Mitigation of Biocorrosion in an Urban Solid Waste Treatment Plant

PATRICIA S. GUIAMET, PAOLA LAVIN, LILIANA GASSA, AND SANDRA GABRIELA GÓMEZ DE SARAVIA, *INIFTA.UNLP, CCT La Plata-CONICET, La Plata, Argentina*

The aim of this work was to study the biofilm formation and the biocorrosion affecting an urban solid waste treatment plant and the application of a commercial antimicrobial agent to mitigate the effects of microbiologically influenced corrosion. The results showed the antimicrobial agent was able to inhibit the growth of microorganisms and mitigate biocorrosion.

Corrosion is an electrochemical process where a reaction between a material and the environment causes metal loss. When microorganisms that have a natural tendency to bond on solid surfaces are present, biofilms are formed. Biofilms are microbial consortia embedded in self-produced exopolymer matrices composed mainly of exopolysaccharides (EPS). Microbes living in these matrices benefit from nutrient and water supplies,[1] improved lateral gene transfer,[2] and protection against adverse environmental conditions such as desiccation and chemicals,[3] including detergents, disinfectants, antibiotics,[4] natural products,[5] and silver nanoparticles.[6] The microorganisms displace ions previously adsorbed to surfaces and produce a series of complex bioreactions.[7] Microorganisms can influence corrosion by modifying the chemical conditions near the metal. This process is called biocorrosion or microbiologically influenced corrosion (MIC).[8]

An industrial plant contains several environments where corrosion and biofilm processes are potentially troublesome.[9] Cooling systems, storage tanks, water and wastewater treatment facilities, filters, piping, and solid waste treatment plants are commonly affected by biocorrosion problems.[10] The biofilm formation and the resulting biocorrosion affect a wide variety of industries and cause economic losses. These problems are common in urban solid waste (USW) treatment plants. For this reason, biocorrosion monitoring must be performed with numerous data obtained from corrosion measurements, processing plant instruments, and biochemical and microbiological laboratory analyses.

The separation of USW at a USW treatment plant is very important to minimize the environmental impact. The aim of this work was to study the biofilm formation and the biocorrosion affecting the USW treatment plant and the application of a commercial antimicrobial agent to mitigate the effects produced by biocorrosion.

The study was performed at the USW treatment plant in Buenos Aires province, Argentina. At this facility, waste-filled bags enter the plant and are unloaded onto a separation belt where waste materials are manually selected, classified, and put into containers according to the type and/or purpose of the waste material. As soon as the inorganic and pathogen wastes are removed, the organic portion is transported by another conveyor belt to an outside grinding machine to homogenize the sizes. In many instances, concrete structures supporting the conveyor and grinding machine are damaged by MIC to the point where major rehabilitation is required in as few as four years. In one case, a total collapse occurred within six years.[11]

The studied USW treatment plant had to replace a concrete platform by a steel conveyor belt that is currently in use.[12] Both materials are highly susceptible to corrosion problems and MIC due to the water present in the system and leachate from the organic material, and the use of biocides or antimicrobial cleaning agents is required. Chemical treatments applied to control biofilm formation consist of biocides or products such as dispersive or penetrating agents, which increase the treatment's efficiency.[13]

FIGURE 1 (a) Biofilm sampler and (b) conveyor belt.

Materials and Methods

Samples

To analyze biofilms, a sampling system was designed that consisted of 10 10-mm diameter SAE 1010 (UNS G10100) metal samples, the same steel as the conveyor belt, placed on a Teflon† base (Figure 1[a]). One was placed on the selection belt in the waste unloading zone, which is in continuous contact with leachate and waste water and susceptible to the biofilm development (Figure 1[b]). The other sample was placed in the grinding machine. All the samples were in contact with the leachate for 24 h and then removed for analysis. The sampling was repeated six times in six different months. As the samples were removed and sent to the laboratory to be processed, they were replaced with clean samples.

Microbiological Studies

Microbiological studies focused on the leachate (planktonic bacteria) and a biofilms sampler from metal samples located in the conveyor belt and the grinding machine. The sessile bacteria were obtained by removing biofilms from the samples by scraping. The growth of total aerobic heterotrophic mesophilic bacteria, acid-producing bacteria, sulfate-reducing bacteria (SRB), fungi, and yeasts[14] were investigated. Parallel to the USW treatment plant sampling, Envirocheck Contact YM† culture slide systems were used to attain a quantitative assessment of the microorganisms present on the conveyor belt surface.

