335
12/31/79
ENERGY

CONFIDENTIAL

LD. 499

CONS 3005-T1
MASTER

MHD AIR HEATER DEVELOPMENT TECHNOLOGY

Report for the Period April 1978—June 1978

December 1978
Date Published

Work Performed Under Contract No. ET-78-C-01-3005

FluidDyne Engineering Corporation
Minneapolis, Minnesota

U. S. DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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

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

Price: Paper Copy \$5.25
Microfiche \$3.00

TABLE OF CONTENTS

	<u>Page</u>
1.0 OBJECTIVE AND SCOPE OF WORK	1
2.0 SUMMARY	2
3.0 DESCRIPTION OF TECHNICAL PROGRESS	4
3.1 Task 1 Design Studies	4
Technical Overview	4
3.1.1 Size/Cost Studies	4
3.1.2 Performance	5
3.1.3 Control Systems	6
3.1.4 Seed/Slag Deposition	6
3.1.5 Valve Design	6
3.1.6 Bed Support	7
3.1.7 Dome Design	7
3.1.8 Electrical Isolation	7
3.2 Task 2 Design Support Tests	7
Technical Overview	
3.2.1 Matrix Tests - Materials	9
3.2.2 Matrix Tests - Analytical Results	12
3.2.3 Matrix Tests - Bed Geometry	13
3.2.4 Matrix Tests - Seed/Ash Deposition & Removal	14
3.2.5 Emissions Control	15
3.2.6 Matrix Tests - Bed Support	15
3.2.7 Valve Tests - Pressurization/Depressurization	
Effects on Insulation	15
3.2.8 Valve Tests - Valve Performance	16
3.2.9 Electrical Isolation	16
3.2.10 Diagnostics	16
3.3 Task 3 Preliminary Design of 5 MW Heater	
Technical Overview	17
3.3.1 Hot Gas Supply System	17
3.3.2 Air Supply System	20
3.3.3 Gas/Air Exhaust Systems	20

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
3.3.4 Air Heater	20
3.3.5 Cooling Water System	21
3.3.6 Emissions Control System	21
3.3.7 Structure and Foundations	21
3.3.8 Coal Preparation System	21
3.3.9 Controls and Instrumentation	21
4.0 CONCLUSIONS	22
TABLES	
FIGURES	
APPENDIX A	

1.0 OBJECTIVE AND SCOPE OF WORK

Work to be done under this contract continues the ceramic heater development program begun under ERDA Contract Nos. E(49-18)-1537 and 76-C-01-2254. The Statement of Work divides the effort into three tasks:

Task 1 - Design Studies

The objectives of this task are to: 1) evaluate full-scale, direct- and indirect-fired regenerative air heater systems for use in MHD power plants; 2) support testing of refractory materials, hot gas valves, and design concepts; 3) support design of a 5 MW test heater.

Task 2 - Design Support Tests

The objectives of this task are to: 1) support design of a 5 MW test heater; 2) identify and evaluate life of promising refractory materials for use in MHD heaters; 3) determine operating conditions and bed geometry (hole size, web thickness) which permit operation without clogging of heater passages due to accumulations of seed/slag or slag alone, 4) test valves for use in hot gas streams which are laden with seed/slag or slag alone.

Task 3 - Vertical Slice Test Bed

The objective of this task is to provide a preliminary design of a test heater which is a vertical slice of a full-scale heater. It will be sized for a thermal input of 5 MW. Testing with hot gas streams containing seed/slag or slag alone will be accommodated in order to simulate both direct- and indirect-firing.

2.0 SUMMARY

During this reporting period work was carried out on all three tasks. Results are summarized as follows.

Under Task 1, Design Studies, the size/cost program was upgraded by improving the way mass losses due to depressurization are computed. In addition, cost accounting of various insulating schemes was improved. Development of the system performance program was continued and preliminary computations made of flow distribution.

Under Task 2, Design Support Tests, a matrix test, Heat 104, was completed. In this test, the unit was operated to intentionally leave a deposit in the bed. The rig was then dismantled and the condition of the matrix bricks was noted. The most important observations were that no evidence of slag-like deposits was found, the matrix bricks were easily removed - they were not fused together by deposits, and the deposit, located at the bottom of the bed, was seed-like, being crystalline in appearance. The deposit was confined to the lower few feet of the bed with practically no seed or slag found in the upper parts of the bed.

Analyses of the deposit will be done in the next quarter.

Design of the valve test rig was reviewed and it was agreed to revise the design to accommodate pressure upstream (hot gas side) of the valve. Initial tests would be with clean gas, then with slag, and finally with seed and slag.

Under Task 3, Design of a 5 MW Heater, efforts were concentrated on heater design and development of a hot gas supply system.

MHD AIR HEATER DEVELOPMENT
TECHNOLOGY

DISCLAIMER

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

Report for the Period
April, 1978 - June, 1978

FluidDyne Engineering Corporation
5900 Olson Memorial Highway
Minneapolis, Minnesota 55422

Date Published - December 1978

Prepared for
United States Department of Energy
Under Contract No. ET-78-C-01-3005

DISCONTINUED
EP

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

A review of possible full-scale heaters was conducted to guide the design effort. The requirement of a hot grate 1530K, (2300°F) required a fresh look at full-scale designs, especially of ways to support the bed. Three possibilities were identified, a ceramic dome, a so-called direct-bearing support consisting of a lattice-like ceramic structure, and a cooled metal grate.

A hot gas supply system was identified in which a gas-fired burner with seed and coal or ash injection was utilized.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORT

1. Contract Identification MHD Air Heater Development		2. Reporting Period April - June, 1978		3. Contract Number ET-78-C-01-3005										
4. Contractor (name, address) Fluidyne Engineering Corporation 5900 Olson Memorial Highway Minneapolis, Minnesota 55422				5. Contract Start Date 3-10-78										
				6. Contract Completion Date 10-10-79										
7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months												10. Percent Complete Actual/Planned
		<div style="display: flex; justify-content: space-around;"> <div>FY 78</div> <div>FY 79</div> </div> <div style="display: flex; justify-content: space-around; font-size: small;"> <div>M A M J J A S O N D</div> <div>J F M A M J J A S O</div> </div>												
1.1	Revised Size/Cost Code	[REDACTED]												100/100
1.2	New Baseline Cases	[REDACTED] Δ												30/30
1.3	Performance Code	[REDACTED] Δ												40/40
1.4	Performance Studies	[REDACTED] Δ												0/0
2.1	Plan & Run Matrix Test 5	[REDACTED]												100/100
2.2	Redesign Rig	[REDACTED]												100/100
2.3	Rebuild Rig	[REDACTED] Δ												0/0
2.4	Plan & Run Matrix Test 6	[REDACTED] Δ												0/0
2.5	Modify Test Rig (As needed)	[REDACTED] Δ												0/0
2.6	Plan & Run Matrix Test 7	[REDACTED] Δ												0/0
2.7	Modify Test Rig (As needed)	[REDACTED] Δ												0/0
2.8	Plan & Run Matrix Test 8	[REDACTED] Δ												0/0
2.9	Analysis of Data & Results	[REDACTED] Δ												20/20
2.10	Purchase Long Lead It. for VTR ^a	[REDACTED]												100/100
11. Remarks #VTR Stands for Valve Test Rig.														
12. Signature of Contractor's Project Manager and Date <i>[Signature]</i> 12-20-78												13. Signature of Government Technical Representative and Date		

