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(DE81026605)

MHD AIR HEATER TECHNOLOGY DEVELOPMENT

Technical Progress Report for the Period January 1—March 31, 1981

April 1981

Work Performed Under Contract No. AC01-80ET15602

FluiDyne Engineering Corporation
Minneapolis, Minnesota

U. S. DEPARTMENT OF ENERGY

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MHD AIR HEATER
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Technical Progress Report
For the Period
January 1, 1981 - March 31, 1981

Prepared for

United States Department of Energy
Office of Magnetohydrodynamics
Under Contract # DE-AC01-80ET15602

Prepared by

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FluiDyne Job 1228
April 1981

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1.0 OBJECTIVE AND SCOPE OF WORK

Work to be done under this Contract will continue the technology development of the directly-fired high temperature air heater (HTAH) for MHD power plants. The work will extend the efforts begun under previous ERDA/DOE contracts, the most recent being Contract DE-AC01-78ET10814. The Statement of Work specifies work to be done under three tasks as described in the following.

Task 1 - Materials Selection, Evaluation, and Development

The major objectives of the work under this task are (1) to identify and encourage development of ceramic materials which are resistant to seed/slag, high temperature, and thermal cycling and to evaluate their performance and life in the HTAH service environment; and (2) to continue development of a HTAH materials data base which will contain the materials data needed to design and construct larger scale HTAH's.

The scope of the work will include several activities directed toward meeting these two objectives. Selection of materials for tests and studies, pre- and post-test materials analyses, development of thermal stress criteria, liaison efforts with refractory manufacturers and users, and liaison with other MHD contractors performing material property measurements will contribute to the first objective; compilation of property data, determination of properties (by FluiDyne) as needed, and development of preliminary material specifications will contribute to the second objective.

Task 2 - Operability, Performance, and Materials Testing

The major objectives of the work under this task are; (1) to perform long term tests of materials for and operability of the HTAH cored brick matrix; (2) to perform long term tests of materials for and performance and reliability of HTAH valves; and (3) to coordinate the test programs at FluiDyne, MSU, and other organizations to insure that testing results are useful to the HTAH development program.

The scope of work will include modifications to and tests of the Matrix Test Facility (MTF) and Valve Test Facility (VTF), both of which were initially built and operated under previous HTAH development contracts to meet the first two objectives, and periodic discussions with other organizations performing HTAH test work.

Task 3 - Full-Scale Design Concepts

The major objectives of the work under this task are: (1) to identify development needs through design studies of full-scale HTAH systems; and (2) to study HTAH performance and system response in order to identify control and instrumentation needs.

The scope of the work will include studies of full-scale air heater design options and layouts of possible heater systems to meet the first objective, and computer analysis of dynamic heater system performance and response to possible control techniques to meet the second objective.

FORM DOE 536
(1/78)

U.S. DEPARTMENT OF ENERGY

MILESTONE SCHEDULE AND STATUS REPORT

1. Contract Identification: MHD Air Heater Technology Development	2. Reporting Period: 1 Jan 1981 through 31 March 1981	3. Contract Number: DE-AC01-80ET15602
4. Contractor (name, address): FluiDyne Engineering Corporation, 5900 Olson Memorial Highway, Minneapolis, Minnesota 55422		5. Contract Start Date: November 26, 1979
		6. Contract Completion Date: May 31, 1983

9. Fiscal Years and Months: FY 81 (O N D J F M A M J J A S), FY 82 (O N D J F M A M J J A)

7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	10. Percent Complete a) Planned	b) Actual
1.1.1	Select Materials		18
1.1.2	Materials Analyses		18
1.1.3	Thermal Stress		5
1.1.4	Liaison - Manufacturers/Users		18
1.1.5	Liaison - Property Meas.		18
1.2.1	Compile Property Data		5
1.2.2	Determine Properties		5
1.2.3	Material Specifications		8
2.1.1	MTF Modifications		8
2.1.2	MTF Testing		10
2.1.3	MTF Analysis		18
2.2.1	VTF Modifications		50
2.2.2	VTF Testing		2
2.2.3	VTF Analysis		0

11. Remarks

Detail by WBS

12. Signature of Contractor's Project Manager and Date: April 17, 1981

13. Signature of Government Technical Representative and Date

FORM DOE 536 (1/78)

U.S. DEPARTMENT OF ENERGY

MILESTONE SCHEDULE AND STATUS REPORT

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MHD Air Heater Technology Development	1 Jan 1981 through 31 March 1981	DE-AC01-80ET15602

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FluiDyne Engineering Corporation 5900 Olson Memorial Highway Minneapolis, Minnesota 55422	November 26, 1979 / May 31, 1983

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2.3	Liaison - Testing			10
3.1.1	Study Design Options	▼A		12
3.1.2	System Layouts	▽A		5
3.2.1	Dynamic Performance	▼A ▽B		10
3.2.2	Control/Instrumentation			5

11. Remarks

Detail by WBS

12. Signature of Contractor's Project Manager and Date	13. Signature of Government Technical Representative and Date
[signature] April 17, 1981	

MILESTONE LOG

Identification Number	Description	Completion Date Planned	Completion Date Actual	Comments
1.1.1A	Select Matls. for VTF 4	Jan 81	Jan 81	
1.1.1B	Select Matls. for MTF Mods.	May 81		
1.1.1C	Select Matls. for VTF 5	Feb 82		
1.1.1D	Select Matls. for MTF 2	Jul 82		
1.1.1	Select Matls.	May 83		
1.1.2A	MTF Heat 203 Analyses	Feb 81	-------------	Samples sent out for analysis; in-house work complete for Heat 203
1.1.2B	VTF 4 Analyses	Dec 82		
1.1.2C	MTF 1 Analyses	Jun 82		
1.1.2D	VTF 5 Analyses	Nov 82		
1.1.2E	MTF 2 Analyses	Mar 83		
1.1.2	Material Analyses	May 83		
1.1.3	Thermal Stress Criteria	May 83		
1.1.4	Liaison - Manuf./Users	May 83		
1.1.5	Liaison - Property Meas.	May 83		
1.2.1	Compile Property Data	May 83		
1.2.2	Determine Properties	May 83		
1.2.3	Material Specifications	May 83		
2.1.1	MTF Modifications	Sep 81		
2.1.2A	MTF Heat 203	Oct 80	Oct 80	
2.1.2B	Modified MTF Test 1	Nov 81		
2.1.2C	Modified MTF Test 2	Sep 82		
2.1.2	MTF Testing	May 83		
2.1.3A	Heat 203 Analysis	Jan 81	Jan 81	
2.1.3B	Test 1 Analysis	May 82		
2.1.3C	Test 2 Analysis	Jan 83		
2.1.3	MTF Analysis	May 83		
2.2.1A	VTF Mods. for Test 4	Feb 81----	Mar 81	-Late start
2.2.1	VTF Mods. for Test 5	Jan 82		
2.2.2A	VTF Test 4	Jun 81		
2.2.2B	VTF Test 5	Mar 82		
2.2.2	VTF Testing	May 83		
2.2.3A	Test 4 Analysis	Nov 81		
2.2.3B	Test 5 Analysis	Oct 82		
2.2.3	VTF Analysis	May 83		

MILESTONE LOG (CON'T)

Identification Number	Description	Completion Date Planned	Actual	Comments
2.3	Liaison - Testing	May 83		
3.1.1A	Define 600 MW Conditions	Feb 81	Feb 81	
3.1.1	Study Design Options	May 83		
3.1.2A	600 MW Example Layout	Jun 81		
3.1.2	System Layouts	Nov 83		
3.2.1A	Complete FY80 Case Analysis	Feb 81	Feb 81	
3.2.1B	Implement 600 MW case on SCAMP	Sep 81		
3.2.1	Dynamic Performance	May 83		
3.2.2	Control/Instrumentation	May 83		

2.0 SUMMARY

During the reporting period from January 1 through March 31, 1981, work was continued on all three tasks. The bulk of the work under Task 1 was related to selection of materials for the VTF and MTF and collection of samples from the MTF for analysis after Heat 203, which was run during the preceding quarter. Materials were selected for use in modifications to the VTF hot gas supply duct, and efforts were made to identify and locate sources for procurement of materials for planned modifications to the MTF. In addition, general contacts were maintained with refractory manufacturers and organizations performing property measurements, and work was continued in defining HTAH material specification needs.

