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Electrochemical Behaviour of 1018, 304 and 800 Alloys in Synthetic Wastewater

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Abstract. Due to the fact that corrosion problems affecting the residual water treatment industry are varied and scarcely studied, this work presents an investigation of the corrosion behavior of important materials of engineering such as steel AISI-1018, AISI-304, and AISI-800 exposed to synthetic residual water under laboratory conditions. The electrochemical techniques used to asses the electrochemical behavior were linear polarization resistance (LPR), cyclic polarization curves (CPC) and electrochemical noise (ECN) techniques to determine corrosion rates, the susceptibility to localized corrosion and the most likely corrosion mechanism, respectively. In order to ascertain the amount of aerobic and anaerobic bacteria present on the steel surface, the Most Probable Number method (MPN) was employed. On the whole, the steels studied showed a better corrosion resistance in the following order: 800 > 304 > 1018. Also, the experimental results indicated that none of the steels demonstrated susceptibility to localized corrosion.

Key Words: Polarization Resistance, Cyclic Polarization, Electrochemical Noise, Steels, Synthetic Wastewater.

Resumen. Debido a que los problemas de corrosión que afectan la industria de tratamiento de aguas residuales son variados y escasamente estudiados, se presenta un estudio del comportamiento de corrosión de los aceros AISI-1018, AISI-304 y AISI-800 expuestos en agua residual sintética para conocer su comportamiento bajo condiciones de laboratorio.
Las técnicas electroquímicas empleadas para determinar el comportamiento de la corrosión fueron resistencia a la polarización lineal (RPL), curvas de polarización cíclica (CPC) y ruido electroquímico (REQ), para determinar velocidades de corrosión, susceptibilidad a corrosión localizada y el mecanismo más probable de corrosión, respectivamente. El método de número más probable (NMP) fue empleado para contar los microorganismos presentes en la superficie de los aceros. En general, los aceros estudiados presentaron una mejor resistencia a la corrosión en el orden siguiente: 800>304>1018. También, se determinó que los aceros no fueron susceptibles a la corrosión localizada durante el proceso de experimentación.

Palabras clave: Resistencia a la Polarización, Polarización Cíclica, Ruido Electroquímico, Aceros, Agua Residual Sintética.

Introduction

The wastewater industry works with some of the most aggressive liquids, some of them presented as organic and inorganic compounds, industrial residues involving all kind of microbial organisms, and gasses. Corrosion affects transport pipelines, pumps, storage tanks, pipelines that feed chemicals reagents to treatment, compromising their integrity. In wastewater systems both metallic (steel, cast iron, stainless steel) and nonmetallic materials (concrete, ABS, PVC etc.) are widely used [1].

For such systems, various strategies that may be used to prevent or minimize corrosion are better design parameters, modification of the environment and selection of construction materials [2]. Also, coal tar epoxy systems applied to the interior of concrete pipes has been reported [3]. Regarding metallic materials issues, some valuable work has been done to evaluate materials performance in water systems by using various techniques. Korshin and co-workers reported a study on the effect of natural organic matter in potable water on the corrosion of leaded brass using XPS and SIMS techniques [4]. Iversen studied the microbial corrosion of AISI 304 and AISI 316 stainless steels in wastewater treatment plants with the open circuit potential technique (OCP) [5]. Tuthill reported polarization curves for as-welded 304L (with heat tint) and as-welded and pickled (heat scale removed) conditions on the corrosion behaviour of austenitic stainless steels in wastewater environments [6]. A recent report indicates that duplex stainless steel offers a good resistance in pumps working in residual water systems. Nevertheless, the report does not indicate the way or method used for the previous statement [7].

From the above, the lack of information about materials performance in residual water using electrochemical techniques motivated this study. Electrochemical techniques can be adapted to determine corrosion rates and the most probable type of corrosion occurring. Thus, the objective of the present work is focused on the determination of the corrosion rate of three alloys with different chromium contents exposed to synthetic wastewater, in addition to its possible tendency to undergo localized corrosion, by using Linear Polarization Resistance (LPR), Cyclic Polarization Curves (CPC) and Electrochemical Noise (ECN) techniques.

