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November 1964

(DESIGN REPORT)

SMALL SCALE SEAL TEST HHT-11

**Astronuclear Laboratory
Westinghouse Electric Corporation**

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(DESIGN REPORT)
SMALL SCALE SEAL TEST HHT-11

by
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ABSTRACT

A small, circular rig which heats hydrogen flowing through a series of steps in an annulus defined by two graphite barrels has been designed, built and run. The initial test data from this rig have proved useful in serving as a basis of comparison with results from analytical studies which employ the same techniques and methods used in the study of heat transfer and hydrogen flow in the reactor lateral support system. Refer to report, Reference 1. Short comings of the rig are reviewed. The rig needs improvements and development in two broad categories. One involves investigation and refinement of temperature distributions in the graphite barrel structures including elimination of hot and cold areas and including a description of axial temperature distributions in the heater element together with end thermal losses. The other involves raising the temperatures of the graphite barrels and of the hydrogen to levels at which hydrogen corrosion can be studied.

It is recommended that development of the rig be pursued along the lines indicated in this report in order to obtain the experimental information required in substantiating the detailed information of the analytic program.

Reference 1. WANL-TME-999

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INTRODUCTION

A small cylindrical rig has been designed and built, and initial testing has been completed to show heat transfer characteristics to and across flowing hydrogen and in turn to show the effect of heating on the characteristics of the hydrogen flow. The results are pertinent in particular to the lateral support system of the reactor. The hydrogen flow system is contained in a stainless steel pressure vessel designed for operation up to 250 psi. Hydrogen flow is through a narrow annular passage defined by two mating graphite concentric cylinders. As the flow progresses axially, the hydrogen is accelerated and decelerated by series of slotted lands and steps in the inner barrel. An electrical-resistance heater element, rated up to 80 KW, supplies heat to the inner barrel from the inside. A water-cooled copper heat exchanger removed heat from the outer barrel. Temperatures, pressures, hydrogen and water flows, and electrical input are measured.

During initial testing, to protect the heater element from hydrogen corrosion, temperatures in the heater element cavity were limited to 2500^oF as measured. A gross asymmetric temperature distribution in the inner and outer graphite barrels and in the heat exchanger was observed. This temperature maldistribution was found to be a function of heater element eccentricity up to 1/16 inch TIR (total indicator reading) at the bottom. A refined heater element of smaller diameter was incorporated to reduce the sensitivity of the test piece to heater element eccentricity. In this subsequent build the eccentricity was held to a maximum of .021 inch TIR. Temperature levels responded properly to the refined heater element design and improved concentricity, yet temperatures as read at points of various circumferential locations were obviously not measurements of mean circumferential temperatures of a particular axial station. A logical decrease of temperature radially outward with the various thermocouples at different circumferential locations was not obtained. Test results, however, demonstrated good trends as a function of hydrogen flow. The response of thermocouples to changes of flow and power were sharp. Data from these runs were determined to be reliable and were used in a comparative study of test data versus results of digital computer analytical codes. These results are currently being reported in Reference 1.

Under conditions of this testing, up to 2500°F, the heater element proved to have a useful life of approximately 1-1/2 hours, limited by hydrogen corrosion. To increase the life of the heater element, and particularly since higher temperatures are anticipated in the running of this rig for hydrogen corrosion study purposes, graphite heater elements have been experimentally coated with tungsten for endurance testing. Of special interest is one coating of Varcum* and tungsten, cured and then heat treated in a methane atmosphere. The heater element with this coating was subsequently tested at a measured 3500°F for 1/2 hours. The coating appeared to be well bonded and protected the graphite from hydrogen corrosion in convincing fashion at this high temperature. In further support of high temperature running, use of a hydrogen preheater is anticipated.

The ability of the test rig to measure discrete radial temperature gradients through the graphite barrels and to measure mean temperatures at specific axial locations has not been satisfactorily demonstrated but it is felt that this could be a limitation of this rig as originally designed and built. Many possible contributing factors are discussed in detail in this report.

An effort is being made to develop the rig further in the interests of raising useful temperature levels and of improving radial temperature distributions. In addition the axial temperature distribution in the heater element and the thermal losses through each end of the rig need to be investigated and described. This effort involves design, procurement, development testing and eventual incorporation of the demonstrated improvements in the final rig configuration for the model testing. It is the purpose of this report to describe the design of the present rig, to recognize its capabilities and limitations, and to describe in some detail the development effort required to overcome present deficiencies.

*Partiality polymerized furfural alcohol.

This development effort involves the refinement of the rig performance for the major purpose of verifying analytical tools and methods employed to describe hydrogen flow and heat transfer in the lateral support system of the reactor.

DESCRIPTION OF PRESENT RIG

The rig is described in detail by drawing number NT 701182 Sheets 1 through 20. Sheet 1 is the basic drawing and serves as an index to each part by item number and sheet number with the exception of instrumentation. Installation and locations of thermocouples and pressure taps are shown on Sheets 18 and 19. These drawings in complete form are not made part of this report but should be referred to in order to gain a complete description of the rig.

