

A STUDY OF VARIABLES THAT AFFECT THE CORROSION OF SOUR WATER STRIPPERS

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FOREWORD

The Battelle report, "A Study of Variables that Affect the Corrosion of Sour Water Strippers", covers the results of an 18-month laboratory study initiated and monitored by the Corrosion Research Panel, Subcommittee on Corrosion, the Refining Department, API. This is a complex corrosion problem principally concerned with the inconsistent corrosion behavior of overhead condenser tubes.

The primary purposes of the present study were to isolate the chemical constituents responsible for corrosion and to identify the conditions under which corrosion would occur. The study was limited to a modest, low-pressure simulation of a condensed liquid environment, dealing only with liquid compositions capable of being contained in atmospheric pressure equipment.

Some members of the Subcommittee feel strongly that cyanides are the primary cause of corrosion, and support for this can be found in the Battelle report. One fact that quickly became obvious during the test program was that it was extremely difficult to control or even measure the concentration of free cyanide in the test solutions. The occurrence of corrosion was often determined by whether cyanides were present or absent. Cyanides could escape from the systems, react with corrosion products to form ferrocyanide, or react with air to form thiocyanate. Air leakage into the system not only consumed cyanide, but formed extraneous materials like elemental sulfur which complicated the solution chemistry. Because of the inability to control cyanide content, it was never possible to establish a reproducible set of base conditions from which we could set out to systematically evaluate the effect of other variables. The elusive nature of cyanides and problems in analyzing for them at low concentrations may explain some of the apparent inconsistencies in sour water stripped corrosion.

Further work is needed to evaluate the effect of higher ammonia concentrations. At the October 1975 Subcommittee meeting, the possibility of corrosive ammonium bisulfide deposits forming on tube surfaces during operation was discussed. These would disappear on flushing out and opening the condensers in line with a similar problem noted on page 14 of the report. Clearly, questions as to the exact mechanism of sour water stripped corrosion have not been totally resolved. However, it is generally agreed that titanium tubes provide a satisfactory solution to the problem.

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ABSTRACT

The variables that affect corrosion in the sour water stripper system $\text{NH}_3\text{-H}_2\text{S-KCN-H}_2\text{O}$ have been studied in an atmospheric pressure glass loop system. Results indicated that as little as 1 to 4 percent NH_3 (saturated with H_2S) was corrosive to steel as long as cyanide was present in the system. The role of the cyanide was to destroy the normally protective sulfide film on the steel probably by forming a soluble ferrocyanide complex (although there were some data that suggested the formation of Fe(SCN)_3 as the corrosion product). Results also suggested that high NH_3 contents in $\text{NH}_3\text{-H}_2\text{S-KCN}$ systems were more corrosive to steel and that high corrosion rates also were associated with NH_4HS in the system (when cyanide also was present). Oxygen in the system reduced the rate of attack on steel presumably by forming polysulfides. Type 304 stainless steel did not corrode under the conditions that produced accelerated attack of steel. However, the stainless steel did corrode at accelerated rates in these solutions when it was activated by cathodic charging to remove its protective film.

TOPICAL REPORT

on

A STUDY OF VARIABLES THAT AFFECT THE CORROSION OF SOUR WATER STRIPPERS

to

SUBCOMMITTEE ON CORROSION, DIVISION OF REFINING,
AMERICAN PETROLEUM INSTITUTE

by

Earl L. White, Warren E. Berry, and Walter K. Boyd

INTRODUCTION

Aqueous sulfide corrosion in sour water strippers is a major expense in maintenance in a large number of refineries. A survey in 1972 sponsored by the Subcommittee on Corrosion, Division of Refining of the American Petroleum Institute, identified the location and severity of attack in sour water strippers⁽¹⁾. This survey expanded the state of knowledge in sour water stripper corrosion and identified a need to define more clearly the effect of such factors as velocity, condensate composition, and design on the corrosion behavior of commonly used materials of construction.

As a follow up to this survey, the API Division of Refining's Subcommittee on Corrosion has initiated an experimental program at Battelle's Columbus Laboratories to study the effects on corrosion behavior of stream composition, velocity, and alloy composition under sour water stripper environmental conditions. This report contains the results of this research program.

BACKGROUND

The results of the API questionnaire revealed that the severity and location of corrosion varied with the design of the stripper. For

(1) References are listed on page 71.

example, in the acidified type unit little corrosion occurs in the overhead section while severe attack is reported in the feed section, stripper tower and in the bottom section. On the other hand in the nonacidified condensing type units, severe attack occurs in the overhead section (tubes) with little corrosion occurring elsewhere in the system. Only negligible corrosion is reported for the nonacidified noncondensing type units.

