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SUBJECT: STRESS CORROSION IN THE HRT MOCKUP

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INTRODUCTION

Because of the present interest in stress corrosion cracking, it is believed that a summary of the failures which have occurred on the mockup should be reported.

There have been eight instances of stress corrosion. However, only four of these failures actually shut the loop down. The other four were found during routine inspections or while correcting other troubles.

SUMMARY

Stress corrosion has been found in the following items: the 1 1/2-in. and 1 in. pipes in the letdown heat exchanger; the stator assembly, a 321 stainless steel O-ring thermal barrier gasket, a 304 stainless steel cap screw from the thermal barrier assembly and possibly the thermal barrier seal weld from the circulating pump; two valve bellows; a 3 1/2-in. stainless steel O-ring and pair of flanges; a 3 1/2-in., .049 wall, pipe cap; some auxiliary 1/2-in. and 1/4-in. piping. All of the failures have occurred in 347 stainless steel parts except the 321 stainless steel O-ring and 304 stainless steel cap screw.

All instances of cracking have been found in areas which contained stagnant liquid or low flow. In several cases, crevice corrosion which was caused by low flow and oxygen depletion were also observed. Solids or scale were found in all cases of the crevice type of corrosion. The failures are summarized in Table I.

The operational life of the different equipment varied from 24 hours to 8000 hours before cracks were found. The temperature at the location of the failures varied from ~150°C to 305°C. All of the failures have occurred in the high pressure system of the loop.

DISCUSSION

Letdown Heat Exchanger

The letdown heat exchanger consists of three concentric 347 stainless steel pipes. The hot letdown stream, which flows through the annular space between the inner pipe and the second pipe, is cooled and the heat is transmitted to the cold

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feed stream in the inner pipe and the purge water flowing to the pressurizer in the outer pipe.

The failure in the 1 1/2-in. outer pipe and the 1-in. second pipe occurred after 1800 hours of operation of the heat exchanger. During 700 hours of this operation, including the 400 hours just prior to the failure, the loop was pressurized with gas and there was no flow through the purge water jacket.

At various times the uranium concentration had varied from 0 to 4 grams per liter in the condensate. At one time, the H_2SO_4 concentration was 3 grams per liter. The pH range had been 6.5 to 1.8. Of the few chloride analyses made on the purge water, the highest was 2 ppm.

The metallographic examination showed that the cracks in the 1 1/2-in pipe started from the inside, Figures 1 and 2, and in the 1-in. pipe from the outside, Figures 3 and 4. The cracks were transgranular which was an indication of stress corrosion cracking which started from the purge water side of the two pipes.

Circulating Pump

Cracking has been found in three different locations in the mockup circulating pump. These will be discussed separately.

A 9 1/2-in. diameter O-ring made of 5/32-in., 321 stainless tubing and a 3/8-in., 304 stainless cap screw and the pump stator were found to be damaged after the pump had operated 200 hours on water and 500 hours on 0.021 molar UO_2SO_4 solution at a temperature of 300°C and 2000 psi. The oxygen concentration was 100 ppm and the chloride analyses showed 2 to 5 ppm.

The O-ring was used to seal the thermal barrier and pump stator assembly junction and the cap screw was one of eight which bolted the thermal barrier to the pump stator. The temperature of the O-ring was approximately 150°C.

The cracks in the pump stator were repaired and the stator has run for 9000 hours. The O-ring and cap screw were submitted for examination.

The metallurgical examination showed that the O-ring had been deformed by high bolting pressure and had then failed due to transgranular cracking which

started from the outside surfaces, Figures 5 and 6. This was followed by corrosion from the inside after UO_2SO_4 solution and purge water had leaked into the O-ring.

A longitudinal section of the cap screw showed cracking had occurred in the cap, Figure 7 and threaded section, Figure 8. There were also some general corrosion in the head of the cap screws.

The corrosion seemed to be more pronounced in areas where stagnant solution existed.

During the 8000 hours of the circulating pump operation with a seal welded thermal barrier, the seal weld has cracked two times. The cracks have started from the motor side of the seal and have been removed while machining the thermal barrier from the pump. Poor weld penetration appears to have been the major factor in these failures. The cracks have been circumferential and in the weld metal. It has not been practical to obtain a specimen for a metallurgical examination.

It is probable that these failures have been stress corrosion cracking initiated in highly stressed regions of poor weld penetration.

While examining the circulating pump after a thermal barrier failure, some small cracks in the pump stator assembly were found by dye-check. The pump had been in operation for 8000 hours.

