

## **Aerobic and Facultative Microorganisms Isolated From Corroded Metallic Structures in a Hydroelectric Power Unit in the Amazon Region of Brazil**

Authors: Correia, Amabel F., Segovia, Jorge F.O., Bezerra, Roberto M., Gonçalves, Magda C.A., Ornelas, Sócrates S., et al.

Source: Air, Soil and Water Research, 3(1)

Published By: SAGE Publishing

URL: <https://doi.org/10.1177/ASWR.S6105>

---

BioOne Complete ([complete.BioOne.org](https://complete.BioOne.org)) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at [www.bioone.org/terms-of-use](https://www.bioone.org/terms-of-use).

Usage of BioOne Complete content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

---

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

## Aerobic and Facultative Microorganisms Isolated From Corroded Metallic Structures in a Hydroelectric Power Unit in the Amazon Region of Brazil

Amabel F. Correia<sup>1</sup>, Jorge F.O. Segovia<sup>2</sup>, Roberto M. Bezerra<sup>3</sup>, Magda C.A. Gonçalves<sup>3</sup>, Sócrates S. Ornelas<sup>4</sup>, Damaris Silveira<sup>5</sup>, José C.T. Carvalho<sup>3</sup>, Sérgio P.S.S. Diniz<sup>6</sup> and Luis I.B. Kanzaki<sup>4</sup>

<sup>1</sup>Central Public Health Laboratory/LACEN, Brasília, DF, Brazil, CEP 70830-010. <sup>2</sup>The Brazilian Agricultural Research Corporation/EMBRAPA, Rodovia Juscelino Kubitschek, Fazendinha, Macapá, AP, Brazil, CEP 68903-419. <sup>3</sup>Laboratory of Drugs, Federal University of Amapá, AP, Brazil, CEP 68902-280. <sup>4</sup>Laboratory of Bioprospection, University of Brasília, DF, Brazil, CEP 70910-900. <sup>5</sup>Faculty of Health Sciences, University of Brasília, DF, Brazil, CEP 70910-900. <sup>6</sup>Laboratory of Natural Products, State University of Maringá, PR, Brazil, CEP 87020-900.

Corresponding author email: [kanzaki@unb.br](mailto:kanzaki@unb.br)

**Abstract:** Aerobic and facultative bacteria belonging to the *Enterobacteriaceae*, *Pseudomonadaceae*, *Bacillaceae*, *Corynebacteriaceae* and *Streptococcaceae* families have been isolated from corroded metallic structures of a hydroelectric power unit in the Amazon region of Brazil. In addition to anamorphic dematiaceous and moniliaceous fungi, members of the archeobacteria kingdom were also detected in the same samples. Scanning electron micrographs of metal bars cultivated with consortia of the isolated microorganisms depicted suggestive images of biofilm formation and corroded metallic structures questioning the possible role of these microorganisms in the corrosion activity. We also found Amazonian medicinal plants exhibiting inhibitory activity against some of the isolated microorganisms. Our new findings need additional studies to confirm the participation of some isolated microorganisms in the process of metallic degradation despite our main question if are there particular microorganisms involved in the corrosion process? or if physicochemical conditions would favor the development of a particular microbiota and consequently the corrosion process would result from its metabolism? Therefore we hypothesize that any microorganism could be potentially involved in the genesis of corrosion process. This is the first report in the literature dealing with microbiologically induced corrosion in the Amazon region which is especially characterized by its high humidity and elevated temperature all year round.

**Keywords:** biocorrosion, microorganisms, metallic surfaces, hydroelectric power unit, amazon region of Brazil, Amapá state

*Air, Soil and Water Research* 2010:3 113–121

doi: [10.4137/ASWR.S6105](https://doi.org/10.4137/ASWR.S6105)

This article is available from <http://www.la-press.com>.

© the author(s), publisher and licensee Libertas Academica Ltd.

This is an open access article. Unrestricted non-commercial use is permitted provided the original work is properly cited.

