5 was insulated with 1/8 inch thick monolithic hot pressed boron nitride insulators, three of which were broken during assembly. These broken insulators between Electrodes 41 through 44 were left in place to test the necessity of having monolithic or bonded joint boron nitride insulators. Each insulator was held in place with a sheet of Garlock 900 and provided for a gas seal by coating the faces of the Garlock with RTV. Electrodes 40 through 44 had austenitic stainless steel frames with Electrodes 41 through 44 having platinum cladding brazed to the anode caps as in Module 1. Electrode 40 had a .005 inch cladding of iridium braze to its anode cap in a similar manner. The remaining electrodes in Module 5 had copper anode caps.

Plans are to run TP 40A during the next quarter. Reporting on the performance of the materials will be made as analysis becomes available.

d. Refractory Tests

Because of the high heat fluxes encountered in the coal combustor, equilibrium thicknesses of most refractory materials with only moderate to low thermal conductivities are very thin (several thousandths of an inch). Therefore, it is believed that most of the refractory failures that occur are mechanical. In an attempt to counter this effect, a phosphate bonded chroma/alumina solid solution ramming mix has been mixed with a silicon carbide powder intended for phosphate bonding. This mix has been installed and will be tested in the upcoming test plan, TP 40A.

Also during this reporting period, a determination has been made of the recommended coatings for plasma spraying the stainless steel liner of the vitiation heater. The two recommendations are as follows:

- 1 A bond coat bore to .006 inch thick consisting of plasma spray powder No. P-443, a second layer of Cermet .006 inch thick METCO powder No. P-412 and a third coat of .006 inch METCO powder No. P-201B-NS-1. (Zirconium Oxide)

- 2 A bond coat from .004 to .006 inch of METCO spray powder No. P-443, a Cermet, .006 inch METCO powder No. P-421 and a final coat .006 inch of METCO powder No. P-210. (Magnesium Zirconate)

Plastic chrome ore and Kemram have been tested in a recently installed refractory test probe located in the radiant furnace of Cell III. Analysis indicates that the Kemram has a superior slag resistance which seems to be attributable to its being composed of more pure aggregates and in its ability to form a spinel with the attacking slag. This spinel has a very high resistance to further attack by the slag.

Future plans for refractory testing include the studding of the exhaust flange of Cell I to provide a test location.

7.7 Diagnostics

Relative plasma temperatures have previously been measured using an optical probe to measure plasma luminosity over a narrow bandwidth (wavelength) where a potassium emission line is located. Since it is also very desirable to measure absolute plasma temperatures, a system has been assembled and tested to perform this function.

The system employs the modified line-reversal method to measure the absolute plasma temperature. The basic plan of this method is to measure both the plasma emission and absorption simultaneously to calculate plasma temperature. A diagram of the system is shown in Figure 22. A tungsten lamp filament emission of a known brightness temperature is focused through an optical chopper into the plasma, and then focused out of the plasma on the other side onto the spectrometer slit. The spectrometer is set to detect light in the wavelength region where an atomic species (such as Na or K) in the plasma emits a characteristic line. The chopper alternately opens and blocks the light path of the lamp into the plasma so that the detector sees two time-resolved intensity signals corresponding to that of the plasma, B_p , and that of the lamp plus plasma B_{L+p} . A signal separator is synchronized with the chopper and separates the time-resolved signal into two separate continuous signals which are recorded by the data acquisition system. The temperature is then calculated by:

$$T_p = \frac{T_L}{1 - \frac{(\lambda T_L)}{C_2} \ln \frac{K B_p}{B_p + B_L - B_{L+p}}}$$

T_p = plasma temperature

T_L = Lamp brightness temperature

λ = wavelength

B_p = measured plasma intensity

B_L = measured lamp intensity (before plasma is present)

B_{L+p} = measured intensity of lamp + plasma

C_2 = 14,380 μ - °K

K = transmission coefficient of optical system between lamp and plasma

The measured temperature, T_p , represents an averaged temperature along the optical path in the plasma.