Under Task 2, the bulk of the work was related to modifications to the VTF hot gas supply duct, which were completed during the reporting period, and preparations for startup of VTF Test 4, which began on March 30. In addition, design of modifications to the MTF was begun and discussions were held with Montana State University regarding an upcoming test in the MSU HTAH test facility.

Under Task 3, preparation of a topical report on performance and control studies of a directly fired HTAH for a 1000 MW_e power plant was begun. Direction has been given by DOE to focus the full-scale studies on a 600 MW_e plant size. Therefore, conditions for a HTAH for a 600 MW_e plant were defined, and various design options were examined with the size/cost computer code to assess their impact on HTAH performance and cost. In addition, conversion of the SCAMP code for implementation on a corporately-owned computer system was begun; this implementation will significantly reduce computer costs in future studies.

3.0 DESCRIPTION OF TECHNICAL PROGRESS

3.1 Task 1 - Materials Selection, Evaluation, and Development

3.1.1 Selection and Evaluation

The work performed under this category is directed toward meeting the first objective of Task 1, i.e., to identify and encourage development of ceramic materials which are resistant to seed/slag, high temperature, and thermal cycling and to evaluate their performance and life in the HTAH service environment. A discussion of the objectives of the various work elements and the progress in each during the reporting period is given in the following.

3.1.1.1 Select Materials For Tests and Studies

Materials having the potential for good performance and long life in a HTAH will be identified and specified for testing in FluiDyne's Matrix Test Facility and Valve Test Facility and in the HTAH Test Facility at Montana State University. Material selection will be based on experience gained in previous work and on knowledge of HTAH requirements. Materials selected for testing will include cored brick matrix, matrix support, matrix and duct hot liner, valve insulation, and duct and heater vessel insulation materials.

Potential materials and corresponding material properties will also be identified for use in the full-scale design studies under Task 3.

During the reporting period, materials were selected for VTF modifications, efforts were made to locate a source for procurement of fusion cast magnesia-spinel material for planned MTF modifications, a plan was developed for improving the suitability of spinel castables for use in HTAH service, and efforts were made to better define the service limits of sintered spinel bricks for use in the HTAH cored brick matrix.

The VTF modifications were made in order to eliminate problems related to accumulation of slag in the upward-firing burner in earlier valve testing work (Reference 1). The material selection need was for the refractory lining in a new horizontal section of the hot gas supply duct and the junction between this section and the existing vertical hot gas supply duct. The duct modifications are described in Section 3.2.2.1.

A three-layer insulation scheme was specified for the VTF hot gas supply duct. A 76 mm (3 in.) layer of rebonded fused grain magnesia chrome (Corhart RFG) was chosen for the hot liner, backed by a 51 mm (2 in.) layer of alumina insulating castable and a 114 mm (4.5 in.) layer of insulating firebrick rated for service to 1700 K (2600 F). The selection was based on earlier experience with the MTF and VTF hot gas supply ducts, and performance of the materials will be evaluated after the next VTF test is completed.

Fusion cast magnesia-spinel has shown excellent corrosion resistance in materials screening tests and earlier tests of the MTF (References 1, 2). However, procurement of this material for use in the HTAH tests has proved difficult. The amount of material needed for tests in the MTF is too small to be produced in commercial scale fusion casting furnaces. Since the material is rarely used in present industrial applications, material stocks do not exist. Furthermore, laboratory furnaces can not be used to produce sufficient amounts for construction of a cored brick matrix for the MTF.

A supply of fusion cast magnesia-spinel was obtained previously from Corhart Refractories Co. when a large order was produced for an industrial user; this supply was used to fabricate the X-317 matrix bricks for MTF Heats 201, 202, and 203. The likelihood of being able to procure an order of X-317 material for the proposed MTF modifications discussed in Section 3.2.1.1 is small due to various factors presently affecting Corhart Refractories Co. Thus, supplies of similar fusion cast magnesia-spinel are being sought from other potential suppliers including Carborundum Co., C. E. Refractories, and Société Europeene des Produits Refractares (SEPR, France). No other potential suppliers of such material have been identified.

A small sample of a fusion cast spinel was produce by C. E. Refractories and delivered to FluiDyne under an earlier contract. During the reporting period a piece from this sample was sent to Montana State University for inclusion in an upcoming test of the MSU HTAH test facility. C. E. Refractories will attempt to produce more of this material if production schedules allow.

Spinel castable and sintered spinel are other materials which have been identified as potential directly-fired HTAH materials, both as matrix bricks and as duct linings. As part of the effort for selection of materials for test evaluation in the MTF, work is being done to determine the maximum temperatures to which these materials could be exposed in HTAH service.

In the case of Norton LS-812, a stoichiometric spinel castable with calcium aluminate bond phase, a plan was formulated for investigation of the behavior of the calcium aluminate cement at high temperatures. It may be possible to improve the performance of the material through choice of a different cement composition.

In order to make this determination, results of work presently underway at Dow Chemical Company concerning possible depletion of the cement at temperatures $\geq$ 1920 K (3000 F) will be analyzed and further actions taken as appropriate.

In the case of sintered spinel brick (Taylor X-13233), samples were sent to Montana College of Mineral Science and Technology and to Montana State University for measurements of hot crushing strength and thermal expansion under load. The results of the measurements will be used to make a judgement as to the highest level in the cored brick matrix at which the sintered spinel bricks could be used. Cored bricks of the sintered spinel material will then be evaluated in the next test of the MTF at the highest level indicated by these results.

Other spinel based materials which were identified during the reporting period are isostatically pressed magnesia-alumina compositions which have been produced by A. P. Green Refractories. Two compositions were developed by Green to improve spalling resistance over earlier spinel materials. The compositions are 68% MgO - 32% Al_2O_3 and 53% MgO - 37% Al_2O_3. Samples of these two materials have been otained and will be evaluated in the next MTF test.

Fusion cast chromia (Carborundum Monofrax E) showed potential for use as a duct lining in areas requiring high erosion resistance in Heat 203 (Reference 1), although its performance in the cored brick matrix was poor. Monofrax E will be evaluated further as an erosion resistant duct lining material in an upcoming test of the MSU HTAH test facility.