## Introduction

Microbiologically induced corrosion is a matter of great concern all over the world. It costs so much to prevent the corrosion process and to replace periodically deteriorated metal structures.<sup>1</sup> The isolation and identification of microorganisms involved in the corrosion process is a necessary and mandatory step in order to design methods to prevent and control it.<sup>2,3</sup> The biofilm formation which is mainly determined by the interaction of a consortia of microorganisms represents the main factor involved in the etiological mechanism of biocorrosion. Composed basically of 95% of water and 5% percent of extracellular polymeric substances including organic molecules produced by the microbial metabolic activity and inorganic molecules, the biofilm generates a highly dynamic environment, promoting the exchange of ions between the metallic surface and itself. Such ionic interactions weaken the arrangement of metallic bonds' structures, causing fissures in its surface that in an amplified scale and at a practical view result in great economic loss.<sup>1,2,4</sup> The algae, fungi and bacteria have been reported to be involved in corrosion processes.<sup>5,6</sup> The members of the *Enterobacter* and *Pseudomonas* genera were found to be potential candidates in the etiology of biocorrosion related processes as these microorganisms are capable to interchange electrons with the adhered surface representing the fundamental mechanism of ionic interplay over the metallic surfaces leading to the corrosion process.<sup>7,8</sup> Also, Sulfate-Reducing Bacteria (SRB), a group of phylogenetically diverse anaerobes that perform the dissimilatory reduction of sulfur compounds including sulfate, sulfite, thio-sulfate and even sulfur to form sulfide, is involved in the corrosion process, in mechanisms producing cathodic depolarization by the removal of hydrogen ions (protons) from the cathodic area on the iron surface catalyzed by bacterial hydrogenases, coupled to sulfate reduction to sulfide that could account for the severe corrosion of iron in an anoxic environment under neutral pH.<sup>9,10</sup>

Here we report for the first time, the isolation and biochemical characterization of microorganisms cultivated from fragments of corroded metallic structures collected at the facilities of Coaracy Nunes hydroelectric power unit, in Amapa state, in the Amazon region of Brazil and found also the suggestive role of the isolated consortiated microorganisms in

the corrosion process, as also preliminary results of antimicrobial activity of Amazonian medicinal plants against the isolated microorganisms. Taking into account our results we are strongly inspired to hypothesize that any microorganism is capable to trigger mechanisms of metallic corrosion dependly mainly on the microenvironment physicochemical conditions and the molecular composition and architecture of the material surface exposed to the local microbiota.

## Materials and Methods

### The hydroelectric power unit "Coaracy Nunes"

The Coaracy Nunes hydroelectric power unit (UHE) is located in northern Brazil, at Ferreira Gomes county, in the Amapa state, delimited at southeast by the Amazon river and northeast by the Oiapoque river, in the boundaries of French Guyana (00°55'00" North and 51°15'00" West) as depicted in Figure 1 (Map of Amapá, Brazil).

### Corroded metallic structures

At the UHE, 10 samples of corroded fragments and 2 water samples from pipelines designated AB1 to AB12 were collected from the metallic surfaces of the pipelines/valves/heat exchanger and from the refrigeration system. The crusts were removed



**Figure 1.** Geographic localization of Coaracy Nunes Hydroelectric Power Unit in the Amapa state, in Ferreira Gomes county.

utilizing a sterile bistouri and blade and collected on sterile falcon tubes containing transport medium (vermiculite) as also water from the pipelines refrigeration system.

### Microbiological culture of corroded metallic fragments and water

In order to isolate and biochemically characterize the microorganisms, the collected samples were inoculated into sterile brain heart infusion medium (BHI) and incubated at  $35 \pm 1$  °C for 24 hours and transferred to blood agar, MacConkey agar and azide agar. The gram staining was performed at this stage. Additional 24 hours incubation period was carried out at the same conditions. The agar grown colonies were recorded considering morphological and staining characteristics. The pure cultures were obtained by reinoculation of isolated colonies in the same media. The complementing biochemical characterization was performed in a semiautomatic Autoscan Walkaway (W/A) system (MicroScan, Sacramento, Calif.) and by the analysis based on the metabolic characteristics of isolated microorganisms.<sup>11</sup>

Also the previously suspended samples in BHI media were transferred to the Sabouraud agar dextrose and Mycosel agar, and kept under incubation for 10 days at 25 °C. The fungi grown colonies were transferred to the Potato dextrose agar and kept at room temperature. The phenotypic identification was based on the macroscopic and staining characteristics likewise the texture, topography and colour of the colonies as also the microscopic features displayed by the reproductive structures, the hyphae and conidia.<sup>12,13</sup>

### Detection of unculturable microorganisms by molecular methods

The samples collected from the metallic corroded structures in BHI medium were submitted to DNA extraction and amplified by the polymerase chain reaction utilizing the Archaeobacteria universal primers.<sup>14</sup> As briefly described, 500 uL of each collected sample, enriched in BHI medium was incubated under agitation for 24 hours at 35 °C. After growth, DNA was extracted utilizing the PureLink Genomic DNA kit (Invitrogen), following the steps of proteinase K digestion of bacterial lisates and RNA degradation by RNase treatment. DNA was extracted

on columns (PureLink Spin Column), washed out and eluted. The quality of obtained DNA was assessed by visualization on 1% agarose gel and quantified in a spectrophotometer.

