

Complementary Use of Laboratory and Plant Tests to Solve Complex Chemical Plant Corrosion Problems[☆]

R.E. McGuire* and D.C. Silverman**

ABSTRACT

Laboratory and in-plant corrosion testing play complementary roles in enabling the corrosion practitioner to make practical corrosion predictions. This paper explores the ways in which these two approaches can be used to arrive at appropriate predictions. The discussion is in terms of three practical case studies: corrosion of steel in a waste stream, evaluation of alloy alternatives to a rubber-lined vessel, and evaluation of a process temperature increase in a waste reactor. Using the three cases as examples, the paper shows how the two protocols fit together.

KEY WORDS: *corrosion, testing, electrochemical impedance, polarization scan, coupon, immersion, laboratory, in-plant, chemical process industries, crevice corrosion, pitting, general corrosion*

INTRODUCTION

Laboratory and in-plant corrosion testing play important complementary roles in practical corrosion prediction. The strength of laboratory tests lies in their ability to provide the corrosion engineer with a means of simulating a number of process conditions fairly rapidly. Experimentation and sample removal for examination are relatively straightforward. The strength of in-plant tests lies in their ability to provide the corrosion engineer with actual in-process information, usually eliminating the uncertainties associated with studying simulated or "as-caught" samples in the laboratory. Equipment inspection falls into this latter

category. One drawback to in-plant testing is that both testing and sample removal can be difficult and can postpone predictions. The decision of which testing protocol to use (laboratory or plant) usually depends on the information required. Two major classes of techniques are available for predicting corrosion resistance of alloys, electrochemical and nonelectrochemical techniques. Among the electrochemical techniques that have been applied successfully to corrosion prediction in the chemical process industries are potentiodynamic polarization scans,¹ the rotating cylinder electrode,² the electrochemical impedance technique,³ corrosion current monitoring,¹ and controlled potential tests for cathodic and anodic⁴ protection. These techniques can be combined in a variety of ways. For example, the rotating cylinder electrode and the electrochemical impedance technique can be combined to provide information on corrosion rates and mechanisms under dynamic fluid conditions.⁵ Though electrochemical techniques have been used most extensively in the laboratory, as long as the appropriate electronics are available, they can be used directly in the plant. Potentiodynamic polarization scans and polarization resistance (linear polarization) techniques have been used extensively for in-plant corrosion monitoring and prediction.^{6,7}

The nonelectrochemical technique that has been used most extensively for both laboratory and plant tests is direct immersion of alloy coupons in the process fluids for a certain period followed by inspection of the coupons. The coupons usually contain artificial crevice type of washers⁸ to evaluate the propensity for localized corrosion to occur. Real-time information can sometimes be obtained using electrical resistance

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* Monsanto Company, FM Road 2917, Alvin, TX 77512.

** Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MD 63167.

probes, a technique that is not electrochemical.⁹ Heat transfer is often examined under static conditions by forcing heat through a coupon acting as a hot wall.¹⁰ Newer devices that introduce fluid flow¹¹ and electrochemical technology¹² with heat transfer are being introduced. Plant inspection can also be considered a nonelectrochemical test technique if one considers the plant as the ultimate corrosion coupon.

However, all test techniques whether used in the laboratory or in the plant, provide imperfect windows through which to observe the corrosion process and make predictions. For example, coupon immersion tests require exposure times of one week or greater to obtain necessary information. This exposure time will average out corrosion effects that vary because of the changing process conditions, e.g., batch type of conditions. Periodic plant inspections also suffer from this drawback. Techniques capable of providing more rapid information, e.g., electrochemical techniques, sometimes cannot be used in the plant and may provide information that may be more difficult to interpret. Therefore, one reasonable approach to evaluating observed corrosion or predicting future corrosion in a plant environment is to use more than one testing technique and to perform the experiments in both the laboratory and the plant. Such an approach can provide complementary information which will lead to more informed decision-making.

The purpose of this paper is to provide examples of the synergism created when combining in-plant and laboratory corrosion testing. Such synergism is possible either when performing both laboratory and in-plant tests or when combining two different tests in either the plant or the laboratory, especially where one of the test techniques would not normally be considered for that setting. The examples are corrosion of steel in a waste stream, materials evaluation for alloy alternatives to a rubber-lined vessel, and evaluation of a temperature increase in a waste processing reactor. The examples show how use of a variety of techniques allows the corrosion engineer to arrive at appropriate, practical answers.

Case 1—Corrosion of Steel in a Waste Stream

Corrosion may be controlled in existing equipment by changing some aspects of the operation. Knowledge of the effects of process variables on corrosion is usually required in order to define appropriate operational boundaries. Two places exist for such a study, the plant and the laboratory. In the case of studying the effect of such process variables as pH, fluid flow, and inhibitor levels in a plant waste stream, the laboratory was the most convenient place to undertake such a study with confirmation arising from coupon or other exposure in the plant itself.

