THE UNIVERSITY OF TENNESSEE
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**TECHNICAL PROGRESS REPORT
FOR
THE MAGNETOHYDRODYNAMICS
COAL-FIRED FLOW FACILITY**

For The Period
April 1, 1995 - June 30, 1995

July 1995

Work Performed Under Contract No. DE-AC02-79ET10815

Prepared for:
The United States Department of Energy

Prepared by:
The University of Tennessee
Space Institute
Energy Conversion Research and Development Programs

TULLAHOMA, TENNESSEE 37388-8897

COAL FIRED FLOW FACILITY

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PREFACE

The purpose of this report is to provide the status of a multi-task research and development program in coal fired MHD/steam combined cycle power production. More detailed information on specific topics is presented in topical reports. Current emphasis is on evaluating technology for the Steam Bottoming Cycle Program. The approach taken was to design test components that simulate the most important process variables, such as gas temperature, chemical composition, tube metal temperature, particulate loading, etc., to gain test data needed for scale-up to larger size components.

Previous reports have provided comprehensive data on NO_x and SO_x control, radiant heat transfer, particulate control (baghouse and wet and dry electrostatic precipitators), environmental monitoring, and analyses of test data on the convective heat transfer components (superheater and air heater) with eastern, high sulfur coal firing. For this quarter, analyses of the data for previously completed eastern coal testing and western coal proof-of-concept (POC) tests continued on a limited basis due to the loss of personnel in downsizing the organization for program closeout. Detailed data analyses will be contained in test reports, topical reports or technical papers to the extent permitted by resources available.

Also during the quarter activities continued in maintaining the CFFF in standby condition, readying the facility and equipment for disposition, fulfilling site environmental compliance and remediation requirements, and the preparation and maintenance of data and documentation for archiving.

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ABSTRACT

In this quarterly technical progress report, UTSI reports on the status of a multi-task contract to develop the technology for the steam bottoming portion of a MHD Steam Combined Cycle Power Plant. The report describes the facility maintenance and environmental work completed, status of completing technical reports and certain key administrative actions occurring during the quarter.

With program resources at a minimum due to closeout the MHD program, no further testing occurred during the quarter, but the DOE CFFF facility was maintained in a standby status, preventive maintenance and repairs accomplished as needed. Plans and actions progressed for environmental actions needed at the site to investigate and characterize the groundwater. Data and documentation on results of the MHD program have been identified for archiving and are being maintained for archival storage.

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SECTION I

OBJECTIVE AND SCOPE OF WORK

Under Contract No. DE-AC02-79ET10815, the overall objective initially was to advance the technology of direct coal-fired MHD components and systems required for MHD power generation operating under conditions simulating those of central power stations. The specific objectives of the DOE Coal-Fired Flow Facility (CFFF) were to resolve experimentally and analytically the key technical areas of concern identified or found to occur in direct coal-fired MHD systems with moderate to high ash carryover. The key areas involved (1) combustor performance, (2) ash/seed particle collection efficiency from the exhaust gas stream, (3) effects of plugging, fouling and corrosion during normal operation, (4) performance of candidate materials in a direct coal fired MHD environment and (5) the operation, conditions, procedures and equipment needed to meet pollution control requirements.

In view of the conclusion of the MHD proof-of-concept program and acquisition of data, DOE directed UTSI to take the following actions:

- a) contract closeout;
- b) property disposition;
- c) reporting and archiving of data; and
- d) environmental remediation

In support of the above objectives and the DOE FY1994 MHD Program Plan, a revised contract statement of work (SOW) and management plan were approved by DOE. The technical approach now focuses on the following four (4) tasks described below:

TASK I - Contract Management and Close Out

This task provides for the overall management of the program which entails the planning, organizing, scheduling, directing, coordinating and controlling of the resources required in the close out of the contract. Specific support staff functions include project control, reporting, accounting and financial affairs, government property administration, and contract administration.

TASK II - Facility and Property Disposition

This task provides for the maintenance of the CFFF in a standby condition until final disposition of the facility is made. All government owned property and equipment will be documented and controlled, and worn or unusable material will be recommended for applicable disposition.