The cracks, Figure 9, shows the worst one, were located in the area between the scroll gasket and the scroll seal weld. This is an area that has contained stagnant UO_2SO_4 solution and precipitated UO_3 at various times. The leaky gasket was oversize because the pump had been machined to remove pits from earlier corrosion. The crack showed the general appearance of stress corrosion attack.

At the time that the cracks was found, the pump operation had been 7200 hours on .042 molar UO_2SO_4 solution, 600 hours on water and 200 hours on 300 gr U/kg H_2O . The loop pressure had been from 1400 to 2000 psi and the loop temperature from 260 to 300°C. Thirty-five hundred hours of operation was on 100 ppm O_2 and 4500 hours on 500 ppm O_2 . The chloride concentration had varied from 1 to 6 ppm.

Valve Bellows

A bellows failed in one of two Fulton-Sylphon block valves which isolated a solid separation loop from the main loop. The second valve also showed signs of corrosion to a lesser degree.

At the time of the failure, a test was being run on the removal of solids which were injected into the mockup and removed by a separator on this side loop.

The mockup was operating on .042 molar UO_2SO_4 with an oxygen concentration of 100 ppm. The loop temperature and pressure were 280°C and 1400 psi.

The solids injected into the loop contained some chlorides and fluorides. Solids found in another area of the loop analyzed 25 ppm Cl^- and 2000 ppm F^- .

When the valves were open, their temperatures were 280°C at the inlet valve and about 260°C at the discharge valve; when closed the valves were below 100°C .

The bellows in the cooler valve failed after 180 hours of operation. Figures 10 to 12 show pictures of the bellows failure. The cause of failure¹ was a combination of stress corrosion cracking in the bellows and crevice corrosion at the base of the bellows. The presence of chlorides and the stresses in the bellows would create the necessary conditions.

The crevice corrosion was caused by solids which collected at the base of the bellows and created a condition of oxygen impoverishment, D in Figure 11, while the main loop operated at 100 ppm O_2 . Similar tests with the O_2 concentration at 500 ppm did not harm the bellows.

The bellows material gave a 0.8 - 1.0 mpm corrosion rate in the boiling nitric acid test.

O-Ring and Flanges

One pair of 3 1/2-in flanges and O-ring in the high pressure loop was dye checked and showed signs of small cracks. The flanges had been in the loop for about 7500 hours of operation and had been bolted and unbolted several times. The flanges were not removed but the stainless steel O-ring gasket which had been in the

flanges for 2450 hours of operation was examined² with the following results.

All of the defects were found on the uranyl sulfate side of the gasket:

1) pits, 2) transgranular cracks, Figure 13, 3) surface cracks and 4) preferential grain attack, Figure 14. Also, there were some deformation due to cold working of the O-ring.

The transgranular cracks were shallow and broad in appearance which was different from most stress corrosion cracks. However, these cracks may have been in the initial stage of formation. The pitting was probably due to contact corrosion in the oxygen depleted area adjacent to the sealing surfaces of the O-ring and flange.

Pipe Cap

A 347 stainless steel, 3 1/2-in. pipe cap with a 0.49 wall was found to contain stress corrosion cracks. The cap was located on the horizontal header between the main loop and the pressurizer. The temperature of the cap was about 305°C while the main loop operated at 300°C and 2000 psi steam. The cap contained two liquid layers, water in the top half and 0.042 molar UO_2SO_4 in the bottom half. A layer of solids containing 25 ppm Cl and 2000 ppm of fluorides was found in the bottom of the cap at the time of the failure.

The cap, Figure 15, was in the loop for 3660 hours of operation and was cut off three times for inspection of the pipe and then rewelded.

Metallographic analysis³ showed that the cracks were transgranular, Figures 16 and 17. The cracks were in the lower part of the cap, and in the base metal adjacent to the weld.

Stresses in the cap were probably caused by welding and then, with a corrosive media, stress corrosion was encountered.

Some pitting was observed in the cap and was probably formed under solids which produced a lack of oxygen and caused this type of corrosion, Figure 18.

Auxiliary Lines

Three auxiliary lines were installed on the high pressure loop and then capped off for further use. These were 1/2-in. and 1/4-in. schedule 80 pipes of 347 stainless steel. The temperature of these stagnant lines were about 200°C.

One 1/2-in. pipe failed after 24 hours of operation and another 1/2-in. pipe and a 1/4-in. pipe failed about 150 hours later.

