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SUMMARY REPORT

DISSOLVED AIR IN PROCESS WATER STUDY

by

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January 21, 1963

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SUMMARY REPORT
DISSOLVED AIR IN PROCESS WATER STUDY

Introduction

During the early part of C-1961, water leak frequency on plant began to pose a mounting problem. At this time, DR reactor exhibited a leak mechanism which, although observed to some extent at other reactors, appeared to be primarily a DR problem. This mechanism can best be described¹ as a trench running longitudinally along the top portion of the process tube. The dimensions vary considerably; however, the lengths attained were generally about two to three feet and the width was roughly one inch. The beginning of the trench appeared to be mainly in the position of 11 to 14 feet from the rear Van Stone flange. The radial position of the trench in the tube runs from about the 10:30 to the 2:30 o'clock position. For lack of a more definitive expression for this corrosion, it will be referred to as a form of "accelerated local corrosion."

This report deals entirely with one possible means of affecting accelerated local corrosion. A layer of gaseous air coming from the dissolved air in the process water could form a heat transfer resistant area. This area would probably exhibit an accelerated corrosion rate due to the higher tube wall temperatures resulting.

While the air layer hypothesis is not restricted to any one reactor, it is felt that because of the lower 190 electric pump suction pressure at 190 DR, these pumps have the best possibility of drawing air into the flow stream. This

1. From personal observations and as described in "Results of Actual Tube Wall Thickness Measurement - DR Reactor", by D. E. Strega, current at the time indicated.

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would probably occur at the point of lowest pressure near the pump impeller center. Tests were conducted to determine the actual dissolved air content in the process water.

Conclusion

From the data obtained and the calculations made in this study, it is apparent that, in general, the hypothesis of gaseous air causing a local accelerated corrosion problem in active process tubes is not valid. However, this does not eliminate the possibility of having a unique pressure point within the tube which is conducive to air coming out of a solution at present coolant temperatures. Installation defects causing a smaller fuel to tube annulus, fuel element misalignment, etc. are examples of conditions giving rise to unique pressure drops of unpredictable magnitude. Although a gaseous air problem could exist in such cases, further investigation would be necessary for conclusive proof.

Observations at the Thermal Hydraulics Laboratory

During the planning stages of the air determination test, the phenomenon of air coming out of solution and forming a bubble "cloud" was observed at the 189 D Thermal Hydraulics Laboratory. A test involving a heating rod simulating fuel elements and a plexiglas tube simulating a reactor process tube was set up. It was noted that, using 189 D process water for test coolant, when the coolant was heated the air came out of solution. The appearance of the gaseous air was a cloud of fine bubbles traveling along the annular space between the test element and test tube wall. A change to deaerated water corrected the problem. Data taken from this test equipment on a subsequent process water run, were used to calculate the saturation air content of the coolant water. When the subsequent actual air content data was obtained using normal process water at 189 D, a comparison with the earlier 189 D saturation content showed that the air distribution agreed with the phenomenon observed. (See Appendix for calculations).

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Using high pressure stainless steel sample bombs, samples were taken from the high pressure process water piping just upstream of the reactor in the DR reactor valve pit. The sample was taken in such a manner as to preserve the air solution conditions as they occur under line pressure. The samples were sent to the mass spectrometer, 325 building, 300 area, for analysis. The sample was subjected to a vacuum in order to remove most of the entrained and dissolved gases. These gases were then analyzed for composition, relative amounts (by constituents) and over-all content in a given sample of water. The latter information was used for the evaluation of the air content.

Reactor Application

From the use of available tube hydraulic data, the pressure at the location of the observed accelerated local corrosion can be reasonably calculated. If it is assumed that the ideal gas law applies, a curve showing saturation air content versus water temperature at the above calculated pressure may be constructed. This curve (figure 1) shows that the worst case temperature is about 100 C assuming that asymptotic conditions exist beyond the drawn curve. The average of the sample results are shown on the graph to determine whether or not saturation is attained.

Results

The average air content in the water samples utilizing six samples was 37 cm³/liter H₂O. These results show that the average air content in the process water is lower than the content needed to come out of solution under process tube conditions by about a factor of 2.3 (See Figure 1.)

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I. 189 D Saturation Calculations

Assume that the ideal gas applies

$$\text{Henry's Law: } p = xH$$

where: p = equilibrium partial pressure of gas in contact with liquid.

H = Henry's constant (fig. 2)

x = mole fract. (gas phase to solution).

To illustrate the phenomenon demonstrated at 189 D, Case 1 shows saturated air content of the coolant when at initial temperature: Case 2 shows content at saturation at the elevated temperature.

Case 1

Test conditions:

Ave. system pressure at location of observation = 13.5 psig.

Temp = 55°F (13°C)

From Figure 2, $H = 5.9 \times 10^4 \frac{\text{atm}}{\text{mole fract.}}$

partial pressure of H_2O @ 13°C = 0.21 psia

partial pressure of air (treat as pure component) = 13.5 + 14.7 - 0.2 = 28.0 psia

$$p = \frac{28.0 \text{ psia}}{14.7 \text{ psia/atm.}} = 1.9 \text{ atm}$$

$$x = P/H = \frac{1.9 \text{ atm}}{5.9 \times 10^4} = 0.323 \times 10^{-4} \frac{\text{mole air}}{\text{mole solution}}$$

$$0.323 \times 10^{-4} \left(\frac{1}{18 \text{ lb } H_2O / \text{lb. mole}} \right) = 1.795 \times 10^{-6} \frac{\text{lb. mole air @ saturation}}{\text{lb. } H_2O}$$

Case 2

Test conditions:

Ave. system pressure at location of observation = 11.8 psig.