The rig is basically a hydrogen flow experiment housed in a stainless steel pressure vessel. Figure 1, an excerpt from Sheet 1 of NT 701182, shows a cross section of the rig. Figure 2 is a photograph of the rig assembled. The test piece housing is a cylindrical pressure vessel 10.75 inches in diameter and 21.75 inches long. This housing is shown in the photograph of Figure 3. The inlet flange of the vessel is stainless steel, Figure 4; the outlet flange, which is water cooled, is Inconel X-750, Figure 5. Hydrogen flow entering is directed through four inlet ports. These ports and an internal annulus plenum chamber aid in the establishment of good flow distribution.

Two concentric graphite barrels are contained by the pressure vessel. The outer barrel of H4LM graphite, impregnated after machining according to Specification WANL-294545 Revision 3, fits into a copper heat exchanger. The inner barrel of ZTA graphite contains the heater element, Figure 6. As shown in Figure 7, three bands of lands and grooves are machined on the outside surface of the inner barrel. The lands are sized to contact the inside surface of the outer barrel. Hydrogen flows through the grooves of each band; 18 grooves are machined to a nominal depth of .007 inch. The heater element of HLM-85 graphite has two identical electrical circuits in parallel, each continuous for 180 degrees of the cylindrical geometry. Each circuit branches from the two common graphite terminals into which the copper electrodes are screwed. The electrodes extend through the inlet end of the pressure vessel as shown in Figure 4. Silicon rubber "O" rings fitted on boron nitride sleeves seal against hydrogen pressure. The boron nitride sleeves insulate the electrodes from the pressure vessel, Figure 8.

When the test piece is under pressure, the electrode end of the heater element seats on a stack of Marinite and aluminum oxide plates. This stack acts as a heat barrier, as an electrical insulator, and as a mechanical stop for the heater element. In the bottom of the inner barrel is an aluminum oxide cup which acts as a heat barrier and as a back-up pilot for the heater element should it tend to shift, Figure 9.

The heat exchanger surrounding the outer barrel is constructed of two concentric pieces of copper pipe, the inner piece machined with 300 shallow axial grooves with lands (or fins) between. When assembled, the outer copper barrel encloses the grooves by fitting to the lands. Water flows into an inlet plenum chamber of the exchanger from a one-inch supply line. From the inlet plenum chamber water flows through the coolant passages in the same direction as the hydrogen flow in the annulus between the graphite barrels. These passages, .031 inch wide by .038 inch deep, exhaust into an outlet plenum chamber. Figures 10 and 11 show the heat exchanger assembled in its stainless steel support spool.

The tolerances and part dimensions of the rig allow ample space for expansion in areas where fits are not held for specific purposes and are not otherwise critical. Critical fits will be described and discussed under specific subject headings subsequently in this text.

The test piece is instrumented with thermocouples to measure temperature in five general regions: 1) heater element, 2) inner barrel, 3) hydrogen gas inlet and outlet, 4) outer barrel, and 5) heat exchanger. Figure 12 is a schematic showing locations of all thermocouples and pressure taps as listed on Figure 12A. A tungsten/tungsten-26% Rhenium thermocouple at the axial mid-section and inside the heater element is used as a control to set heater element temperatures, Figure 13. It is read continuously on a potentiometer during test. Four precalibrated chromel/alumel thermocouples measure the inner barrel temperatures, installed axially into the barrel from the top end. One is at the first land and groove axial location; three are at the middle land and groove axial location at different radial distances from the center line. These thermocouples are read on a Multi-point recorder. Two copper/constantan thermocouples measure hydrogen inlet temperature;

and three chromel/alumel thermocouples measure hydrogen outlet temperature. All five are shielded to prevent thermal radiation effects from surrounding surfaces. The inlet thermocouples are inserted through two diametrically opposite inlet ports. Two of the three outlet gas thermocouples are mounted through the outer barrel structure; the third is inserted through the outlet port; all three are in the same axial location, two opposite inner barrel grooves and one opposite a land. Five precalibrated chromel/alumel thermocouples measure the outer barrel temperatures; all are installed at an oblique angle through the structure of the outer barrel, the leads contained in axial grooves on the outer surface of the outer barrel. One of these instruments is located at the first land and groove axial location; another, opposite the third land and groove axial location; each is centralized in the outer barrel wall structure. The three other thermocouples in the outer barrel are at the second land and groove axial location, each at a different radial position from the center line and each at different circumferential locations. As with the inner barrel thermocouples, a Multipoint recorder is used for the readout. Seven copper/constantan thermocouples measure water temperatures in the heat exchanger and read out on their own Multipoint recorder. Each thermocouple is at a particular axial location; three are on one side and four on the other, diametrically opposite, see Figures 10, 11, 12 and 12A.

Wall static openings measure pressures at the inlet to the test section, between the first and second land and groove axial locations, between the second and third land and groove axial locations, and in the exit plenum chamber. The inlet and exit plenum statics read out on a strip recorder in the test control room; the other pressures are read from gages.

As shown on schematic Figure 14, the test piece is installed in a system of flow controls and data indicating and recording instruments. Automatic valves control the pressure of hydrogen gas supplied to and exhausted from the test piece, Figure 15. Pressure levels as high as 250 psi and pressure differentials as high as 30 psi can be obtained. The hydrogen flow through the test piece is measured by means of a sharp-edged orifice. Pressure and temperature upstream and pressure differences across the orifice are measured. Water

flow is regulated by a manual valve; a rotameter measures and indicates the flow; up to 7 gallons per minute can be obtained.