DNA samples were amplified by the polymerase chain reaction utilizing 0.5 uM of archael primer pair A571F and UA1204R (16S rRNA), 0.2 mM of dNTPs, 1.0 U of Taq polymerase in 2.5 uL of buffer (Roche) and 1.5 mM of Mg<sup>++</sup> in a final volume of 25 uL. The thermocycler was programmed to 94 °C/2 min., followed by 30 cycles of 94 °C/1 min., 55 °C/1 min., 72 °C/1 min. and finishing at 75 °C/10 minutes. After amplification, 12.5 uL of reaction volume was analyzed by electrophoresis on 1% agarose gel and ethidium bromide staining.

### Analysis by scanning electron microscopy

The corroded fragments and water (AB1 to AB12) collected in individual sterile falcon tubes were transferred to BHI sterile medium in tubes containing a metallic bar measuring 1 cm long × 1 cm large and 1 mm deep. Each 24 hours after inoculation, the turbidity of the medium was measured in an ELISA reader at 600 nm wavelength. After 14 days, the metal bars were washed out in distilled water, dried at room temperature and observed under the scanning electron microscope, in a JEOL-JSM, T-330 A model, coupled to an analyzer of dispersive energy, a photographic camera and a LEO microscope Leica-Zeiss, 440 model coupled to EDX and WDX detector in a 50× magnifier.<sup>15</sup>

### Results

Aerobic and facultative bacteria belonging to the Enterobacteriaceae, Pseudomonadaceae, Bacillaceae, Corynebacteriaceae and Enterococcaceae families were isolated from the corroded metallic structures and biochemically characterized. The isolates of the Enterobacteriaceae family included the *Enterobacter cloacae*, *Escherichia coli*, *Hafnia alvei* and *Serratia marcescens*, and pertaining to the Bacillaceae family we isolated the *Bacillus polymyxa*, *Bacillus thuringiensis*, *Bacillus brevis* and *Bacillus alvei*. The *Corynebacterium pseudodiphthericum*, *Pseudomonas aeruginosa* and *Enterococcus faecalis* were the sole representatives of the Corynebacteriaceae, Pseudomonadaceae and Enterococcaceae families

respectively. All biochemical parameters analyzed, manually and automatically, were displayed in Tables 1, 2 and 3. Phenotypical and metabolic profiles of isolated microorganisms were assorted and based on these data, identified in the W/A system's computer software at the genera and species level.<sup>11</sup> All identified members of the Enterobacteriaceae family, *Enterobacter cloacae*, *Escherichia coli*, *Hafnia alvei* and *Serratia marcescens* presented bacilar morphology, gram negative staining, oxidase and cetrinide negative test, ornithine and ortho-nitrophenyl- $\beta$ -D-galactosidase positive tests, being all of them capable to utilize glucose, allowing us to differentiate them from the Pseudomonadaceae family member, *Pseudomonas aeruginosa* (Table 1). Members of the Bacillaceae and Corynebacteriaceae family reacted positively by the gram staining, being identified mainly by their property to ferment glucose, sucrose and lactose in the TSI test. The *Bacillus polymyxa* and *Bacillus thuringiensis* utilized all carbohydrates and the *Bacillus brevis* and *Bacillus alvei* just fermented glucose and, the solely identified species in the Corynebacteriaceae family, the *Corynebacterium pseudodiftherium* did not ferment any sugar (Table 2). Just one species, *Enterococcus faecalis*, in the Enterococcaceae family was identified, yielding catalase negative test, growth on 6.5% NaCl broth and esculine positive test and did not hemolyze blood in agar (Table 3).

