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September, 1965

Westinghouse Astronuclear Laboratory

TEST SERIES HHT-16

CAVITY CORROSION TEST
(Title Unclassified)

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TEST SERIES HHT-16

CAVITY CORROSION TEST
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by H. F. O TIC, date SEP 11 1973
by _____

R. R. Burghardt
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ABSTRACT

A hot periphery core, in which a substantial portion of the temperature drop between the core and reflector would occur within the lateral support system, has been proposed as a solution to the problem of interstitial corrosion. The cavities in the lateral support system would thus operate with one wall at high temperature and one at low temperature. Limited corrosion in these cavities would build up a methane concentration which would inhibit corrosion within the core itself.

A series of tests was performed to study corrosion and deposition in an annular cavity simulating the core periphery, at surface temperatures of 3000°R and 4000°R and hydrogen pressures to 600 psia. It was determined that for a cavity sufficiently isolated from a source of fresh hydrogen, minimal corrosion would occur within the cavity, with a build-up of methane definitely indicated under certain conditions by the deposition of pyrolytic graphite.

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INTRODUCTION

The cavities on the periphery of the core, located radially between the filler strips and reflector, and axially between adjacent seal segments, contain essentially stagnant hydrogen at pressures slightly greater than the gas pressures within the core. The purpose of this arrangement is to maintain a positive bundling force on the core. An undesirable side effect, however, is that this slight pressure differential causes radial flow of hydrogen from these cavities into the interstices between the filler strips and between adjacent fuel elements. The result is corrosion of these uncoated outside surfaces of the fuel elements.

A proposed remedy for this corrosion is the hot-periphery core, in which the pyrolytic graphite in the filler strip area is removed or altered in such a way that a substantial part of the temperature drop between the core and reflector occurs within the lateral support system. The cavities in this location thus would consist of a stagnant region of hydrogen enclosed by a hot wall on one side, with the filler strips at 3000°R to 4000°R, and a cooler wall on the opposite side, with the reflector at substantially lower temperature. The hydrogen is expected to circulate within this cavity, causing corrosion in areas in which the methane concentration in the hydrogen is lower than the equilibrium concentration at the surface temperature, and deposition in areas where the methane concentration is higher than the equilibrium concentration at the surface temperature. With only a small fraction of the

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original gas leaving the cavity (through the scarf joints in the seal segments and into the core) the build-up of methane would be fairly rapid, reaching an equilibrium value and inhibiting further corrosion. The gas entering the core radially from the lateral support system would then have a concentration of methane greater than the equilibrium concentration at the higher temperatures within the core and would tend to deposit pyrolytic graphite rather than corrode the surfaces.

This hypothesis ignores the hydrogen-carbon-acetylene reaction for which the equilibrium constant increases with temperature and may predominate at temperatures of 4000°R and higher. The purpose of the series of tests reported herein was to study the nature of corrosion and deposition which might be expected to occur within the lateral support system cavities under the proposed conditions.

EXPERIMENTAL EQUIPMENT

The experimental set-up is shown in Figure 1. The test piece itself consisted of two "graphitite G" components which were threaded together to form an annular cavity with a length of one inch, an inner diameter of 0.625 inches, and an outer diameter of 1.125 inches. The inner section was drilled out to form a 0.062-inch wall which served as the primary electrical resistance. The outer section had a 20-mil gap which served to direct the heating current through the inner cylinder only, with the outer surface heated by radiation. In later tests this gap was closed by means of a boron nitride ring in order to minimize the amount of fresh hydrogen entering the cavity.

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One end of the test piece slid into a copper bushing which was directly attached to the vessel head. The other end of the test piece slid into a stainless steel bushing which was attached with hose clamps to a flexible copper braid. The braid was then attached to the vessel head. This method of attachment was developed in order to allow for thermal expansion and to avoid breaking the test piece during assembly. Stainless steel was selected for the bushing at one end since it was to be exposed to the high temperatures of the test piece and was not attached directly to the water-cooled flange as was the copper bushing on the other end. In all of the higher temperature tests, the stainless steel melted slightly at its interface with the graphite, preventing accurate determination of the weight loss of one of the test pieces.