Corrosion rate and mechanism information was required as a function of process variables. Therefore, in the laboratory, the electrochemical impedance technique was combined with the rotating cylinder electrode to make an initial evaluation of the effect of pH, fluid flow, inhibitor concentration, and upset condition on corrosion rate. The material of construction of the existing operation was steel. In-plant coupon immersion and Corrosometer[†] (electrical resistance) tests accompanied the laboratory tests.

EXPERIMENTAL

The system examined was carbon steel (UNS G10180) in a combined waste stream from an entire chemical plant. The solutions were made by combining waste samples in their "normal" proportions from each of the units in the plant. The problem is that waste streams are always changing so that one composition may represent the average composition only qualitatively. This problem will affect the ability to relate laboratory predictions to in-plant coupon test results and the actual performance in the plant.

Water was the predominant component in the waste. The exact composition is not known and could not be determined. However, the mixed solution is known to have small amounts of iminodiacetic acid, nitrilotriacetic acid, low molecular weight organic acids, some other organic components, and ammonium sulfate among other inorganic ions. The inhibitor, when added in these tests, was usually present at the level used in the plant, 40 ppm by weight. The inhibitor is a proprietary sulfite-containing material. The pH was adjusted as required to 7.5, 8.0, and 9.0 using reagent grade ammonium hydroxide. The temperature was 49°C (322°K), the highest expected temperature. Reagent-grade sulfuric acid was used to reduce the pH of 9.0 to 7.5 in the experiment in which the effect of an upset in pH was examined. The pH of 9.0 is the highest allowable from process considerations. A nitrogen blanket (slight positive pressure) was maintained at all times.

The equipment and procedure for generating the electrochemical impedance spectra have been described in detail elsewhere.^{3,5,13} The electrochemical impedance technique was chosen over polarization resistance techniques because of the increased ability of the former technology to provide both corrosion rate and corrosion mechanism information fairly rapidly especially for the poorly defined system studied here. As discussed previously, the electrochemical impedance technique (or electrochemical impedance spectroscopy as it is sometimes named) can be a powerful tool for conducting rapid corrosion screening for corrosion rates lying between 2.5×10^{-4} mm/y and 250

[†] Trade Name

mm/y.⁵ Most of the impedance spectra were generated at 200 rpm to 0.001 Hz. The spectra at 1000 rpm were generated to 0.01 Hz to minimize the time at that higher rotation rate. The rotating cylinder electrode and electrochemical cell to accommodate it as described previously¹⁴ were used for this study. The rotation rate was maintained at 200 rpm throughout most of the experiment except for brief excursions to 1000 rpm to study the effect of fluid motion on corrosion rate.

The impedance spectra were analyzed by non-linear regression using the simple analogous circuit models described elsewhere.⁵ The models that were most applicable to the spectra in this study were a single relaxation time constant, two relaxation time constants, and in several cases, pseudo-inductance. These circuits tend to model a single charge transfer reaction, an imperfectly covered electrode as might be found with an inhibitor or porous coating, and an adsorbed intermediate that might create pseudo-inductance. All models allow for dispersion of the capacitive time constant. The maximum number of adjustable constants was kept to a minimum to try to avoid as much as possible the problem of having so many adjustable parameters that one model could fit any spectrum. The time-averaged corrosion rate calculated from the estimated "instantaneous" corrosion rates was compared to the corrosion rate estimated from the short-term mass loss to aid in corroborating that the polarization resistances as determined from the electrochemical impedance technique were reasonable. Lastly, steel corrosion coupons and Corrosometer probes were placed in the actual waste stream in the plant for long-term exposure before and after the laboratory study was made.

RESULTS AND DISCUSSION

Figure 1 shows a plot of the corrosion rate as a function of time, pH, and rotation rate. As discussed previously, the corrosion potential was reasonably stable during the periods in which the impedance spectra were generated. Some of the spectra had to be modeled only to 0.01 Hz because of the possibility that results at lower frequency were made invalid by the drift in steady state from the corrosion potential at which the experiment was controlled. The validity of the results is supported by the agreement between the corrosion rate estimated by mass loss and that estimated from the polarization resistances as determined from the impedance spectra. The time-averaged corrosion rates at pH values of 7.5, 8.0, and 9.0 were 0.47, 0.15, and 0.034 mm/y from the impedance spectra and were 0.56, 0.12, and 0.05 mm/y from the mass loss. A Tafel constant of 0.025 V was assumed to relate the polarization resistance to a corrosion current. This value is not unreasonable for corrosion of steel in aqueous solutions.¹⁵ The agreement strongly suggests