The *Myceteeae* kingdom was represented by the isolates of anamorphic dematiaceous and moniliaceous fungi. The morphological and staining characteristics of colonies of fungi grown in Sabouraud agar are shown in Figure 2A and 2B. The dematiaceous fungi exhibited dark coloured, grayish or grayish-brown powdery and felt-like colonies, and their dark reverse showed curves to straight conidia, containing three to four septa and septated and dematiaceous hyphae, characteristic of *Curvularia* spp (Fig. 2A). The moniliaceous fungi presented white cotton-like colonies and a brown reverse colour with double verticillated conidiophores exhibiting globolous conidia and septated and hyaline hyphae, characteristic of *Penicillium* spp (Fig. 2B).

Preliminary metagenomic analysis of DNA extracted from collected mixed water and corroded metallic samples detected a band in the gel after

**Table 1.** Biochemical characterization of Enterobacteriaceae and Pseudomonadaceae species isolated from corroded metallic structures in the Coaracy Nunes Hydroelectric Power Unit, Amapa state.

Microorganisms Family/species	Fermentation												OF																
	Glucose	Sucrose	Sorbitol	Raphnose	Ramnose	Arabinose	Inositol	Adonitol	Melbiose	Urea	Hydrogen sulfite	Indole	Lysine	Arginine	Ornithine	Tryptophan deaminase	Esculin hydrolysis	Voges- Proskauer	Galactosidase (ONPG)	Citrate	Malonate	Tartrate	Acetamide	Cetrinide	Nitrate	Base	Glucose	Oxidase	
<b>Enterobacteriaceae</b>																													
<i>Enterobacter cloacae</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Escherichia coli</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Hafnia alvei</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Serratia marcescens</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<b>Pseudomonadaceae</b>																													
<i>Pseudomonas aeruginosa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Abbreviations: +, positive; -, negative; ONPG, ortho-nitrophenyl- $\beta$ -D-galactosidase; OF, oxidation and fermentation.

**Table 2.** Biochemical identification of species belonging to the bacillaceae and Corynebacteriaceae families isolated from corroded metallic structures in Coaracy Nunes Hydroelectric Power Unit, Amapa state.

Microorganisms	Blood agar hemolysis	Catalase	Urea	TSI up/bottom	H <sub>2</sub> S
<b>Bacillaceae</b>					
<i>Bacillus polymyxa</i>	β	+	–	A/A	–
<i>Bacillus brevis</i>	β	+	+	Alc/A	–
<i>Bacillus alvei</i>	β	+	+	Alc/A	–
<i>Bacillus thuringiensis</i>	β	+	+	A/A	–
<b>Corynebacteriaceae</b>					
<i>Corynebacterium pseudodiphtherium</i>	β	+	+	Alc/Alc	–

**Abbreviations:** +, positive; –, negative; β, β-hemolysis; TSI, triple sugar iron; Alc/A, alkaline and acid reaction in TSI.

submission to electrophoresis of amplified DNA fragments by the PCR assay, corresponding to 1,300 bp fragment stained by ethidium bromide as depicted in Figure 3. The band was not resolved in sequential gel analysis in order to check out if more than one band was present.

Previously mentioned isolated microorganisms were found to be associated in the corroded fragments and water removed from the metallic surfaces and pipelines respectively. The scanning electron micrographs exhibiting colonies of the isolated bacteria and biofilm formation on the surface of the metallic structures are depicted in Figures 4 and 5 as also the metallic dissolution represented by the spectra of energy dispersion of molecular oxygen and iron ions (Fig. 5). The bacterial growth over the surface of the metallic bars in the liquid medium in consortiated groups as designated in material and methods from AB1 to AB12 did not show any significant difference in turbidity parameters, all starting the lag phase in the second day of cultivation, determined by the measurement of the optical density values in an ELISA reader at 600 nm wavelength (Fig. 6). Also we detected fissures in the surface of the metallic bars colonized in vitro by the consortiated microorganisms

that were previously biochemically characterized. They were not assayed individually as in the natural environment those microorganisms are found associated as we corroborated in our experiments.

Of 30 distinct medicinal plants collected in the Amapa state, we detected preliminarily 5 plant extracts exhibiting antimicrobial activity. All plants assayed in this research work are traditionally utilized by native people in the Amazon region to cure their diseases. The ethanolic extracts of *Copaifera reticulata*, *Tabebuia serratifolia*, *Brosimum rubescens* and *Carapa guianensis* presented activity against gram positive bacilli of the *Bacillus* genera, and the ethanolic extract of *Aspidospermum carapanauba* showed activity against the gram positive bacilli and *Pseudomonas aeruginosa*. Despite these data be preliminary, most of the microorganisms susceptible to the plants extracts are multiresistant to commonly used antibiotics (data not shown).