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORT

1. Contract Identification MHD Air Heater Development		2. Reporting Period April - June, 1978		3. Contract Number ET-78-C-01-3005										
4. Contractor (Name, address) Fluidyne Engineering Corporation 5900 Olson Memorial Highway Minneapolis, Minnesota 55422				5. Contract Start Date 3-10-78										
				6. Contract Completion Date 10-10-79										
7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months												10. Percent Complete Actual/Planned
		<div style="display: flex; justify-content: space-around;"> <div>FY 78</div> <div>FY 79</div> </div> <div style="display: flex; justify-content: space-around; font-size: small;"> <div>M A M J J A S O N D</div> <div>J F M A M J J A S O</div> </div>												
2.11	Final Design of VTR													100/100
2.12	Construct VTR													0/0
2.13	Plan & Run Valve Test 1													30/30
2.14	Modify VTR (As needed)													0/0
2.15	Plan & Run Valve Test 2													0/0
2.16	Analysis of Data & Results													0/0
3.1	Hot Gas Supply													25/25
3.1a	Select Hot Gas Simulator Concept													100/100
3.1b	Design Hot Gas Simulator													25/25
3.2	Air Supply													20/20
3.3	Gas/Air Exhaust													20/20
3.4	Vessel/Matrix Insulation													30/30
3.5	Cooling Water System													0/0
3.6	Emissions Control													0/0
11. Remarks The intermediate event shown is a decision point. Date for completion of the design will be reviewed at that time.														

12. Signature of Contractor's Project Manager and Date 12-20-78	13. Signature of Government Technical Representative and Date
--	---

[illegible]

3.0 DESCRIPTION OF TECHNICAL PROGRESS

3.1 Task 1 - Design Studies

Technical Overview

The system size/cost subroutines were revised and verified, and now provide greater accuracy and flexibility when comparing air heater systems for various MHD system configurations. A separate leakage and pressurization mathematical model has been formulated and programmed. Coefficients used within this model will ultimately be adjusted to fit test data derived from the valve test rig. Insulation schemes have been conceived and evaluated as to impact on cost and technical risk. Material costs and properties were reviewed, and redefined effective July 1, 1978.

The performance program development is continuing. Computer time (and costs) were reduced by selecting a solution algorithm that is efficient in computer time and storage and yet has satisfactory convergence reliability. The flow/ ΔP part of the program was checked on a single case of a heater system and worked well.

3.1.1 Size/Cost Studies

Revision and verification of size/cost subroutines have been completed. Beside the general objective of increased program generality and refinement, a number of program changes were made. The geometric calculations for vessel and manifold nozzles are now computed with a non-dimensionalized function of radius ratio. This gives greater accuracy in case-to-case comparisons of costs and heat and pressurization losses. Options for generalized cylindrical and conical plenums were programmed as well as provisions

for multiplicity in numbers of ducts and manifolds, and in vessel-manifold patterns. The residual mass of gas in the vessels is calculated with more precision so that predictions of pressurization/depressurization losses and/or carryover are more reliable. Insulation schemes for vessels, ducts, and manifolds can be broken down in greater detail to improve the accuracy of system comparisons. Valve heat loss and leakage prediction models have been revised to accommodate arbitrary insulation and sealing arrangements. This was done in anticipation of the test data and operating experience in the valve test program.

Several vessel, duct, and manifold insulation schemes have been conceived which have varying risks and cost/performance penalties associated with them. These will be evaluated with the aid of the revised system size/cost subroutines. A new insulation concept for the valve gates has also been evaluated and is described in Section 3.1.5.

Most material costs and properties have been reviewed, and a new cost basis has been established effective July 1, 1978. It was found that square hole matrices led to 15% reduction in system cost compared to round holes. These results will be presented in greater depth later after completion of the insulation study.

3.1.2 Performance

Work is continuing on development of the system performance program. A significant effort was spent in reducing the matrix solution and storage time for systems with 16 or more vessels. Several algorithms were applied and then compared. The selection criteria included run time, memory requirements, and convergence reliability for all valve alignments. A sparse, non-banded solver was selected with a substantial decrease in both run time and

memory. If required, further reduction in time and size may be possible by utilizing out-of-core solution libraries. The approximate solution would then be corrected by perturbation equations.

Programming of the thermal subroutines is continuing, with many of the supportive and accounting subroutines having been written and partially debugged. The characteristic heater algorithm is now being formulated.

A mixing loss coefficient model for manifold "Tee's" has been selected, and written into the performance program. This will permit rapid estimates of vessel-to-vessel flow maldistribution for arbitrary valve sequencings and manifold geometry. The selected "Tee" model is generalized and applicable for both combining and dividing flows.

3.1.3 Control Systems

No work was scheduled or done on this sub-task.

3.1.4 Seed/Slag Deposition

No work was scheduled or done on this sub-task.

3.1.5 Valve Design

An insulation concept that would use a 2-layer anchored castable on the valve gate has been developed. Preliminary evaluation indicates a reduction in heat loss by a factor of twenty. An uncertainty is the behavior of the insulation during pressurization and depressurization with a potential need for venting.

3.1.6 Bed Support

Support was provided to the design of the 5 MW heater (task 3).

3.1.7 Dome Design

Conical plenum concepts have been formulated, and may be evaluated as an option of the size/cost program.

3.1.8 Electrical Isolation

No work was scheduled or done on this sub-task.

3.2 Task 2 - Design Support Tests Technical Overview

The experimental work under Task 2 consists of air heater materials and operability testing in three basic areas. The three types of testing are:

1. Matrix Tests - Conducted in the five meter cored brick matrix test facility. The primary objective of these tests is to obtain heater performance and operability data.
2. Valve Tests - Conducted in the valve test facility. The objectives of these tests are to obtain valve performance and operability data and to assess the effects of pressure cycling on insulation and valve performance.
3. Materials Tests - Conducted either as "piggyback" tests in the matrix test facility or in a smaller test module using the hot gas supply for the

matrix test facility. The primary objective of these tests is for refractory and metal materials screening for air heater service.

The testing work in these three areas will provide needed information for the development of MHD air heaters. The work under Task 2 is coordinated with the Task 3 design work to aid in development of design criteria and with the Task 1 analytical work to provide experimental data against which mathematical predictions can be compared.

The fifth test with the original RFG matrix in the test facility, Heat 104, was begun on April 17 and completed on April 28. The slag source for this test was Montana Rosebud coal injected in the propane stream of the hot gas supply rather than coal ash as used in previous heater tests. The seed material was a mixture of 99% potassium sulfate and 1% potassium carbonate. During Heat 104, the bottom of the matrix was first heated to approximately 1650K (2500°F) with clean fuel to remove any residual material from previous tests in the hot gas ducting and matrix. After this material was melted out, the test rig was operated with seed and coal injection. The operability test conditions of Heat 103, which were reported in the previous quarterly progress report, were repeated, and the test was finally terminated with a restriction in the matrix in order to preserve deposited material for analysis.

The matrix rig was disassembled following Heat 104, and analysis of the deposited material as well as the matrix and insulating refractory is under way. Present plans call for rebuilding the matrix with a different material and geometry during the next quarter.