A view of the control room is shown in Figure 16. The electric power for the system is supplied by two direct current Westinghouse industrial welders connected in parallel, Figure 17. Two water cooled leads conduct current to the electrodes on the rig. Controls on a console set the power level up to a maximum of 80 KW, Figure 18. Power is calculated from measurements of current and voltage through and across the heater element. A high-resistance, direct-current voltmeter in parallel with the element measures the voltage; a millivolt meter in parallel with a shunt calibrated to read a 50 millivolt drop for every thousand amperes measures the current. All flow connections to the test piece contain a section of plastic tubing at least six inches long; the flow system is electrically grounded but not through the hydrogen or water flow systems.

Significant Dimensions

1. The lands and grooves of the inner barrel were inspected in detail. The diagram, Figure 19, and the tabulation, Figure 20, describe the results of this inspection. Note that the measurement across the lands are uniform within several tenths of mils and that this dimension is measured to be within the blueprint tolerance $(3.874 \begin{smallmatrix} +.000 \\ -.001 \end{smallmatrix} \text{ inches})$ and near the upper limit. The groove depths at the three axial locations averaged .0066, .0068 and .0073 inches from inlet to exit respectively compared to the blueprint dimension of $.007 \begin{smallmatrix} +.001 \\ -.000 \end{smallmatrix} \text{ inches}$.
2. The inside diameter of the outer barrel before assembly was determined to be within blueprint limits $(3.875 \begin{smallmatrix} +.001 \\ -.000 \end{smallmatrix} \text{ inches})$ and was toward the mean.
3. The outside diameter of the outer barrel was fitted to the inside diameter of the heat exchanger.
4. The inside diameter of the copper heat exchanger assembly had been machined after brazing, to approximately .005 inches under blueprint limits $(4.939 \begin{smallmatrix} +.001 \\ -.000 \end{smallmatrix} \text{ inches})$.

Critical Fits and Alignments

1. When the outer graphite barrel was fitted to the heat exchanger inside diameter, a snug slip fit was obtained. Yet, when the seven thermocouple leads and the four pressure-tap, stainless-steel tubes were assembled in the axial slots machined in the outer surface of the outer graphite barrel, this outer graphite barrel had to be pressed into the copper barrel of the heat exchanger with screw jacks.
2. The fit of the inner graphite barrel in the outer graphite barrel before assembly of the outer barrel in the heat exchanger was $.0017 \pm .0003$ inches loose. By feel, the fit appeared to be as tight as possible without binding. After assembly of the outer barrel in the heat exchanger, the fit of the inner barrel appeared to be unchanged.

During the initial running at 2500°F in the heater element cavity characteristic temperatures in the inner barrel and the outer barrel rose to $500 \pm 50^{\circ}\text{F}$ and $250 \pm 50^{\circ}\text{F}$ respectively. It is estimated that the most probable mean fit of the lands in the inner barrel under these temperature conditions was .0008 inches loose (.0004 inches on a side). This estimate is based on considered choice of values under conditions of uncertainty of the following items: coefficients of thermal expansion, temperature level and distribution, degree of restraint of thermal growth in graphite barrels by containment in heat exchanger. For ZTA graphite, uncertainty in values of coefficients of thermal expansion lead to percent changes in fit from thermal effects as great as 51%; for HLM graphite including uncertainty of grain orientation, as much as 28%. Temperature level uncertainties lead to percent differences in fit changes up to 9%. Considering the heat exchanger to offer full restraint and alternatively no restraint to the graphite barrels, the uncertainty of the change in fit due to thermal effects is as much as .0016 inches. In estimating the most probable mean fit (.0008 inches loose when heated), as quoted above, National Carbon Company data was used at mean temperature

levels; 50% restraint of the outer graphite barrel by the heat exchanger was assumed. If the temperature levels in the inner and outer graphite barrels were doubled (500°F and 1000°F respectively), the most probable mean fit of the lands of the inner barrel in the outer barrel would be calculated as .0002 inches tight.

3. The design of the stainless-steel spool which supports the heat exchanger provides jack screws to center the heat exchanger in the assembly. As machined, the inside diameter of the spool was undersized, which decreased the range of effectiveness of the jack screws. The first run, as mentioned previously, was made with eccentricities of the heater element to the inner barrel measured at $1/64$ inches TIR at the top and $1/16$ inches TIR at the bottom. On subsequent builds pivot points and attaching screws were assembled through the top housing flange to pick up the flange of the heat exchanger support spool and thus control its alignment. The run out of the heater element to the inner barrel was then held to .021 inches TIR maximum.

RESULTS FROM TESTING

Temperature Distribution

In all the runs, smooth trends of temperature are observed as hydrogen flow is varied. At various power levels and under the influence of differences in builds the shapes of the curves and the relative level of the temperature of each thermocouple are not predictable. Reasons for these uncertainties in most cases can only be surmised.

Build 3 Run 2 represents the most comprehensive and best controlled results to date. Point 7 from this run was compared in Reference 1 to the results of the digital computer analytical study. Figures 21 through 24 show the results of this run. Figure 21 plots the inner barrel graphite temperatures decreasing in general as hydrogen flow increases and with power input constant. Figure 22 shows the outer barrel temperatures decreasing, with the exception of OBT1. Temperature OBT1 increases at a substantial rate with increasing flow; no explanation is offered.