All three pipes were deeply grooved, probably in the original drawing process as shown in Figure 19, which is from the first pipe failure. All three pipes had transgranular cracks which started at the inner surface, Figures 20 to 22. Some of the cracks appeared to be related to the grooves in the pipe although some were found in areas without grooves. The failures of all three pipes were caused by stress corrosion.

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2. T. M. Kegley and J. P. Hammond, O-Ring from HRT Mockup, ORNL-CF-57-1-51, January, 1957.
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TABLE I.

Item	Operating Time Hrs.	Estimated Temp. at Crack	Solution Contact. Failure	Solids Deposited at or Near Cracks		Disposition of Crack
				Extent	Composition	
1) Letdown heat exch. purge jacket	1800	200°C	a) Distilled H ₂ O b) 0-4 g/l UO ₂ SO ₄ c) 0-3 g/l H ₂ SO ₄ d) Cl ⁻ ≤ 2 ppm	Heavy	Reduced uranium oxides, Fe ₂ O ₃ . These may have deposited following failure.	Metallographic exam.
2) Circ. pump O-ring	700	~150°C		Heavy	Uranium oxides	Metallographic exam.
Circ. pump cap screw	700	~300°C	a) Distilled H ₂ O b) .021 m UO ₂ SO ₄ c) .003 m H ₂ SO ₄	Heavy	Uranium oxides	Metallographic exam.
Circ. pump stator	700	~150°C		Heavy	Uranium oxides	Assembly remachined to remove crack.
3) Circ. pump Thermal Barrier seal weld	1) 5000 2) 400	~150°C	a) .042 m UO ₂ SO ₄ b) 1.2 m UO ₂ SO ₄	Heavy	Uranium oxides	Assembly remachined.
4) Circ. pump stator	8000	~150°C	a) .042 m UO ₂ SO ₄ b) 1.2 m UO ₂ SO ₄	Heavy	Uranium oxides	Assembly examined and still in service.
5) Valve bellows (2)	180	~250°C ~200°C	a) .042 m UO ₂ SO ₄ b) .021 m H ₂ SO ₄ c) Fe ₂ O ₃ -ZrO ₂ slurry	Heavy	Fe ₂ O ₃ , ZrO ₂ from solid injections F ⁻ and Cl ⁻ contamination of solids.	Metallographic exam.
6) 3 1/2-in. cap	3660	305°C	ditto	Heavy	ditto	ditto
7) 3 1/2-in. Flanges and O-ring	7500	300°C	a) .042 m UO ₂ SO ₄ b) .021 m H ₂ SO ₄ c) 1-6 ppm Cl ⁻	Heavy	Iron and chrome oxides, injected solids	Flanges still in use. O-ring-metallographic examination.
8) Auxiliary 1/4-in. and 1/2-in. pipes 3 failures	1) 24 2) 175	~200°C	a) .042 m UO ₂ SO ₄ b) .021 m H ₂ SO ₄	None		Metallographic exam.

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Figure 1 Outer Surface of 1 1/2-in. Pipe. Arrows indicate location of cracks

Figure 2 Cracks Initiating at Inner Surface of 1 1/2-in. Pipe-10X

Figure 3 Cracks on Outer Surface of Intermediate Pipe - 10X

Figure 4 Transgranular Cracking in Intermediate Pipe - 750X

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Figure 5 Transverse Section of 321 Stainless Steel O-Ring

Figure 6 Transgranular Cracking in O-Ring

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Figure 7 Cracks in Head of 304 Stainless Steel Cap Screw

Figure 8 Transverse Section Showing Cracks in Threads of Cap Screw

Figure 9 Cracks in Stator Assembly of Circulating Pump

Figure 10 Bellows Assembly Showing Location of Failure

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Figure 11 Transverse Section of Bellows, Showing Stress Corrosion, A, B, C and Crevice Corrosion D

Figure 12 Stress Corrosion Cracking, C in Figure 11

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Figure 13 Transgranular Cracks in 347 Stainless Steel O-Ring-500X

Figure 14 Preferential Grain Attack in O-Ring, 250X

Figure 15 3 1/2-in. .049 Wall Pipe Cap, Crack at A

Figure 16 Portion of Section Through Cracked Area of End Cap

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Figure 17
Transgranular Cracking
in End Cap, A in
Figure 15 - 250X

Figure 18 Pit Found at B in Figure 15 - 50X

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Figure 19 Grooves from Drawing Process for 1/2-in. Pipe

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Figure 20 Transgranular Cracking in 1/2-in. Pipe

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Figure 21 and Figure 22 Transgranular Cracking in 1/2-in. Pipe

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