The design of the valve test facility was reviewed with DOE in Washington, D.C., on June 8. As a result of this

review meeting, the test facility design will be modified such that the components of the test channel upstream of the test valve (i.e. mid spray chamber, slag tap, slag tap spray chamber) will be capable of withstanding pressure comparable to that envisioned for indirectly fired air heaters with pressurized combustion. This modification will cause a delay in completion of the valve test facility. As decided in the June 8 review meeting, valve tests under the present contract will be run initially with clean gas flow, then with slag only, and finally with seed and slag. These tests will be conducted with atmospheric combustion only.

Plans were finalized to conduct materials tests by using the hot gas supply leg of the matrix test facility. This concept will allow further materials testing to be accomplished during rebuilding of the matrix test facility at a cost much lower than required to operate the matrix facility.

3.2.1 Matrix Tests - Materials

Acquisition and evaluation of heater materials continues. Those acquired during the past quarter are listed in Table 1 with properties available from the manufacturer and other sources. Several of these materials have been developed specifically for the direct fired MHD heater (e.g., Lab Numbers 97 and 98) while others are commercial or semi-commercial materials developed for other applications. Although some may be impractical due to cost or fabrication concerns, they are included to help elucidate degradation mechanisms. A brief description of the materials follows.

The two brands of silica brick, Lab Numbers 89 and 96, are examples of a refractory used with success in various steel-making applications. They combine low thermal expansion, stability and strength up to the melting point of

silica (2000K) with low cost. They will be evaluated as a back-up to the hot liner since gas temperatures exceed their melting points and reaction with potassium is known to occur with formation of lower melting compounds.

The four Trans-Tech materials are high density, high purity isostatically pressed bodies made for micro-electronic substrates. They were selected to show the dependence of corrosion resistance on composition (magnesia-spinel ratio). In a cooperative effort, Dr. G. Youngblood at Montana Energy and MHD Research and Development Institute (MEMRDI) is developing additional data on this material. Figure 1 shows the relationship of composition to other spinels. Densities for all except S-78 are in the 98% of theoretical range.

SEM/EDX analyses have been performed. The as fired surface of S-71 (stoichiometric spinel) shows two distinct forms: triangles, which could be sides of spinel octahedra and a smaller less regular form. The fractograph shows slight intragranular porosity and a crack terminating at one of these pores (see Figure 3). Grain size is about 20-25 μm as noted by Youngblood (2). The EDX maps of magnesium and aluminum suggest that this is a single phase material.

Figures 4 and 5 show as-fired and fracture surfaces of sample S-78 (spinel/MgO molar ratio = 3.25). This material has an irregular surface with no evidence of tetrahedra. Of the four samples in this series, it has the highest measured porosity which, from the fractograph, appears to be intergranular. The grain size is 10-15 μm and is somewhat smaller than S-71.

Figures 6 and 7 show as-fired and fracture surfaces of sample S-98 (spinel/MgO molar ratio = 0.22). Of

this series, the composition of S-98 is closest to X-317. However, as expected, their microstructures are quite different. While X-317 has discrete magnesia grains surrounded by a continuous spinel phase, the sintered material, S-98, appears to be comprised of adjoining grains of each phase.

Sample S-110 (spinel/MgO molar ratio = .082) was examined only as a fractograph (Figure 8). For this series of samples, X-ray maps were not very revealing. The spinel and MgO phases were evidently so fine-grained and evenly distributed as to be non-distinguishable by mapping.

Despite compositional differences, these four materials are quite similar. It is expected that they should tolerate the gas temperature and chemistry but may be subject to damage by thermally induced stress as they have a continuous microstructure which is fine-grained, and non-porous and hence not crack-tolerant.

Two samples of thoria ceramic were obtained from Zircoa. One was a dense, 7% Y_2O_3 , 10 mm diameter tube and the second was a porous tile 1/2" x 2" x 2".

A spinel castable, Taylor X-13337 was specially prepared by the manufacturers using stoichiometric fused grain and a phosphate binding. The material has not yet been characterized but a test panel has been prepared for a future test.

A sample of isostatically pressed spinel with excess MgO was prepared by A.P. Green Refractories Company. A sample has been sent to MEMRDI for slag wettability and thermal diffusivity measurements. It is planned to include it in future tests.

Likewise, a hot-pressed billet of stoichiometric spinel was obtained.

One test was made during this reporting period, Heat 104. As described elsewhere in this report, its primary objective was to study operability, that is to establish what conditions would permit continuous operation without permanent solids deposition in the flow passages. However, it was possible to include a materials test while operability data were being generated.

The following materials were studied: Monofrax E, and K-3, Taylor X-13249, Cohart RX-317 as the hot liner, K-3, X-317 and RFG as the matrix, S-71, 78, 98 and 110; Zircoa thoria, Coors AD-998 and Vistal; Eagle Picher Silicon Carbide and Man Labs Zirconium Diboride Silicon Carbide as above-the-bed test pieces, De Gussa SP-23 spinel as thermocouple sheaths, Green X-Sil, K-30, Horizons C, M and foam as back-up insulation. Figure 9 shows these materials in place.

Results of testing are discussed in the next section.

3.2.2 Matrix Tests - Analytical Results

Figure 10 shows the top of the matrix after Heat 104. Although some degradation of materials is evident, it did not affect performance of the heater for the duration of the test. Both spinel thermocouple protection tubes failed early in the test. One is seen lying on the S-110 test bar. The various hot liner bricks appear to be damaged little. Likewise the back-up insulation appears structurally sound but discolored, due probably to chrome and iron from the magnesia chrome hot liner. The X-sil shows signs of local melting where it contacted the hot liner.

Based on visual appearance, the high density test bars, with the exception of S-78, were degraded minimally. The test bars were set above the matrix on two fusion cast X-317 spacers. These spacers showed no sign of deformation. More detailed analyses of the test samples will be done in the next quarter.

The matrix comprised primarily magnesia chrome cored brick with the exception of the uppermost layer. This was formed of fusion cast X-317 (magnesia and spinel) and K-3 Alumina-chrome. Both performed well with minimal erosion but some web fracture.

In cooperation with MEMRDI work is progressing to better understand the behavior of X-317. Figure 11 shows the separation of a magnesia grain from the adjacent spinel matrix, and Figure 12 shows the probable consequence of this to thermal conductivity.

3.2.3 Matrix Tests - Bed Geometry

All of the tests with the 5m (17 ft) matrix completed to date (Heats 100-104) have been run with 229 mm (9 in) x 114 mm (4 1/2 in) matrix bricks. The bed geometry in this matrix consisted of 19 mm (3/4 in) holes on triangular pitch and 6 mm (1/4 in) webs. Thermal performance and operability results obtained during Heats 100-104 will thus provide a basis for comparison with results obtained from matrix testing with other geometries.

The matrix rig will be rebuilt with a 5m (17 ft) matrix having 25 mm (1 in) holes and 13 mm (1/2 in) webs before the next matrix test. Thermal performance and operability data will be compared with the results from Heats 100-104 as well as with any available analytical models.