During the next reporting period, other potential materials will also be evaluated for possible use in the next MTF test, and a scheme will be developed for incorporating the various materials to be tested in the most instructive manner. The various materials will include previously tested bricks of X-317 and other fusion cast spinel materials which can be procured in time to be tested, sintered and pressed spinel bricks, and other compositions which will be evaluated as to corrosion resistance and to the degree that seed/slag deposits adhere to the material surfaces.

3.1.1.2 Pre- and Post-Test Materials Analyses

Analyses of materials selected for testing will be obtained before and after exposure to the HTAH environment. The analyses will be made in order to evaluate the performance of potential HTAH materials and to make material life projections. Possible analytical methods include scanning electron microscopy, x-ray diffraction, quantitative chemical analysis, energy dispersive x-ray diffraction, and optical microscopy. Various material characteristics will be studied using these or other techniques as necessary. Analyses may be done by FluiDyne, by commercial laboratories, or by MERDI, MSU, or other organizations.

During the reporting period, several material samples were collected from the MTF following Heat 203. The samples were distributed to MERDI and to Carborundum and Norton for post-test analysis. Several observations based solely on visual observation are discussed in the following.

Norton LS-812 spinel castable from the hot liner surrounding the cored brick matrix performed satisfactorily up to solid temperatures on the order of 1750 K (2700 F). At higher temperatures the material appears to have suffered some degradation. LS-812 castable used for the matrix support appeared to have performed well.

Norton SX-471 sintered spinel brick used in the bottom 0.5 m (1.7 ft) of the 5.2 m (17 ft) matrix performed well. The mechanical condition of the bricks was somewhat better than that of adjacent fusion cast magnesia-spinel (X-317). Deposits in the flow passages appeared to have adhered more readily to the sintered spinel than to the fusion cast spinel.

Carborundum Monofrax E fusion cast chromia performed poorly as the top three matrix bricks but performed well in the "target" area above the matrix which deflects the reheat gas flow downward into the bed.

Results of the analyses by MERDI, Carborundum, and Norton will be interpreted in terms of material performance and life projections when the analytical work is completed.

3.1.1.3 Thermal Stress Criteria

Criteria will be developed to define allowable thermal stress limits for HTAH materials which must be crack-tolerant, such as potential matrix and matrix support materials. Data from property measurements by refractory manufacturers and other organizations as well as information from subscale tests will be used to develop these criteria.

The primary data upon which the thermal stress criteria will be based will be obtained from Montana Tech, as described in Reference 1. No results were obtained during the reporting period.

3.1.1.4 Liaison - Manufacturers and Users

Liaison will be maintained with several manufacturers and users of refractory materials. These manufacturers and users will be kept informed as to the status of the HTAH development program and to HTAH material development needs. The goals of these liaison efforts are to encourage development of potential HTAH materials which can be tested and evaluated for performance and life in the HTAH environment and to encourage development of techniques for fabricating HTAH materials. Specific manufacturing techniques under development by various organizations include fusion casting to produce uniform density material and cored brick shapes and manufacture of castable insulation materials.

During the reporting period, contacts were maintained with several manufacturers, primarily with regard to attempts to locate sources of fusion cast and other spinel materials, as discussed in Section 3.1.1.1.

Information was provided to UTSI regarding wear rates of refractories previously tested in the MTF. The interest in this information was related to the design of the HRSR test facility.

3.1.1.5 Liaison - Property Measurements

Other DOE contractors, including MERDI, MSU, and Montana Tech, are performing measurements of properties of HTAH materials as parts of their DOE projects. Liaison will be maintained under this work element to define requirements and test conditions for these measurements to insure that the property measurements are producing data which is useful to the HTAH development program. Property measurements are ranked as to priority and types of material for which they are needed according to the overall HTAH development needs.

General contacts were maintained during the reporting period, and samples were supplied for hot strength measurements as discussed in Section 3.1.1.1.

3.1.2 Data Base

The work performed under this category is directed toward meeting the second objective of Task 1, i.e., to continue development of a HTAH materials data base which will contain the materials data needed to design and construct larger scale HTAH's. A discussion of the objectives of the various work elements and the progress in each during the reporting period is given in the following.

3.1.2.1 Compile Property Data

Property data for HTAH materials will be compiled in the data base. This activity will define what information is known about the various candidate materials and what is needed before larger scale HTAH's can be designed and built. The data will be compiled from the property measurements by other DOE contractors, manufacturers data, the open literature, and measurements made by FluiDyne (see Section 3.1.2.2). The compilation will be made so that the data is readily accessible for design studies.

No efforts were expended toward actual compilation of data during the reporting period.

3.1.2.2 Determine Properties as Needed

Properties which are needed to fill priority gaps in the data base and which can be measured by

FluiDyne will be determined on an as-required basis. Property measurements which are being made elsewhere will not be duplicated, but if measurements are not available from other existing programs, they will be made as needed.

No property measurements were made during the reporting period.

3.1.2.3 Material Specifications

Specifications for the materials used in all parts of the HTAH will be developed as property data, test results, and conceptual full-scale information become available. The information will be collected in the form of preliminary procurement specifications for the various required materials which will be continually updated as more information is generated through the HTAH development program.

The refractory materials currently included in the size/cost computer code as potential candidates for directly-fired HTAH systems were reviewed during the reporting period. These materials will be classified into two groups: those refractories which can be safely covered by existing specifications (ASTM, etc.), and those for which specifications must be developed. Outline specifications, which indicate what properties will be needed for future procurement specifications, will be developed for the materials in the latter group.

3.2 Task 2 - Operability, Performance and Materials Testing

3.2.1 Matrix Test Facility (MTF)

Long term tests of matrix materials and operating conditions to prevent fouling of the cored brick matrix due to seed and slag will be conducted in the MTF. In addition to these main objectives, information will also be obtained concerning the matrix support and duct and heater vessel insulation materials. A discussion of the objectives of the various work elements and the progress in each during the reporting period is given in the following.

3.2.1.1 Modifications

The existing MTF will be redesigned to incorporate a larger matrix flow area and a larger flow rate and to include a circular cross-section and a matrix support dome. These modifications will be made to improve the degree to which the MTF simulates actual air heater conditions regarding both materials and operability. Specifically, the increased flow rate and larger flow area will allow operation with a smaller percentage of heat loss while allowing lower velocities through the flow passages (previous tests have been run with higher than desired velocity to overcome heat losses), and the circular cross-section will result in more realistic thermal gradients. The use of a matrix support dome will provide experimental information concerning heater operability with this matrix support concept.

The design plan was completed during the reporting period and sizing calculations and design layout work were begun. In addition to the features described above, the modifications will include a more flexible control system incorporating equipment presently used for control of the VTF and an improved design for the outlet gas region to deal with accumulation of seed/ash material which is discharged from the cored brick matrix in a non-intrusive manner.

3.2.1.2 MTF Testing

Two long term tests will be run in the MTF after the modifications described in Section 3.2.1.1 are completed. The MTF will be disassembled for inspection between the two tests, and materials will be replaced or refurbished if required.

No efforts were expended under this work element during the reporting period.

3.2.1.3 MTF Analysis

The test data from the MTF will be analyzed to determine performance parameters of the facility in order to identify any changes resulting from operation in the simulated HTAH environment. Determination of rates of deposition of seed and ash in the matrix flow passages is a specific goal of the operability testing. In addition, chemical analyses will be made of seed/ash material or other deposits in the test facility related to heater operability concerns. These analyses are to be distinguished from ceramic materials analyses described under Section 3.1.1.2.