While there are several different types of sour water strippers, they all operate in essentially the same manner. That is, the sour water is passed downward through a multistaged tower while the upward flow of stripping gas (steam, flue gas, etc.) removes the H_2S and NH_3 . In the nonacidified condensing strippers, a part of the gas stream is condensed to reduce the water content of the off gas. This gives rise to a highly corrosive condition. In addition, water droplets in the high velocity stream may lead to impingement and erosion-corrosion.

The sour water feed to the stripper comes from a number of sources, for example, the crude unit, desalter, catalytic cracker, etc. In general, the sour water contains varying amounts of H_2S , NH_3 , chlorides, cyanides, thiocyanates, polysulfides, thiosulfates, phenols, mercaptans, and carbon dioxide. The amounts of the various constituents fluctuate depending upon the type of crudes processed and the source of the water.

As would be expected, the corrosivity of the sour water stripper environments varies over a wide range regardless of the materials of construction, thus, service experience has been mixed. That is, good performance is reported by some plants for, say, carbon steel while in others corrosion rates are excessive for similar types of units. The same is true for other common materials of construction such as austenitic stainless steels, 410 stainless steel, Monel, Inconel, and aluminum.

The nonacidified condensing type unit is extensively used in the industry. In this type of unit, the overhead systems often exhibit rather severe corrosion and/or erosion-corrosion. The data suggest that the corrosion of carbon steel which is accelerated by high level fluid velocities and turbulence is related to the bisulfide ion content of the water^(2, 3, 4). The presence of cyanides can also accelerate corrosion since they may initiate dissolution of protective sulfide scales⁽⁵⁾. Improved design to reduce velocity and turbulence and the use of corrosion-resistant materials

and inhibitor injections has helped to alleviate corrosion problems. However, data are needed to quantify the effects of variables in the system on corrosion rates.

APPROACH

It is difficult to obtain the type of data needed from actual plant operations because of the variance in the sour water feed compositions and the difficulty in maintaining precise controls during plant operation. Problems also arise in attempting to duplicate the sour water stripper environment in the laboratory. This is particularly true for velocity effects. However, it appeared that laboratory studies using a loop system similar to that designed by Gutzeit⁽⁵⁾ would provide useful data regarding most operating parameters. The only variables which are not easily studied in this type of loop are pressure, fluid stream velocity, and turbulence. On the other hand, the latter two variables are amenable to study by rotating electrode techniques.

Accordingly, a program was developed jointly by the Corrosion Subcommittee and Battelle to establish the environmental variables that affect the corrosivity of H_2S - NH_3 sour water stripper solutions, to define the environmental parameters under which carbon steels exhibit satisfactory corrosion behavior, and, if possible determine more suitable materials of construction for those conditions that are corrosive to stainless steel.

Initially the following environmental conditions were to be:

- 10 and 25 percent NH_3 saturated with H_2S
- 100 and 150 F
- 20 and 100 fps
- 0 and 1000 ppm cyanides
- No oxygen - no chlorides
- Possibly phenol and mercaptan additions
- Possibly inhibitors.

Upon completion of the initial experiments, the ammonia composition range was broadened to include 4 and 35 percent, and it became obvious that cyanides must be added continuously to maintain the corrosivity of the solution. Otherwise, the cyanide apparently was lost from the system as volatile HCN.

AISI 1010 steel and Type 304 stainless steel were selected as the reference materials to be studied. Initially, a number of alternative materials were selected to be investigated. These included:

3003 aluminum

50A titanium (unalloyed) and Ti-0.5 Pd alloy

Other stainless steels such as 410, 316, 317, 329, E-Brite 26-1, Carpenter 20, and CF-8M

Nickel-base alloys such as Inconel 600, Hastelloy B and C, Monel, and Incoloy 800

Gray cast iron and Ni-Resist castings.

However, efforts to study these materials were abandoned when the Type 304 stainless steel did not corrode excessively in the environments studied.

The linear polarization method for determining corrosion rates was employed because it measures instantaneous rates and provides an indication of the change in corrosion rate with time.