3.2.4 Matrix Tests - Seed/Ash Deposition and Removal

Several observations concerning seed/ash deposition and removal were made during Heat 104. During the initial heatup period, slag-like material was observed to flow from the bottom of the matrix, possibly comprising residual material in the hot gas ducting and matrix, from previous tests. This observation suggests the feasibility of cleanout of a long-term solids buildup, even from a cold start, with a cored brick regenerative heater. Following this cleanout period, conditions similar to those presented in the previous progress report were established (see Tables 2 and 3) and the matrix was operated first in a stable mode and then in an unstable mode. The increase in bed pressure drop shown in Table 3 was eliminated in approximately 90 minutes by heating the bed with seed/slag laden gas at the conditions shown in Table 3 for the gas cycle. These observations indicate that comparable results were obtained using either coal or ash as the slag source.

Following the above experiments, a third set of conditions shown in Table 4 was established. The test rig was then allowed to run until the pressure drop across the matrix reached 1.6 times that shown in Table 3 for the gas phase with no attempt to clean out the deposited material. Heat 104 was concluded with this deposited material in the matrix, and the test rig was then dismantled.

Initial observation revealed that the upper matrix bricks showed little evidence of deposition (Figure 13). The first deposits occurred roughly 3.2m from the top of the 5m matrix (Figure 14), and deposition became more severe toward the bottom of the matrix (Figure 15). No consistent pattern of deposition in the flow passages was evident; holes with deposits in a given brick did not necessarily show deposits in the bricks immediately above or below.

3.2.5 Emissions Control

Prior to Heat 104, the flue gas reheat system was modified from the configuration used in previous testing. This system is used to vaporize residual water after spray quenching at the discharge from the test rig. This is necessary to avoid moisture in the baghouse which will cause the particulate layer to stick to the bags in the baghouse. The reheat system was moved to a point roughly 25 pipe diameters upstream of the baghouse in order to allow more residence time for vaporization. In marked contrast to previous testing with coal injection and potassium carbonate in the seed material (e.g. Heat 88-91 under ERDA Contract EX-76-C-01-2254), no problems with excessive pressure drop across the baghouse were encountered during Heat 104.

3.2.6 Matrix Tests - Bed Support

The stepped arch bed support used for the 5m matrix is shown in Figure 16 after completion of Heat 104. A similar support concept with a different material will be used in the next matrix installation.

3.2.7 Valve Tests - Pressurization/Depressurization Effects On Insulation

Disassembly of the matrix test rig showed little degradation of the insulating refractories in any of the several insulation lay-up schemes. Since the pressurization/depressurization effect in this test rig has a magnitude of less than 10 kPa (1.5 psi) when cycling between gas and air phases, this result does not provide information concerning actual heater performance; however, the fact that little degradation is evident is very encouraging.

The insulation scheme designed for the pressurization/depressurization tests in the valve test

facility is shown in Figure 17. These tests will provide needed design information on air heater insulation materials.

Further discussion of this matter is included in a document entitled "Objectives of the Valve Test Rig," included as Appendix A of this report.

3.2.8 Valve Tests - Valve Performance

Requirements for the various valves needed for directly fired air heaters are indicated in Table 5. The valve purchased from Zimmermann and Jansen, Inc. is intended to model the gas inlet valve (GI) as indicated in this table. The valve tests to be performed by Fluidyne will simulate the service requirements of this valve concerning temperature, pressure, gas chemistry, and operability. The six inch diameter is obviously a rather severe scaledown from expected full scale valves. Any of the valves shown in Table 5 could be tested to a similar degree of simulation, as could valves for certain applications of indirectly fired air heaters, in the valve test facility.

Further discussion of valve testing is included in Appendix A of this report.

3.2.9 Electrical Isolation

No further effort was expended in this area. Feasibility studies for electrical conductivity measurements are expected to continue during the next quarter.

3.2.10 Diagnostics

Further efforts were made during Heat 104 to assess the validity of temperature measurements with optical pyrometry. Figure 18 shows a comparison of the top of

matrix temperature during the heatup period measured with disappearing filament type optical pyrometers and with two thermocouples installed in the matrix brick. The thermocouples ceased to function after seed and coal feeding were begun. This figure, in addition to the material presented in the previous quarterly progress report, provides a basis for evaluation of the optical pyrometer measurements.

Further evaluation of temperature measurement apparatus will be conducted during future tests as appropriate.

3.3 Task 3 Preliminary Design of 5 MW Heater Technical Overview

During this reporting period, effort was concentrated on conceptual designs of the air heater and of the hot gas supply system.

The air heater conceptual design work has led to a technical and economic evaluation of various heater concepts which will be reviewed with DOE later. The concepts for the 5 MW heater permit it to operate as either a direct-fired or an indirect-fired system.

Emphasis in the development of the hot gas supply system has shifted from using a coal combustor to using a propane-fired combustor. The propane-fired combustor can operate with seed, ash, or coal injection, provide a range of gas inlet temperatures to the heater and provide either an oxidizing or reducing atmosphere at the heater inlet.

3.3.1 Hot Gas Supply System

A preliminary arrangement for the hot gas leg is being developed with primary emphasis on the components from the heater to the main burner. The principle components

in the hot gas leg consist of: ducting, hot gas valve, gas bypass spray chamber, combustion chamber, main burner, air preheat system, reducing gas system and primary air supply. (See Figure 19). The hot gas flow with the present arrangement is vertically upward thus minimizing ducting and attachment difficulties.

The hot gas system will supply 1.97 kg/sec (4.35 lb/sec) gas to the heater at a controlled temperature in the range 1800-2140K (2800-3400°F). The burner will produce either reducing or oxidizing gas as needed. Normal operating pressure will be at 1.1 atm, but the pressure housing will be designed for the maximum system pressure of 7 atm. The heat loss in the components between the main burner and the heater will cause a temperature drop of approximately 250°F.

The combustion chamber is sized to provide sufficient volume for combustion to occur under reducing conditions. The combustion chamber together with the ducting provides sufficient residence time for total vaporization of seed particles smaller than 100 μm which make up 95% of a typical particle size distribution. The inside of the combustion chamber is lined with insulation.

The ducting consists of extra strong pipe insulated to obtain an 18 inch inside diameter flow duct. The exact materials and thicknesses for the insulation liners have not been determined.

The 18" hot gas valve, mounted for vertical flow, is envisioned to be a water-jacketed gate type valve. Results from hot valve tests [152 mm (6 in) valve] will be used to help specify the 457 mm (18 in) valve. The valve will be subjected to 690 kPa (100 psi) pressure during the

air phase and 110 kPa (16 psi) pressure during the gas phase. Components upstream of the 457 mm (18 in) valve will be designed to accommodate the 690 kPa (100 psi) pressure which could occur if the valve failed to open.

When the hot gas valve is closed and the heater pressurized to simulate the air heating cycle, the combustor will be turned down and flow bypassed to the emission control device. Turn-down ratio will depend on capabilities of the main burner. As shown in Figure 19, a spray chamber will be used to cool the gas to $\sim 339\text{K}$ (150°F) and remove some particulates.

In the selection of the main burner, the turn down ratio, pressure drop, tolerance to preheat air, oxidizing and reducing combustion and flame size are being considered. Approximately 2.1×10^6 joule/hour (20×10^6 Btu/hr) heat output at the main burner is required with a maximum preheat air temperature of 644K (700°F).

The preheat air for the main burner will be generated in a commercially available, gas-fired heat exchanger. The heat exchanger will provide 644K (700°F) maximum preheat at a flow of 1.97 kg/sec (4.35 lb/sec).