During the reporting period, deposits from the matrix flow passages after MTF Heat 203 were collected for analysis. Samples were sent to MERDI, and results of the MERDI work will be presented when completed. In addition, a limited amount of work was performed at our laboratory and at a local analytical laboratory to characterize the deposits.

Deposits were collected from four locations in the 5.2 m (17 ft) matrix: 1.2 m (4.0 ft), 2.2 m (7.2 ft), 2.9 m (9.5 ft), and 5.0 m (16.5 ft) from the top of the matrix. The deposits were found to be insoluble in water or strong mineral acids. Major amounts of potassium and silicon were found in all deposits through SEM/EDX analysis. These results suggest the formation of some form of potassium silicate(s) during the running of Heat 203 from the seed and ash present in the reheat gas. As discussed in Reference 1, the hot gas supply duct refractories do not appear to have contributed to the formation of deposits during Heat 203, as had been the case in Heats 201 and 202.

Since similar deposits did not appear to form during previous tests in the MTF during Heats 100-104, in which matrix bricks were made of magnesia chrome (Corhart RFG), there is some evidence that products of reaction between seed and ash may adhere to the magnesia-spinel (X-317) material but not to the magnesia chrome (RFG). This possibility is also supported by steel industry experience, in which chrome containing refractories are found to be somewhat more free of slag accumulation problems, and by studies of the wettability of various materials by coal slag (Reference 3). The RFG matrix bricks used in Heats 100-104 will be retrieved from storage and examined for evidence of potassium silicate type deposits in order to help clarify this hypothesis.

3.2.2 Valve Test Facility (VTF)

The second objective of the work under Task 2 is to perform long term tests of HTAH valves. Tests will be run in the VTF to assess performance and reliability of a HTAH gas inlet valve; information will also be obtained regarding effects of pressure cycling on refractory insulation materials. A discussion of the objectives of the various work elements and the progress in each during the reporting period is given in the following.

3.2.2.1 VTF Modifications

Modifications to the VTF hot gas supply duct were planned to eliminate a problem of slag accumulation in the outlet of the main burner which was experienced in earlier tests of the VTF (Reference 1). This problem was related to the need to simulate MHD channel exhaust gas which passes through the valve.

Upon completion of Valve Test 4 (see Section 3.2.2.2), additional modifications will be made to the VTF to allow operation with a reducing gas chemistry or other conditions as deemed appropriate. The insulation in the valve will also be replaced and the valve seats resurfaced so that testing under reducing conditions will begin with a valve in new condition and effects due to the reducing atmosphere will be distinguished from the earlier test effects with oxidizing gas conditions.

During the reporting period, the hot gas supply duct modifications were completed. The modifications are illustrated in Figures 1 and 2. The major change was to eliminate the previously used upward-firing main burner. The main burner now fires into a horizontal duct which is mated to the previously existing vertical duct by a "cross" piece. The segment of the cross opposite the main burner includes a short (225 mm, 8.8 in.) duct segment which acts as a hydraulic cushion. The section below the cross is a chamber to allow for accumulation of seed/slag material which may be disentrained from the gas stream.

A second solids transport line was also added to the VTF system in order to allow injection of the seed and ash at different points in the hot gas supply duct. Seed injection is to be made through the main burner, as in previous tests. Sufficient volume and thus residence time was allowed in the horizontal duct for the seed material to vaporize before the flow turns vertically upward. The ash is to be injected at the cross piece upward into the vertical gas supply duct. This arrangement was chosen in order to minimize erosion of the refractory duct lining and disentrainment of the ash particles, both of which would be expected to be more severe if the ash were required to make the 90° turn with the gas stream.

The modification to the hot gas supply duct required design, procurement, and installation of four shell pieces and their internal refractory linings as well as some additional support structure changes. The refractory insulation consisted of a three layer scheme as described in Section 3.1.1.1; installation of the refractories in the cross section represented a challenging problem with regard to intersection of the central duct and surrounding layers of refractory in four directions.

3.2.2.2 VTF Testing

Following the completion of the gas supply duct modifications described above, VTF Test 4 was begun. Upon completion of Test 4 and modifications to allow operation under reducing conditions as described above, VTF Test 5 will be run.

Test 4 was begun on March 30. No results were available at the conclusion of the reporting period. The objectives of Test 4 are as follows:

1. Operate the VTF for 1000 hours with seed/ash injection.
2. Determine the rate of leakage of pressurized air through the test valve over the course of the test.
3. Continue to assess the performance of the test valve refractories through heat loss measurements and post-test inspection and analysis.

4. Continue to assess the performance of refractories in the pressurized section of the VTF through thermal conductivity determinations, heat loss measurements, and post-test inspection and analysis.
5. Assess the extent of deposition of seed/ash material in the body cavity of the test valve and its effect on valve operation.

Results of the test will be presented in the next quarterly progress report.

3.2.2.3 VTF Analysis

The test data from the VTF will be analyzed to determine performance parameters of the valve and insulation in order to identify any changes resulting from operation in the simulated HTAH environment. Determination of the valve leakage rate over the course of testing is a specific goal of the valve testing. In addition chemical analyses will be made of seed/ash material or other deposits in the test facility related to valve reliability and operability. These analyses are to be distinguished from ceramic materials analyses described under Section 3.1.1.2.

No efforts were expended under this work element during the reporting period.

3.2.3 Liaison - HTAH Testing

The third objective of the work under Task 2 is to coordinate HTAH test work being done by other organizations in order to insure that test results are useful to the HTAH development program. Specifically, heater test work at Montana State University will be planned to complement the work at FluiDyne. Liaison will be maintained with the MSU organization to insure efficient transfer of information between the two test programs and to plan the test work to be done at FluiDyne and MSU.

In addition, contact will be maintained with other organizations performing heater test work, such as the General Electric Company, Space Division.

Several discussions were held with MSU and MERDI personnel regarding an upcoming test in the MSU HTAH test facility. The test will be run under conditions simulating the directly-fired heater, whereas all previous runs were run under ash-only conditions simulating an indirectly-fired HTAH. The conditions for the MSU test have been chosen to represent a HTAH receiving a radiant boiler exhaust gas flow at a temperature of 1870 K (2900 F) at the HTAH inlet, whereas the conditions for tests in the MTF have simulated a HTAH inlet gas temperature of 1980 K (3100 F). Thus the MSU test will help to clarify differences in material performance due to variation in the maximum temperature level. Other conditions will be the same as in the next test of the MTF, with the exception that the hole size in the MSU cored brick matrix will be smaller, as shown in Table 1.

The cored brick matrix for the MSU test will be constructed of fusion cast magnesia-spinel (Corhart X-317).

3.3 Task 3 - Full-Scale Design Concepts

3.3.1 Identify Development Needs

Work performed under this category is directed toward meeting the first major objective of

Task 3, i.e., identifying development needs through design studies of full-scale HTAH systems. A discussion of the objectives of the work elements and the progress in each during the reporting period is given in the following.

3.3.1.1 Study Design Options

Studies of full-scale air heater systems will be made in order to investigate the impact of various design options on system size, cost, and performance as well as on overall MHD plant performance. The size/cost computer code and the STRHEX computer code, developed in earlier work under the HTAH development program, will be used in performing these studies. Additional models of specific aspects of the air heater will be developed as needed.