The test piece was placed within a stainless steel pressure vessel constructed of 2-inch, schedule 80 pipe with bolted end flanges. The vessel was designed for operation at 600 psig and 1000°F and has been tested at 800 psi at atmospheric temperature. The flat heads of the vessel were brazed to the water-cooled electrodes and insulated from the vessel by the asbestos gaskets and micarta sleeves around the bolts. Power for electrical heating of the test piece was supplied by a 40-kw, 1000-ampere direct current welder.

During a test, the system was evacuated to about 28 inches of mercury (vacuum), pressurized with helium and checked for leaks, purged with helium, and evacuated a second time. Hydrogen was then introduced and the flow

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stabilized before power was turned on. The initial current of about 100 amps was rapidly increased to the required level of 600 to 900 amps within about 15 seconds. The desired temperature level was reached within two minutes and the current adjusted as required to obtain the desired temperature. Temperatures were read through an optical pyrometer, which had been calibrated under test cell conditions using a calibrated tungsten lamp. A small hole in the outer sleeve permitted a view of the inner cylinder. The test piece temperature and hydrogen flow rate were then held essentially constant for 20 minutes, after which the power was rapidly decreased and the system purged with helium.

The hydrogen flow rate was measured with a thin plate orifice and differential pressure transmitter and recorded on a strip chart. It was held constant for all tests at a given temperature, at a level sufficient to cool the pressure vessel, as indicated by preliminary tests.

Recorded on the data sheet were the inlet pressure to the test vessel, the input current and voltage, and the temperatures of the inner and outer surfaces of the test piece. Also recorded were the cooling water flow rate and the temperatures of the pressure vessel surface and outlet nozzle.

The weights of the test pieces were determined to the tenth of a milligram before and after each test, with the weight loss reported to the nearest milligram. The significant dimensions of the test piece were also determined before and after each test.

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RESULTS AND DISCUSSION

This test series was originated under the premise that a simple configuration could be quickly designed and tested at essentially atmospheric pressures to illustrate the nature of corrosion and deposition which might be expected in the lateral support system under the proposed temperature conditions. As a result the initial testing was done in a loop limited to a maximum pressure of 300 psig. Since the low pressure tests gave little information, it was decided to perform tests for a series of pressures up to 300 psig to determine the effect of pressure and possibly extrapolate to reactor pressures if the pressure effect was not too extreme. It was found, however, that such an extrapolation would be rather difficult. At 50 psig very little corrosion was observed. At higher pressures the amount of corrosion increased substantially but with no deposition of pyrolytic graphite observed. The conclusion was made that tests at reactor pressure of about 600 psi would be necessary to obtain meaningful results. It is from the later tests at this higher pressure that most of the conclusions are drawn.

The results of all tests except the first few are tabulated in Table 1. The first few tests are omitted since they contributed only to the development of the test apparatus. The weight losses included in this tabulation when available, are not directly applicable to the corrosion within the cavity since most of the corrosion occurred downstream of the cavity on the 1/2-inch diameter extension of the test piece. It was not possible to obtain weight losses in all cases because of arcing at the interfaces between the

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electrodes and the graphite as well as some melting of the electrodes at these interfaces.

The earlier low pressure tests did provide useful information in that they generally showed that there was a considerable amount of fresh hydrogen entering the cavity during the course of a test and that it was this hydrogen that was primarily responsible for the corrosion that occurred. In tests Nos. 8 and 9 in particular, corrosion was observed on the hot surface directly beneath the viewing hole. A considerable amount of hydrogen was apparently entering the cavity through the viewing hole and leaving through the gap in the outer sleeve. In Test No. 11, when the viewing hole was plugged, corrosion seemed to be concentrated near the gap.

As a result of these tests, a boron nitride ring was inserted in the gap as shown in Figure 1 for Tests No. 14 and 16 through 19. All other tests were run with a 20-mil gap in the outer sleeve. The insertion of this ring definitely decreased the interchange of gas between the cavity and its surroundings, and is believed to have given a good simulation of the lateral support system cavities, at least at the higher temperature.