It is felt that at this power level, 26.47 KW, the mid-section of the heater element in an axial sense becomes cooler and that the top or entering end becomes at least relatively hotter with increased hydrogen flow. This cooling effect at the mid-section is reflected in the same results of heater element temperatures as read, i. e., a measured decrease under the same changing flow conditions. This shifting temperature distribution is perhaps exaggerated at constant power input by a decreasing electrical resistivity of the heater element graphite as the material temperature decreases. Of particular significance in assessing the limitations of the rig and the development effort required is the fact that in neither the inside nor the outside barrels are the radial temperature gradients in logical sequence, logical in the sense that the temperatures would be decreasing outward if the temperature at each axial station were uniform throughout the 360 degrees of perimeter. Accordingly it is suggested that these temperatures as read are not mean temperatures. Relatively hot and cold areas in a circumferential sense are suggested since rigorous and careful checking show the thermocouples to be accurate and function properly.

Figure 23 plots water temperatures in the heat exchanger increasing with axial location downstream and decreasing as hydrogen flow increases. The fact that three of the thermocouples in the heat exchanger are 180 degrees from the other four in a circumferential sense is indicative, among other observations, that there is good basic circumferential alignment in this Build 3 Run 2 which was lacking, for instance, in Build 2 Run 1 as witnessed by Figure 27.

Figure 24 shows the entrance and exit gas temperatures decreasing as functions of increasing hydrogen flow. The trends are smooth; the levels are compatible with the analytical results of Reference 1 which show heat balance closure within 5%.

Build 2 Run 1 results, at a power level of 22.5 KW, are plotted on Figures 25 through 28. This build had excessive run out (1/16 inches TIR) of the heater element, as mentioned previously, in the plane -60 degrees and 120 degrees with the shifting toward the 120 degree location. In Figure 25, which shows the inner barrel material temperatures, the outside thermocouples, IBT4, reads colder than the middle, IBT2, yet the inside, IBT3, reads an intermediate temperature level. In Figure 26, which shows the outer barrel material temperatures, the inside temperature, OBT4, is colder than the middle temperature, OBT3; the outside temperature, OBT2, is at an intermediate level. IBT2 at 107° 30' and OBT3 at 120 degrees are associated with the hot side of the axis of eccentricity; OBT5 at -45 degrees is associated with the cold side. Compare Figure 25 with 21 and Figure 26 with 22. Although at the higher power (26.47 versus 22.5 KW) IBT4 at a relatively neutral circumferential location, -120 degrees, increased approximately 150°F, IBT2 remained at the same temperature level. Although at the higher power level OBT2 at a relatively neutral circumferential location, 45 degrees, increased approximately 45°F, OBT3 decreased approximately 50°F and OBT5 increased approximately 80°F. The temperature levels, according, responded reasonably to the concentricity adjustment. Extreme sensitivity of temperature level to misalignment of the heater element is demonstrated. A refinement of eccentricity from .062 inches TIR to .021 inches TIR affected the temperature level in the inner barrel by as much as 150°F; in the outer barrel, as much as 100°F, Figures 12 and 12A.

Nevertheless, the eccentricity adjustment incorporated in Build 3 Run 2 did not remedy the apparent hot and cold areas which make the determination of mean temperatures and radial distributions unsuccessful. In Figure 21 which shows the inner barrel material temperatures, the outside thermocouple IBT4 is considerably hotter than the middle IBT2. In Figure 22, which shows the outer barrel material temperatures, the outside thermocouple OBT2 is hotter than the inside and middle thermocouples, OBT4 and OBT3, respectively. On the other hand as mentioned previously whereas the water jacket temperatures were not uniformly increasing in an axial sense before the alignment adjustment, they were consistent after the adjustment.

The suggestion is that whereas a gross symmetry can be obtained by refining concentricity, other factors are operating to set up circumferential temperature gradients. Correlation of these apparent hot and cold areas with locations of potential perturbations in the mechanical and fluid systems has not proved successful by inspection, further suggesting the complex and perhaps compounded nature of the phenomenon. Figures 29 and 30, describing characteristic temperatures of Build 7 Run 1 at high power inputs (66 KW), indicate that these temperature distributions in question change pattern as a function of power level. Many factors probably contribute to prevent temperatures from one circumferential location to another from being uniform including differences in local orientation to lands and grooves in the inner barrel, to slots in the heater element, to thermocouple leads and pressure tap tubing in the graphite, to instrumentation in the hydrogen gas stream, to non-uniform physical contact of the outer barrel with the water jacket, to differences in material properties such as grain orientation and density from one circumferential location to another in the graphite barrels, to non-uniform seating of lands of the inner barrel in the outer barrel as the two barrels expand under thermal growth, and to small eccentricities of the heater element of the order of .005 inches.

Pressure Distribution

Figure 31 from Run 2 Build 3 shows the static pressure distribution for Point 7, which is representative of the distribution at lower temperature levels. Pressure drops of 6, 5.6, and 4.4 psi are measured across each of the three land and groove locations from upstream to downstream. A decreasing pressure drop through series of comparable restrictions under conditions of heat input to the flowing hydrogen suggests that the downstream row of lands are not seated as well as those upstream. There is not corroborating evidence, however, available to support the hypothesis of progressive increased clearance under the lands from upstream to downstream. At the temperature levels of Build 3 Run 2 the most probable mean clearance under the lands, as explained previously, is .0004 inches. Under the higher temperature running of Build 7 Run 3 the most probable mean fit of the lands is .0005 inches tight. Figure 32 plots the static pressure distribution for Point 4 of this run. The pressure drops are 6.2, 6.3, and 4.8 psi upstream to downstream. No significant change in distribution is observed from a substantial increase in fit.