## Discussion

The Amazon region is characterized by high humidity and elevated temperatures all over the year. In Amapa state, the Ami and Amw climates predominate. According to Köppen classification, the former

**Table 3.** Biochemical identification of the Streptococcaceae family species isolated from corroded metallic structures of the Coaracy Nunes Hydroelectric Power Unit, Amapa state.

Microorganism	Hemolysis in blood agar	Catalase test	NaCl at 6.5%	Bile + Esculin test
<b>Streptococcaceae</b>				
<i>Enterococcus faecalis</i>	Without hemolysis	–	+	+

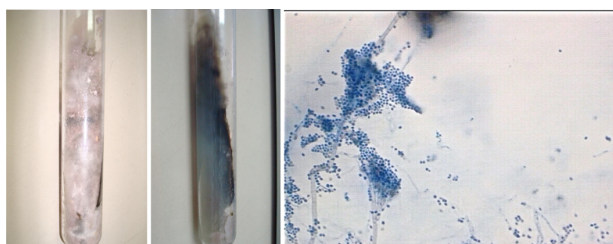
**Abbreviations:** +, positive; –, negative.



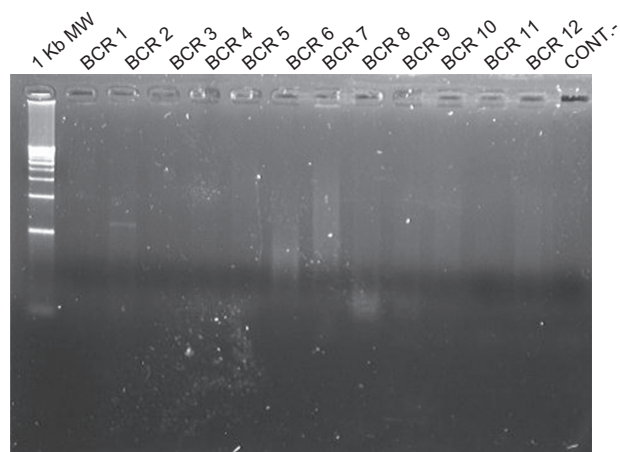
**Figure 2A.** Fungus *Curvularia* spp. cultivated in Agar Sabouraud. Agar surface (left). Agar reverse side (middle). Optical microscopy (40×), stained with lactophenol, showing conidia and septated dematiæ hyphae (right).

is characterized by tropical rainy weather, presenting a well defined dry season, lacking pluviometric precipitation from August to December, and the latter is also characterized by tropical rainy weather but without a defined dry season, thus raining regularly during all year round.<sup>16</sup> The Coaracy Nunes hydroelectric power unit is localized in the transition limits of both climate pattern above described. The proper maintenance of metallic structures in a hydroelectric power unit, particularly in the amazon region requires periodic painting and substitution of corroded structures, demanding excessive financial costs making the final product, the electricity, so expensive to the population.

The rich microbiota in the Amazonian tropical forest greatly contributes to the widespread colonization of microorganisms in all surfaces of any material such as wood, metals, plastics whatsoever. The metallic structures composing important industrial facilities, including the electricity power unit, suffer enormous losses due to the corrosion processes, mainly induced by microorganisms. In our work, we could confirm the findings of many laboratories and also, observe *in vitro* the suggestive role of the

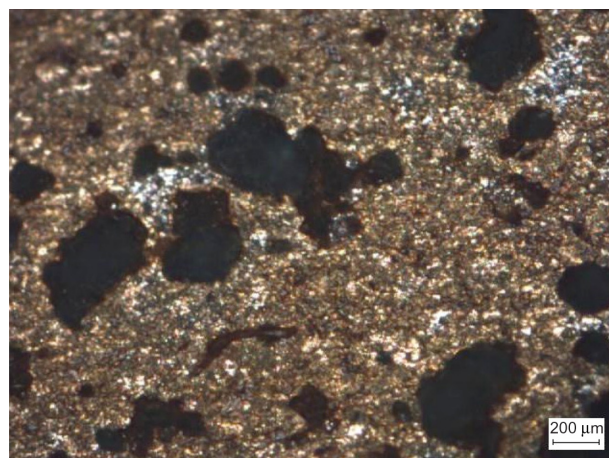


**Figure 2B.** Fungus *Penicillium* spp. cultivated in Agar Sabouraud. Agar surface (left). Agar reverse side (middle). Optical microscopy (40×), stained with lactophenol cotton blue, showing double verticillated conidiphores exhibiting globulose conidia and septated and hyaline hyphae (right).