The reducing gas system (Figure 19) will burn $\sim 110\%$ stoichiometric fuel. Approximately 30% of the air and fuel will be burned in the secondary burner and the enthalpy removed by passing the flow through a spray cooler. The cooled air is then mixed with the remaining 70% air and passed thru the preheat heat exchanger and into the main combustor where further combustion occurs with 80% fuel. Preheat would be supplied if high temperatures were required at the heater inlet.

Oxidizing combustion will be achieved by burning 90% stoichiometric fuel in the main burner with preheated air furnished for higher heater inlet temperatures. The secondary combustor and spray cooler would not be required for oxidizing combustion.

The primary air supply will consist of a 0.13 cu m/sec (3500 CFM) (approximately) 93 kw (125 H.P.) turbo-compressor. The anticipated pressure drop thru the hot gas leg component is 34 kPa (5 psi) thus eliminating the possibility of using a two stage blower.

3.3.2 Air Supply System

No design work was done on these components during this reporting period.

3.3.3 Gas/Air Exhaust Systems

No design work was done on these components during this reporting period.

3.3.4 Air Heater

Various conceptual designs for a 5 MW heater are being developed. The pressure vessel for the heater will be about five feet in diameter and forty feet high overall. The ends of the vessel may be spherical to be compatible with a simpler lay-up of insulation across the top of the vessel and around the openings. Spherical ends are also easier to reinforce around the pressure-vessel openings.

The heater arrangement is adaptable to several matrix configurations utilizing vertical flow geometries. One scheme has a "Bailey" brick matrix with the bottom flow

exiting through an outside flow annulus. Another scheme has a concentric ring matrix supported by a spherical support dome.

The 5MW heater has been studied in relationship to potential full-scale heaters. The principal objective of the full-scale heater study was to assure simulation of design concepts and the technical problems in the 5MW test program. The results of this study will be issued as a topical report.

3.3.5 Cooling Water System

No design work was done on these components during this reporting period.

3.3.6 Emissions Control System

No design work was done on these components during this reporting period.

3.3.7 Structure and Foundations

No design work was done on these components during this reporting period.

3.3.8 Coal Preparation System

No design work was done on these components during this reporting period.

3.3.9 Controls and Instrumentation

No design work was done on these components during this reporting period.

4.0 CONCLUSIONS

Operability tests indicate that steady operation of a directly fired heater is possible, with no clean-out cycle required, if the temperature at the bottom-of-the-bed is above the seed freezing temperature at the end of the gas (reheat) cycle. Dismantling of the heater after the last test showed no slag-like deposits in the upper parts of the bed. Matrix bricks were not fused together and could be removed relatively easily.

TABLE 1

MHD CANDIDATE MATERIALS RECEIVED DURING SECOND QUARTER CY 1978

Lab No.	Type	Designation	Mfr.	Shape	MOR Ambient kPa (psi)	MOR 1600K kPa (psi)	Bulk Density g-cm ⁻³ (lbm ft ⁻³)	Thermal Expansion K ⁻¹ x10 ⁻⁶ (F ⁻¹ x10 ⁻⁶)	Thermal Conductivity W/M-K 1500K (Btu/hr-ft-F)	Specific Heat KJ/kg-K (Btu/lbm-F)	Porosity w/o	Cost \$/kg (\$/lbm)	Al ₂ O ₃	MgO	SiO ₂	Fe ₂ O ₃	Cr ₂ O ₃	CaO	Na ₂ O ₃	Other
89	Silica	246 φFL-S18	Dr.C.Otto & Co.	9 Arch	1500 (218)	-	0.80 (50)		0.60 (0.0963)	66%			1.5	-	93.0	0.7	-	4.5	-	
90	Spinel	S-71	Trans-Tech	1"x1" x6"			3.488 (217.7)	7.1 (3.9)		2.2	165.00 (74.80)		71.0	29.0	-	-	-	-	-	
91	Spinel	S-78	Trans-Tech	1"x1" x6"			3.416 (213.3)	7.8 (4.3)		5.0	165.00 (74.80)		66.0	34.0	-	-	-	-	-	
92	Spinel	S-98	Trans-Tech	1"x1" x6"			3.492 (218.0)	9.8 (5.4)		1.9	165.00 (74.80)		32.0	68.0	-	-	-	-	-	
93	Spinel	S-110	Trans-Tech	1"x1" x6"			3.484 (217.5)	11.0 (6.1)		1.9	165.00 (74.80)		16.0	84.0	-	-	-	-	-	
94	Thoria	-	Zircoa	10mm tube																
95	Thoria	-	Zircoa	2"x2" x1/2"																
96	Silica	XSil	A.P.Green	9"x4 1/2" x2 1/2"	70000 (10150)	N.A.	1.83 (114)	N.A.			0.20 (0.09)		0.20	-	96.5	0.70	-	2.65	0.03	
97	Spinel Castable	X-13337	Taylor	Bulk	49000 (7100)	N.A.	2.75 (172)	N.A.	N.A.				70.0	28.0					1.0 P ₂ O ₅	
98	Iso Pressed Spinel	B-3346	A.P.Green	2"x2" x7"	63500 (9200)	1430 (207)	3.47 (217)	11.0 (6.1)		6.0			59.9	39.1	0.14	0.10	-	0.15	-	
99	Hot Pressed Spinel	12-138	Ceradyne	1"x1" x6"																
100	Fused Alumina	Mono- frax A	Carbo- rundum	4"x6" x18"	40000 (5800)		3.76 (235)	7.9 (4.4)	7.2 (1.16)	1.17 (0.279)	1.1 (1.84)	4.05	99.34	-	0.08	0.06	-	0.13	0.39	
101	Fused β Alumina	Mono- frax H	Carbo- rundum	Random Cullet	10000 (1450)		3.06 (191)	6.4 (3.6)	3.5 (.56)		4.9		93.9		0.18	0.8		0.1	5.6	
102	Sintered Spinel	-	Coors	0.95" Disc																
103	Spinel Cement	VS- 145	Norton	Bulk	15000 (2175)		2.72 (1.70)			24.1			69.3	28.3	0.5	0.2		0.9		0.8
104	Spinel	X- 13249	Taylor	9"x4 1/2" x2 1/2"																

TABLE 2
CONDITIONS WHICH PRODUCED STABLE OPERATION
(NO NET SOLIDS BUILDUP IN 30 HOURS)

	HEAT 103		HEAT 104	
	<u>Gas</u>	<u>Air</u>	<u>Gas</u>	<u>Air</u>
Cycle Time, minutes	60	30	60	30
Flow Area, m ² (ft ²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)
Mass Flow Rate, kg·s ⁻¹ (lb _m ·s ⁻¹)	0.11 (0.24)	0.12 (0.26)	0.10 (0.22)	0.09 (0.20)
Mass Flux, kg·s ⁻¹ ·m ⁻² (lb _m ·s ⁻¹ ·ft ⁻²)	13.0 (2.66)	14.0 (2.87)	12.0 (2.46)	10.8 (2.21)
Solid Temperature, K (F) Top	1865 (2897) (max)	1615 (2447) (min)	1840 (2852) (max)	1620 (2456) (min)
Bottom	1450 (2150) (max)	1230 (1754) (min)	1410 (2078) (max)	1190 (1682) (min)
Initial ΔP, kPa (psi)	10.0 (1.45)	7.5 (1.09)	7.5 (1.09)	5.0 (.725)
Ultimate ΔP, kPa (psi)	10.0 (1.45)	7.7 (1.12)	7.2 (1.04)	4.8 (.70)