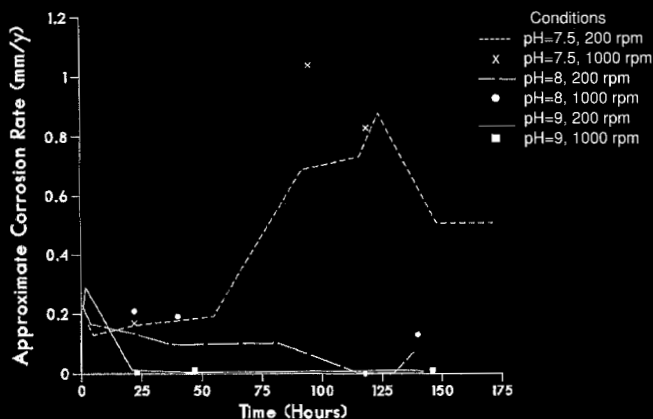


FIGURE 1. Corrosion rate of steel in the plant waste solution at 49°C (322 K) as a function of time, pH, and rotation rate. Results from electrochemical impedance technique.

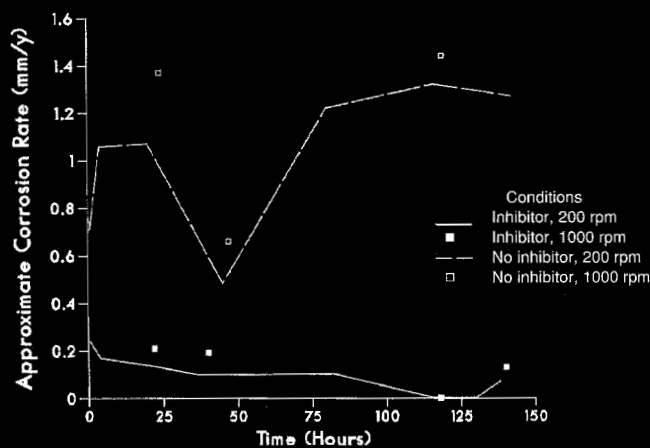


FIGURE 2. Corrosion rate of steel in the plant waste solution as a function of inhibitor presence and rotation rate. The pH is 8. Results from electrochemical impedance technique.

that the corrosion rates estimated from the impedance spectra provide reasonable estimates of the corrosion rates that might be expected.

The practical conclusions from Figure 1 are as follows. In the presence of the inhibitor, the optimum pH lies between 8 and 9. Controlling pH at 7.5 could result in significantly higher corrosion rates. Fluid velocity can have a deleterious effect to corrosion at the lower pH but should have little effect on corrosion if the pH is controlled between 8 and 9.

The waste system always had a corrosion inhibitor. The question is if the inhibitor is, indeed, required. Figure 2 shows a plot of the corrosion rate with time in the presence and absence of the inhibitor and as a function of fluid velocity. Both experiments were run at a pH of 8, the lower bound of the recommended pH limit. After about 50 hours of exposure (or about the time required for steady state to be achieved), the corrosion rate is about an order of magnitude less when the inhibitor is present. Fluid motion is somewhat

TABLE 1

Corrosion Rate as a Function of Time—
Impedance vs Mass Loss
pH = 9 until 53 Hours, pH = 7.5 after 53 Hours

Time (h)	Resistance (ohm-cm ²)	Corrosion Rate (mm/y) Impedance
1	1.5 × 10 ³	0.20
4	1.4 × 10 ³	0.21
21	8.0 × 10 ²	0.37
45	2.8 × 10 ^{5(A)}	0.001
pH Changed at 53 Hours		
71	9.9 × 10 ³	0.03
73	9.8 × 10 ³	0.03
106	1.2 × 10 ⁴	0.025
170	1.5 × 10 ⁵	0.02

(A) The corrosion rate decreased at 45 h, and the steel passivated. Corrosion rate averaged from impedance spectra is 0.065 mm/y. Corrosion rate determined from mass loss of electrode is 0.057 mm/y.

deleterious to corrosion in the absence of inhibitor. The practical conclusions are that the inhibitor is required and its presence greatly diminishes the effect of fluid motion.