As the study progressed, it became apparent that there were major differences between service experience and corrosion results obtained in the experimental apparatus particularly with respect to critical NH_3 , H_2S , and CN concentrations. In retrospect, much of this difference can be attributed to the laboratory apparatus being run at ambient pressure whereas sour water strippers are operated to 200 psia. Other differences include a steady state condition in the sour water stripper where NH_3 , H_2S , and CN are continuously being replenished at a more or less constant rate in a dynamic condensing system. This is best illustrated by the loss of HCN by volatilization in the laboratory apparatus whereas in the pressurized service units an equilibrium would be established so that CN would be in the solution at all times.

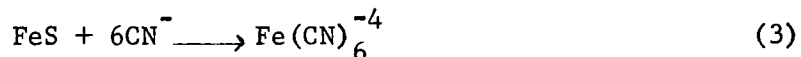
The solution chemistry in a sour water stripper is complex, particularly with respect to $\text{NH}_3\text{-H}_2\text{S}$ reactions, cyanide reactions, and effects of oxygen (air) on both the cyanide and $\text{NH}_3\text{-H}_2\text{S}$ reactions.

The $\text{NH}_3\text{-H}_2\text{S}$ reactions can proceed as follows:

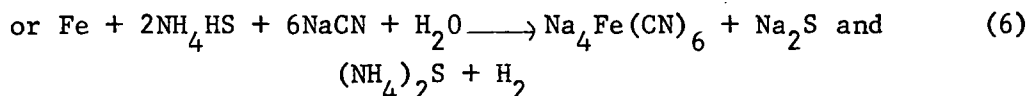
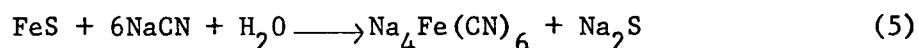
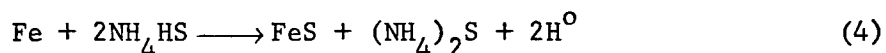


Thus, if H_2S is added to ammonia solution the initial composition is $\text{NH}_3 + (\text{NH}_4)_2\text{S}$ until all the ammonia is reacted to produce $(\text{NH}_4)_2\text{S}$; then the continued addition of H_2S produces $(\text{NH}_4)_2\text{S} + \text{NH}_4\text{HS}$ until all of the former is converted to NH_4HS ; then the continued addition of H_2S should result in $\text{NH}_4\text{HS} + \text{H}_2\text{S}$. However, H_2S apparently is not readily soluble in NH_4HS solutions and the resultant pH stabilizes at ~ 8.8 . NH_4HS can, and infrequently does exist as a solid. At least one attempt in the current program to neutralize a strong NH_3 solution with H_2S resulted in plugging with a white solid in the coldest region of a condenser above the liquid. While attempting to open the plugged equipment by heating and additions of water the solid suddenly disappeared presumably by sublimation.

The action of the ammonium sulfides on steel is to form a black iron sulfide corrosion product. The reaction rate initially is rapid but slows down to a metal corrosion rate of several mils/yr. The role of cyanides is to destroy the protective nature of the iron sulfide film. Apparently the reaction is ⁽⁶⁾:

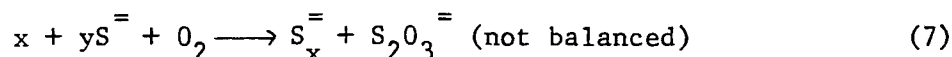


Thus the iron-sulfide reaction can continue as long as there is cyanide present in the system. The reactions probably are:



It has also been postulated that cyanide ions react with the protective sulfide films at $\text{pH} > 8.0$ to form thiocyanate.

The effect of oxygen (from air) on sulfides is to form polysulfides:

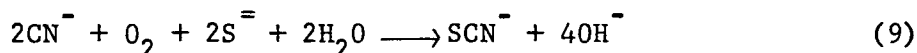


When polysulfides are present, it is believed that the cathodic reaction is ⁽⁶⁾:



This reaction is slower (presumably because of mass action effects) than the reduction of hydrogen ($H^+ + 2e \longrightarrow H^0$) which is the cathodic reaction when only sulfides are present. Thus, oxygen forms polysulfides. These in turn are involved in a slow cathodic reaction which ultimately reduces the amount of corrosion attack.

Oxygen also can affect the rate of corrosion by reacting with cyanide to form thiocyanates which are harmless from a corrosion standpoint. A possible reaction is:



EXPERIMENTAL PROCEDURES

Apparatus

The apparatus used in this study was designed to accomplish several objectives. In order to exercise optimum control over variables, it was necessary to make up solutions of NH_3 and H_2S in the absence of air and to exclude air from the system during a run; to have a large solution volume to corroding specimen surface area ratio (so an all plastic and glass unit was chosen); to provide for adding chemicals either by continuous feed or by batch additions; to control temperature during heating and cooling; to include means for making electrochemical measurements without opening the unit to the air; and to provide a flow rate as high as 100 ft./sec.