Figure 22. Line Reversal System

The line-reversal system was applied to the measurement of plasma temperatures in the recent TP 41 test series in Cell III. The initial tests were used to debug the system and to measure the plasma emission spectrum. A typical plasma emission spectrum which was obtained during TP 41-04 is shown in Figure 23. The major spectrum peaks correspond to K emission (765 nm) and Na emission (589 nm). This K peak shows a self-reversal effect which is seen as a dip in intensity at the peak and is probably due to the presence of a relatively high concentration of colder K atoms in the boundary layer which re-absorbs some of the radiation emitted by the hotter K atoms in the central region of the plasma. This effect was not seen in plasma spectra of tests where K seed was not added; this is due to the low concentration of K atoms in the boundary layer. Several lesser intensity K peaks (405 nm, 579 nm, and 691 nm) and one small Na peak (554 nm) were also observed in the plasma spectrum as well as a possible singly-ionized K peak (624 nm).

During the later tests of this series, after debugging was completed, the system indicated plasma temperatures in the range of ~2620 to 2750K for normal test conditions, which appears to be reasonable. A typical time-plot of measured plasma temperatures for TP 41-13 is shown in Figure 24. The test plan for TP 41-17 provided for several changes in combustion stoichiometry and the plasma temperature changes as indicated by both the conventional optical luminosity probes and the line-reversal system were found to follow closely the changes in oxygen flow rate as would be expected. Figure 25 shows the gross correlation of these three parameters. This correlation among luminosity probes, the line reversal system and the oxygen flow rate indicates that the line-reversal system is operating properly.

7.8 Generator Loading

The activities in this area during the last quarter were limited largely to review of previous work and a literature search. These efforts were directed toward structuring a program that would lead to a practical power take-off inverter system. Previous experimental work has demonstrated that resistors and diodes can be effective means of current limiting for a single operating point of the generator. However, they provide no means of adjustment to provide the optimum current distribution on the electrodes during periods of turndown and change in operation of the generator. On the other hand the active devices that have been proposed all involve complex power semiconductor switching which leaves considerable doubt about their economic practicality.

7.9 Process Control

The incremental model for the MHD/steam plant was used to design the algorithms necessary to control a plant via power-frequency control, and the resulting controlled plant was analyzed. This endeavor is still being pursued in an effort to determine the best cost functions to use in designing the controls to give reasonable response to a step change in load.

A more representative plant--with nearly equal MHD and steam sections--will be treated next. In the use of the optimal control techniques a more realistic cost function involving both frequency deviations and all fuel inputs will also be utilized in an attempt to improve the plant's economic

characteristics. Subsequent work will deal with model improvement and construction of the control necessary to respond to external faults, load division requirements, and internal parameter variations.

Figure 23. Plasma Emission Spectrum

Figure 24. Time Plot of Plasma Temperature for TP 41-13

Figure 25. Correlation of Plasma Temperature, Oxygen Flow, and Optical Luminosity Probe Signals

SECTION IV. CONCLUSIONS

Discussions with refractory specialists about the optimum refractory type to use in the radiant slagging furnace have resulted in the decision to use a chrome-ore based gunning mix.

Toward seed regeneration progress, an economic analysis of the Tomlinson Tampella and Formate processes was made. A preliminary conclusion is that the Tomlinson Tampella process is best for high sulfur coal MHD plants.

In materials evaluation, investigations show that the major degradation of the capped electrode cladding still present is at the leading edge of the capped anode. It is apparently encouraged by the microfractures caused at this location during the bending operation, particularly with the use of iridium. Because of the high heat fluxes encountered in the coal combustor, equilibrium thicknesses of most refractory materials with only moderate to low thermal conductivities is very thin. Therefore, it is believed that most of the refractory failures that occur are mechanical. It has been concluded that a phosphate bonded chroma/alumina solid solution ramming mix with a silicon carbide powder will counter this adverse effect.

The most significant development in the R&D Program this year was the successful test of a generator in which some electrodes were constructed of copper caps isolated electrically from the cooling water passages. This was intended originally to acquire current distribution data in the generator. It performed this function and may have application to the construction of generators in which the electrode frame is segmented and the current distribution around the frame can be controlled.

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