Upon total disassembly of the test rig a crack was found in pressure tap Number 4. The crack was found in the tube where it passed through the inlet flange. This area of the test rig is in an area of high pressure which would influence the pressure this probe was measuring. This influence would cause P4 to be high as read which would make ΔP_{3-4} read lower than it actually was. This is a reasonable explanation for the low measured pressure differential obtained for ΔP_{3-4} during hot runs on this configuration, and explains why there was no significant change in pressure distribution from the substantial increase in land fit. Tests of this configuration will be run with a repaired pressure tap to show that the crack was the cause of the low measured pressure reading.

Heater Element Life

Indications of hydrogen corrosion were observed after initial testing; at the end of Build 3 Run 3 excessive hydrogen corrosion was recognized. The heater element had run in hydrogen at moderate temperatures between 2200 and 2700°F for 2-1/2 hours. During Run 3 a hot side had appeared in the inner and outer barrel temperature patterns.

Inspection disclosed heavy corrosion, more severe at the 180 degree location than at the 0 degree location; comparison of other diametrically opposite locations showed corrosion, heavy but equal, as if the electrical loading shifted and thus balanced the wear except where the two parallel circuits have common connections. See photographs Figures 33 through 36. The heater element had served successfully through Run 2 without indications of locally hot sides; under these conditions of running this uncoated heater element is judged to have a useful life of 1-1/2 hours.

In the interest of increasing heater element life, and particularly for high temperatures at which hydrogen corrosion in the graphite barrels can be studied, several protective coatings are being tried. An initial element was plasma-flame sprayed with tungsten after careful preconditioning of the graphite surface. This work was done by the Westinghouse Research Center in Churchill. This coating proved unsuccessful as tested for 1/2 hour in hydrogen at 3000^oF. The coating cracked and stripped, demonstrating no permanent bond, Figures 37 and 38. A Varcum-tungsten coating painted on, cured and heat treated in a methane atmosphere has proved initially successful. Figure 39 shows the coated heater element after several minutes processing in methane; Figures 40 and 41 show an apparent tungsten-carbide coating well bonded to the graphite surface, when the carbon deposits shown in the previous figure were removed. It is significant that this coating has adequately wetted the graphite surface. Figure 42 shows this heater element after processing with 5% methane in hydrogen for 1 hour; a thin, hard (pyrolytic perhaps) carbon or graphite layer has been deposited over the tungsten-carbide; no soot was formed. Figures 43 and 44 show this heater element after 1/2 hour running at 3500^oF in hydrogen. The coating was not impaired by hydrogen corrosion. As shown in the photographs the element was damaged by arcing but not by corrosion. The arcing was not caused by the coating. This coating was initiated in conjunction with the Materials Laboratory; a joint patent disclosure is being prepared; the coating is being duplicated currently by the Materials Laboratory in their furnaces.

A heater element coated with niobium carbide by vapor deposition is being procured for testing; other elements with Varcum-tungsten painted coatings will be tested. Complete success in protecting the heater element from hydrogen corrosion with a coating would greatly simplify the design of the rig for high temperature use.

Graphite Barrel Temperature Levels

It is pertinent to future planning for the rig to determine what temperatures are obtainable in the inner and outer graphite barrels without resorting to preheating of the entering hydrogen and to thermally insulating the outer barrel from its jacketing heat exchanger. This investigation was performed in conjunction with the testing of the heater element at high temperatures. The testing was accomplished up to the power limits of the two available Westinghouse welder power supplies in parallel; at the highest temperatures achieved, a maximum of 70.7 KW was used. Figure 45 shows heater element temperature plotted against material temperatures in the inner and in the outer barrels. Convenient, yet characteristic, thermocouple locations in each barrel were used, OBT2 and IBT2. These temperature levels are a strong function of hydrogen weight flow; to simplify the plot only points run between .005 and .006 pounds/second are included. Maximum temperatures of 1600°F and 700°F were obtained in the inner and outer barrels respectively.

Miscellaneous Items

Both Alundum RA98 (low density aluminum oxide) and high density beryllium oxide were used as insulators in the hottest locations. The aluminum oxide is fragile to mechanical shock but did not apparently break under changing thermal conditions; the beryllium oxide has greater tensile and compressive strength but appeared to fracture, crack and chip under thermal shock during the start up and cooling down of the rig. When using both materials, these transients were completed in no less than 10 minutes and no longer than 15 minutes in routine fashion.

Arcing across the split base of the heater element in one case, Figure 46, was attributed to carbon accumulation on the surface of the aluminum oxide plate sandwiched

between the two terminals as an insulator. Cleaning the aluminum oxide surfaces and chamfering the graphite edges opposite the aluminum oxide surface have prevented this type of failure from recurring.

No hot areas have been observed in the rig structure; the electrode and bottom plate water cooling systems are adequate under maximum power and minimum hydrogen flow conditions; the 7 gallons-per-minute maximum water flow through the copper heat exchanger is sufficient to keep the water temperatures below 200°F.

The tungsten/tungsten-26% Rhenium thermocouple sheathed with molybdenum has proved expendable, as expected, when thermally cycled through the recrystallization temperatures. The molybdenum sheath cannot withstand even the slightest touch after testing.