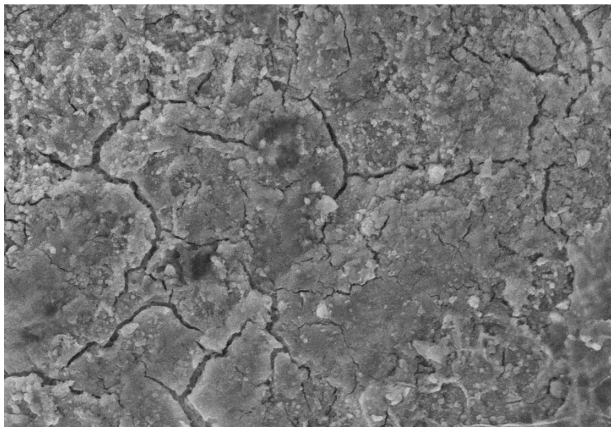


**Figure 3.** PCR assay of uncultured microorganisms DNA amplified utilizing Archae universal primers (16S ribosomal RNA gene). First Lane/1 Kb MW (left) showing bands of DNA molecular markers and lane/BCR 2 showing a 1,300 bp fragment and last Lane/CONTR as a negative control.

isolated microorganisms consortiated in the corrosion process. The detection of biofilm production as also the precipitated salts on the metallic bars allied to the detection of spectral patterns of metallic ions (Figs. 3 and 4) likewise, decrease in iron ions concentration, carbon atoms and molecular oxygen increase besides the alteration in the concentration of other elements (Fig. 5) suggests the occurrence of corrosion processes of microbial etiology. Interestingly, the microorganisms usually reported in pathological processes in humans and animals as *Serratia marcescens*, *Escherichia coli*, *Enterobacter cloacae*, *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Hafnia alvei*

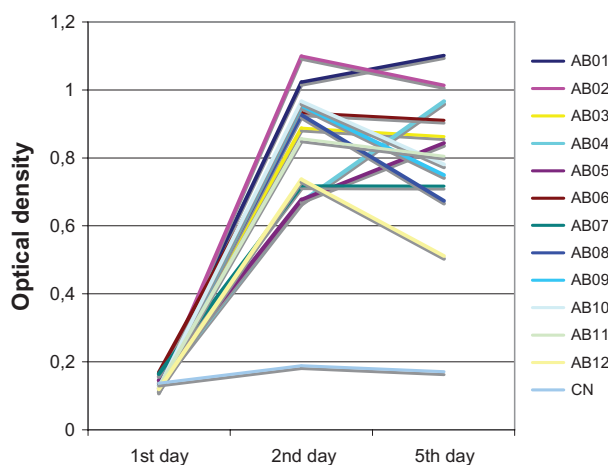


**Figure 4.** Optical micrograph magnified 50× showing deposits of metallic salts and corroded areas (black spots) in metal bars incubated with consortiated microorganisms isolated from corroded metallic structures of Coaracy Nunes Hydroelectric Power unit in Amapa state.



**Figure 5.** Scanning electron micrograph magnified 200.000 $\times$  showing surface fractures over the metal bar after microbial growth of samples obtained from corroded metallic structures of the Coaracy Nunes Power unit in Amapa state.

and *Corynebacterium pseudodiphtheriticum* were detected in metallic corrosion processes too.<sup>17–19</sup> Anyway, other microorganisms uncommonly causing diseases, known as opportunistic organisms are usually widely spread in the environment, victimizing immunosuppressed humans, animals and plants.<sup>20,21</sup> Therefore, under this viewpoint, bioorganisms defend dynamically themselves against invading and colonizing microorganisms<sup>22</sup> contrary to inert material like metals that need technological devices<sup>23</sup> to protect their surfaces against environmental microorganisms' colonization and consequential ions exchange between the microorganisms metabolic products and metal ionic surface, which generally early or later results in corrosion processes, as generally proposed to certain microorganisms.<sup>24</sup>