The most useful results were obtained from Tests No. 12 and 17 (at about 3000°R) and 15, 16, and 18 (at about 4000°R), all at a pressure of 615 psia. Post-test photographs of these test pieces are shown in Figures 2 through 6. A typical pre-test photograph is shown in Figure 7.

The two lower temperature tests were run under similar conditions of temperature, pressure, and hydrogen flow rate. In both tests a view hole

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was used, but in Test No. 17 the boron nitride ring was inserted into the gap. Both test pieces exhibited very little corrosion within the cavity, with maximum surface regression of about 0.4 mil on each. This maximum occurred in the center in Test No. 12 and at one end in Test No. 17. The similarity of the results led to the conclusion that the rate of corrosion at this temperature is not sufficiently high in comparison with the rate of fresh hydrogen entering the cavity, considering the concentration of methane required for deposition. Hence, although a significant amount of methane may have been generated within the cavity, no conclusion can be drawn except that its concentration within the cavity was apparently less than the equilibrium concentration of about 3.5 percent at this temperature since there was no visible deposition. On the other hand the methane concentration may have slightly exceeded this value, but for an insufficient time to produce a visible deposit.

The three higher temperature tests were also run under similar conditions of temperature, pressure, and hydrogen flow rate, but with differences in the view hole and gap. Test No. 15 was run with a view hole and a 20-mil gap. There was a small amount of deposition and moderate corrosion. The surface regression was about 0.4 mils on the end near the threads and about 0.2 mils over the remainder of the surface. Test No. 16 was run without a view hole and with a boron nitride ring in the gap. The flow rate, pressure, and input power of the previous test were duplicated and the assumption was made that the temperatures were the same. The outer surface temperature was read to be about 130°R lower than in Test No. 15, but it appears that the previous reading was

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affected by glare from the bright inner surface and that the latter reading was more accurate for both tests. On the inner surface of test piece No. 16, there was slight corrosion near the threads, with a measured surface regression of about 0.1 mils. The remainder of the surface was covered by a pyrolytic graphite coating measured to be about 0.5 to 0.7 mils in thickness. A photomicrograph of the cross-section verified that the coating was pyrolytic graphite and indicated that its thickness was about 0.2 mils. Surface roughness was of the order of 0.5 mils, which may account for the difference. Also to be considered in regard to these measurements is that the micrometer used is accurate to the mil, with the tenth of a mil estimated. Test No. 18 was run with a view hole and with a boron nitride ring. The results were quite similar to those of Test No. 16 except that there appeared to be slightly more corrosion on the surface facing the view hole. Also the deposited coating was darker and apparently thinner. There was no measurable surface regression at the surface which appeared corroded and the coating was measured to be 0.3 to 0.4 mils in thickness, but judging from Test No. 16, its thickness was probably between 0.1 and 0.2 mils.

With the gap closed by the boron nitride ring, the cavity was apparently sealed sufficiently that the methane concentration exceeded the equilibrium concentration of about 1.3 percent at the maximum surface temperature, so that deposition could occur. This would probably be a sufficient concentration to retard corrosion within the core.

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The outer surfaces were generally unaffected, except for a slight amount of sooting in some cases. Their weight changes unfortunately could not be obtained because of the damage which invariably occurred at the electrode and because of the corrosion which occurred on the upstream extension of the test piece.

CONCLUSIONS

In evaluating the results of these tests, it is important to realize how complex the experimental model is. Corrosion is primarily a function of the gas temperature rather than the surface temperature. In an enclosed volume such as this cavity, the temperature of the gas within a boundary layer near the surface will approach the surface temperature, but its exact value cannot be measured. The rate at which gas was entering and leaving the cavity also could not be accurately determined.

The ratio of the hot surface area to the cavity volume in the experimental model was 2.86 in.^{-1} compared with a ratio of about 0.97 in.^{-1} in the reactor. The higher ratio in the test piece would cause a more rapid build-up of methane, but the reactor cavities would be more isolated from a source of pure hydrogen. Since the degree of isolation of the test piece cavity cannot be accurately determined, the relative effects of these two conditions cannot be evaluated.