The types of design options which will be studied include size and arrangement of ducts and manifolds; size and arrangement of heater vessels; various concepts for insulation of ducts, manifolds, and heater vessels; matrix support concepts; and other aspects which impact the heater system and which may require development in order to improve heater performance or reduce cost. A ceramic, regenerative type heater for delivering air at temperatures up to about 1140 K (1600 F), a so-called intermediate temperature air heater (ITAH), will also be considered as a design option.

Direction has been given by DOE to focus the full-scale studies on a 600 MW_e plant size, as opposed to the 1000 MW_e plant size used in earlier work (Ref 1). During the reporting period, conditions for a HTAH for a 600 MW_e plant were defined, and various design options were examined with the size/cost computer code to assess their impact on HTAH performance and cost.

Some effort was made to obtain conditions to define the HTAH at this scale, i.e., flow rates, pressure losses, etc., from MHD system studies performed by other contractors. However, studies at the 600 MW_e scale were not readily found. Since a large effort to define the HTAH conditions could not be justified, the conditions used previously for the 1000 MW_e plant were simply scaled down to select the conditions for a 600 MW_e plant.

The HTAH for a 600 MW_e plant is described in Table 2. The design constraints employed in defining the HTAH were the same as those used in defining the HTAH for a 1000 MW_e plant (Ref 1). The 600 MW_e plant HTAH represents a particular configuration of 16 identical heaters which are sized and arranged to deliver the indicated air flow rate and temperature, given the indicated reheat gas flow and temperature. In studying various HTAH design options, the same basic conditions will be used with other possible configurations and arrangements. The effects of the design options will be assessed by comparing the performance and cost of the HTAH systems with the system described in Table 2. Thus, this HTAH design does not represent a recommended design for an actual full-scale HTAH, but rather a vehicle for assessing the effects of design options in order to identify HTAH development needs.

A number of variations were examined to study the effects of design considerations on HTAH size and cost. The results are shown in Tables 3-6. Each design case was required to produce the same performance, i.e., the same inlet air temperature and the same outlet air flow and temperature are required for each case, including the effects of secondary heat loss and mass exchange due to valve leakage and pressurization/depressurization losses. Thus, the size of individual heaters and the flow rate of inlet air were increased or decreased as required in successive iterations to account for the secondary losses.

The results shown in Table 3 show the desirability of employing castable insulation schemes. The results of a similar comparison for the 1000 MW_e plant HTAH (Ref 1) showed a similar ranking of the various insulation schemes, although the magnitudes of the relative costs were somewhat different due to the overall HTAH size difference and some modifications to the costing models.

An interesting conclusion of the results shown in Table 4 is that decreasing the heat loss through increased insulation is not necessarily cost effective. A surface heat loss rate of 1340 W/m^2 (425 $Btu/hr\text{-}ft^2$) was initially used as a nominal value in determining insulation thicknesses. However, a rate of 1890-2520 W/m^2 (600-800 $Btu/hr\text{-}ft^2$) may be more effective, since using less insulation reduces the pressurization/depressurization losses even though the heat loss is increased. A tradeoff between the penalty due to increased heat loss and that due to increased mass loss will be required in actual design of a HTAH. The range mentioned above for heat loss is based on estimated "costs" due to heat and mass losses. Further work in this area will be done in the future.

Table 5 illustrates the range of performance and cost penalties or advantages which result from the selection of various types of plenums at the top and bottom of the heater vessels, in conjunction with various insulation schemes. With the four layer insulation scheme, choice of different plenum designs can result in a 10% cost increase and corresponding increases in heat and mass losses of 17% and 28%. The highest cost system, of those options studied, corresponded to the lowest risk brick insulation scheme with a cylindrical plenum concept. The lowest cost system corresponded to a 3-layer castable insulation scheme with a conical upper plenum and cylindrical lower plenum. The magnitude of the cost variations were thus seen to range from 1.46 times the base case to 0.87 times the base, or a range of up to 68% of the lowest cost system. This illustrates the importance to the overall HTAH program of developing the most cost effective insulation and plenum schemes.

Table 6 shows the degree of cost variation which can result from the use of smaller heat exchanger flow passages. Present expectations are that 25 mm (1.0 in) holes will be the smallest practical for a full-scale directly fired HTAH; if this could be reduced to 19 mm (0.75 in), the cost reduction is on the order of 12%. Test work planned at Montana State University (Section 3.2.3) will help to determine whether 19 mm (0.75 in) holes can be used without an excessive degree of accumulation of seed/slag deposits in the flow passages.

3.3.1.2 System Layouts

Layout drawings of full-scale air heater systems will be made in order to assist in developing design options for the full-scale studies and in providing a basis for comparison of the various options. As directed by DOE, the full-scale studies will be focused on a nominal 600 MW_e MHD power plant rather than the previously studied 1000 MW_e plant. Air heater system layouts will be prepared for this smaller plant size.

No effort was expended under this work element during the reporting period.

3.3.2 Performance and Controls

Work performed under this category is directed toward meeting the second major objective of Task 3, i.e., study of HTAH performance and system response in order to identify control and instrumentation needs. A discussion of the objectives of the work elements and the progress in each during the reporting period is given in the following.

3.3.2.1 Dynamic Performance Studies

The dynamic performance of a HTAH system will be studied under conditions representative of MHD plant operation. The previously developed SCAMP computer code will be the primary tool used in these studies. Dynamic, cyclic performance of the 600 MW_e plant HTAH system will then be studied, followed by studies of system response to various changes in operating conditions.

During the reporting period, efforts consisted of work in preparing a topical report on the dynamic performance and control of the 1000 MW_e example system and conversion of the SCAMP code for implementation on a computer which will be installed in the near future. Use of the corporately owned computer will significantly reduce the cost of dynamic performance analysis.

3.3.2.2 Control and Instrumentation Studies

Concepts will be identified for control of a HTAH system, and instrumentation needs resulting from these control concepts will be identified. Concepts will be identified for control of temperatures, pressures, and/or flow rates which have been established as operability or system life criteria within the HTAH. Concepts will also be identified for control of air delivered to the MHD combustor and gas delivered to the bottoming steam plant components. The control concepts will be evaluated through computer simulation with the SCAMP code. Capability of the control concepts to maintain the desired degree of control during system upsets and plant load changes will be investigated.

No effort was expended under this work element during the reporting period.

4.0 CONCLUSIONS

Spinel based refractory materials, in particular fusion cast magnesia-spinel, have continued to show good corrosion resistance in the directly-fired HTAH environment. Continued evaluation of such materials is planned. Procurement of material is difficult, however, and tests may need to be run using less of these materials than desired.

MTF testing has indicated that accumulation of seed/ash materials in the cored brick matrix may be more severe for spinel materials than for chrome containing refractories. Future MTF tests will examine methods for arranging materials in the cored brick matrix in such a way as to prevent or minimize the accumulation of deposits through use of various materials in the lower portion of the matrix while retaining the good corrosion resistance of spinel materials in the upper portion of the matrix.

Full-scale studies of a directly fired HTAH for a 600 MW_e plant have indicated that allowing surface heat losses of 1890-2520 W/m^2 (600-800 $Btu/hr\text{-}ft^2$) may provide the most cost effective HTAH design rather than designs requiring lower heat loss rates as suspected in the past.