Results and Discussion

Linear polarization resistance

Table 3 shows the values of linear polarization resistance (LPR), i_{corr} and corrosion rate averages obtained for each material. It is observed that the 1018 steel presents the higher corrosion rate, noticing significant differences between alloys: the corrosion rate values between stainless steels and the 1018 steel are of one order of magnitude. This demonstrates a greater corrosion resistance of steel 304 and 800 at the conditions of the present study. Nevertheless, it is interesting to observe that although steel 800 has a greater alloy content (see Table 1) its corrosion rate is very comparable to the one registered for stainless steel 304. Normally, it would be expect that 800 steel had a superior corrosion resistance in comparison with the 304 steel, due to its greater alloy content. However, the result obtained is in agreement with Schweitzer [8], who reported that in watery atmospheres the resistance of 800 steel can be inclusively inferior to the 304 stainless steel. From figures 1, 2 and 3 it can be observed that the bacteria *Pseudomonas aeruginosa* (PA) and the iron oxidizing bacteria (IOB) presented a uniform development until the ninth day of exposition. In the first case, to a greater period of time the bacteria do not present a constant stationary phase, but quickly appears a phase of cellular loss. The IOB after the ninth day present a constant latency phase. With respect to the sulphate-reducing bacteria, (SRB), it was observed a small tendency to development, but in ascending order, in particular to 1018 and 800 steels. As appreciated in figures 1, 2 and 3, there was no diminution in the polarization resistance due to the presence of microorganisms. This may indicate that these bacteria more than deteriorate these materials, provide a certain capacity to protect them by biofilm formation, at least in the present work conditions. To some extent, these results are in agreement with the reported by Nagiub and Mansfeld [9], where they mentioned a corrosion inhibition process due to the presence of microorganisms.

Cyclic polarization curves.

The test results from CPC (figure 4) indicate that the general behaviour for the alloys was different. The anodic curve shape for steel 1018 shows a uniform corrosion behaviour since it does not display a passivation process. The curves for 304 and 800 steels show a wide range of passivation potential, being

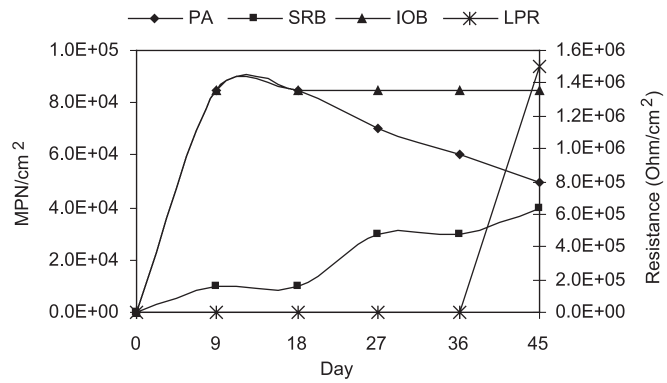

Fig. 1. Most probable number vs. Polarization resistance of 1018 steel

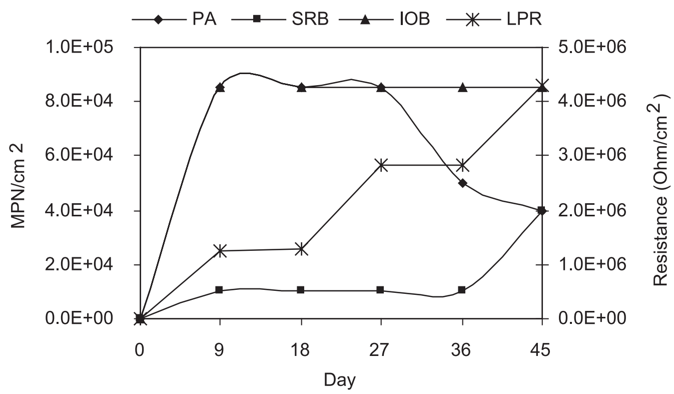

Fig. 2. Most probable number vs. Polarization resistance of 304 steel

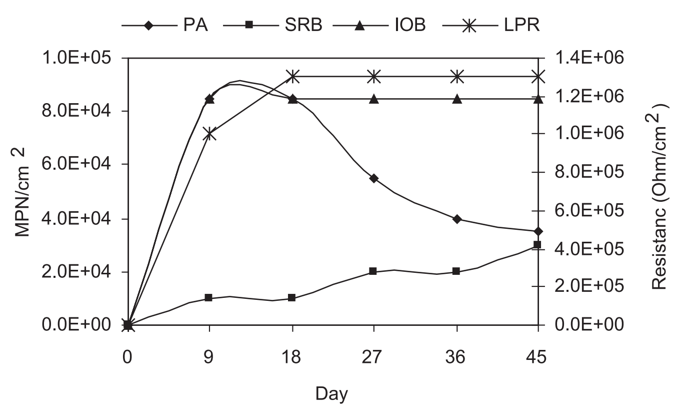

Fig. 3. Most probable number vs. Polarization resistance of 800 steel.

Table 1. Chemical composition of the studied alloys (% w.t.)