TASK III - Data Reporting and Archiving

The contractor shall collect all data generated during the proof-of-concept testing program and place in a retrievable condition by identifying and documenting in accordance with its nature, format, quantity and repository. Data to be archived will be selected on the basis of certain criteria.

TASK IV - Site Environmental Compliance and Remediation

The Coal Fired Flow Facility site shall be subject to a DOE-directed project environmental characterization whereby site compliance and remediation requirements and actions will be identified and documented. The contractor shall accommodate this effort by providing accessibility to all pertinent areas and relative information and documentation as needed to perform the environmental characterization.

The contractor shall be prepared to perform the tasks necessary for site remediation and site restoration as determined by the site characterization study and as decided upon by the U.S. Department of Energy, and within the limitations of allocated costs.

CFFF PROGRAM GOALS AND SCHEDULE

Figure 1 shows the major program tasks presently scheduled/completed during the April through June 1995 period.

UTSI/CFFF MAJOR ACTIVITIES & SCHEDULE
OCTOBER 1, 1994 - SEPTEMBER 30, 1995

FIGURE 1. Scheduled Tasks

SECTION II

SUMMARY OF TECHNICAL PROGRESS

This section addresses the technical progress of work conducted during the period April 1 through June 30, 1995, according to the objectives and scope of work tasks outlined in Section I. Figure 2 is an overview of the DOE MHD Coal Fired Flow Facility (CFFF) at UTSI, and Figure 3 is a schematic of the current LMF test train.

TASK I - CONTRACT MANAGEMENT AND CLOSEOUT

The final October-December 1994 and January-March 1995 Quarterly Technical Progress Reports were issued to DOE.

Monthly Contract Status Reports for March, April and May 1995 were prepared and sent to DOE.

The Subcontracting Report for Individual Contracts for the period ending March 31, 1995 was issued to DOE.

Dr. Harold Chambers of DOE/PETC visited UTSI to review the MHD program status and to discuss follow-on contract work after completion of the current MHD contract.

The 33rd Symposium on Engineering Aspects of Magnetohydrodynamics was hosted by UTSI and ERC, Inc. during June 12-15, 1995.

A no-cost contract extension (MOD #M112), extending contract performance through September 30, 1995, was received, signed and returned to DOE.

During this quarter UTSI was developing a contract proposal package for follow-on work after completion of the current MHD contract. Specific areas addressed were:

- Provide for the completion of all remaining efforts of reporting and archiving pertaining to the MHD research program at the UTSI.
- Complete the environmental restoration and remediation effort for the Coal-Fired Flow Facility (CFFF).
- Maintain the CFFF and government property in good standby condition.

FIGURE 2. Overview of the Coal-Fired Flow Facility

FIGURE 3. CFFF Integrated MHD Bottoming Cycle Schematic

- Prepare contingency plans for either reactivation or decommissioning of the CFFF.
- Review and assess potential uses for the UTSI/CFFF.
- Provide services to others by utilizing the unique knowledge and capabilities of the UTSI/CFFF.

TASK II - FACILITY AND PROPERTY DISPOSITION

No MHD testing was performed this quarter.

Activities this quarter continued to be concentrated on the facility preventive maintenance/repairs required to maintain the Coal Fired Flow Facility in a standby condition. Weekly and monthly equipment maintenance procedures were performed for facility air compressor systems, cooling water pumps, coal processing system motors, steam boiler systems, ID and FD fans, and fire water system equipment.

The reconditioning of the CFFF process cooling water tower continued this quarter. An interior protective polyurethane coating was applied on the bottom of each cooling tower quadrant. Cooling tower improvements will be completed next quarter with installation of the replacement cooling panels in each quadrant.

Semi-annual maintenance on the fire protection system was initiated this quarter. All fire hydrant boxes were checked for proper contents, and each fire hose was pressure checked. Painting of all ten fire stations and crossover valves was started this quarter.

The main electrical substation power monitoring equipment installed earlier this year has been operating very reliably and accurately. Power usage data is being continuously logged and periodically plotted. Preliminary plans are being made to expand the power monitoring measurements to the unit substation.