†Trade name.

Measurements of pH, chlorides, sulfates, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were made (Table 1).

Antimicrobial Agent

The USW treatment plant uses a commercial antimicrobial agent, SENDECO Chlor Send†, as a biocide and anticorrosive agent. It is composed of anionic detergent, chlorinated aromatic hydrocarbons, glycol ether solvent, and phenolic disinfectant. It is manually applied in a 1:100 dilution to clean the facilities.

Microbiological studies were conducted using metal samples exposed to leachate with and without treatment with the biocide.

Metal samples exposed to leachate with and without treatment with the biocide were observed with a JEOL JSM-6360 LV† scanning electron microscope (SEM). To preserve the biological specimens, samples were fixed with a solution of 2% glutaraldehyde in a phosphate buffer, washed in distilled water, and dried on a gradual series of acetone up to 100% by the critical point technique for SEM observation.

Cyclic Voltamperometry Tests

Cyclic voltamperometry and open circuit potential technique measurements were carried out to characterize the corrosion phenomena of the SAE 1010 used in the plant. Pitting susceptibility was measured in particular. For this purpose, a conventional electrochemical cell was used, employing SAE 1010 samples ($A = 0.95\ cm^2$) as work electrodes. Potential scanning was performed at a rate of 2 mV/s between −1.0 and 4.4 V in a control solution containing sodium chloride (NaCl) and sodium sulfate (Na_2SO_4) at the same concentrations as those found in the leachate (pH 4.45), in the leachate of the treatment plant (pH 4.45), and in the commercial antimicrobial agent. The work temperature was controlled at 25 ± 0.2 °C.

TABLE 1. CHEMICAL ANALYSES

Parameters	Leachate	USW
pH	4.45	4.42
Chloride (mg/L)	3,670	1,360
Sulfate (mg/L)	473	160
BOD (mg/L)	394,000	—
COD (mg/L)	323,000	—

Results and Discussion

Voltamperometry Tests

Figure 2 shows the SAE 1010 response E/j to different media tested. It shows the effect of each solution employed on the pitting susceptibility of the material. In the control saline solution case, it can be seen as a peak of anodic current at E = −0.85 V, but following with the potential scanning to more anodic values, SAE 1010 reaches passivity and there is no pitting observed within reach of potential scanning.

When the SAE 1010 response to the leachate and antimicrobial agent is

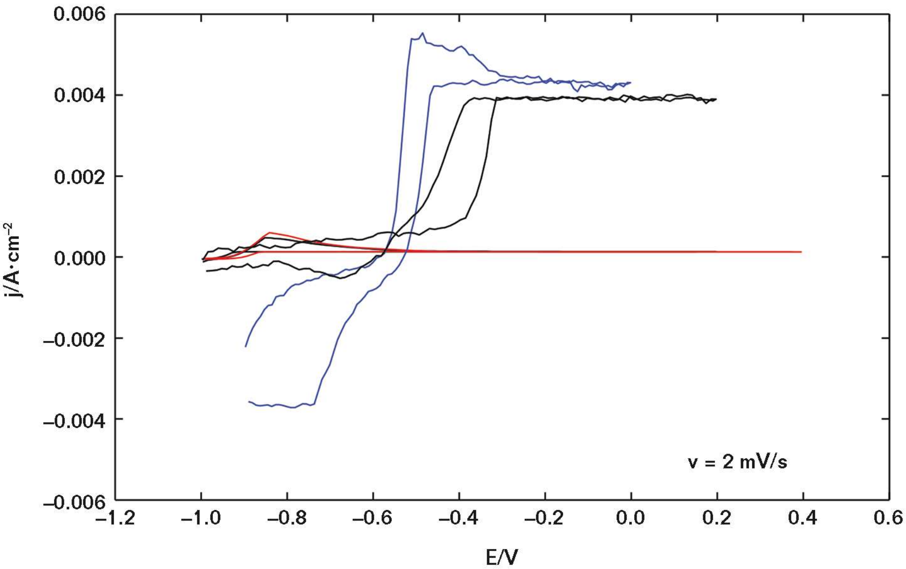

FIGURE 2 Voltamperograms of SAE 1010 in control, NaCl + Na_2SO_4 (—) solution, leachate (—), and the antimicrobial agent (—).