Alloy	Name	Fe	C	Mn	S	P	Cr	Ni	Si	Ti	Al	Cu
AISI 1018	1018	Balance	0,15-0,2	0,6-0,9	0,05	0,04	-	-	-	-	-	-
AISI 304	304	Balance	0,08	2	0,03	0,045	18	8	1	-	-	-
AISI 800	800	Balance	0,1	1,5	0,015	-	21	32,5	1	0,6	0,6	0,75

Table 2. Synthetic wastewater characteristics

Parameter	Concentration
Biochemical Oxygen Demand	776 ppm
Chemical Oxygen Demand	1293 ppm
Temperature	21°C
pH	8

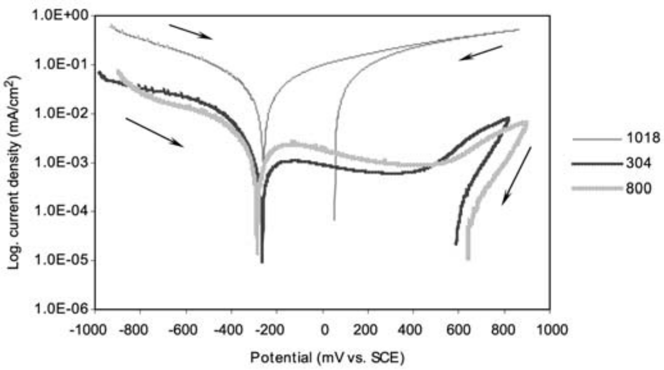

Fig. 4. Cyclic polarization curves general behavior after 45 days of exposure.

somewhat greater for the 800 alloy. For example, the repassivation potential for steel 304 is near 815 mV, whereas for steel 800 is near 890 mV. The cyclic polarization curves of stainless steel exhibited an instantaneous repassivation on the reverse potential, that is to say, they did not display hysteresis indications. These results are similar to the reported tendencies using stainless steels exposed to diluted sulphuric acid at 30°C [10]. In summary, under the experimental conditions of the present work, the steels studied did not present susceptibility to located corrosion.

Electrochemical noise

The potential noise and current noise signals registered in the period for the three types of steels are in figures 5, 6 and 7. The current noise and potential noise signals initially obtained were treated to remove its tendency according to the method of removal trend average [11]. It can be observed that the amplitude of voltage fluctuations is in the same order of magnitude for all the alloys, indicating that there is no significant difference between steels. Also, the signals displayed similar form i.e. there was no indication of combined variations of amplitude and low frequency fluctuations. Thus, the observed current fluctuations for the steels followed the same behaviour indicating low active interfaces. The value of the standard deviations of potential noise and current noise allows the calculation of the noise resistance, R_n, for each material in the following form:

$$R_n = \sigma_v/\sigma_i \quad (1)$$

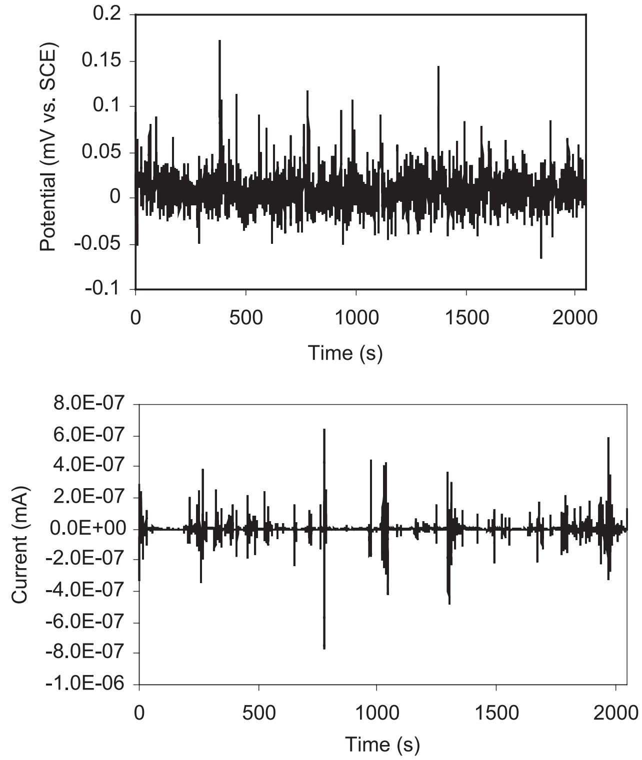

Fig. 5. Electrochemical noise of 1018 steel. a) potential noise and b) current noise.