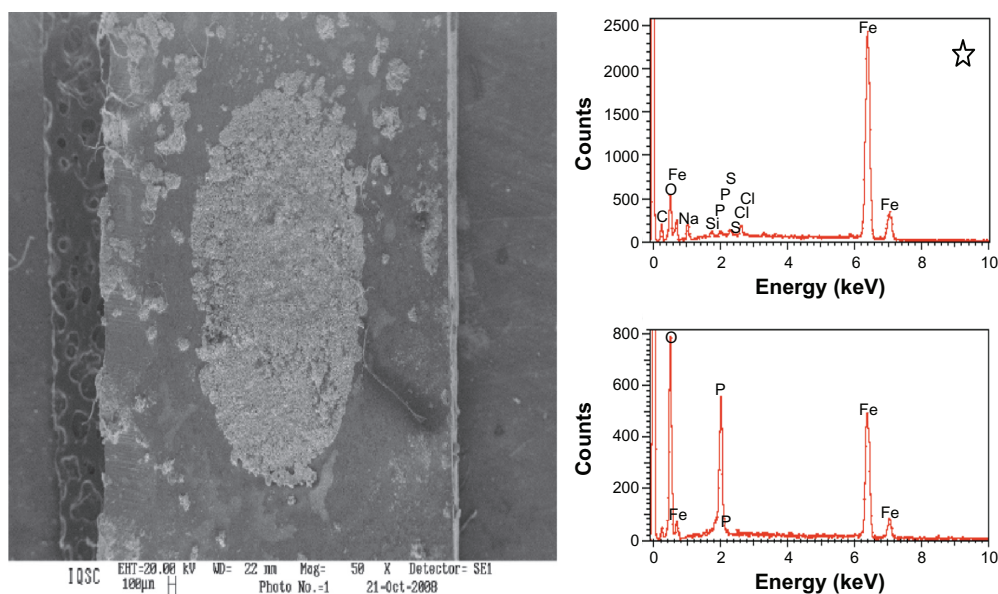
**Figure 6.** Growth curve (lag phase) of consortiated groups of bacteria (AB01 to AB12) in the experiment to reproduce biocorrosion *in vitro*.

Just a minimum percentage of microorganisms in distinct environments are cultivated by conventional microbiological methods.<sup>25</sup> Uncultured microorganisms have been detected by preliminary metagenomic analysis. In our study, the solely band found by the PCR assay of the isolated DNA samples of consortiated microorganisms could represent the amplification of multiple microorganisms DNA fragments.<sup>26</sup> Utilizing molecular tools to detect ribosomal DNA segments from fragments of industrial pipelines carrying crude oil, about 31 distinct archaeobacteria composing the *Methanobacteriales*, *Methanomicrobiales* and *Methanosarcinales* order were found, despite it is not known the role of these microorganisms in biocorrosion processes.<sup>27</sup> As expected, common soil microorganisms were found among the analyzed samples, mainly represented by members of the Bacillaceae family. Ongoing studies are aiming for the isolation and characterization of anaerobes which were partially initiated by metagenomic studies and considering their important roles in biocorrosion processes.<sup>9,10</sup>

Despite the current knowledge to find culprits for corrosion processes, our results allied to other reports in the literature suggest that there are not particular microorganisms involved in the mechanisms of corrosion but, the physicochemical conditions of the environment determines that the particular microbiota of any surface and therefore the metabolic activity of any microorganism would interact with metallic surfaces or in other words, the redox reactions would occur initiating the corrosion process of metallic surfaces.

Presently we are looking for local solutions for the problem, besides to what actually has been done, likewise the removal of damaged metallic structures and their periodic painting. As an alternative way to chemical pollutants utilized in paintings composition, we are testing Amazonian medicinal plant extracts looking at growth inhibition or destruction of microorganisms found colonizing the metallic structures. We have shown growth inhibition of multiresistant bacteria involved in human nosocomial infections by extracts of Amazonian medicinal plants.<sup>28</sup> As many of our microorganisms isolates from corrosion processes are also involved in human and animal diseases, we proposed in this study to assay Amazonian plants as antimicrobial agents to eliminate corrosion. If from the plants assayed, crude antimicrobial agents against





**Figure 7.** Scanning electron micrograph magnified 50× showing metallic salts deposit (white area) and smooth zone displaying metallic dissolution as confirmed by energy spectral dispersion showed in the graphics (right side) of mainly iron and oxygen ions picks dislodgment.

consortiated microorganisms could be developed, the benefits would prevail as the plants are not toxic to the environment, they could be cultivated and locally processed and would also contribute to the improvement of quality of life of local communities.