The corrosion experiments were conducted in a circulating system with a large reservoir (Figures 1 and 2). The solution reservoir was a 3.5 gallon pyrex bottle that held 10 liters of solution plus a headspace.

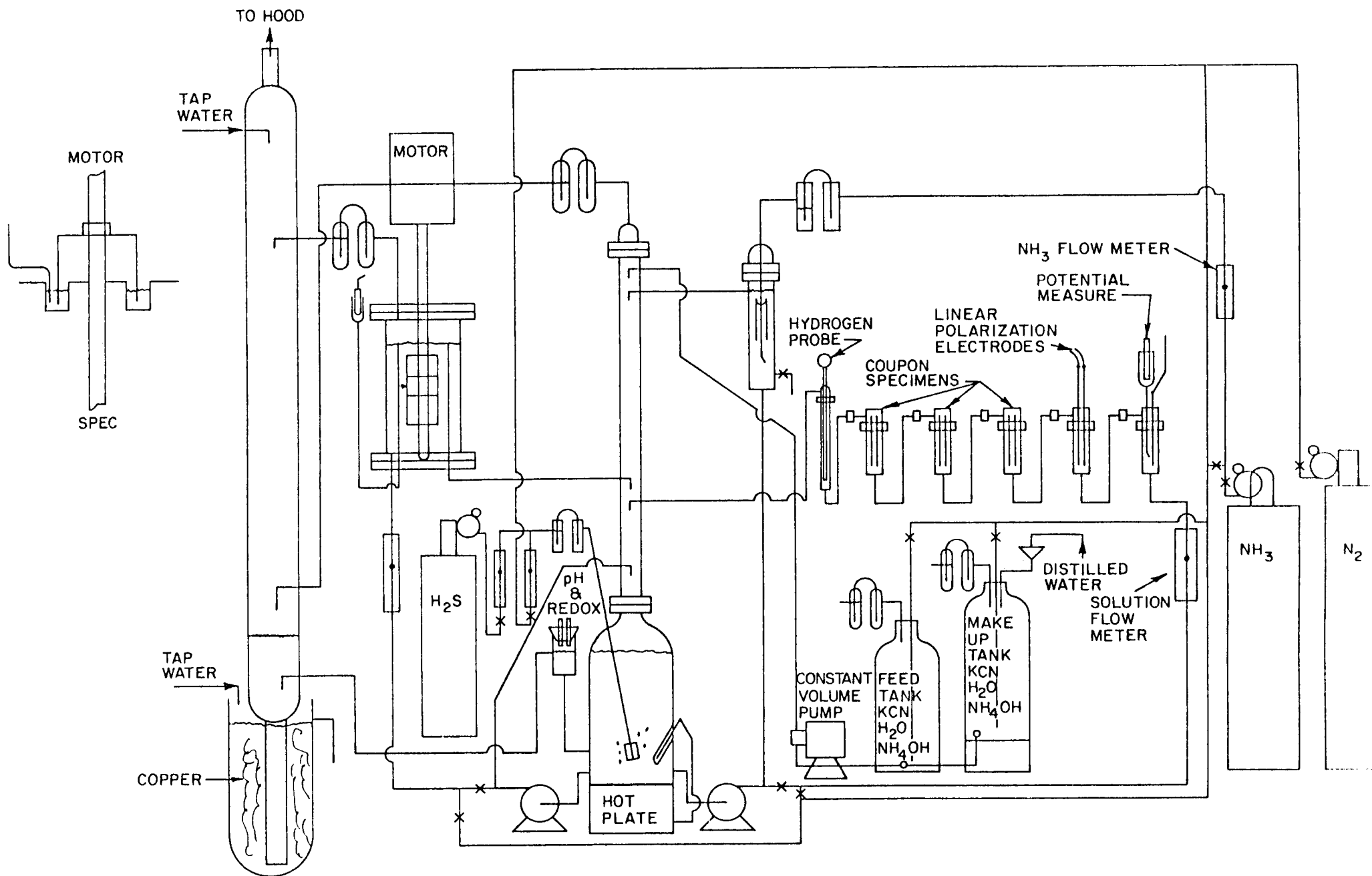
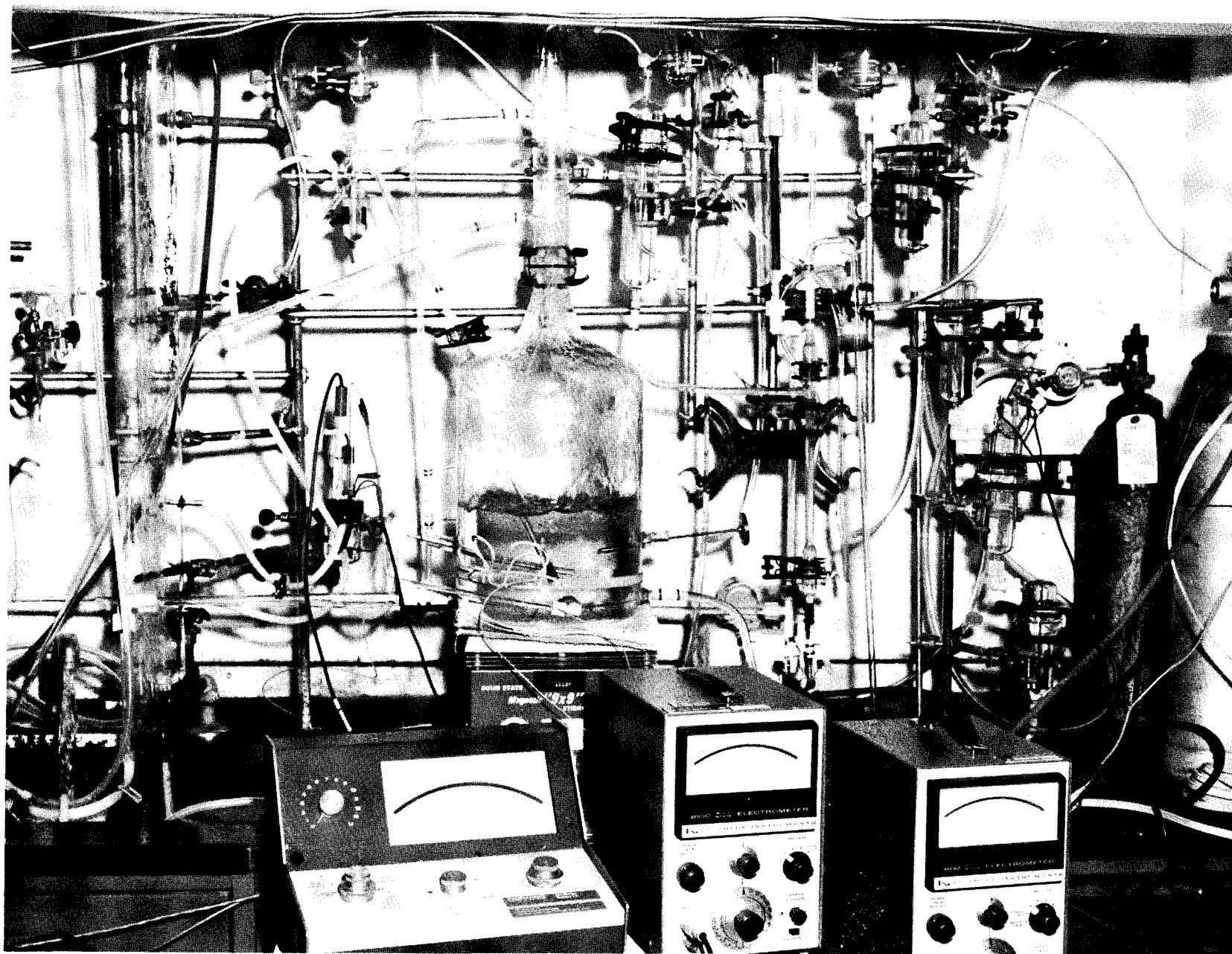