REFERENCES

1. FluiDyne Engineering Corporation, "MHD Air Heater Development Technology," Annual Report for Contract DE-AC01-80ET15602; March 1981.

2. FluiDyne Engineering Corporation, "MHD Air Heater Development Technology," Final Report for Contract DE-AC01-78ET10814; March 1981.

3. Guidotti, L., et al, "Wettability and Corrosion of MHD Ceramics by Rosebud Coal Slag," 18th Symposium, Engineering Aspects of MHD, Butte, Montana, June 18-20, 1979.

TABLE 1. CONDITIONS FOR MATRIX TESTS - SERIES 1

Parameter	FluiDyne	Montana State University
Matrix height	5.2 - 6.1 m (17-20 ft)	∿ 6.1 m (20 ft)
Hole diameter	25.4 mm (1.0 in)	19.0 mm (0.75 in)
Web thickness	12.7 mm (0.5 in)*	7.6 mm (0.30 in)
Spacing/diameter ratio	1.5*	1.4
Spacing geometry	triangular*	triangular
Matrix cross section	hexagonal	hexagonal
Gas inlet temperature	1978 K (3100 F)	1867 K (2900 F)
- K_2SO_4 wt. %	2.3	2.3
- Ash wt. %	0.1	0.1
- Mass velocity	7.86 kg/m^2-sec (1.61 lbm/ft^2-sec)	6.93 kg/m^2-sec (1.42 lbm/ft^2-sec)
- Gas phase duration	1800 sec	1990 sec
Air inlet temperature	922 K (1200 F)	922 K (1200 F)
- Mass velocity	As required to approximate temp. profiles in Fig 3	As required to approximate temp. profiles in Fig 4
- Air phase duration	720 sec	800 sec
Time to change phases	∿ 60 sec	∿ 60 sec

*May be changed for compatibility with perforated dome matrix support.

TABLE 2

DESCRIPTION OF DIRECTLY - FIRED
HTAH FOR 600 MW_e PLANT

ITEM	MHD GAS	AIR	UNITS
Flow In	503 (1109)	412 (908)	kg/sec (lbm/sec)
Flow Out	509 (1122)	406 (895)	kg/sec (lbm/sec)
T_{in}	1977 (3099)	922 (1200)	K (F)
T_{out}	1333 (1940)	1784 (2752)	K (F)
P	107 (15.58)	867 (125.8)	kPa (psi)
ΔP	4.5 (.65)	17.2 (2.5)	kPa (psid)
Vessels	11	4	Heaters
Flow Duration	1837	735	Seconds
Air Heating Rate	710 (6.74×10^5)		MW (BTU/sec)
Bed Diameter	4.3 (14)		m (ft)
Bed Height	6.6 (21.5)		m (ft)
Thermal Stress	31 (4500)		MPa (psi)
Hole Size/Web	25/14 (1.0/.55)		mm (inches)
P/DP Units	1		Vessels
Inlet Valve Diameter	2.3 (7.5)	.9 (2.8)	m (ft)
Outlet Valve Diameter	1.9 (6.2)	1.2 (3.8)	m (ft)
Heat Loss	1.8		Percent of Air Heating Rate

TABLE 3

HTAH COMPARISON (FOR 600 MW_e PLANT)
WITH VARIOUS INSULATION SCHEMES

INSULATION SCHEME	HEAT LOSS (% OF AIR HEATING RATE)	MASS LOSS (% OF DELIVERED AIR)	RELATIVE COST
4-Layer Insulation	1.8	1.2	1.00 (Base)
3-Layer Castable	1.8	1.2	.83
Lowest Risk Brick	2.0	1.3	1.31
Higher Risk Brick	1.8	1.2	.92
Combined Brick/Castable	1.8	1.2	1.00

TABLE 4

HTAH COMPARISON (FOR 600 MW_e PLANT)
WITH VARIOUS SURFACE HEAT FLUXES

FLUX		HEAT LOSS (% OF AIR HEATING RATE)	MASS LOSS (% OF DELIVERED AIR)	RELATIVE COST
W/m^2	($Btu/hr\text{-}ft^2$)			
858	(272.0)	1.4	1.2	1.17
1342	(425.4)	1.8	1.2	1.00 (Base)
1912	(606.2)	2.2	1.1	.94
2575	(816.3)	2.7	1.1	.93

TABLE 5

HTAH COMPARISON (FOR 600 MW_e PLANT) WITH VARIOUS INSULATION AND PLENUM OPTIONS

INSULATION SCHEME	PLENUM OPTION UPPER	PLENUM OPTION LOWER	HEAT LOSS (% OF AIR HEATING RATE)	MASS LOSS (% OF DELIVERED AIR)	RELATIVE COST
4-Layer	3	2	1.8	1.2	1.00 (Base)
4-Layer	1	1	2.3	1.4	1.10
4-Layer	2	1	1.9	1.2	1.00
Lowest Risk Brick	1	1	2.6	1.5	1.46
3-Layer Castable	2	1	2.0	1.3	.87

UPPER PLENUM OPTIONS:

1 Extended cylinder

2 Concical side intersection on angle

3 Conical side intersection on cylinder

LOWER PLENUM OPTIONS:

1 Extended cylinder

2 2-to-1 elliptical head

TABLE 6

HTAH COMPARISONS (FOR 600 MW_e PLANT) WITH VARIATIONS IN HOLE DIAMETER

HOLE DIAMETER		WEB THICKNESS		HEAT LOSS (% OF AIR HEATING RATE)	MASS LOSS (% OF DELIVERED AIR)	RELATIVE COST
mm	(in.)	mm	(in.)			
25	(1.0)	14	(.55)	1.8	1.2	1.00 (Base)
19	(.75)	10	(.41)	1.6	1.3	.88