When examining the effect of process conditions on corrosion, one must always consider the effect of process excursions on corrosion. Excursions in pH, especially to lower pH, are one possibility. The effect of a pH excursion was addressed by examining the effect on corrosion of having an initial control at a pH of 9 followed by a drop to a pH of 7.5. As shown in Figure 1, a pH of 7.5 could cause corrosion to be an order of magnitude faster than at a pH of 9. Table 1 shows the corrosion rates as a function of time and pH. The important feature is that pre-exposure to high pH has a beneficial effect on corrosion. That is, if the surface is already rendered passive to some degree, e.g., by exposure to higher pH, excursions to lower pH are not as harmful as would be the case if the surface is not in this somewhat passive state. Since the steel surface in the existing process already has corrosion products or a barrier layer present, excursions to lower pH, if short-lived, probably would not cause a catastrophic failure. However, the corrosion rate is affected to some degree since it does increase. The practical conclusion is that excursions can be tolerated most likely if they do not occur for extended periods.

Single corrosion coupons and Corrosometer probes were installed in this process over a period that brackets this process change. The results are shown in Table 2 and Figure 3. The coupons were changed periodically. The attempts at better control of the process were implemented between June 1987 and January 1988. A significant decrease in corrosion is seen in Figure 3 starting in 1988. The results suggest that process

TABLE 2

Corrosion Results from In-Plant Monitoring
of Waste Stream

Dates Immersed	Corrosion Rate (mm/y)
2/86 - 4/86	0.16
4/86 - 6/86	0.28
6/86 - 7/86	0.33
7/86 - 10/86	0.17
10/86 - 6/87 ^(A)	0.26
Control of pH Implemented	
6/87 - 12/87	0.12
12/87 - 7/88	0.15

(A) Several deep pits observed on coupon and severely roughened surface noted on internal pipe spool surface.

Waste Stream Corrosometer Data
Carbon Steel

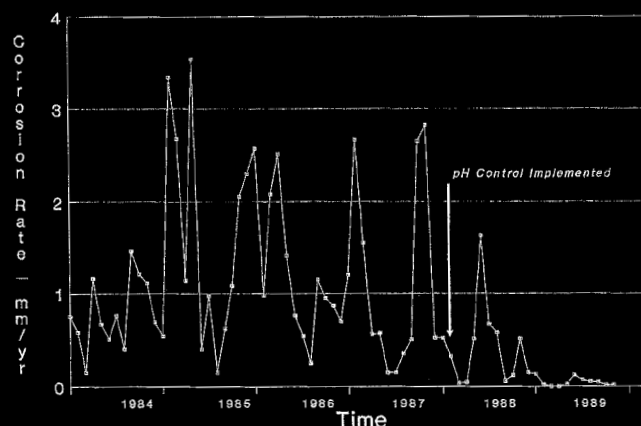


FIGURE 3. Waste stream Corrosometer data. Better pH control was implemented between June 1987 and January 1988.

control following the recommendations of this study have had some beneficial effect on corrosion. However, agreement between laboratory and field results is hurt by the surface being passivated to some degree prior to the process change, and in the case of coupons, by the corrosion rates being time averaged over rather long periods of time and many different waste stream compositions. The laboratory results are derived from samples caught at one time and may only be qualitatively related to a time-averaged composition during the in-plant measurement. This example does show the power of using electrochemical laboratory techniques for rapid screening of the effects of process conditions on corrosion followed by in-plant corrosion monitoring to verify that the changes implemented are beneficial.

Case 2—Selection of Material of Construction for Process Vessel

A vessel lined with soft natural rubber had a history of problems associated with the lining. After a period of field testing of alternative rubber lining compounds, the originally used soft natural rubber lining was replaced with a lining of chlorobutyl rubber. There was only a marginal improvement in performance. The vessel had been relined repeatedly, and the most recent liner had lasted only one year. An alloy vessel was concluded to be needed to replace the rubber-lined steel.

The process environment is somewhat harsh. It is an aqueous, acidic mixture with a pH of 3.5 to 4.5 containing chloride ions at a concentration of 2000 to 3000 ppm by weight. Additionally, organic nitrile compounds and solids are present in the mixture. The process temperature is 40°C (313 K). The challenge was to identify an appropriate alloy replacement.

Other process equipment and piping in the system are constructed primarily of rubber-lined, polypropylene-lined, and polytetrafluoroethylene (PTFE) (Teflon[†])-lined carbon steel. Crevice corrosion has been experienced over the years with nickel-based alloys that are used in several limited applications in the process. Therefore, the most probable form of corrosion to occur would be crevice corrosion.

EXPERIMENTAL

An evaluation program was defined to obtain needed corrosion information for the selection of alloys for the replacement vessel. The test procedure had to identify if crevice corrosion could occur. The test program had both laboratory electrochemical polarization scans and field exposure of corrosion coupons of the candidate alloys. Type 316 stainless steel (S31600), alloy 20Cb3[†] (N08020), alloy 825 (N08825), and alloy 276 (N10276) were evaluated in the laboratory and in the plant exposure.