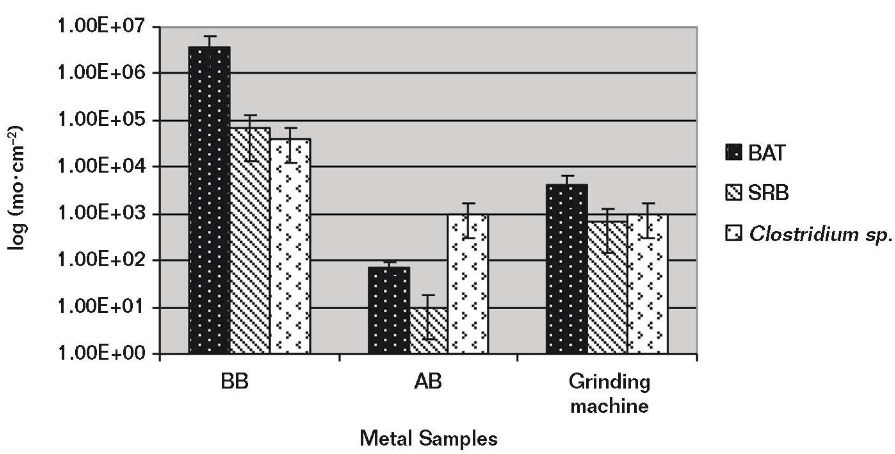

FIGURE 3 The effect of biocide on biofilms on metal samples on the conveyor belt (BB before biocide, AB after biocide) and on metal samples located in grinding machine.

analyzed, the corrosion current values registered are higher (particularly in the leachate) and it is possible to observe in the profiles the response of a material that is being pitted (noise in the current and curve hysteresis in the potential scanning in a reverse direction). Even though the dissolution current obtained at the biocide tests is slightly lower than that obtained in the leachate, the pitting process is important in this case.

Microbiological Counts

The result of the culture slide systems performed on the metallic conveyor belt for the total heterotrophic mesophilic bacteria was 3.5 CFU·cm^{-2}, both before and after applying the biocide. In the fungi and yeast cases, values varied from 6 CFU·cm^{-2} before application to 2.3 CFU·cm^{-2} after application. Microbial counts obtained from the sample scrapings for the microorganisms studied varied between 1×10^6 mo·cm^{-2} and 1×10^4 mo·cm^{-2} before applying the biocide (Figure 3).

In the case of the metal samples, the effect of the biocide decreases about five orders of magnitude for the acid-producing bacteria (>1×10^2 mo·cm^{-2}), four orders of magnitude for the SRB (>1×10^1 mo·cm^{-2}), and an order of magnitude for the sulfite-reducing bacteria (*Clostridium* sp) (>1×10^3 mo·cm^{-2}) (Figure 3).

In the SRB and the acid-producing bacteria cases, the antimicrobial agent had only a bacteriostatic effect, as observed in Figure 3. This indicates that the biocide is able to decrease the microbial quantity; however, their metabolism contributes to the corrosion process.[15]

The presence of microorganisms leads to a great MIC potential.[16] In the case of SRB, the biocide effect was less than that in the SRB and the acid-producing bacteria cases due to the greater resistance of the species forming spores, as in the case of *Clostridium* sp.[13] The acidification produced by the acid-producing bacteria checked in the laboratory (a decrease of more than two units of pH) can have a synergic effect on the corrosion of inorganic origin and accelerate the deterioration processes in the plant facilities.

The concentration of sulfate (an element necessary for SRB growth) in the leachate (Table 1) would corroborate the count mentioned previously.[17] On the other hand, chlorides in the leachate (Table 1), together with the presence of sulfides, would have a synergic effect on the corrosion of the plant facilities.[18] The values of chlorides and sulfate found in the leachate, 3,670 and 473 mg/L, respectively, are significantly higher than those found in the USW, 1,360 and 160 mg/L, respectively. This shows the aggressive behavior of the leachate on the plant facilities. A large amount of inorganic corrosion products could be observed as a result of the steel corrosion on the samples (Figure 4[a]) before applying the biocide (Figure 4[b]). After applying this product to the surface, the samples showed a lower amount of corrosion products (Figure 4[c]). This demonstrates that the biocide could not only act as bacteriostatic agent but also protect the steel structures of the plant from generalized corrosion.

