Understanding biocorrosion in practical cases of different industrial systems

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Abstract

Microbiologically influenced corrosion (MIC) is mediated by microorganisms attached to the metal surface and embedded in a gelatinous organic matrix (biofilm). Microbial adhesion processes lead to an important modification of the metal/solution interface, inducing changes in the type and concentrations of the liquid microenvironment or the interface. Practical cases can identify a number of situations where failure by corrosion of fouling is due to the interaction of microorganisms with industrial materials and systems. The cases presented show that the phenomenon is common to a great variety of material environmental conditions and locations through the world and that there is extensive concern about the problem. The aim of this work is to show the results about biocorrosion on metallic structures of different plants (urban waste treatment, steel plants, located in Buenos Aires province). The strain of different bacteria *Pseudomonas* sp., acid producing bacteria, sulfate reducing bacteria and *Hormoconis resinae* were isolated from the plants. These microorganisms are directly related to their capacity of biofilm formation and aggressive conditions created at the fixation points that are the main causes of the localized biocorrosion of the metal.

Keywords: MIC, industry, microorganisms, microbial adhesion, biofilm

Introduction

The microorganisms displace ions previously adsorbed to surfaces producing a series of complex bioreactions (1). Microorganisms can influence on the corrosion modifying the chemical conditions near to metal, this process is called biocorrosion or microbiologically induced corrosion (MIC) (2, 3).
The corrosion in processing plants is generally characterized by a great number of variables (4). For this reason, biocorrosion monitoring must be performed with numerous data obtained from corrosion measurements, processing plant instruments and biochemical and microbiological laboratory analysis. Unfortunately, there are not enough papers about biocorrosion problems in urban solid waste (USW) treatment and metalworking plants.
On many occasions MIC has damaged concrete structures so much so that major rehabilitation was required after four years, in our case a total collapse occurred within six years (5, 6).

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This USW plant had to replace a concrete platform by a steel conveyor belt which is currently used. Both materials are highly susceptible to corrosion problems and MIC due to the water present in the system and leachate of the organic material, requiring the use of biocides or antimicrobial and cleaning agents. Chemical treatments applied to biofilm control consist of the application of biocides or products such as dispersive or penetrating agents, which increase the treatment efficiency (7, 8).
The aim of this work is to show the results about biocorrosion on metallic structures of different plants (urban waste treatment, steel plants, located in Buenos Aires province). The strain of different bacteria *Pseudomonas* sp., acid producing bacteria, sulfate reducing bacteria and *Hormoconis resinae* were isolated from the plants. These microorganisms are directly related to their capacity of biofilm formation and aggressive conditions created at the fixation point, the main causes of the localized biocorrosion of the metal. The practical cases presented in this work permit to identify a series of possible biocorrosion situations. These situations can be caused by wrong controls and monitoring of the materials in the different industrial systems. Several items in common are described, which are the clue to demonstrate the influence of the microorganisms on the biocorrosion process. In spite of the numerous variations it is evident that similar cases can occur with different materials in different environments or systems.

Materials and Methods

The studies were carried out on two different industrial systems: a) pipes and tanks of steel rolling mill emulsion of a metalworking plants in Buenos Aires, Argentine. The samples were two emulsions, E1, light and almost liquid and oxygenated, E2, heavy and almost black colored of muddy aspect, and a third sample from filters, they were sent to the laboratory to be subsequently processed; b) the USW treatment plant in Buenos Aires province, Argentine (Figure 1). In this system there was a biofilm sampler (Figure 2) placed with 10 coupons of the same steel than that of the conveyor belt, SAE 1010 of 1 cm^2 of diameter, put in the waste unloading zone, on the selection belt, which is in continuous contact with leachate and waste water and susceptible to the biofilm development. All of the samples were in contact with the leachate for one day. Then, they were removed and sent to the laboratory to be subsequently processed. They were replaced by clean samples. The study was carried out during six months.