Corrosion coupons with artificial crevices created by specially fabricated PTFE washers were installed in the liquid and vapor phases in the vessel. The coupons were exposed for a period of three months. Polarization scans of the four alloys were generated in the laboratory in liquid samples taken from the process system and which were believed to represent the normal process composition. Coupons were evaluated by mass loss and by visual examination under low-power magnification (20X).

Laboratory polarization scans were generated in one liter "resin kettle" glassware using 650 cc of process fluid. The vessel contents were blanketed with nitrogen. The test cell contained two platinum counter electrodes and an external saturated calomel reference electrode connected to the solution through a Luggin-

Haber capillary. The working electrode, placed between the counter electrodes, was shaped like a bullet, 4.5 cm long and 0.6 cm in diameter. The surface of the working electrode was prepared by sanding with 600 grit silicon carbide paper. The polarization scans were generated using Petrolite Model 4100 Potentiodyne[†] Analyzer.

A steady state corrosion potential was obtained by allowing the corrosion process to reach steady state. About 24 hours was required for the corrosion potential to become constant. The polarization scans were started at that time. The scans were generated by driving the potential in the anodic (noble) direction to current densities of 10 to 100 $\mu\text{A}/\text{cm}^2$. The scan direction was reversed at that point. The voltage was then driven back past the originally measured corrosion potential into the cathodic (active) region. The scan rate was 2 V/h for all scans.

RESULTS AND DISCUSSIONS

Figures 4 through 6 show polarization scans for 316 SS at a pH of 4.5 and alloy 825 at pH values of 3.5 and 4.5. The polarization scan for 316 SS is representative of an alloy that is expected to behave poorly in the environment while the polarization scan for alloy 825 is representative of an alloy that is expected to have good corrosion resistance. Tables 3 and 4 show the results of the in-plant immersion test.

The polarization scan for 316 SS shown in Figure 4 is characterized by a sharp increase in current at a potential of approximately +0.32 V (SCE). This sharp increase suggests that +0.32 V can be considered to be the approximate pitting potential in this environment. The current generated during the forward and reverse portions of the scans are not the same. Those generated during the reverse portion are greater than those generated during the forward portion suggesting that the passive oxide film on the alloy surface was damaged and had difficulty in re-establishing itself back to its original state. The reverse portion of the scan returned to the lowest current density (0.1 $\mu\text{A}/\text{cm}^2$) very close to the originally measured corrosion potential. This type of behavior strongly suggests that the alloy would suffer localized corrosion in the environment most likely in the form of crevice corrosion.^{16,17}

The polarization scans for alloy 825 as shown in Figures 5 and 6 strongly suggest passive behavior because the measured current is lower on the reverse portion of the scan than on the forward portion. In addition, the alloy repassivates at a potential that is far more noble than the corrosion potential indicating that the alloy is passive by the time the corrosion potential is reached.

[†] Trade name.

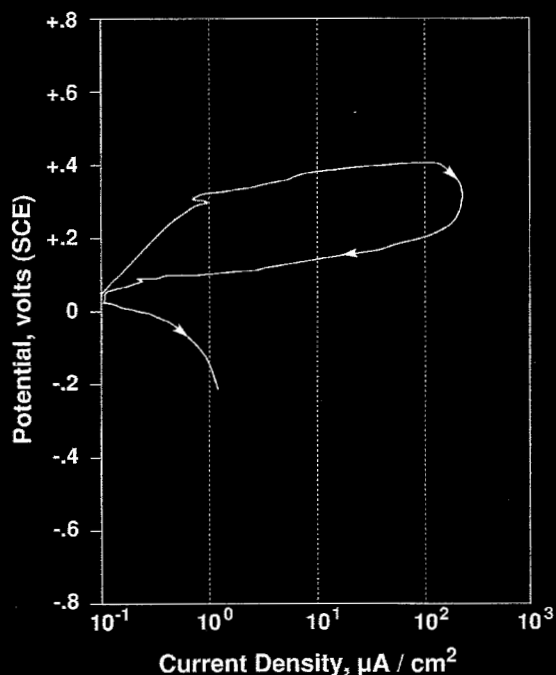


FIGURE 4. Polarization scan for 316 SS in process fluid at pH value of 4.5 and 40°C (313 K).