The hydrogen flow controls have proved to be effective and reliable.

PROPOSED DEVELOPMENT

To meet prescribed purposes, the rig needs development in two main areas. One involves investigation and refinement of temperature distributions in the graphite barrel structures including elimination of hot and cold areas and including a description of axial temperature distribution in the heater element as well as end thermal losses. The other involves raising the temperatures of the graphite barrels and of the hydrogen to levels at which hydrogen corrosion can be studied. The first involves design, procurement and testing of development hardware to isolate the pertinent variables. After these development steps, the test piece, in the form to be useful in studying the reactor, will be redesigned and rebuilt to incorporate the possible improvements. The second involves design and incorporation of a hydrogen preheater and of a muff of insulation between the outer graphite barrel and the copper heat exchanger in addition to the development of a heater element for reasonable life at high temperatures.

Temperature Distribution Definition and Improvement

The various variables involved need be isolated and evaluated. Tabulated below is an outline listing the variables in a reasonable chronological order of study. Each is classified as to the magnitude of its expected importance: A, B and C. Each is tabbed with an indication of the handling technique: I for Investigation, E for Elimination, C for Control (without investigation). Development Configurations 1, 2 and 3 associated with each variable indicate, where applicable, what hardware will be used for the investigation. Where "component experiment" is noted, it indicates that the experiment will not be performed on the Small Scale Seal Rig, but in a furnace or wherever convenient. Development Configurations 1, 2 and 3 are described in Drawings 710 J 530, 711 J 231 and 711 J 232 respectively. Excerpts from these drawings are included in this report and are referred to in the text. Development Configuration 1, which is shown in Figure 47, incorporates a graphite outer barrel shrunk into the inside diameter of the heat exchanger. The outside surface of the outer

Order	Variable	Importance Rating	Method Approach	Development Configuration
1	Concentricity of Heater Element	A	I	1
2	Orientation of Heater Element Slots	B	I	1
3	Orientation of Inner Barrel Land Slots	B	I	2
4	Orientation of Seated and Unseated Lands	A	I	2
5	Holes in Graphite for Thermocouples	A	I	1 or 2
6	Thermocouples and Sheathes in Holes	B	I	1 or 2
7	Slots in Graphite Outer Barrel	A	E	1 and 2
8	Orientation of Varying Contact Between Outer Barrel and Heat Exchanger	A	E	1 and 2
9	Variations in Heater Element as Functions of Machining and Time	A	C	
10	Orientation of Grain Direction in Inner and Outer Barrels	C	C	
11	Orientation of Circumferential Variations in Graphite Density, Thermal Conductivity, etc., in the Inner and Outer Barrels	C	I	Component Experiment
12	Orientation of Circumferential Variations in Electrical Resistivity of Heater Element	B	I	Component Experiment
13	Variations of Temperatures as Read From Installation Refinements such as the Hot Junction Being Bottomed, Cemented, etc.	B	I	Component Experiment
14	Axial Temperature Distribution Determination	A	I	3
15	Thermal End Loss Determination	B	I	3

barrel will be unbroken by any slots or holes. The outer barrel will be fabricated from HLM-85 graphite bar stock. Four chromel/alumel thermocouples will be inserted axially from the upstream end 90° apart. The inner barrel will have two bands of grooves and lands, the same as the present inner barrel configuration except with the middle band removed. The inner barrel will be match fitted to the inside diameter of the outer barrel to assure a .0003 to .0006 inch loose fit, uniform for each pair of diametrically opposite lands. The thermocouples in the outer barrel will be located axially between the two bands of lands and grooves at widely separated circumferential locations and with two at the same circumferential locations as the heat exchanger thermocouples. There will be no instrumentation in the inner barrel, initially at least. One shielded chromel/alumel thermocouple will measure gas temperature leaving; this thermocouple will be installed through the exit port. Static pressures will be measured entering and leaving the respective plenum chambers.

Inside the inner barrel will be fitted a ceramic cylinder, closed at the bottom end, to pilot the heater element in controlled fashion. This ceramic cylinder will be fabricated from high-purity, high-density, impervious aluminum oxide or from beryllium oxide depending on temperature level required and the proven durability of each. Concentricities will be carefully controlled from the pilot of the heater element to the inside diameter of the heat exchanger.

Development Configuration 2, shown as an excerpt from Drawing 711 J 231 in Figure 48, is the same as Configuration 1 except that the four thermocouples in the outer barrel are to the axial depth of the first band of lands and grooves in the inner barrel and located specifically opposite grooves in the inner barrel when this barrel is positioned as drawn.

Development Configuration 3, shown as an excerpt from Drawing 711 J 232 in Figure 49, is different from the first two arrangements in respect to the inner barrel design and to thermocouple locations. The inner barrel will incorporate three narrow axial lands equally spaced. The lands will be .007 inches high and will be fitted to the inside diameter of the outer barrel thus forming three wide axial hydrogen passages, uniform and continuous throughout

the length of the barrels. The outer barrel will contain four chromel/alumel thermocouples distributed at evenly spaced axial locations all in line and opposite the center of one of the hydrogen flow passages but not opposite either of the two circumferential locations of the thermocouples in the heat exchanger. These thermocouples will be fitted obliquely through the outer barrel wall with the leads channeled between the outer barrel and the heat exchanger. There will be a chromel/alumel shielded thermocouple both at the entrance and exit of the flow passages. Static pressures entering and leaving will be measured as in the other configuration.