The data acquisition system is being kept operational, and periodic checks are made to ensure that it is functional. Maintenance, upkeep and repair continues on exterior security lighting on grounds and plant structures, electrical equipment, and plant power distribution systems. An electrical distribution addition was made in the CFFF test building to make it easier to obtain 480 VAC power for future test programs.

Continued improving the computer communications from CFFF to other campus buildings through ethernet, and from off-site through a new SLIP link to the CFFF

Sparcstation 2. The Sparcstation 2 operating system was upgraded to Solaris resulting in improved access to the campus Sparc computers and software applications.

A plan to upgrade the aging CFFF data acquisition and control system is being developed. The present centralized system has been in operation for 15 years and has been modified many times. The system requires a high level of maintenance due to the aging electronic components and wear on connectors. Replacement parts are difficult to obtain and expensive, while some parts are not available at all. The centralized nature of the system causes any change or addition to the system to be very labor intensive due to the multi-pair cabling installation and the documentation requirement. The plan involves replacing the entire system with a distributed data acquisition and control system.

TASK III - DATA REPORTING AND ARCHIVING

Superheater/ITAH Tube Corrosion Studies

Measurement and evaluation of the corrosion of alloy tubes tested in the Coal Fired Flow Facility (CFFF) during LMF5-E to LMF5-J with an accumulated exposure duration of 985 hours continued during this quarter. A list of the alloys tested and their nominal compositions are given in Table 1. Placement of those alloys in Test Sections (TS) 1 and 2 of the Superheater Test Module (SHTM) of the LMF flow train was as shown in Figure 4.

Measurements and evaluations of corrosion from tube samples from TS1 and TS2 were completed this quarter and preparation of a Topical Report on the findings is underway. Three types of evaluations have been performed. One was measurement of the thickness of the predominantly oxide scale formed on the outer tube surfaces and the depth on internal oxide/sulfide penetration due to interaction with the potassium sulfate/potassium carbonate deposit under the oxidizing flue gas environment. The sum of scale thickness and penetration depth was used as an approximate measure of the amount of affected metal or of effective wall thinning. The second type of evaluation was of actual wall thinning, taken from pre-exposure ultrasonic wall thickness measurements and post-exposure microscopic or micrometer wall thickness measurements. That is, cross-section samples at some locations were prepared for microscopic examination, and the remaining wall was measured with a dial displacement gage attached to a microscope stage. At other locations, tube samples were glass bead blasted and wall thickness measured with a tube or "inside" micrometer. The third type of evaluation was a qualitative assessment of the corrosion scale, penetration, and near-tube deposit morphologies.

TABLE 1. Nominal Composition of Test Alloys

	Cr	Ni	Cr/Ni	Fe	Mo	W	V	Nb	Ti	Mn	Si	P	S	Al	C	N
SA192	-	-	-	Bal.	-	-	-	-	-	0.45	0.20	0.03	0.03	-	0.15	-
T11	1.25	-	-	Bal.	0.50	-	-	-	-	0.45	0.75	0.03	0.03	-	0.15	-
T22	2.50	-	-	Bal.	1.00	-	-	-	-	0.45	0.50	0.03	0.03	-	0.15	-
T9	9.00	-	-	Bal.	1.00	-	-	-	-	0.45	0.40	0.03	0.03	-	0.15	-
316	17.0	12.0	1.42	Bal.	2.50	-	-	-	-	2.00	1.00	0.05	0.03	-	0.07	-
347	18.0	11.0	1.64	Bal.	-	-	-	0.70	-	2.00	1.00	0.05	0.03	-	0.07	-
RA85H	18.0	14.0	1.29	Bal.	-	-	-	-	-	0.50	3.50	-	-	1.00	-	-
304H	19.0	9.00	2.11	Bal.	-	-	-	-	-	2.00	1.00	0.05	0.03	-	0.07	-
MA 956	20.0	-	-	Bal.	-	-	-	0.50	-	-	-	-	-	4.50	-	-
800H	21.0	32.5	0.65	Bal.	-	-	-	-	0.38	0.80	0.50	-	-	0.38	0.08	-
253MA *	21.0	11.0	1.91	Bal.	-	-	-	-	-	0.80	1.70	0.04	0.03	-	0.10	0.17
Temp A3	22.0	15.0	1.47	Bal.	-	-	-	0.70	-	1.37	0.40	0.03	0.01	-	0.05	0.19
556 **	22.0	20.0	1.10	Bal.	3.00	2.50	-	-	-	1.00	0.40	-	-	0.20	0.10	0.20
310	25.0	20.0	1.25	Bal.	-	-	-	-	-	2.00	1.50	0.05	0.03	-	0.25	-
HR3C	25.0	20.0	1.25	Bal.	-	-	-	***	-	2.00	1.50	0.05	0.03	-	0.08	0.10
HR-160 †	28.0	Bal.	0.74	4.0	-	-	-	-	-	0.50	2.75	-	-	-	0.05	-
IN 690	29.0	Bal.	0.47	9.0	-	-	-	-	-	-	-	-	-	-	-	-
CR30A	30.5	Bal.	0.62	17.7	2.10	-	-	-	0.18	0.20	0.27	-	-	0.14	0.06	-
CR35A	35.0	Bal.	0.76	18.2	-	-	-	0.50	-	-	0.07	-	-	-	0.07	-