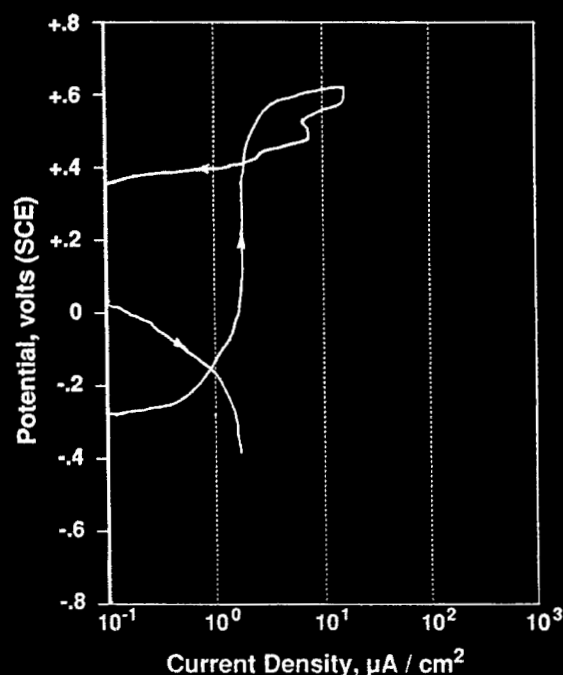


FIGURE 5. Polarization scan for Alloy 825 in process fluid at pH value of 3.5 and 40°C (313 K).

The polarization scan for alloy 20Cb3 shown in Figure 7 does not exhibit a pitting potential but does have a negative hysteresis between the forward and reverse portions of the scan. However, the current reaches $0.1 \mu\text{A}/\text{cm}^2$ at a potential that is 0.3 V noble relative to the corrosion potential. This behavior suggests that alloy 20Cb3 would be more prone to crevice corrosion than alloy 825 but less so than 316 SS. The initial prediction was that any of the candidates, alloy 20Cb3, alloy 825, or alloy C276 would be acceptable as a material of construction for the new vessel with some increased risk of localized attack with the alloy 20Cb3.

As shown in Tables 3 and 4, type 316 SS suffered crevice corrosion under the PTFE washer on coupons exposed in the plant equipment suggesting that this alloy would suffer crevice corrosion in the environment. Alloy 20Cb3 suffered less crevice corrosion than 316 SS, but crevice corrosion nevertheless was observed. The alloy 825 coupon exposed to the liquid phase suffered no general or localized corrosion in agreement with the polarization scans shown in Figures 5 and 6. The alloy 825 coupon exposed to the vapor phase showed one very minor site for the initiation of crevice corrosion. Note that polarization scans generated in the liquid phase cannot predict behavior in the vapor phase. No detectable corrosion was found on the alloy C276 coupons.

After considering the laboratory and in-plant test results, both alloy 20Cb3 and alloy 825 were judged to be reasonable candidates for the replacement vessel

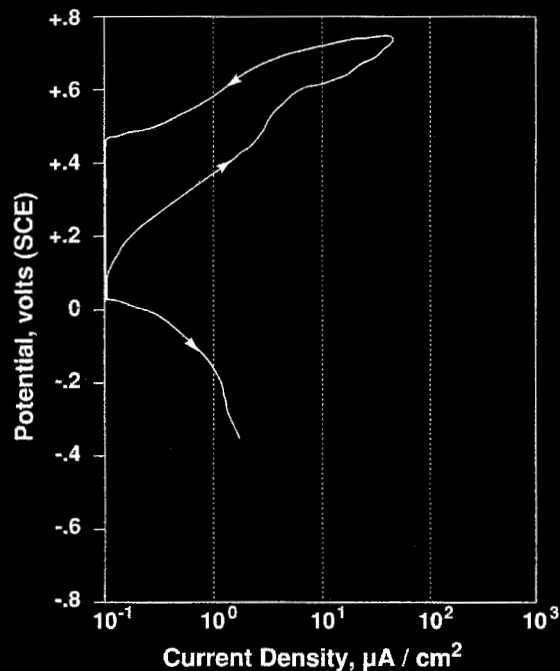


FIGURE 6. Polarization scan for Alloy 825 in process fluid at pH value of 4.5 and 40°C (313 K).

with the probability of crevice corrosion being greater on alloy 20Cb3. Alloy 825 was ultimately selected since its cost of fabrication was estimated to be only 3% higher than for alloy 20Cb3. The observation of crevice corrosion on the coupons exposed in the plant led to the use of C276 weld overlay on critical flange-

TABLE 3

Results of Corrosion Coupon Exposure
in Liquid Phase of Process Vessel
for 90 Days

Alloy	Mass Loss ^(A) /g	Observations
S31600	0.0026	Crevice attack under TFE washer. No general attack.
S08020	0.0019	Crevice attack under TFE washer. No general attack.
N08825	0.0019	No visible attack.
N10276	0.0006	No visible attack.

^(A) Calculation of average corrosion rate is meaningless in the presence of localized corrosion.