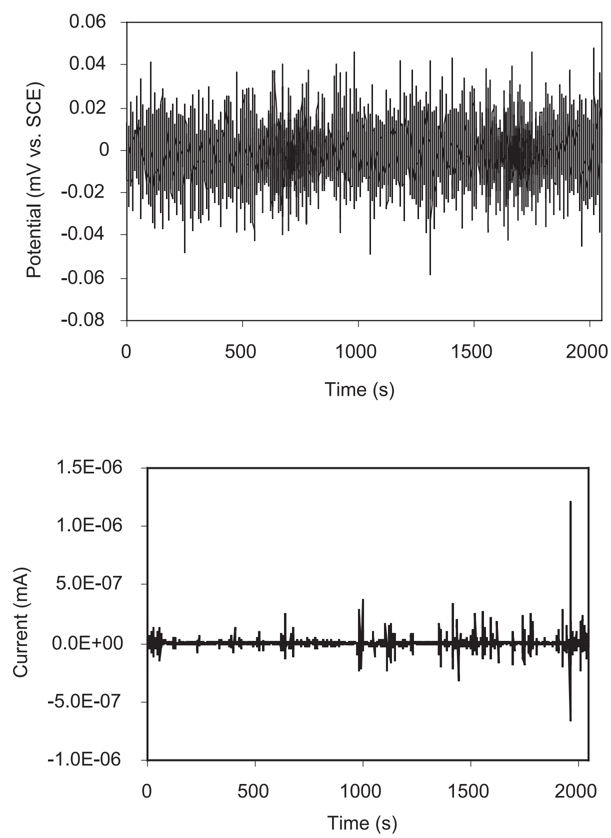

Fig. 6. Electrochemical noise of 304 steel. a) potential noise and b) current noise.

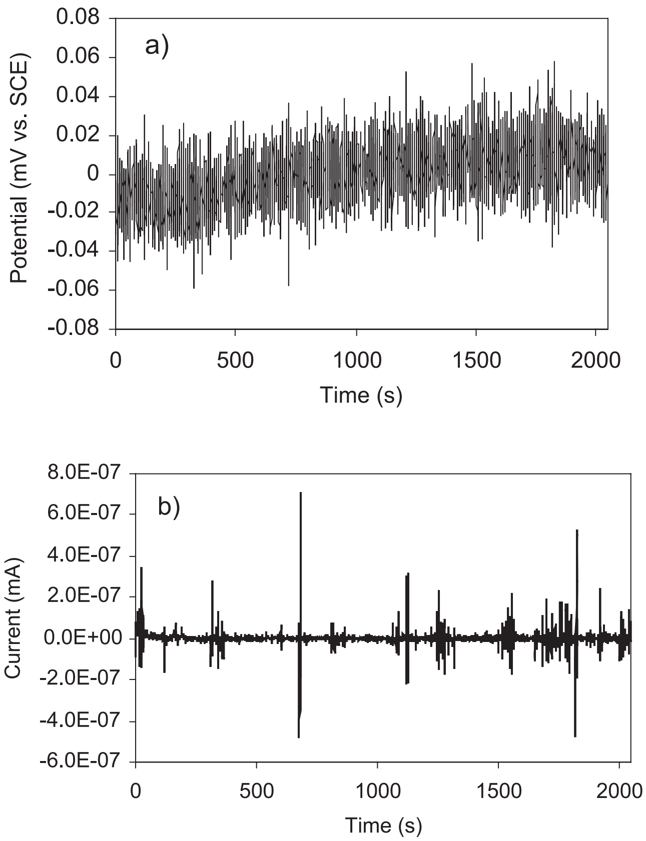

Fig. 7. Electrochemical noise of 800 steel. a) potential noise and b) current noise.

where σ_v is the standard deviation of the potential noise and if σ_i the standard deviation of the current noise [12].

In general, R_n values are compared very frequently with Rp values. In our case, with the exception of steel 1018, the stainless steels presented very similar Rn and Rp values, as it is observed in Tables 3 and 4.

Regarding the nature of attack, the localization index, LI, is defined as:

$$LI = \sigma_i / I_{rms} \quad (2)$$

where I_{rms} is the root mean square of the average of the value of current noise. The LI values falls in the range of 0,001 to 1. Values on the order of 0,001 indicated that uniform general corrosion is the predominant mechanism, whereas values approaching 1 indicate the predominance of a localized corrosion mechanism [13,14]. The LI value (Table 4) for each material was smaller than 0,001 indicating that the predominant mechanism was uniform corrosion. The 1018 carbon steel used disclosed the highest corrosion rate. However, it is worthy to mention that from an engineering viewpoint, the corrosion rates derived for the various materials can be considered very low [15]. The study presented here shows initial results on the behaviour of engineering materials in simulated residual water without inoculous. It is clear that the effect of variables such as content of dissolved gases, chloride level, pH and temperature is important, and studies in this direction are currently in progress.