* Contains 0.05% Ce ** Contains 18.0% Co, 0.6% Ta, 0.02% La, 0.02% Zr *** 1% Nb+Ta

† Contains 27% Co

FIGURE 4. Placement of Test Alloys in TS1 and TS2

Partial results from scale and penetration measurements were reported last quarter. Figure 5 presents data from all measurements. The white portion of stacked bars represents scale thickness and the shaded portion represents penetration. The two are stacked since, together, they provide a measure of the total extent to which the external tube surface has been affected by the exposure environment. This measure is most useful for comparing the performance of the various tested alloys to each other or for comparing effects at various positions along a tube. Of the two bars in each bar group of the plot, the left one is for TS1 and the right one for TS2. The order of bar groups along the plot axis was the order of placement of alloys as tubes in the test module.

Looking at the more highly alloyed tube materials at the higher exposure temperatures of Pass 1, nickel-base alloy CR35A with 35% chromium is seen to be the best performer, while chromized alloy 800H was by far the worst. A statistical ranking of scaling and penetration performance of Pass 1 alloys in TS1 and TS2 was as follows from best to worst: CR35A, 310, 556, MA956, 253MA, HR3C, HR-160, CR30A, RA85H, and cr-800H. As a result of much scatter in the small data sample, however, the ranking may not necessarily represent the population. The ranking indicates the importance of both high chromium content and high chromium to nickel ratio. The low Cr:Ni ratio of CR35A is overcome by the high Cr content. Alloy 310 with moderate Cr content compared to CR35A performed nearly as well due to its high Cr:Ni ratio. Alloy MA956, with no nickel, did rather well with only 20% chromium, as did alloy 253MA with 21% Cr. A high chromium content is necessary to overcome nickel's susceptibility to sulfidation. Alloy HR3C is a variation of 310 with Nb, and should have as good or better performance. Its greater scaling and penetration in these tests was attributed to higher metal temperatures resulting from lower steam flow velocity through the larger tube. The chromizing treatment to alloy 800H, intended to raise its surface chromium content and Cr:Ni ratio, was clearly ineffective. The effect of higher tube temperatures with distance upward along Pass 1 is clearly shown by increasing scaling and penetration. Differences between data for TS1 and TS2 appear, however, to represent random scatter. Gas temperatures at TS1 were 500-600°F higher than at TS2 and deposits were accordingly much thicker and more sintered. It may be concluded that the corrosion mechanisms were dependent on metal and deposit temperatures but had little or no dependence on gas temperatures or the thickness, hardness, density, temperature, or other characteristics of deposits remote from the tube/deposit interface.