TABLE 3
CONDITIONS WHICH PRODUCED UNSTABLE OPERATION
(EXCESSIVE BUILDUP & PRESSURE DROP IN 4 HOURS)

	HEAT 103		HEAT 104	
	<u>Gas</u>	<u>Air</u>	<u>Gas</u>	<u>Air</u>
Cycle Time, minutes	30	30	30	30
Flow Area, m ² (ft ²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)
Mass Flow Rate, kg·s ⁻¹ (lb _m ·s ⁻¹)	0.10 (0.22)	0.08 (0.18)	0.10 (0.22)	0.07 (0.15)
Mass Flux, kg·s ⁻¹ ·m ⁻² (lb _m ·s ⁻¹ ·ft ⁻²)	12.0 (2.46)	9.5 (1.9)	12.0 (2.46)	8.5 (1.7)
Solid Temperature, K (F)	1810 (2798) (max)	1670 (2546) (min)	1740 (2672) (max)	1575 (2375) (min)
	Bottom 1365 (1997) (max)	1090 (1502) (min)	1280 (1844) (max)	1120 (1556) (min)
Initial ΔP, kPa (psi)	10.0 (1.45)	7.2 (1.04)	7.2 (1.04)	4.8 (.70)
Ultimate ΔP, kPa (psi)	13.9 (2.02)	9.2 (1.3)	9.6 (1.4)	6.6 (.96)

TABLE 4
 CONDITIONS PRECEDING SHUTDOWN OF HEAT 104
 (DEPOSIT RETAINED IN MATRIX)

	<u>Gas</u>	<u>Air</u>
Cycle Time, minutes	45	30
Flow Area, m ² (ft ²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)	8.5 x 10 ⁻³ (9.1 x 10 ⁻²)
Mass Flow Rate, kg·s ⁻¹	0.09 (0.2)	0.7 (0.15)
Mass Flux, kg·s ⁻¹ ·m ⁻²	10.6 (2.17)	8.2 (1.7)
Solid Temperature, K (F) Top	1740(2672) (max)	1575(2375) (min)
Bottom	1340(1952) (max)	1140(1592) (min)
Initial ΔP, kPa (psi)	6.2 (.90)	2.0 (.29)
Ultimate ΔP, kPa (psi)	15.3 (2.22)	2.6 (.38)

TABLE 5 SERVICE REQUIREMENTS FOR VALVES FOR
DIRECTLY FIRED AIR HEATERS

Valve	Temperature K (F)		Pressure kPa (psia)		Fluid When Open	Seed & Slag	Leakage		Direction of AP	Full Scale Dia (ft) m	Cycles per Year	State of Art
	Max.	Min.	Max.	Min.			Fluid	Direction				
G1	2033 (3200)	1810 (2800)	814 (118)	117 (17)	Gas	Yes	Air	To Gas Manifold	To Gas Manifold	~2.4 (~8)	9,000	No
GO	1256 (1800)	1089 (1500)	827 (120)	110 (16)	Gas	Yes	Air	To Gas Manifold	To Gas Manifold	~2.4 (~8)	9,000	No
A1	1144 (1600)	1006 (1350)	827 (120)	827 (120)	Air	No	Air	To Heater	To Heater	~1 (~3)	9,000	Yes
A0	1922 (3000)	1810 (2800)	814 (118)	814 (118)	Air	Yes	Air	To Heater	To Heater	~1 (~3)	9,000	No
AP	1144 (1600)	1006 (1350)	827 (120)	827 (120)	Air	No	Air	To Heater	To Heater	<.3 (<1)	9,000	Yes (?)
AD	1922 (3000)	1810 (2800)	827 (120)	110 (16)	Gas	Yes	Air	To Gas Manifold	To Gas Manifold	<.3 (<1)	9,000	No

FIGURE 1. Phase diagram for the MgO:Al₂O₃ system showing the compositions of magnesia-rich magnesia-alumina spinels in terms of MgO:MgAl₂O₄ concentration as well. Also L = liquid, P = periclase, S = magnesia-alumina solid solution, and C = corundum phases.

FIGURE 2. As-Fired Surface of a Dense, Stoichiometric Spinel Sample (S-71)

FIGURE 3. Fracture surface of S-71. Note pores within the grains and especially the microcrack terminating at one of these pores.

FIGURE 4. As-fired surface of a dense spinel/MgO sample (S-78, spinel/MgO molar ratio = 3.25).

FIGURE 5. Fracture surface of S-78. Note the irregularity of the surface compared with S-71 and intergranular cracks.

FIGURE 6. As-fired surface of a dense spinel/MgO sample (S-98, spinel/MgO molar ratio = 0.22)

FIGURE 7. Fracture surface of S-98. Note surface irregularity, presence of intragranular pores, and absence of intergranular cracks.

FIGURE 8. Fracture surface of S-110 (spinel/MgO molar ratio - 0.082). Note irregularity of the surface and presence of intragranular pores.

FIGURE 9. Configuration of test refractories at the top of the matrix (Heat 104).

FIGURE 10. Condition of test refractories at the end of Heat 104. Note damage to S-78. Spacers of X-317 supported the test bars and were not damaged.

FIGURE 11. Fusion cast MgO/spinel, X-317. Note microcrack between MgO grain and spinel matrix.

FIGURE 12. Thermal diffusivity vs. temperature for X-317. Hysteresis is thought to be due to opening and closing of microcracks between MgO grains and spinel matrix. (Courtesy of G. Youngblood, MEMRDI)

FIGURE 13. Matrix brick 0.08m from top of bed (Heat 104)

FIGURE 14. Matrix brick 3.81m from top of bed (Heat 104)

FIGURE 15. Bottom matrix brick (Heat 104)

FIGURE 16. Support for 5m RFG matrix (Heat 104)

FIGURE 17. Insulation Scheme for Pressurized Section of Valve Test Rig

FIGURE 18. Comparison of the Top-of-the-bed Temperatures Measured by Disappearing Filament Optical Pyrometry and Thermocouples.

Appendix A

Objectives of the Valve Test Rig

1.0 INTRODUCTION

FluidDyne Engineering Corporation will be testing a high temperature valve for dirty gas service as part of DOE Contract No. ET-78-C-01-3005. In the work statement of that contract, Item Numbers 2.7 and 2.8 cover this effort and are shown below:

- 2.7 Establish the effect of pressure cycling on seed/slag penetration of insulation and air valve performance.
- 2.8 Conduct preliminary tests of existing valve designs to establish reliability, loss and wear rates.

These two items of the work statement correspond to the two main objectives of the valve test program:

- 1. valve operability, and
- 2. insulation integrity in response to pressurization/depressurization cycles.

In order to meet these objectives usefully, simulation of valving in full-scale heater systems has been considered. To the extent that it is possible, simulation of full-scale conditions will be done in the test hardware.