Despite these drawbacks, the tests did give an indication of the behavior of hydrogen within a cavity subjected to the proposed temperature

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conditions and indicated a definite methane build-up under certain conditions. Whether or not this build-up is sufficient to reduce interstitial corrosion within the core has not been answered by these tests, but corrosion within the cavity itself will definitely be suppressed by the build-up of corrosion products.

RECOMMENDATIONS

A clearer picture of the corrosion behavior of the lateral support system under the proposed hot periphery conditions could be obtained by a mock-up of at least a segment of the actual core periphery--filler strips, seal segments, and reflector--with at least five seal segments included. This would permit testing the periphery over a range of temperatures, and actual concentrations of gas within the cavities and into the core could be determined by providing a means of analyzing the exit gases. Alternately, the inclusion of a hot periphery in a reactor test could provide the necessary information for operation at a single temperature.

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Figure 1

TEST FIXTURE

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Figure 2

SPECIMEN FOR TEST NO. 12 AFTER TEST

Figure 3

SPECIMEN FOR TEST NO. 15 AFTER TEST

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Figure 4

SPECIMEN FOR TEST NO. 16 AFTER TEST

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Figure 5

SPECIMEN FOR TEST NO. 17 AFTER TEST

Figure 6

SPECIMEN FOR TEST NO. 18 AFTER TEST

Figure 7

SPECIMEN FOR TEST NO. 16 BEFORE TEST

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TABLE 1a CAVITY CORROSION TESTS NEAR 3000°R

Pressure (psia)	Test Number	<u>Surface Temp.</u>		Hydrogen Flow Rate (lb/sec)	Test Duration (min.)	<u>Weight Loss</u>		Remarks
		Inner (°R)	Outer (°R)			Inner (grams)	Outer (grams)	
65	5	3134	2043	.0019	20	.013	.007	Very little corrosion observed.
165	6	3151	2056	.0027	20	.059	.014	Slightly more corrosion than Test No. 5.
312	7	3209	2145	.0020	20	.473	.021	More corrosion than Test No. 6, but weight loss seems excessively high.
615	12	3230	2100	.0019	20	-	.032	Downstream corrosion substantial; Hot-section corrosion slight.
615	14	3230*	1892	.0020	20	.056	-	View hole plugged, conditions of Test No. 12 duplicated. Resulting corrosion indicates temperature was probably lower than estimate.
615	17	3157	2017	.0020	20	.205	.037	Boron Nitride Ring in gap. Resulting corrosion similar to Test No. 12.

* Estimated Temperature From Previous Test

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TABLE 1b CAVITY CORROSION TESTS NEAR 4000°R

Pressure (psia)	Test Number	Surface Temp.		Hydrogen Flow Rate (lb/sec)	Test Duration (min.)	Weight Loss		Remarks
		Inner (°R)	Outer (°R)			Inner (grams)	Outer (grams)	
66	10	3936	2504	.0023	20	.100	—	Corrosion slight. No noted concentration near viewing hole.
165	8	3931	2331	.0053	18	.290	—	Most of corrosion on hot surface just below viewing hole.
165	11	3931*	2116	.0052	20	.340	—	Test No. 8 duplicated, but with viewing hole plugged. Corrosion concentrated near gap.
312	9	3914	2220	.0056	20	—	—	Corrosion again concentrated near viewing hole, greater than Test No. 8.
312	19	3935	2248	.0036	20	—	0.105	With Boron Nitride Ring in Gap. Minimal corrosion within cavity; narrow ring of pyrolytic graphite deposited on hot surface.
615	15	3932	2210	.0050	20	1.939	—	Spot of pyrolytic graphite on hot surface. Light corrosion in cavity, substantial downstream.
615	16	3932*	2080	.0050	20	1.067	—	B-N Ring in gap and view hole plugged. Deposit of pyrolytic graphite over most of hot surface, with minimal corrosion at one end. Less corrosion downstream than Test No. 15.
615	18	3918	2228	.0050	20	1.541	0.243	B-N Ring in gap but with view hole. Post-Test appearance almost identical with Test No. 16.

* Estimated Temperature From Previous Test.

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