The tube metals of Pass 2 of TS1 and TS2 were generally less highly alloyed than those of Pass 1 due to the lower exposure temperatures there. The extent of scaling and penetration was rather low except for chromized alloy T9, for which penetration was very deep although scaling was low. Little or no difference was indicated along the length of Pass 2 or between Pass 2 and the 93" elevation of Pass 1, indicating a threshold in tube temperature at about 1200°F, above which corrosion increased much more rapidly. The performance ranking from best to worst was:

FIGURE 5. Corrosion Scale Thickness and Penetration Depth (in micrometers) for CFFF Superheater/ITAH Tubes Exposed to 985 Test Hours Under LMF5 Conditions

253MA, 310, 304H, 347, 316, Temp A3, 690, and chromized T9, based on average scaling + penetration, as shown in Figure 6. For alloys other than Temp A3, 690 and chromized T9, the magnitude of penetration was similar to the magnitude of scaling.

Wall thinning data from pre-exposure ultrasonic and post-exposure micrometer measurements are given in Figure 7 for TS1 and in Figure 8 for TS2. No trend is seen with respect to location along the tube and thus, tube temperature. Also, no particular difference is seen between TS1 and TS2. Therefore, data for all of each pass and for both TS1 and TS2 are averaged in Figure 9 and sorted from least to greatest thinning. Although there are differences, there are also numerous similarities between this ranking and the ranking list from the scaling and penetration evaluation. Both show CR35A as best with 310 as a close second. It is important to note that 310 outperformed, according to both evaluation methods, several more highly alloyed and more expensive alloys. A correlation of data with average exposure metal temperature will be included in the Topical Report.

The morphological evaluations revealed that all alloys possessed some similar morphological characteristics as a result of interacting with the predominantly potassium sulfate deposit. None of the alloys was completely immune to interaction. Differences were primarily a matter of degree or severity as a result of alloy composition or exposure metal temperature. Oxide scales were formed, sometimes containing fine sulfide precipitates. However, these scales were, in general, not sufficiently protective to prevent inward oxygen and sulfur diffusion to result in both inward scale growth and internal penetration or to prevent outward diffusion of metal atoms to cause both outward scale growth and diffusion into the deposit. Diffusion of metal atoms into the deposit produced a red zone which appeared to be primarily iron sulfate. Within that red zone, metal oxide precipitates formed of the same composition and appearance as the outer layer of scale at the interface. The metal oxide precipitates in the deposit constituted a dispersion of metal into the deposit. The inward and outward scale growths, the effective dissolution of scale into the deposit, and thermal expansion differences between scale layers often resulted in scale being of highly irregular thickness, fractured, or dispersed as precipitates. Most of the tested alloys, although the amounts of scaling or penetration were not excessive for the relatively very short exposure time, could not be expected to survive long term exposure under such conditions, since chromium would be depleted from the surface region and catastrophic or breakaway corrosion would occur.

All data and documentation developed thus far on the MHD/CFFF project and identified for archiving have continued to be maintained for archival storage.

FIGURE 6. Average Scale Thickness and Penetration Depth for Alloys in Pass 2 of TS1 and TS2

FIGURE 7. Wall Thickness Changes for Test Section 1 CFFF Superheater/TAH Tubes Exposed to 991 Test Hours Under LMF5 Conditions

Pass 1, 21" Elevation

Pass 1, 45" Elevation

Pass 1, 69" Elevation

Pass 2, 21" Elevation

Pass 2, 45" Elevation

Pass 2, 69" Elevation

FIGURE 8. Wall Thickness Changes for Test Section 2 CFFF Superheater/ITAH Tubes Exposed to 991 Test Hours Under LMF5 Conditions

FIGURE 9. Average Wall Thickness Changes for Tested Alloys

TASK IV - SITE ENVIRONMENTAL COMPLIANCE AND REMEDATION

Since completion of the LMF5 POC test series, the MHD-related analytical services have been characterized by environmental monitoring, evaluation of materials, and maintenance of the Chemistry Lab. Monitoring and treatment of the holding pond effluent was continued to comply with the UTSI water discharge permit. Water was checked for pH, temperature, flow rate, oil and grease content, total dissolved solids, and total suspended solids. Laboratory analytical procedures were reviewed and it was determined that approximately twenty of them require updating. This work is continuing.

Two UTSI staff members received training from a consulting firm in the use of groundwater equipment, and the preparation and handling of samples for groundwater analysis.

No ambient air data is being recorded at present. Work completed involves only that to keep the weeds under control and the cooling operational.

Groundwater compliance monitoring work has basically come to a halt due to severe funding limitations.