Some discussion of full-scale systems is given in this report. Conceptual designs have been prepared and used to set various experimental conditions. These are useful but it

must be recognized that full-scale designs are conceptual and based on assumptions that may or may not be reasonable. For example, the gas velocity in hot gas ducts has been limited to 53 m/sec (175 ft/sec). This in turn has been used to set the diameter of hot gas valves. Erosion is the reason for this limit. The test work will help clarify the validity of this assumption.

A set of drawings which show the test valve, various views of the test rig, and process diagrams indicating how the rig will operate are included with this report.

2.0 VALVES IN FULL-SCALE HEATER SYSTEMS

The basis for many of the decisions regarding the experimental valve test rig has been analysis of full-scale systems. Estimates of the size of heaters and valves have been made based on reasonable choices for process variables. Those variables which affect valve sizes most are the allowable velocity in ducts and the number of heaters in a system. The major consideration which bears on specification of duct velocity is erosion of refractory. Allowable ripple in delivered air temperature, pressure, and flow rate bear on the number of heaters. The size of hot blast valves which have already been produced is of secondary but not negligible importance. As shown in Table A, the largest manufactured hot blast valve has a flow diameter of 2.2 m (7.25 ft). A twenty-four heater system for a 1000 MWe power plant would require hot gas inlet valves of about 2.5 m (8.2 feet) in diameter. We believe that increasing the size of existing hot blast valves from 2.2-2.5 m (7.25 to 8.2 feet) would be feasible. There are, however, a number of other considerations and it is these that the valve test rig is intended to address.

Inspection of Table A1 suggests that a relatively minor extension of existing hot blast valve technology could lead to acceptable valves for MHD heater service. The operating conditions in the most modern steel plants are close, in terms of temperature, pressure, and flow velocity, to projected operating conditions for MHD heater systems. There is one important exception, viz. the quantity of particulates and condensibles present in the gas reheat stream. Reheat gases in steel plants are much cleaner than either the MHD exhaust in a directly fired system or the hot gas from a coal-fueled combustor which heats an indirectly fired system. As indicated earlier this difference could:

1. Impair the operability of hot gas valves by causing sticking or sealing problems, and
2. Cause rapid degradation of refractory linings of valves, heater vessels, and ducts.

The major objectives in valve testing are related to these concerns.

The specification of operating conditions for the valve test rig will be based on estimates of these conditions for full-scale systems. Figure A1 is a sketch showing the location of valves around a typical heater and the sequence of operations which they will undergo. How pressure will vary is also shown. Valves numbered (1) through (4) switch heaters on or off, air or gas. Valves (5) and (6) are needed because the large, main valves cannot be stroked against a large pressure difference.

In making the simplified pressure vs. time sketches, also shown on Figure A1, the effect of leakage has been ignored. An obvious result of excessive leakage will be difficulty in achieving either:

1. Depressurization if an air valve [either (3) or (4)] is leaking, or
2. Pressurization if a gas valve [either (1) or (2)] is leaking.

One could speculate that if this difficulty occurred in a full-scale heater, it would be a signal that one or more valves needed to be serviced.

The question of how much leakage can be tolerated before it becomes impossible to achieve either pressurization or depressurization is somewhat complicated. If the geometry of a system is specified, calculations can be made which will address that question. In FluidDyne's size/cost program, some preliminary steps have been taken in this direction but more work is needed.

3.0 OBJECTIVES OF VALVE TEST RIG

There are two major objectives of testing in the valve test rig:

1. To assess the operability of a hot blast type valve in an MHD exhaust gas
2. To assess the performance of refractories in response to pressurization/depressurization cycles in an atmosphere of hot, corrosive gases.

These major goals can be broken down into a number of more specific concerns which deserve study as shown below:

1. Accumulation of material (seed/slag, etc.) on the body and gate of the valve and the housing in which the gate moves to an extent which could interfere with operation of the valve.
2. Deposition of material on sealing surfaces when the valve is stroked and subsequent wear of these surfaces causing a gradual increase in leakage.
3. Corrosion/erosion or thermal-stress induced damage to castable refractory linings or facings of the body, gate, and follower ring of the test valve.
4. Penetration of corrosive gases into refractories lining the pressurized section and damage to those refractories.
5. Loss of insulating value of refractories due to filling of open pores by seed/slag in the gas.

In addition to determining the validity of these concerns, data will be collected that will be useful in design and feasibility studies. Rates of heat loss to the valve will be determined and at least a preliminary estimate made of the effect of coolant flow rate on valve performance.

4.0 TEST VARIABLES

Table 2 is a list of test variables which has been generated to aid in design of the test rig. Each of the dependent variables is discussed separately followed by a somewhat broader discussion of the independent variables.

TABLE 2
TEST VARIABLES

Dependent:	Valve operability
	Heat losses
	Wear/leakage
	Integrity of castable lining of valve
	Integrity of refractory lining of pressurized section
	Insulating value of refractory lining
Independent:	Temperature on gas heating cycle
	Temperature on pressurized air cycle
	dP/dt on pressurization & depressurization
	dT/dt
	Gas flow rate
	Seed concentration
	Slag concentration
	Seed type
	Slag source
	Oxygen partial pressure on gas cycle
	Refractory lay-up in pressurized section
	Cycle time

Operability

A major variable of interest is operability which, in this particular case, relates to the ability to stroke the valve and effect an adequate seal. Good operability implies that trouble free service for periods of, for example, one or two years between regularly scheduled maintenance periods can be achieved.

Heat Loss

Heat loss to the valve can be determined by measuring heat absorption by the cooling water. This information will be useful to both design and feasibility studies.

Leakage

Measuring leakage rates of the valve during testings may prove difficult. It is intended to pressurize the rig and then supply air at a rate needed to maintain pressure. Measuring both the quantity of air needed to achieve pressurization and the rate of addition while the rig is under pressure will provide some guidance. However, the requirement for air is to balance leakage and loss in temperature, with resultant increase in density, due to heat loss. Since two effects are involved, measurement of the consumption of air will not necessarily define leakage. Our intent is to get the rig up and running first and sort this out later.

The manufacturer specifies a bubble-tight seal on a new valve. Leakage of the test valve can be measured while the rig is cold, i.e. prior to the start of testing. After testing, the rig can be cooled down with the valve in the closed position and leakage measured again.

Castable Ceramic in Valve

A potential problem area is the castable ceramic used on the valve gates and body to protect it from the hot, corrosive gas. We will specify the material to be applied by the manufacturer and are looking at various possibilities.

The only available castable bond material for service temperatures as high as 1900K (3000°F) is calcium aluminate. Thus,

the only viable options for castable materials are various grains such as stoichiometric spinel, spinel plus excess magnesia, magnesia chrome, alumina chrome, etc. with a calcium aluminate bond.

A stoichiometric spinel castable with calcium aluminate bond was tested in the matrix test rig recently and performed well. This is the principle choice on the basis of availability of the possible grains. It is likely that this material will be specified for lining the interior valve surfaces.

The forms used to apply castable to the valve will be provided by the manufacturer along with the valve. If a failure occurs, new material can be cast in place at our laboratory.

It should be noted that ramming mixes provide a greater choice of bond materials. In its present configuration, however, the valve is not suitable for use with a ramming mix. If castable insulation proves unworkable, modification for use with a ramming mix may be considered.

Refractory Lining of Pressure Vessel

Pressurization/depressurization cycles provide a pumping mechanism for intruding hot, corrosive gas into the refractory lining. Major goals of the test program are to assess the severity of this problem and to develop refractory lay-up methods/designs which work.