Figure 1 - USW treatment plant

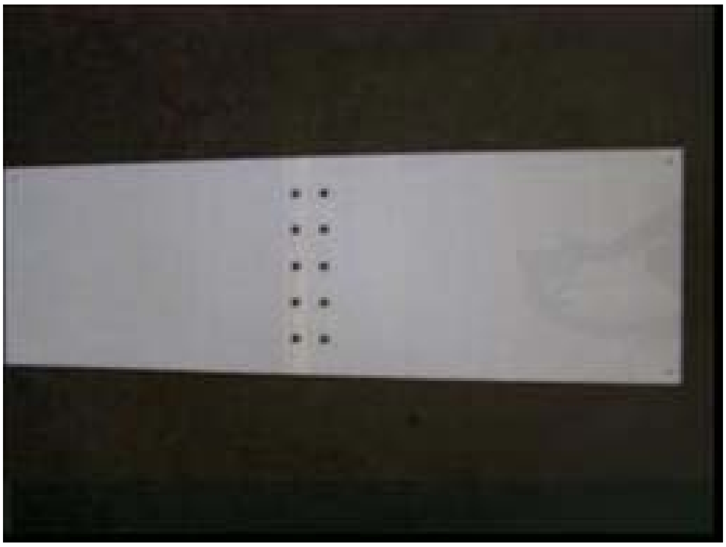

Figure 2 - Sampler

Microbiological studies

In a) and b) the growth of heterotrophic mesophilic bacteria, acid producing bacteria, sulphate reducing bacteria (SRB), reducing sulphite bacteria, iron bacteria, *Pseudomonas* sp. fungi and yeasts (9) were investigated. In parallel, in the USW treatment plant sampling, Envirocheck Contact YM® slide culture systems were used to attain a quantitative assessment of the microorganisms present in the conveyor belt surface.

Chemical analysis

Measurements of pH, chlorides, sulphates, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were made.

Microscopic observations

All the samples of two cases a) and b) were observed with JSM6360LV scanning electron microscope and with Olympus BX51 optic microscope. To preserve the biological specimens, samples were fixed with a solution of glutaraldehyde at 2% in phosphate buffer, washed in distilled water and dried on gradual series of acetone up to 100% and by the critical point technique (9).

Results

Microbiological studies

In Table 1 and Figure 3 it can be seen the count obtained of different samples.

Table 1 - Microbial count (mo/mL)

SAMPLE	Acid producing bacteria	Sulphate reducing bacteria (SRB)	Iron oxidizing bacteria	Fungi and yeasts
E1	1000-10000	1-10	1-10	50
E2	100-1000	10-100	10-100	(-)
Organic waste leachate	10000- 100000	10000- 100000	(-)	(-)

(-) growth was not observed.

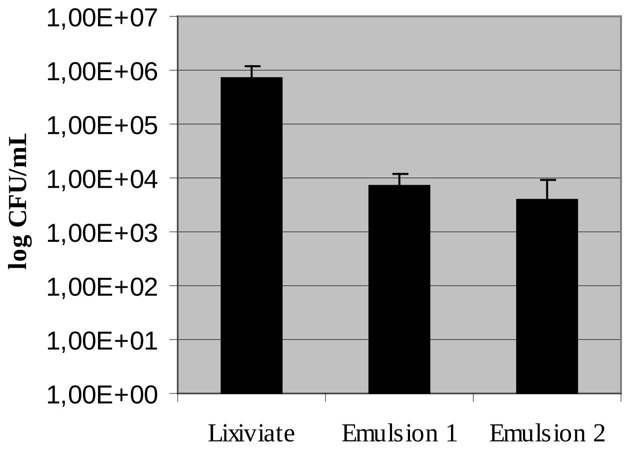

Figure 3 - Total heterotrophic mesophilic bacteria

Tabla 2 - Chemical analysis

Parameters	USW plant		Metalworking plant
	Organic waste leachate	Lixiviate	Emulsion
pH	4.45	4.42	5
Chloride (mg/l)	3670	1360	30
Sulphate (mg/l)	473	160	Not analyzed
BOD (mg/l)	394000	-	Not corresponding
COD (mg/l)	323000	-	Not corresponding

Microscopic observations

It can be observed a photograph of optical microscope of the Gram stain from the E1 and E2 samples (Figure 4) that allow to examine and corroborate the development of microbial consortiums formed by Gram (-) bacillus mainly *Pseudomonas sp*., fungi (*Hormoconis resinae)* and yeasts coming from the emulsions.

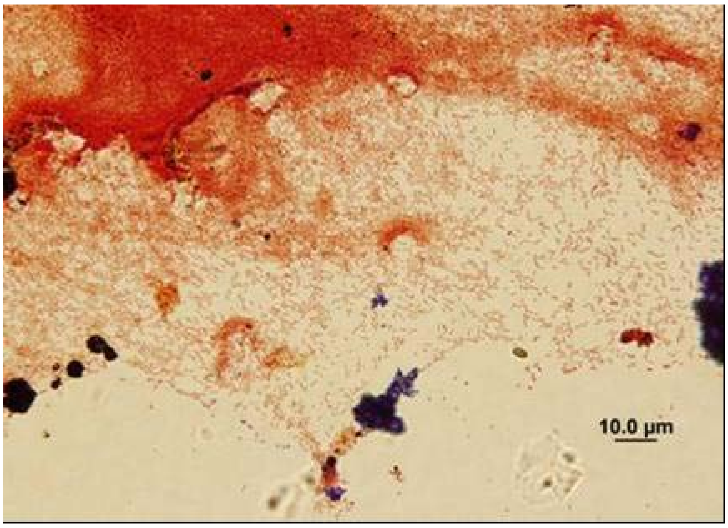

Figure 4 – Optic microscope photograph where Gram (-) and fungi can be observed

Figure 5 shows the sample from the filter after removing sediments, orange or chestnut-brown colored zones and a general attack can be observed. In figure 6 the zone attacked by pitting can be observed.