FIGURE 1. DIAGRAM OF SOUR WATER CORROSION TEST EQUIPMENT



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FIGURE 2. PHOTOGRAPH SOUR WATER CORROSION TEST EQUIPMENT

The bottle was modified by; (1) attaching an o-ring glass joint to the neck, (2) a 1/2-inch outlet tube near the bottom, (3) a temperature sensor in the side below the liquid level, (4) a sparge tube with glass frit extending to near the bottom, for the introduction of H_2S gas, (5) a bottom inlet tube, and (6) a small tube leading to a level adjusting outlet. For runs above room temperature the bottle was wound with an electric heating tape and set on a stirrer hot plate with temperature control sensor.

Attached to the top of the reservoir was a scrubber tower equipped with a cold finger condenser. The bottom outlet line from the reservoir was attached to an all Teflon magnetic driven pump. This pump supplied solution to four separate glass loops assembled with polypropylene fittings. Demountable joints were glass with Viton o-ring gaskets.

In the first loop the solution passed through one glass cell and back to the reservoir via the scrubber. When redox potentials were measured, the electrodes were in this cell. The reference electrode was positioned outside the glass loop and was connected to the solution by a string bridge. This ensured that no air could enter. Saturated calomel electrodes were used as reference electrodes. The cell also contained a tube through which dry NH_3 gas could be introduced to the system as needed. A stop cock on the cell provided a means for sampling the solutions for making pH measurements and spot tests. The main purpose of this loop was to provide circulation of solution during H_2S saturation and make up, and to allow sampling and measurements of redox while the test specimens were still under nitrogen in the second and third loops and not exposed to the test solution.

The second loop was equipped with a flow meter and six multi-purpose glass cells. The cells could be modified to serve several purposes, namely;

- (1) accommodate weighed specimens
- (2) contain linear polarization electrodes

- (3) measure metal half-cell potentials with string bridge assemblies
- (4) apply direct current through a platinum electrode to activate specimens
- (5) expose a hydrogen probe to the solution

A nitrogen line was connected to this loop just beyond the pump, so that specimens could be installed and blanketed with nitrogen while the solution chemistry was being established in the reservoir and first loop. When the test was started, flow was maintained at about 400 ml per minute through the test cells. This rate was sufficient to ensure a fresh supply of solution but was not so fast that it produced a velocity effect. The solution returned to the reservoir through the scrubber.

The third loop, also a test loop, contained the spinning unit for evaluation of velocity effects. The velocity cell was an 18-inch section of Teflon lined pipe fitted with Teflon flangeplates on both ends. An air motor was mounted on the top flange. The shaft extended to the bottom flange where it rotated in a Teflon bearing. Rings of the materials being tested were mounted on Teflon wheels on the shaft. The unit held three 3-inch rings and three 5/8-inch rings. The motor was capable of 12,000 rpm and was operated to produce an angular velocity of 100 ft./sec. on the 3-inch rings and 20ft./sec. on the 5/8-inch rings. The shaft was fitted with a liquid mercury seal at the top.

Four 3/8-inch Teflon tubes passed through the bottom flange and deadended into the top flange of the velocity cell. Three of these tubes contained small holes at the desired liquid level and were connected together outside the cell. Solution entered the cell from the bottom and over flowed out these tubes back to the reservoir. The fourth tube had one small hole just opposite the top 3-inch ring and was connected through a string bridge to a reference cell outside so that the half-cell potential of this ring could be measured. The top ring was connected to the shaft and the circuit was completed through the mercury seal on top. These four tubes also acted as baffles to reduce the solution spin. The tubes touched the cell wall and cleared the surface of the 3-inch rings by about 1/16-inch.

The fourth loop was also a mixing loop, but it contained a by pass to a glass bulb. Chemicals could be placed in the bulb and added batch wise to the system during solution make up or later during a run. Air could also be introduced in known volumes a bulb full at a time. When cooling was necessary, a glass coil was installed in this loop and immersed in a container of ice and water.

Provision also was made for introducing a concentrated solution of a desired chemical species continuously. A plastic metering pump was connected between a small reservoir and the scrubber. It could be set to deliver the desired amount of an additive such as KCN as a concentrated solution.

Disposal of the H_2S , NH_3 , and KCN was accomplished by having either the off gas or over flow liquid empty into a second scrubbing tower. A copper sulfate solution was circulated through the tower and over flowed into a sodium hydroxide bath and then down to drain being flushed with large quantities of water.

The low pressure sour water test equipment provided a large reservoir of solution which continually refreshed the test cells with a solution of the desired chemistry. The test cells provided the means of measuring the following:

- (1) Low velocity corrosion rates by weight change
- (2) Low flow rate instantaneous corrosion measurements by linear polarization
- (3) Redox potentials
- (4) Hydrogen probe activities
- (5) Low flow rate metal half-cell potentials
- (6) Anodic or cathodic charging by direct current
- (7) The effect of two velocities on corrosion
- (8) The effect of velocity on metal half-cell potentials
- (9) pH and chemical analyses.