Numerous variations of each development configuration will be used, such as with the inner barrel turned 10 degrees, with the heater element turned 20 degrees, with certain lands of the inner barrel refitted, with holes simulating thermocouple installations drilled into the inner and outer barrels at useful locations. Abbreviated testing at relatively low temperature levels will be taken advantage of as opportunity offers, yet it is judged that long-term development is involved in this temperature distribution area of effort.

Temperature Level Increase in Inner and Outer Barrels

This effort involves development of a high temperature heater element, incorporation of a hydrogen preheater in the rig system and the introduction of thermal insulation between the outer graphite barrel and the heat exchanger.

As described previously, the Varcum-tungsten painted graphite heater element has had initial success. Other coatings such as niobium carbide, vapor deposited, will be tested. If necessary, the ceramic tube which will pilot the heater element to the inner barrel can be sealed with an "O" ring for pressurization with helium. This development effort will require a series of 1/2 hour endurance runs with periodic inspection of the heater element.

Without insulation between the outer graphite barrel and the heat exchanger, tests have shown maximum temperatures of 1600°F and 700°F in the inner and outer barrels when run to the limits of the power supply. Graphite cloth or felt, 1/8 inch thick, on the outside of the outer graphite barrel will initially be used to substantially raise the temperature levels of the graphite in contact with hydrogen in the flow annulus.

An electrical resistance hydrogen preheater will be required. This preheater must provide at least 800°F increase in hydrogen temperature entering. The temperature level of the gas in relation to that of the graphite can be more readily controlled; considerable power reduction in the main heater can be realized; high hydrogen gas flows can be maintained without excessive cooling of the graphite.

Consolidation of Improvements in the Final Design

A redesign of the production rig will be undertaken incorporating the necessary changes. It is expected that a minimum of testing will be required to prove out the improved rig.

Figure 1

Small Scale Seal Rig
Excerpt From NT 701182 Sheet 1

Figure 2

Rig on Test Stand

Figure 3

Pressure Vessel Housing

Figure 4

Inlet Flange Showing Electrodes and Four Inlet Port Elbows

Figure 5
Water Cooled Outlet Flange

Figure 6

Heater Element, Inner Barrel and Outer Barrel

Figure 7

Heater Element, Inner Barrel and Outer Barrel

Figure 8

Top Flanges, Plates, Electrodes and Insulators

Figure 9

Inner Barrel Showing Ceramic Cup at Bottom

Figure 10

Heat Exchanger Assembled Inside Support Spool

Figure 11

Heat Exchanger Assembled Inside Support Spool

Figure 12

Small Circular High Pressure High Temperature Heat Transfer Test
Schematic Showing Location of Instrumentation

Figure 12A

Thermocouple Listing

Thermocouple	Radial Position (inches)	*Axial Position (inches)	Angle From 0° (degrees)
<u>Inner Barrel</u>			
IBT1	1.604	9.425	-72° 30'
IBT2	1.604	12.240	+107° 30'
IBT3	1.509	12.240	-96° 30'
IBT4	1.742	12.240	-50°
<u>Outer Barrel</u>			
OBT1	2.140	9.400	-45°
OBT2	2.260	12.180	+45°
OBT3	2.115	12.170	+120°
OBT4	1.985	12.129	-120°
OBT5	2.140	15.450	-45°
<u>Gas</u>			
ST5	1.840	15.980	-170°
ST6	1.740	15.890	+30°
ST7	1.740	15.890	+10°
ST8	1.880	6.590	-120°
ST9	1.880	8.520	+60°
<u>Water</u>			
WT1	2.601	7.632	0°
WT2	2.601	8.632	180°
WT3	2.601	10.262	180°

Figure 12A (Continued)

Thermocouple	Radial Position (inches)	*Axial Position (inches)	Angle From 0° (degrees)
WT4	2.601	11.382	0°
WT5	2.601	13.132	0°
WT6	2.601	14.262	180°
WT7	2.601	16.262	180°
<u>Heater</u>			
HT1	0	11.720	---

*Measured from the top of the inlet flange.

Figure 13

Heater Element Assembled in Top Plate
View From Bottom Showing Thermocouple at Center

Figure 14

Small Circular High Pressure High Temperature
Heat Transfer Test Schematic Test Loop

Figure 15

Test Rig Installation Showing Valves, Controllers and Flow Measuring Orifice

Figure 16

Control Room With Test Rig and Instruments Beyond Window

Figure 17

Power Supply

Figure 18

Console and Temperature Recorders

Figure 19

Small Scale Seal Test
 Hydrogen Flow Annulus
 Measured Inner and Outer Graphite Barrel Dimensions
 Build 3

FIGURE 20

SMALL SCALE SEAL TEST
INNER GRAPHITE BARREL SEAL DIMENSIONS (INCHES)