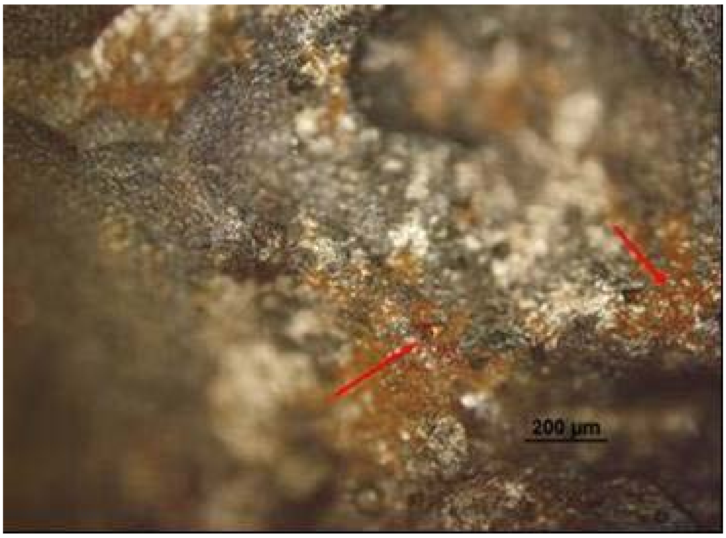

Figure 5 - Photograph of the filter. Orange colored zones (indicated) and brilliant streaks can be observed (10X)

Figure 6 - Photograph of the filter. The attacked zone by pitting is indicated (10 X)

In figure 7 it can be observed the attack by pitting on a SAE 1010 steel coupon coming from the sampler placed in the USW treatment plant (Figure 2).

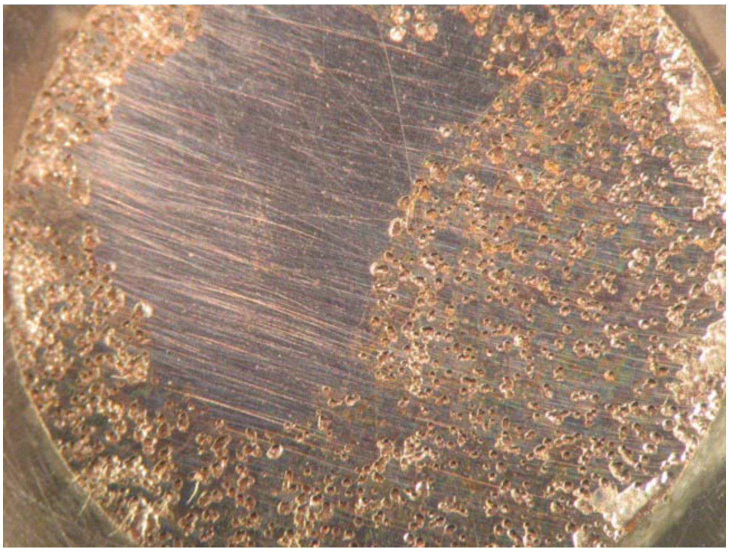

Figure 7 - Photograph of the SAE 1010 sample. Pitting can be observed of the samples of the USW treatment plant

In Figure 8 it can be seen conidia and biofouling and Figure 9 shows corrosion products.

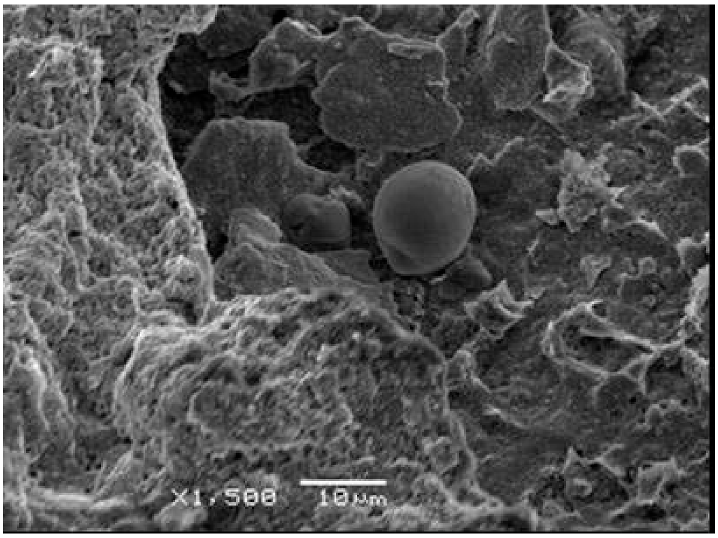

Figure 8 – Scanning electron microscope micrograph of the filter, showing conidia and biofouling attached