Operation

The usual start up procedure was to deaerate deionized water by nitrogen sparging in a primary storage reservoir from which the test apparatus was filled. The apparatus was cleaned out after each run and was left empty but with a continuous nitrogen flush. The amount of deaerated water needed was transferred to the reservoir of the test equipment by a plastic pump with the nitrogen sparge still flowing. Reagent grade ammonium hydroxide was added to obtain the desired ammonia concentration. (In tests with 28% NH_3 , concentrated NH_4OH was used and no water was added.) Circulation was started through the first and fourth loops while nitrogen flow continued in the two specimen loops. Hydrogen sulfide gas was then introduced into the reservoir via the sparge tube. The flow of H_2S was continued until the pH, measured by drawing a sample, reached the desired level. Where H_2S additions were continued for long periods, the pH leveled off at about pH 8.8 indicating that all of the reaction of H_2S with ammonia had occurred. At this time the copper sulfate in the waste scrubber would begin to darken indicating that H_2S was passing through the system to waste. At this time the flow of H_2S was reduced. The solution was then ready to be opened into the test loops. Nitrogen flow was turned off in the test loops but continued in the waste scrubber to reduce the back diffusion of air to the solution. Potassium cyanide feed was started when desired, usually after the $\text{NH}_4\text{HS}^-(\text{NH}_4)_2\text{S}$ solution was established. Other modes of operation were also used such as starting with water saturated with H_2S and adding ammonium hydroxide or adding ammonia gas to an established solution to reduce the S to NH_3 ratio. An effort was always made to exclude air except when it was intentionally added.

During the runs, solution samples were drawn periodically, pH was measured, and a spot test was made for free sulfur, cyanide ion, thiocyanate ion, and ferrocyanide.

The pH was measured with a glass electrode corrected for the temperature of the sample. The free sulfur spot test was made with freshly prepared thallous sulfide paper⁽¹⁾. Standard solutions of sulfur in pyridine (10,100,1000 ppm S) were tested at the same time on the same paper. Comparison of these spots to the sample spot gave an estimate of the amount

of the polysulfide present. Free cyanide was determined by spot test on ammoniacal copper sulfate paper prepared once a day. Little success was had with semiquantitative determinations using standards, but presence of cyanide was determined at levels above 25 ppm. Ferrocyanide was determined by the double spot test with ferric chloride. The same test indicates thiocyanate, blue for ferrocyanide and red for thiocyanate. The sensitivity for ferrocyanide is about 30 ppm. An attempt was made to analyze for sulfide with a sulfide specific ion electrode, but this was unsuccessful because it became apparent that the electrode was also measuring CN or SCN, thus giving a false reading. The flow rate of H_2S to the unit was recorded but there was no measurement of the amount that passed through. It is assumed that except for special occasions the solution was saturated with H_2S . The cyanide feed also was controlled, but spot tests indicated that retention was not great. The cyanide either passed out on a gas or was converted to another compound such as thiocyanate.

Corrosion Rate Determinations

Corrosion rates were determined by both weight loss and by linear polarization methods. Both linear polarization and weight change corrosion specimens were 1/8-inch diameter by 4.5-inch long. The corrosion product was removed chemically from the weight loss specimens (inhibited phosphoric acid for steel and stainless steel). The corrosion rates determined by weight loss represented an average of all of the conditions to which the specimen was exposed during the experiment. The linear polarization corrosion rates are instantaneous rates and thus they indicate the rate of attack at the time the measurements are taken. This is particularly important when chemical additions are being made or temperatures are changed. In general, the correlation between an integrated average (with respect to time) of the linear polarization rates and the weight loss corrosion rates was good.

For those not familiar with the linear polarization method, it utilizes two equal size electrodes of the same material. The electrodes are periodically polarized so that one is a few millivolts (here 2.5 mV)

more negative and the other a few millivolts more positive than the natural corrosion potential of the material. The resulting current flow is measured. Periodically the polarity of the two electrodes is reversed. The average steady-state current is determined and is used to calculate a corrosion rate from empirical equations established by Stern and Geary⁽⁷⁾. The corrosion rates (I_c) are determined as follows. At small values of ΔE such as 5mV, a linear relationship exists between ΔE and ΔI . Within this linear region the corrosion rate (I_c) is related to ΔE and ΔI by the relationship

$$I_c = \frac{B_A B_C}{2.3 (B_A + B_C)} \cdot \frac{\Delta I}{\Delta E} \cdot \frac{1}{\text{Area}} \quad \text{amperes/unit area}.$$