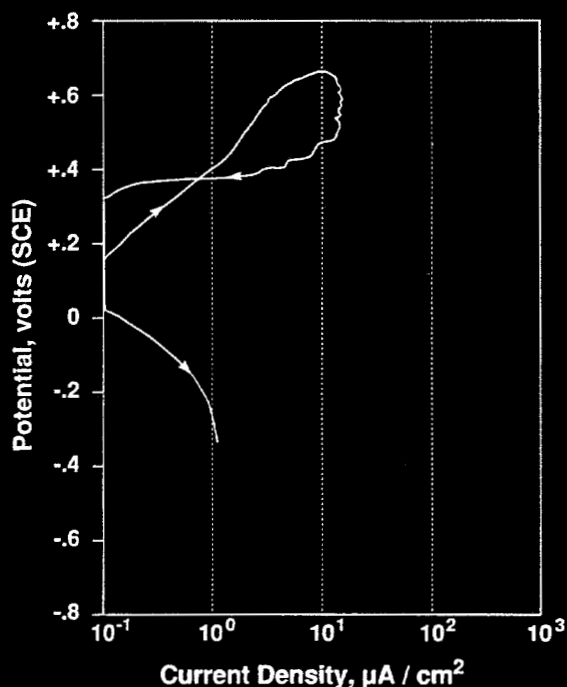


FIGURE 7. Polarization scan for Alloy 20Cb3 in process fluid at pH value of 4.5 and 40°C (313 K).

face gasket surfaces. The vessel has been in service for 3-1/2 years. Vessel inspections and coupon monitoring to-date have revealed no problems.

Case 3—Evaluation of a Proposed Waste Reactor Temperature Increase

There was a need to increase the operating temperature of a waste processing reactor in order to achieve improved conversion and capacity. The reactor was fabricated from alloy 825 and had an internal steam coil fabricated from alloy 20Cb3. That coil was originally specified to be alloy 825, but an availability problem with the needed alloy 825 pipe during vessel fabrication led to the use of alloy 20Cb3 for the coil.

TABLE 4

Results of Corrosion Coupon Exposure
in Vapor Phase of Process Vessel
for 90 Days

Alloy	Mass Loss ^(A) /g	Observations
S31600	0.0013	Crevice attack and one pit. No general attack.
S08020	0.0012	Crevice attack. No pits or general attack.
N08825	0.0008	One small crevice initiation site under washer. No pits or general attack.
N10276	0.0005	No visible attack.

^(A) Calculation of average corrosion rate is meaningless in the presence of localized corrosion.

The vessel receives an acidic waste fluid. This waste fluid reacts with an organic compound and sodium hydroxide. The process fluid had a normal chloride concentration of approximately 10,000 ppm. The vessel had been run at 65°C (338 K), and an increase to 80°C (353 K) was needed in order to satisfy the new process requirements.

EXPERIMENTAL

The urgency surrounding this need for a temperature increase meant that the effect of increased temperature on corrosion had to be evaluated rapidly. A test program consisting of polarization scans and a coupon immersion test in the laboratory was proposed. This test program was to be followed by coupon monitoring in the plant and an internal vessel inspection at the next annual shutdown. The field coupons would be removed after several months of operation to confirm that no damaging corrosion had occurred.

Polarization scans were run on both alloy 20Cb3 and alloy 825 at the proposed 80°C (353 K) process temperature. The laboratory apparatus and procedure were the same as described in Case 2. Coupon immersion tests were run using the two alloys at both 65°C (338 K) and 80°C (353 K).

RESULTS AND DISCUSSION

Figures 8 and 9 show polarization scans for alloy 20Cb3 and alloy 825 at 80°C (353 K) and a pH of 10.5. The shape of the polarization scans at 80°C (353 K) very closely duplicated the scans run at 65°C (338 K). Both scans suggest that both alloys would suffer at most a small amount of general corrosion. No localized attack in the form of crevice corrosion or pitting is predicted.