Reading Number	Seal Land Diameter			Groove Depth			Groove Width		
	Up- Stream	Middle	Down- Stream	Up- Stream	Middle	Down- Stream	Up- Stream	Middle	Down- Stream
1	3.8738	3.8736	3.8737	.0062	.0065	.0070	.4340	.4387	.4426
2	3.8738	3.8737	3.8737	.0067	.0066	.0071	.4338	.4380	.4435
3	3.9739	3.8736	3.8736	.0066	.0065	.0071	.4354	.4379	.4452
4	3.8739	3.8738	3.8737	.0067	.0068	.0072	.4356	.4378	.4435
5	3.8739	3.8738	3.8737	.0067	.0067	.0073	.4361	.4376	.4427
6	3.8740	3.8740	3.8736	.0067	.0069	.0073	.4367	.4376	.4432
7	3.8740	3.8739	3.8735	.0062	.0069	.0073	.4347	.4391	.4378
8	3.8740	3.8740	3.8736	.0066	.0070	.0072	.4357	.4387	.4393
9	3.8739	3.8738	3.8737	.0062	.0067	.0071	.4364	.4379	.4388
10				.0064	.0065	.0073	.4354	.4392	.4382
11				.0066	.0066	.0070	.4362	.4390	.4398
12				.0069	.0068	.0070	.4362	.4391	.4400
13				.0069	.0068	.0071	.4349	.4332	.4425
14				.0068	.0070	.0076	.4358	.4392	.4440
15				.0069	.0070	.0078	.4355	.4384	.4438
16				.0068	.0071	.0077	.4350	.4350	.4433
17				.0063	.0067	.0075	.4350	.4390	.4454
18				.0067	.0065	.0075	.4352	.4393	.4441
Average	3.8739	3.8738	3.8736	.0066	.0068	.0073	.4354	.4385	.4421

Power Input - $26.47 \pm .29$ KW

Figure 21

Small Scale Seal Test
 Inner Barrel Material Temperatures Versus Hydrogen Weight Flows
 Build 3 Run 2

Power Input - 26.47 ± .29 KW

Figure 22

Small Scale Seal Test
Outer Barrel Material Temperatures Versus Hydrogen Weight Flow
Build 3 Run 2

Power Input - $26.47 \pm .29$ KW

Figure 23

Small Scale Seal Test
Heat Exchanger Water Temperatures Versus Hydrogen Weight Flow
Build 3 Run 2

Figure 24

Small Scale Seal Test
 Hydrogen Gas Temperatures Versus Hydrogen Weight Flow
 Build 3 Run 2

Figure 25

Small Scale Seal Test
 Inner Barrel Material Temperatures Versus Hydrogen Weight Flow
 Build 2 Run 1

Power Input - $22.5 \pm .3$ KW

Figure 26

Small Scale Seal Test
Outer Barrel Material Temperatures Versus Hydrogen Weight Flow
Build 2 Run 1

Power Input - $22.5 \pm .3$ KW

Figure 27

Small Scale Seal Test
Heat Exchanger Water Temperatures Versus Hydrogen Weight Flow
Build 2 Run 1

WT-3 was not in sequence - obtain on Figure 23

Figure 28
 Small Scale Seal Test
 Hydrogen Gas Temperatures Versus Hydrogen Weight Flow
 Build 2 Run 1

Power Input - $65.35 \pm .25$ KW

Figure 29

Small Scale Seal Test
 Inner Barrel Material Temperatures Versus Hydrogen Weight Flow
 Build 7 Run 1

Figure 30

Small Scale Seal Test
Outer Barrel Material Temperatures Versus Hydrogen Weight Flow
Build 7 Run 1

Figure 31

Small Scale Seal Test
Static Pressure At Axial Locations
Build 3 Run 2 Point 7

Figure 32

Small Scale Seal Test
Static Pressure at Axial Locations
Build 7 Run 3 Point 4

Figure 33

Heater Element at End of Build 3 Run 3, Zero Degree Orientation
Showing Hydrogen Corrosion

Figure 34

Heater Element at End of Build 3 Run 3, 90 Degree Orientation
Showing Hydrogen Corrosion

Figure 35

Heater Element at End of Build 3 Run 3, 180 Degree Orientation
Showing Heaviest Hydrogen Corrosion

Figure 36

Heater Element at End of Build 3 Run 3, 270 Degree Orientation
Showing Hydrogen Corrosion

Figure 37

Heater Element With Flame Sprayed Tungsten Coating
Showing Cracking and Stripping After Test

Figure 38

Heater Element With Flame Sprayed Tungsten Coating
Showing Cracking and Stripping After Test, End View

Figure 39

Heater Element With Varcum-Tungsten Coating After Processing in Methane

Figure 40

Heater Element With Varcum-Tungsten Coating
After Processing in Methane and Removal of Carbon Deposits

Figure 41

Heater Element With Varcum-Tungsten Coating
After Processing in Methane and Removal of Carbon Deposits

Figure 42

Heater Element With Varcum-Tungsten Coating
After Processing With 5% Methane in Hydrogen

Figure 43

Heater Element Originally Coated With Varcum
and Tungsten and Processed, Condition After 1/2 Hour Test at 3500° F in Hydrogen

Figure 44

Heater Element Originally Coated With Varcum
and Tungsten and Processed, Condition After 1/2 Hour Test at 3500°F in Hydrogen

Figure 45

Small Scale Seal Test
 Graphite Barrel Temperatures Versus Heater Element Temperatures

Figure 46

Heater Element at End of Build 7 Run 1
Showing Failure Caused by Arcing

Figure 47

Excerpt From 710 J 530

Figure 48

Excerpt From 711 J 231

Figure 49

Excerpt From 711 J 232