Table 3. Rp, i_{corr} and corrosion rates obtained from polarization resistance.

Alloy	LPR (Ohms-cm^2)	i_{corr} (mA/cm^2)	Corrosion rate (mm/y)
1018	3,03E05	8,59E-05	4,34E-04
304	3,12E06	8,33E-06	8,62E-05
800	3,0E06	2,12E-05	8,92E-05

Table 4. Electrochemical noise parameters.

Alloy	σ_v	σ_i	R_n	Localización index (LI)	Description
1018	2,05	5,02E-07	4,08E06	0,0005	Uniform corrosion predominantly
304	1,42	3,04E-07	4,68E06	0,0002	Uniform corrosion predominantly
800	2,72	4,96E-07	5,5E06	0,0008	Uniform corrosion predominantly

Conclusions

The behaviour of corrosion of 1018, 304 and 800 steels exposed in synthetic residual water was examined by several electrochemical techniques. The LPR results indicated that steel 800 exhibited the higher corrosion resistance, followed by the 304 steel. The higher corrosion rate was registered for the 1018 steel. At the study conditions given, the presence of microorganisms was not an important factor in the deterioration of steels. The behaviour indicated by cyclic polarization curves and electrochemical noise was that these materials did not present susceptibility to localized corrosion in this type of environment, and the most probable corrosion process was uniform corrosion.

Experimental procedures

The materials under study were carbon steel AISI-1018, an austenitic stainless steel AISI-304 and an AISI-800 superalloy. Their chemical compositions are presented in Table 1.

Material preparation

Specimens (working electrodes) were cut from rods of different materials into coupons. The dimensions of specimens were: 1.27 cm of diameter × 2.00 cm of height. These specimens were mounted in epoxy resin. After that, each specimen was polished with silicon carbide sandpaper 1200, washed with distilled water, degreased with acetone and dried. The synthetic residual water was prepared using 5 g of dissolved organic matter in 1 liter of potable water, and the total used in the experimental equipment was 70 liters. Table 2 shows the analytical characterization of the synthetic residual water used.

Electrochemical techniques.

The electrochemical experiments were carried out using a ACM Gill 8 with internal potentiostat/galvanostat, zero resistance ammeter (ZRA), and frequency response analyzer equipment controlled with a personal computer. All the potentials were measured against a saturated calomel reference electrode (SCE). Linear polarization resistance (LPR) measurements were carried out applying a small sweep from -20 to + 20 mV around the corrosion potential at a scan rate of 1.5 mV/s. Corrosion rates were calculated in terms of current density, i_{corr}, The i_{corr} values were calculated according to the Stearn and Geary equation[16]:

$$i_{corr} = 26/R_p \qquad (3)$$

where 26 is a Tafel constant value given by the software used and Rp is the polarization resistance. From the i_{corr} values obtained, the corrosion rates in mm/y were calculated using Faraday's law. Polarization resistance values and the most probable number method values were compared in order to know if the bacterial presence of the potable water, fed by the dissolved organic matter, represented a deterioration factor in these materials. In this work, cyclic polarization curves (CPC) were included according to the ASTM G61-86 norm [17] to evaluate the materials tendency to suffer localized corrosion. Here, the applied potential varied from -900 mV to +900 mV at a scan rate of 1.5 mV/s. Electrochemical noise measurements (ECN) were based on the ASTM STP 1277 standard [18]. In order to detect the current noise, an arrangement of two nominally identical electrodes was used. The current noise was measured as the galvanic coupling current between two identical electrodes by using a Zero Resistance Ammeter (ZRA) connected to a personal computer. To obtain potential noise data, the potential of one working electrode was measured relative to a reference electrode (SCE). Both measurements (potential noise and current noise) were monitored simultaneously at a sampling interval of 1 s. For each alloy, signals were collected during 2048 sec.

The most probable number method (MPN) was employed to ascertain the amount of aerobic and anaerobic bacteria present on the steel surface, and specific cultive were: Postgate B for sulphate reducing bacteria (SRB), Iron-Oxidizer for iron oxidizing bacteria (IOB) and Cetrimide for *Pseudomonas aeruginosa*. To recover and count microbial, cylindrical test tubes of about 20 cm^2 area for each type of steel were used. In all cases, experiments were made during 45 days at room temperature, monitoring every 9 days for the electrochemical and microbiological analysis.

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