Not knowing in advance of testing how severe this problem will be, we believe it is prudent to protect the metal surfaces of the pressurized section of the test rig against over-temperature. It has been decided to provide water cooling to the exterior of the pressurized part of the rig.

In matrix testing, relatively rapid failures of refractory have occurred. These have been the result of penetration of hot seed-bearing gas behind the hot liner. Insulating fire brick, located between the hot liner and the metal shell was attacked rapidly. Hot spots on the metal appeared. These tests were not pressurized and hence these incidents, although alarming, were not nearly so hazardous as they would have been in a pressure vessel. Hence, we are designing the test rig carefully to prevent failure of the hot, pressurized section of the rig.

Insulation Value of Refractories

Use of water cooling should also provide the means for determining loss of insulating value of the refractories. Baseline insulating values will be determined with clean fuel firing of the test rig. Deterioration of insulating value will cause heat losses to rise with time, and this should be measurable on the water side.

Independent Variables

At least initially, the hot gas source will be a propane burner with seed/ash or coal injection. No provision will be made to run with reducing atmospheres for the first tests. A modification which will permit oxidizing/reducing cycles is planned later in the program. Operating temperatures, pressures, and flow rates for full-scale systems are indicated in Table A1 and can be simulated fairly closely in the test rig. Transient conditions which occur during pressurization/depressurization will be more difficult to simulate. In particular, the conditions on the high pressure side of the valve will differ from full-scale but in general be more severe as far as demands on refractories are concerned. Hence, test results bearing on refractory performance should be

conservative. The rate of change of pressure with time is the driving force for causing flow of hot, corrosive gas through refractories. To the extent that full-scale predictions of this rate are reliable, we can simulate this independent variable. The rate of change of temperature with time will be higher in the test rig because it is a higher surface/volume ratio system and hence loses heat to the surroundings more rapidly. To the extent that rapid changes in temperature cause refractory degradation, results from the test rig will rate refractories conservatively.

Cycle times for full-scale systems vary depending on the configuration, but in general, approximately equal time on gas or air is typical. In the test rig, time on gas will have to be considerably greater than time on air in order to overcome heat losses. Air preheated to 1100K (1500°F) will be provided to pressurize the rig. To obtain a meaningful test of the effect of P/DP cycles on refractories requires that the materials be hot enough to permit some penetration and subsequent condensation or deposition of seed or ash particles. The design of the rig will accommodate this need.

It is likely that a relatively long time (i.e. hundreds of hours) will be needed to see deterioration in either valve performance or integrity of refractories. Under those circumstances, it would not be wise to change seed type or slag source frequently. A reasonable choice of seed type and ash source will be made for the first test and no change will be made during that test.

5.0 TEST RIG OPERATION

Figure 2 is a drawing showing the test rig and indicating process flows. Basic operation will be as follows:

1. VALVE open; main flow through VALVE and out through upper spray chamber; storage heater on reheat (~ 25 min.)
2. VALVE open; open mid spray chamber outlet valve
3. CLOSE TEST VALVE
4. VALVE close; pressurize by blowing down storage heat (~ 2 min.)
5. VALVE close; bleed in air to maintain pressure; hold for ~ one minute
6. VALVE closed; depressurize through orifice (~ 2 min.); open upper spray chamber
7. OPEN TEST VALVE
8. VALVE open; close mid spray chamber

Operating the test valve in this fashion will expose its sealing surfaces to flow of hot, dirty gas when it strokes. In this respect, at least, test rig operation simulates full-scale conditions. In full scale, the hot gas inlet valve must operate against a small differential pressure due to the difference in gas manifold pressures. As indicated, the cycle times are approximate and can be adjusted if needed.

All of the details concerning data acquisition have not been worked out. Certainly it will be necessary to collect the following data:

- Gas flow to all burners
- Air flow to all burners
- Cooling water flow through the test valve
- Temperature rise of valve cooling water
- Cooling water flow through the jacket of the pressure section
- Temperature rise of jacket cooling water
- Solid temperature of duct just upstream of valve
- Solid temperature of duct just downstream of valve
- Pressurization air flow rate
- Make-up air flow rate while system is pressurized
- Seed feed rate
- Coal/ash feed rate

Round-the-clock operation is anticipated and the laboratory is staffed to handle this requirement. Before a test run is started, a training period will be needed during which laboratory personnel will learn the operation of the unit. Previous experience with the matrix test rig will help.

Fairly long tests, ~ 500 hours, are planned. It is likely that a shake-down period will be required before a long test can be successfully completed. Allowance has been made for this in the schedule.

TABLE A1
ESTIMATED VALVE SIZES AND PRESSURE LEVELS
FOR FULL-SCALE HEATERS (24 HEATERS⁽¹⁾ 1000 MWe)

Valve I.D.	Flow ⁽²⁾ Diameter m (feet)	Throat ⁽³⁾ Velocity m/sec (ft/sec)	Max. Op. Temperature °K (°F)	ΔP Across In Closed Position kPa (psi)	Particulate ⁽⁴⁾ Loading g/m ³ (gr/ft ³)	Minimum ⁽⁵⁾ Stroke Time sec	Manifold ⁽⁶⁾ Pressure kPa (psia)
Hot Gas Inlet	2.5 (8.2)	53.3 (175)	1978 (3100)	731 (106)	2 (0.9)	~30	112 (16.2)
Gas Outlet	2.1 (6.9)	53.3 (175)	1400 (2060)	731 (106)	2 (0.9)	~25	108 (15.6)
Air Inlet	.82 (2.7)	53.3 (175)	1068 (1463)	731 (106)	?	~10	841 (122)
Air Outlet	1.07 (3.5)	53.3 (175)	1867 (2900)	731 (106)	?	~10	820 (119)
Pressurization	.15 (0.5)	~400 (~1300)	~1068 (~1463)	731 (106)	?	~5	841 (122)
Depressurization	.15 (0.5)	~400 (~1300)	~1810 (~2800)	731 (106)	?	~5	820 (119)

(1) Distribution of heaters: 8 on air, 13 on gas, 1 on standby, 1 on clean out, 1 on pressurization/depressurization.

(2) Largest hot blast valve 2.29 m (7.25 ft) flow diameter, operates at 1867°K (2900°F), purchased in 1970.

(3) Values for large valves were set to minimize erosion; value for pressurization/depressurization valve is sonic velocity.

(4) Assumed to be 1% by weight and includes condensibles (seed).

(5) Based on hot blast valve vendor literature.

(6) Pressure of the hot blast air in steel plants is ~550 kPa (~80 psi).

On Gas 1,2 Open 3,4,5,6 Closed	1,2 close	5 open	3,4 open	5 close	On Air 3,4 Open 1,2,5,6 Closed	3,4 close	6 open	1,2 open	6 close	On Gas 1,2 Open 3,4,5,6 Closed
---	--------------	-----------	-------------	------------	---	--------------	-----------	-------------	------------	---

FIGURE A1. SKETCH OF A TYPICAL MHD AIR HEATER TOGETHER WITH AN INDICATION OF VALVE SEQUENCING AND PRESSURE vs TIME PLOTS.

FIGURE A2.

FIGURE 19. Hot gas supply system for the 5 MW heater.