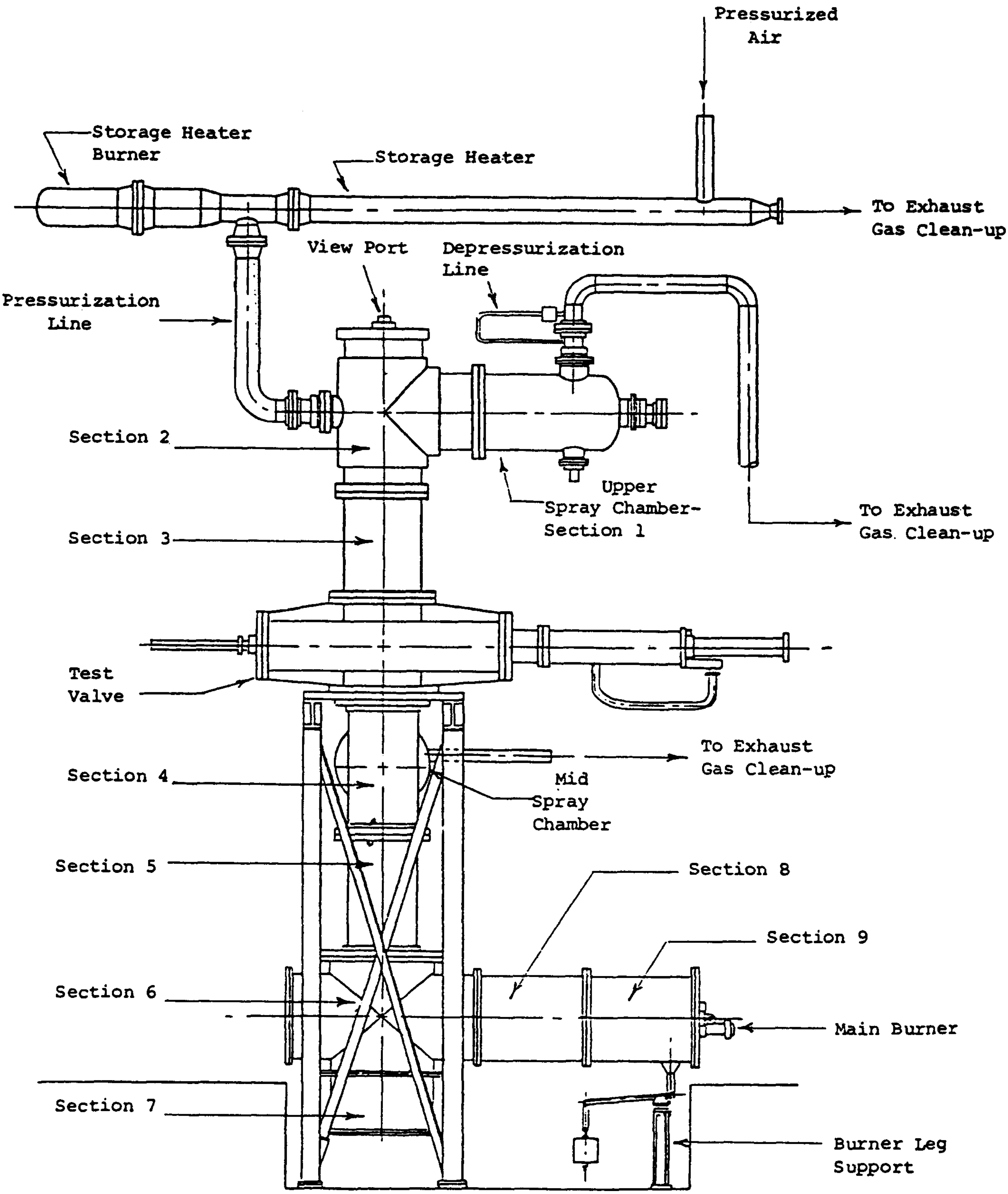

FIGURE 1. SKETCH OF VALVE TEST FACILITY SHOWING MODIFIED HOT GAS SUPPLY DUCT

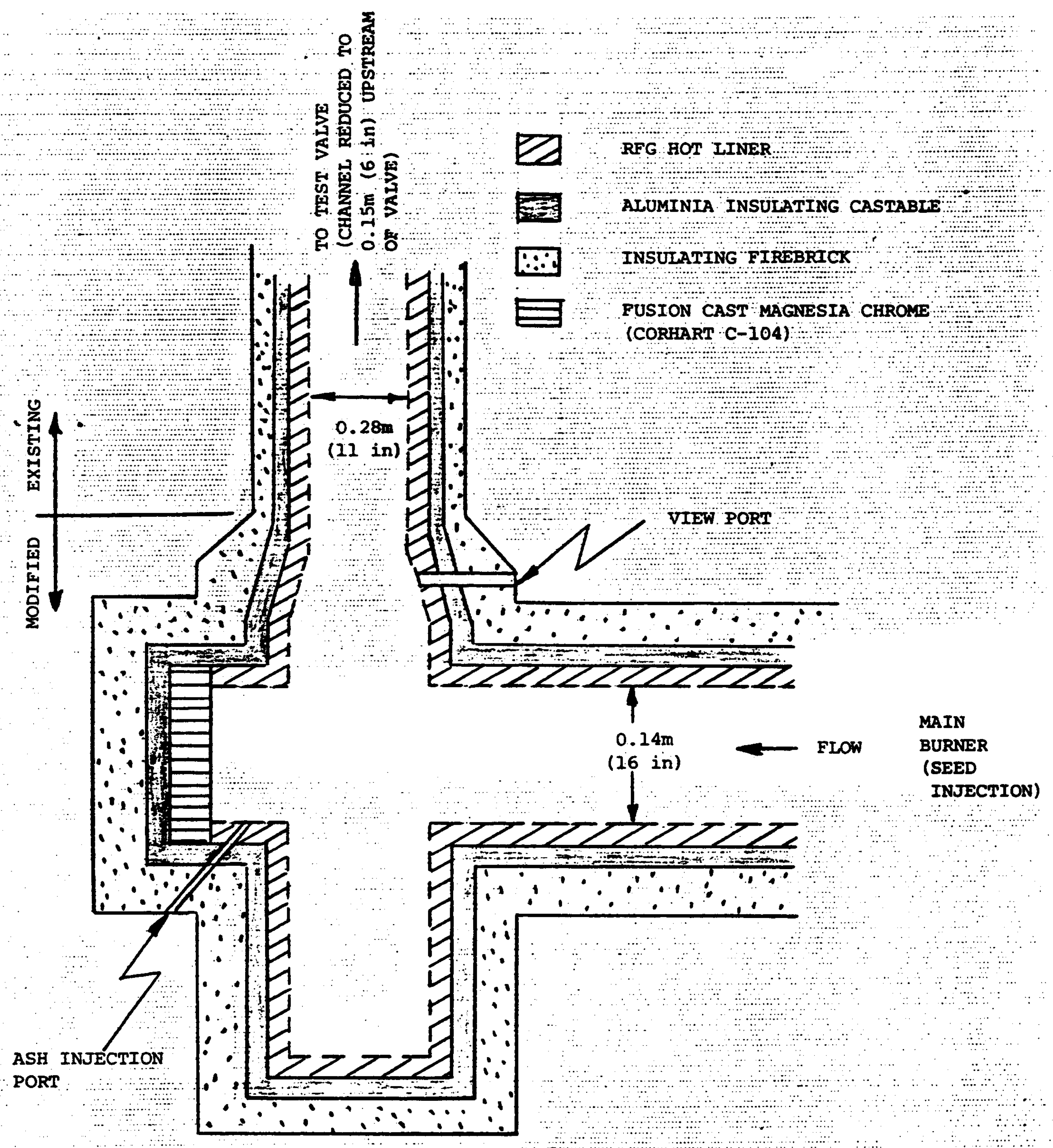

FIGURE 2. CONFIGURATION OF MODIFIED VTF HOT GAS SUPPLY DUCT FOR TEST 4

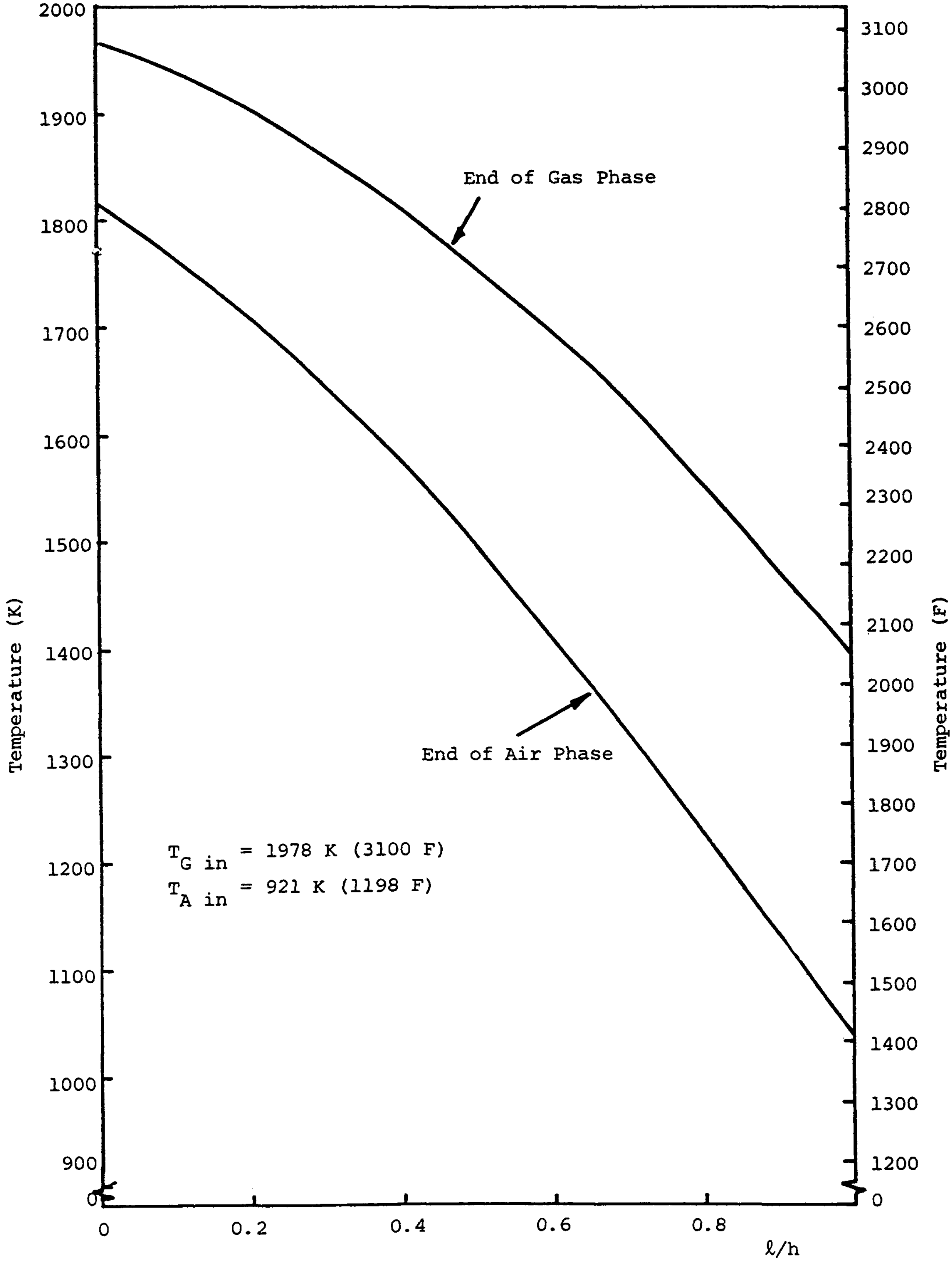