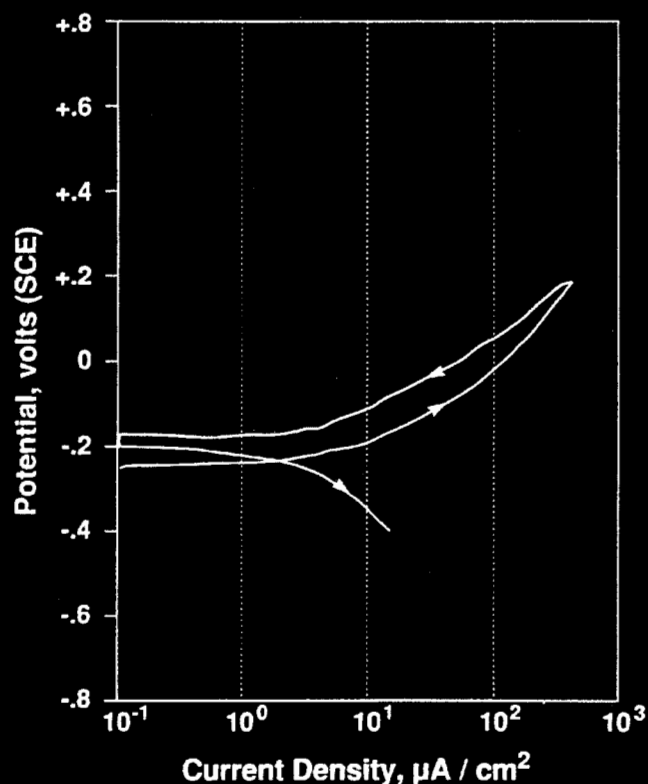


FIGURE 8. Polarization scan for Alloy 20Cb3 in waste fluid at pH value of 10.5 and 80°C (353°K).

Both polarization scans suggest that the alloys will corrode at a very low uniform corrosion rate. The hysteresis that appears between the forward and reverse portions of the polarization scan in Figure 8 is probably an artifact caused by the alloy surface not being at steady state as the potential is changed at 2 V/h. Had the surface been at steady state at all potentials, the hysteresis probably would not have appeared. Note that large segments of the forward and reverse portions of the polarization scan in Figure 9 do overlap. The fact that a large difference exists between the potential at which the reverse portion of the anodic scan reaches 0.10 $\mu\text{A}/\text{cm}^2$ and the potential at which the cathodic scan rises above 0.10 $\mu\text{A}/\text{cm}^2$ strongly suggests that the corrosion rate would be extremely low. No log-linear behavior is observed. Thus, the corrosion rate could not be estimated by using the intersection of the anodic and cathodic Tafel regions at the corrosion potential.

Coupon immersion tests were run on alloy 20Cb3 and alloy 825 at 65 and 80°C (338 and 353°K) for a period of 13 days. Only very slight weight gains were observed at 20X magnification with no detectable corrosion.

The temperature increase was implemented based on the laboratory electrochemical and coupon immersion test results. Subsequent coupon monitoring in the process vessel and a follow-up internal inspection confirmed that corrosion rates have remained

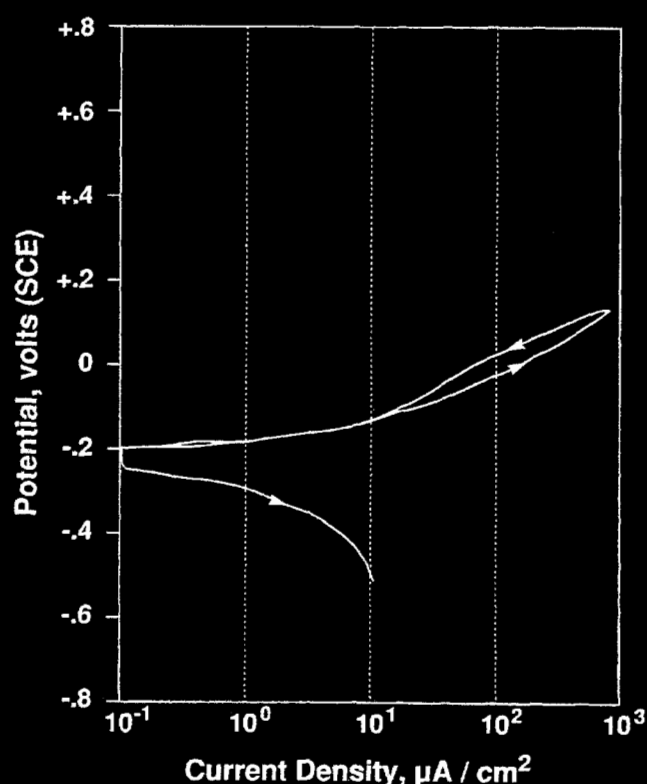


FIGURE 9. Polarization scan for Alloy 825 in waste fluid at pH value of 10.5 and 80°C (353°K).

acceptably low and that the higher process temperature is permissible.

CONCLUSIONS

- ❖ Laboratory and in-plant corrosion tests complement each other when used together to solve complex chemical plant corrosion problems.
- ❖ Appropriate use can be made of both electrochemical and nonelectrochemical techniques only when their limitations are fully understood.
- ❖ Plant and laboratory tests, when used alone, may lead to erroneous results since each approach has limitations. Two of these limitations are difficulty in confirming the probability of localized corrosion with in-plant coupons alone or the effects of varying process composition/conditions not being simulated in the laboratory tests.

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