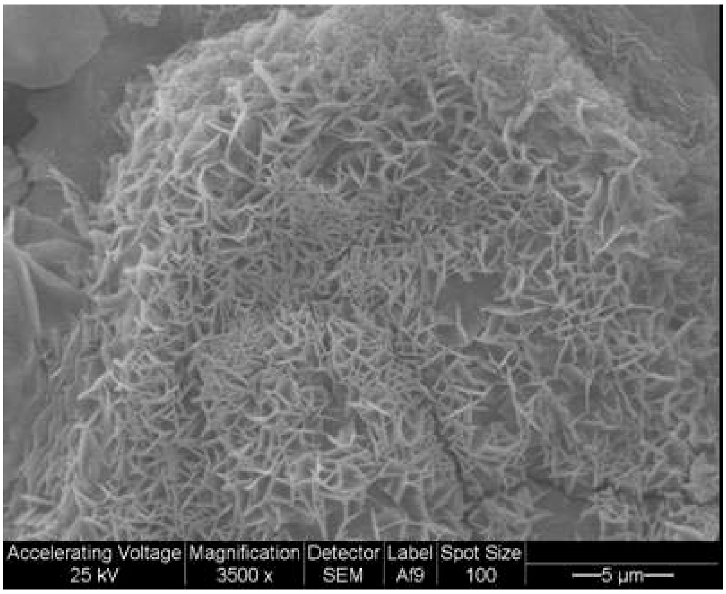

Figure 9 - Scanning electron microscope micrograph of SAE 1010 after 1 day exposure to lixiviate

Discussion

The growth of aerobic heterotrophic bacteria and facultative anaerobic ones (*Pseudomonas* sp. among them) generates a microenvironment encouraging the biofilm formation and the subsequent growth of oxidizing iron bacteria and yeasts. The last ones through their metabolic routes bring about pH decreases allowing the fungi development such as *Hormoconis resinae*

isolated from these systems (Table 1) (10, 11). The pH decreases at acid values (10) could be given by the activity of the *Hormoconis resinae* fungi.
Pseudomonas sp. is a microorganism able to growth at the expense of the synthetic oil in demineralized water at 4 % (of oil), to use the compounds present in these emulsions such as esters and emulsifiers (12, 13), to degrade them and to adhere to surfaces forming biofilms (14,15). These biofilms originate zones of different oxygen gradients that accelerate the biocorrosion processes (14, 15).
In the USW treatment plant the results obtained by the SRB countings of levels reaching to 1 x 10^6 mo/cm^2, suggest that both the risk area (steel conveyor belt, Fig.1) and the area sampled can show an important potential of MIC (16, 17). It is important to highlight the presence of acid producing bacteria that would be involved in the MIC processes. The acidification produced by these bacteria that was verified at the laboratory (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 structures of the USW treatment plant. The pH measures of the samples of the 1 and 2 emulsions allow confirming a pH decrease of about 5 in two units compared with the pH of the original emulsion (10, 11). This decrease could be given by the presence of acid metabolites coming from the bacterial and fungal activity broking the steel passivity and causing biocorrosion emergence.
The surface studies with optical microscopy on the filters allow to observe brilliant zones and the formation of ocher-orange-colored tubercles together with pits irregularly distributed on the surface (Figures 5 and 6). This was corroborated by the growth of viable microorganisms indicated in table 1. These microorganisms are involved in the MIC processes (10, 11, 18).
The MEB results for the sample 3 (filter) allow to observe the presence of biofouling represented by bacteria and conidia (Figure 8), this could not be corroborated by means of the microbiological studies performed since the sample was not properly taken by the workers of the plant, whereas in the USW treatment plant case the right planning of the studies allow to evaluate the biofilm present (19).
It is important to remark that biocorrosion processes (14, 15) are clearly of electrochemical nature. In both systems studied the corrosion process was developed in the long term and was not controlled by workers.

Conclusions

Levels reported of the aerobic heterotrophic mesophilic bacteria, the acid producing bacteria, SRB and sulphite reducing bacteria, iron bacteria for each case suggest a potential biocorrosion.
Besides this situation, promising conditions are generated for the growth of *Hormoconis resinae* that causes pH decrease. These also suggest biocorrosion risk.
The growth of *Pseudomonas* sp. could take place at the expense of the compounds present in the emulsion what could lead to its deterioration.
The low values of pH, the chloride and sulphate concentrations present in the plants could prove an inorganic corrosion risk at the different sampling areas of the plants.
It is necessary to set monitoring plans at long term by means of physicochemical and microbiological studies, with staff training, in order to avoid stopping the plant and replacing pieces. It means a potential risk of significant economic losses in the plant facilities.

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