In the above relationship, B_A and B_C are electrochemical parameters for the anodic and cathodic reactions, respectively. A value of $B_A = B_C = 0.05$ volts is a good approximation for most purposes. When $\Delta E = 5$ mV the above relationship becomes

$$I_c = 2.2 \frac{\Delta I}{\text{Area (cm}^2\text{)}} \quad \mu\text{a/cm}^2.$$

RESULTS

Ammonia

Three preliminary experiments were conducted with the initial six structural materials in ammonia alone. Results are presented in Table 1. Note that the corrosion rates of the iron-base alloys were low in the low flow 10 percent NH_3 solution at both temperatures. Velocity had no effect on the Type 304 and 316 stainless steels where corrosion rates were < 0.5 mil/yr. However, velocity had a marked effect on the corrosion rate of the mild steel. Maximum corrosion rates were observed at 20 fps (24.6 and 10.7 mils/yr at 100 and 150 F respectively).

Corrosion rates were much higher for the iron-base alloys in the 29 percent NH_3 solution at 115 F than in the 10 percent solution at 100 or 150 F. The corrosion rate of steel and Type 304 stainless steel increased to 5.7 and 2.1 mils/yr under low flow conditions. Velocity had an adverse effect on both materials with the maximum rate of attack at 20 fps for

TABLE 1. SUMMARY OF THREE PRELIMINARY 7-DAY EXPERIMENTS WITH 10% and 29% AMMONIA

Materials	Corrosion Rates - mils/year ^(a)											
	Run No. 1				Run No. 2				Run No. 3			
	10% NH ₃ , 100 F				10% NH ₃ , 150 F				29% NH ₃ , 115 F			
	pH-10.2, Redox-450mv				pH-9.7, Redox-480mv				pH > 11, Redox-610mv			
	Velocity-ft/sec				Velocity-ft/sec				Velocity-ft/sec			
	100	20-100	20	Slow	100	20-100	20	Slow	100	20-100	20	Slow
304 Stainless Steel	0.1	< 0.1	0.5	0.1	< 0.1	0.1	1.0	< 0.1	< 0.1	3.5	0.7	2.1
316 Stainless Steel	0.1	-	0.5	< 0.1	< 0.1	-	0.1	< 0.1	< 0.1	-	< 0.1	0.9
410 Stainless Steel	-	-	-	0.3	-	-	-	< 0.1	-	-	-	0.5
Titanium 50A	-	-	-	< 0.1	-	-	-	< 0.1	-	-	-	0.2
3003 Aluminum	-	-	-	2.4	-	-	-	10.3	-	-	-	2.8
Steel	8.9	18.6	24.6	1.3	5.8	2.1	10.7	1.2	8.6	5.6	15.3	5.7
Steel by linear polarization	-	-	-	1.2	-	-	-	0.8	-	-	-	6.5

(a) Extrapolated from weight loss data except for the linear polarization results.

steel and 20 to 100 fps for Type 304. Velocity improved the performance of Type 316 stainless steel which exhibited corrosion rates < 0.1 mil/yr at 20 and 100 fps compared with 0.9 mil/yr under low flow conditions.

Titanium was resistant to all environments with corrosion rates of < 0.2 mil/yr.

On the other hand, Aluminum 3003 alloy corroded appreciably in all environments with the maximum corrosion rate being 10.3 mils/yr in the 10 percent NH_3 at 150 F. Velocity effects were not studied with the aluminum or titanium alloys.

Note that the corrosion rates determined for steel by linear polarization agreed well with those determined by weight change.

Thus, these initial studies indicate that the higher concentration NH_3 is more corrosive; velocity markedly increases the corrosion rate on carbon steel with the attack being greater at 20 fps than at 100 fps; and corrosion rates obtained by linear polarization agree well with those obtained by weight loss.

Ammonia-Hydrogen Sulfide

Initial experiments also were conducted with H_2S added to NH_3 . The results for the six structural alloys under low flow conditions in 10 percent NH_3 are presented in Table 2. Note that the corrosion rates were no greater for the iron-base alloys under these conditions than they were when no H_2S was present (Table 1). In fact, the steel corroded at a lower rate. Note the high rate of attack on the 3003 aluminum in the 100 F solution. This occurred before H_2S was introduced into the system. In the subsequent test at 150 F, the solution was not introduced to the specimens until H_2S had bubbled through the 10 percent NH_3 for some 16 hours (overnight). This precaution led to a much reduced rate of attack on the 3003 aluminum in the 150 F NH_3 - H_2S solution.

In Figure 3 are plots of time vs corrosion rate as determined by linear polarization in the same NH_3 - H_2S solutions as those described in Table 2. Note that the corrosion rate decreased rapidly during the