Temp. = 133°F (56°C)

From Figure 2, $H = 9.9 \times 10^4 \frac{\text{atm}}{\text{mole fract.}}$

partial pressure of H_2O @ 56°C = 2.4 psia

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partial pressure of air = $11.8 + 14.7 - 2.4 = 24.1$ psia

$$p = \frac{24.1 \text{ psia}}{14.7 \text{ psia/atm}} = 1.64 \text{ atm}$$

$$X = 1.64 \text{ atm} / 9.9 \times 10^4 \text{ atm/mole fract.}$$

$$X = .166 \times 10^{-4} \text{ mole air/mole solution}$$

$$.166 \times 10^{-4} \left(\frac{1}{18 \text{ lb H}_2\text{O/lb mole}} \right) = 0.922 \times 10^{-6} \frac{\text{lb. mole air @ saturation}}{\text{lb. H}_2\text{O}}$$

Actual content by sample of DR process water

$$= 1.67 \times 10^{-6} \frac{\text{lb. mole air}}{\text{lb. H}_2\text{O}}$$

By comparison it can be seen that in Case 1, the coolant is close to, but not at saturation. In Case 2 the coolant is well beyond the saturation point.

III. Theoretical Reactor Conditions Saturation Calculations

In this calculation, using the stated conditions, the saturated air content at possible tube conditions existing near the location of the "trench"-type local accelerated corrosion is found. A comparison of this value to actual air content should indicate whether, in general, the air would come out of solution.

Front header pressure = 520 psig.

ΔP to point of start of "trench" corrosion - 310 psi.

(assume this point to be at 29th fuel element from front)

System pressure at corrosion point = $520 - 310 = 210$ psig.

Assume temperature of worst case = 100°C (close to asymptote, See Figure 1)

Partial pressure of H_2O @ 100°C = 14.7 psia

partial pressure of air = $210 + 14.7 - 14.7 = 210.0$ psia

$X = 10.7 \times 10^4 \text{ atm/mole fract.}$ (From Figure 2)

$$p = \frac{210 \text{ psia}}{14.7 \text{ psia/atm}} = 14.3 \text{ atm.}$$

$$X = \frac{P}{E} = \frac{7.48 \text{ atm}}{10.7 \times 10^4 \text{ atm/mole fract.}}$$

$$X = 0.70 \times 10^{-4} \text{ mole air/mole solution}$$

$$0.70 \times 10^{-4} \left(\frac{1}{18 \text{ lb/lb. mole H}_2\text{O}} \right) = 3.88 \times 10^{-6} \text{ lb. lb moles air} \\ \text{lb. H}_2\text{O}$$

$$\text{Air content from samples} = 1.67 \times 10^{-6} \frac{\text{lb moles air}}{\text{lb H}_2\text{O}}$$

$$\text{Air content at saturation} = 2.3 \times \text{air content of process water.}$$

III. Miscellaneous Calculations and Conversions

1. Calculation of average molecular weight of dissolved gases.

From Samples Ave. Vol. %

$$\text{N}_2 = 54 \%$$

$$\text{O}_2 = 29 \%$$

$$\text{CO}_2 = 12 \%$$

$$\text{CO} = 2 \%$$

$$\text{A} = 2 \%$$

$$\text{H}_2 = 1 \%$$

Assume: 1 lb-mole of mixture

$$\text{N}_2 = .54 \times 28 = 15.1 \text{ lb.}$$

$$\text{O}_2 = .29 \times 32 = 9.3 \text{ lb.}$$

$$\text{CO}_2 = .12 \times 44 = 5.3 \text{ lb.}$$

$$\text{CO} = .02 \times 28 = .6 \text{ lb.}$$

$$\text{A} = .02 \times 40 = .8 \text{ lb.}$$

$$\text{H}_2 = .01 \times 4 = .04 \text{ lb.}$$

$$29.54 \text{ lb/lb-mole}$$

2. Density Calculation

$$\frac{29.54 \text{ lb-gas}}{\text{lb-mole}} \times \frac{\text{lb-mole}}{359.1 \text{ ft}^3} = 0.0822 \text{ lb/ft}^3 \text{ (std)}$$

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3. Conversion of sample to lb-mole gas/lb. H₂O

$$\begin{aligned} \text{Sample } \frac{\text{cm}^3}{\text{liter}} & \times 1.32 \times 10^{-6} \frac{\text{lb. Gas ltr.}}{\text{lb H}_2\text{O cm}^3} \times \frac{\text{lb-mole}}{29.54 \text{ lb. gas}} = \frac{\text{lb-mole}}{\text{lb H}_2\text{O}} \\ \text{Sample in } \frac{\text{cm}^3}{\text{liter}} & \times .0448 \times 10^{-6} = \text{Sample in } \frac{\text{lb-moles}}{\text{lb-H}_2\text{O}} \end{aligned}$$

IV. Tabulation of Results

1. Average concentration of air in process water:

Approx. water temp. = 15°C; approximate pressure at point of sampling = 560 psia

average of six samples = 37.21 $\frac{\text{cm}^3}{\text{liter}}$ total gas

$$2. \quad 37.21 \frac{\text{cm}^3}{\text{liter}} \times .0448 \times 10^{-6} = 1.67 \times 10^{-6} \frac{\text{lb mole gas}}{\text{lb H}_2\text{O}}$$

FIGURE - 1

SATURATION CONCENTRATION VS. TEMPERATURE

Air - Water System

Nominal System Pressure - 110 PSIG

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FIGURE -2
HENRY'S CONSTANT VS. TEMPERATURE

Gas - Water Systems

Ref: Perry, John H., Chem. Eng. Handbook
Indust. & Engr. Chemistry, May, 1952

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