Conclusions

- The biocide was able to decrease the microbial quantity present on the conveyor belt and in the leachate.
- The acid products coming from the microbial metabolism synergically interacted with the leachate and caused a biocorrosion hazard in the plant facilities.
- The reported levels of biofilm formation due to aerobic heterotrophic mesophilic bacteria, acid-producing

bacteria, and SRB suggest a potential biocorrosion risk in each case for the conveyor belt of the USW plant. The low pH values, the chloride, and sulfate concentrations in the leachate could prove to be an inorganic corrosion risk at the different sampling areas of the plant, which means a potential risk of significant economic loss in the plant facilities.
- Although the biocide protected the steel structures from generalized corrosion, the bacteriostatic behavior from microorganisms remains; thus it would be advisable to use biocides and other products to increase the treatment efficiency.

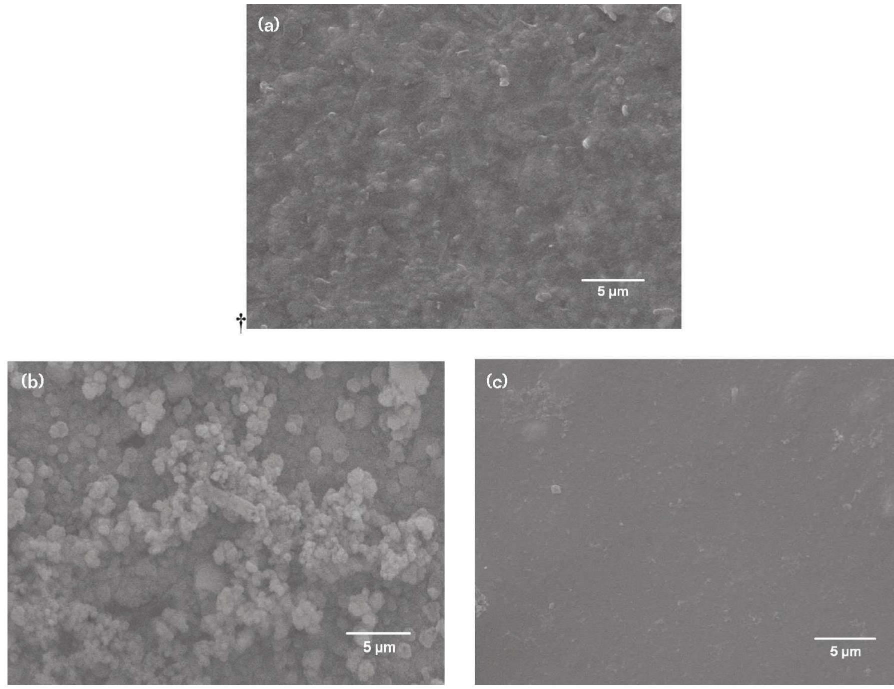

FIGURE 4 SEM micrographs (3500X) of metal samples: (a) control, (b) before, and (c) after application of the biocide.

Acknowledgments

The authors thank the Universidad Nacional de La Plata (UNLP 11N 713 and 11X 632), the Comisión de Investigaciones Científicas de la Provincia de Buenos Aires (CICBA-243/13), and the Consejo Nacional de Investigaciones Científica y Técnica (CONICET, PIP 0200) for their financial support.