FIGURE 3. SOLID TEMPERATURE PROFILES FOR POSSIBLE FULL-SCALE HTAH WITH d_h = 25.4 mm (1.00 in.) - BASIS FOR FLUIDYNE SERIES 1 MATRIX TESTS

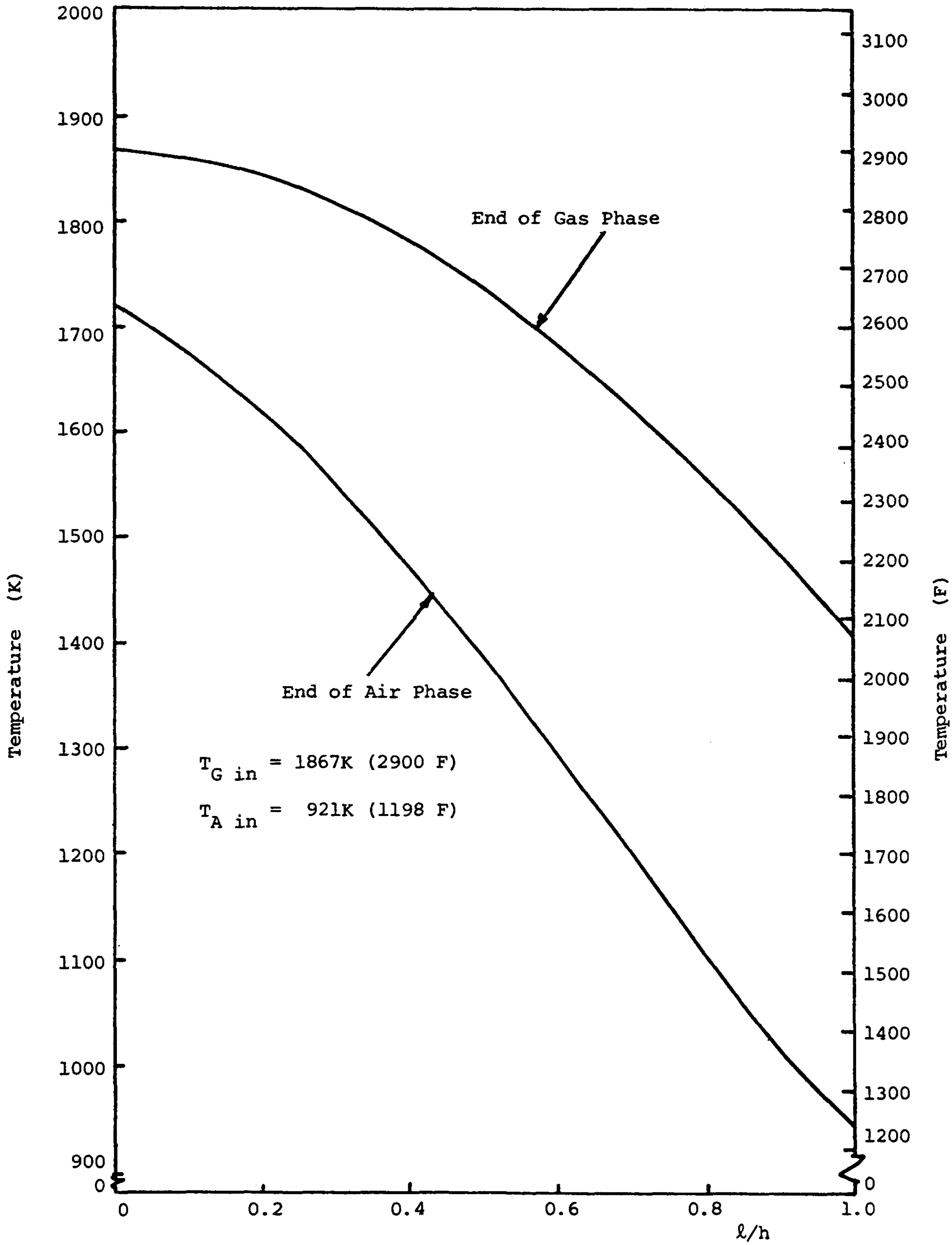

FIGURE 4. SOLID TEMPERATURE PROFILES FOR POSSIBLE FULL-SCALE HTAH WITH d_h - 19.0 mm (0.75 in.) - BASIS FOR MSU SERIES 1 MATRIX TESTS

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