References

1 C.C. Goller, T. Romeo, "Environmental Influences on Biofilms Development," *Curr. Top. Microbiol. Immunol.* 322 (2008): pp. 37-66.
2 T.F. Maha, G.A. O'Toole, "Mechanisms of Biofilm Resistance to Antimicrobial Agents," *Trends Microbiol.* 9 (2001): pp. 34-39.
3 P.S. Guiamet, S.G. Gómez de Saravia, "Laboratory Studies of Biocorrosion Control Using Traditional and Environmentally Friendly Biocides: An Overview," *LAAR* 35 (2005): pp. 295-300.
4 J.W. Costerton, "Bacterial Attachment to Surfaces," C. Eckey, ed., *The Biofilm Primer* (Berlin, Germany: Springer, 2007), pp. 36-43.
5 S. Gómez de Saravia, S. Borrego, P. Lavin, O. Valdés, I. Vivar, P. Battistoni, P. Guiamet, "Environmentally Friendly Products from Plants in the Control of Biodeteriogen Agents," *NPAIJ* 9, 5 (2013): pp. 167-174.
6 F. Martinez-Gutierrez, L. Boegli, A. Agostinho, E. Morales Sánchez, H. Bach, F. Ruiz, G. James, "Anti-Biofilm Activity of Silver Nanoparticles against Different Microorganisms," *Biofouling* 29, 6 (2013): pp. 651-660.
7 B. Pesic, V.C. Storhok, "Biocorrosion of Iron with Thiobacillus Ferrooxidans-Linear Polarization Study," CORROSION 2001, paper no. 1255 (Houston, TX: NACE International, 2001).
8 D.A. Jones, P.S. Amy, "A Thermodynamic Interpretation of Microbiologically Influenced Corrosion," CORROSION 2002, paper no. 58 (Houston, TX: NACE, 2002).
9 W.G. Characklis, "Influence of Microbial Biofilms on Industrial Processes," Proc. Argentine-USA Workshop on Biodeterioration (H.A. Videla, ed.) (Sao Paulo, Brazil: Aquatec Quimica, 1986), pp. 181-216.
10 C.C. Gaylarde, H.A. Videla, "Localized Corrosion Induced by a Marine Vibrio," *Int. Biodegr.* 23 (1987): pp. 91-104.
11 G. Welton, M. Ribas Silva, C.C. Gaylarde, L.K. Herrera, X. Anleo, N. De Belie, S. Modry, "Microbial Impacts on Building Materials—Weathering and Conservation," *Mater. Struct.* 38 (2005): pp. 883-893.
12 P.S. Guiamet, A. Mugnolo, S.G. Gómez de Saravia, "Microbiological Biodeterioration of the Structural Materials in a Solid Waste/Recycling Plant in an Urban Buenos Aires Province," Proc. 14th International Symposium on Biodeterioration and Biodegradation, held October 6-11, 2008 (Messina, Italy: IBBS, 2008), p. 40.
13 H.A. Videla, P.S. Guiamet, S.G. Gómez de Saravia, L.K. Herrera, C. Gaylarde, "Environmentally Friendly Approaches to Inhibit Biocorrosion, An Overview," CORROSION 2004, paper no. 04574 (Houston, TX: NACE, 2004).
14 M.T. Madigan, J.M. Martinko, P. Dunlap, D. Clark, eds., *Brock Biology of Microorganisms,* 12th ed. (San Francisco, CA: Benjamín Cummings, 2009), p. 1,168.
15 H.A. Videla, P.S. Guiamet, O. Pardini, M.S. Freitas, E. Echarte, "Monitoring Biofilms and MIC in an Oilfield Water Injection System," CORROSION/91, paper no. 103 (Houston, TX: NACE, 2001).
16 R.G. Edyvean, H.A. Videla, "Biological Corrosión," *Interdiscipl. Sc. Rev.* 16 (1991): pp. 267-284.
17 R.A. King, "Monitoring Techniques for Biologically Induced Corrosion," *Bioextraction and Biodeterioration of Metals,* C.C. Gaylarde, H.A. Videla, eds. (Cambridge, U.K.: Cambridge University Press, 2009), pp. 271-305.
18 D. Cetil, A. Mehmet Levent, "Corrosion Behavior of Low-Alloy Steel in the Presence of *Desulfotomaculum* sp." *Corros. Sci.* 51, 8 (2009): pp. 1,584-1,588.

PATRICIA S. GUIAMET is a professor at the University of La Plata, Laboratory of Biodeterioration of Materials, INIFTA-UNLP-CONICET, St. 64 and Diag. 113 S/N CC 16, Suc. 4 (1900), La Plata (FCV), Argentina, e-mail: pguiamet@inifta.unlp.edu.ar. She has 30 years of experience in the research and mitigation of biodeterioration, biocorrosion, and problems in the field of cultural heritage. She is a member of NACE International.

PAOLA LAVIN is a Ph.D. student at the University of La Plata, Laboratory of Biodeterioration of Materials, INIFTA-UNLP-CONICET, e-mail: paolalavin@gmail.com. He is involved in the prevention and control of the biodeterioration of materials important to heritage. He conducts research on organic and inorganic materials and biodeterioration by the activity of complex microbial communities.

LILIANA GASSA is an engineering researcher at the University of La Plata, INIFTA-UNLP-CONICET. She studies the electrochemical behavior of additive compounds on various metals, electrode kinetics, and mechanisms of metal electrodeposition reactions and electrodissolution of materials of technological interest.

SANDRA GABRIELA GÓMEZ DE SARAVIA is a Ph.D. researcher CICBA and professor at the University of La Plata (FCNyM), Laboratory of Biodeterioration of Materials, INIFTA-UNLP-CONICET, e-mail: sgomez@inifta.unlp.edu.ar. Her research interests include biofouling and biocorrosion in seawater and in various industrial systems and biodeterioration of cultural heritage materials. She also studies the biocidal activity of natural extract and essential oils. *MP*