## Disclosures

This manuscript has been read and approved by all authors. This paper is unique and not under consideration by any other publication and has not been published elsewhere. The authors and peer reviewers report no conflicts of interest. The authors confirm that they have permission to reproduce any copyrighted material.

## Acknowledgements

We are grateful to Eletronorte/ANEEL for the financial support to carry out this study and particularly to Eletronorte/Amapa staff for the logistic support during samples collection in the Hydroelectric Power Unit Coaracy Nunes.

## References

- Beech IB, Gaylarde CC. Recent advances in the study of biocorrosion: an overview. *Rev Microbiol.* 1999;30(3):117–90.
- Dinh HT, Kuever J, Musmann M, Hassel AW, Stratmann M, Widdel F. Iron corrosion by novel anaerobic microorganisms. *Nature.* 2004;427(6977):829–32.
- McNamara CJ, Perry TD, Leard R, Bearce K, Dante J, Mitchell R. Corrosion of aluminum alloy 2024 by microorganisms isolated from aircraft fuel tanks. *Biofouling.* 2005;21(5–6):257–65.
- Beech IB, Sunner JA, Hiraoka K. Microbe-surface interactions in biofouling and biocorrosion processes. *Int Microbiol.* 2005;8(3):157–68.
- Smirnov VF, Belov DV, Sokolova TN, Kuzina OV, Kartashov VR. Microbiological corrosion of aluminum alloys. *Prikl Biokhim Mikrobiol.* 2008;44(2):213–8.
- Scheerer S, Ortega-Morales O, Gaylarde C. Microbial deterioration of stone monuments—an updated overview. *Adv Appl Microbiol.* 2009;66:97–139.
- Neria-González I, Wang ET, Ramírez F, Romero JM, Hernández-Rodríguez C. Characterization of bacterial community associated to biofilms of corroded oil pipelines from the southeast of Mexico. *Anaerobe.* 2006;12(3):122–33.
- Yuan SJ, Pehkonen SO. Microbiologically influenced corrosion of 304 stainless steel by aerobic *Pseudomonas* NCIMB 2021 bacteria: AFM and XPS study. *Colloids Surf B Biointerfaces.* 2007;59(1):87–99.
- Jan-Roblero J, Romero JM, Amaya M, Le Borgne S. Phylogenetic characterization of a corrosive consortium isolated from a sour gas pipeline. *Appl Microbiol Biotechnol.* 2004;64(6):862–7.
- Videla HA, Herrera LK. Microbiologically influenced corrosion: looking to the future. *Inter Microbiol.* 2005;8(3):169–80.
- Kelly MT, Leicester C. Evaluation of the Autoscan Walkaway system for rapid identification and susceptibility testing of gram-negative bacilli. *J Clin Microbiol.* 1992;30(6):1568–71.
- Lacaz CS, Porto E, Martins JEC. *Micologia médica: fungos, actinomicetos e algas de interesse médico.* 8th ed. São Paulo: Sarvier, 1998:695.
- Minami PS. *Micologia: métodos laboratoriais de diagnósticos das micoses.* São Paulo: Manole, 2003:199.
- Baker BJ, Banfield JF. Microbial communities in acid mine drainage. *FEMS Microbiol Ecol.* 2003;44:139–52.
- Wang H, Liang C. Electrochemical behavior of antimicrobial stainless steel bearing copper in sulfate reducing bacterial medium. *J Wuhan Univ Tech Mater Sci.* 2008;23(1):113–7.
- Köppen W. Das geographische System der Klimate. In: Wladimir Köppen und Rudolf Geiger, Hg., *Handbuch der Klimatologie in fünf Bänden, Bd. 1: Allgemeine Klimalehre* 1936.
- Kramer A, Schwabke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect Dis.* 2006;6:130.
- Koachere JF, Bughe RN, Oben BO, Ndip LM, Ndip RN. Phenotypic characterization of human pathogenic bacteria in fish from the coastal waters of South West Cameroon: public health implications. *Rev Environ Health.* 2009;24(2):147–56.



19. Camello TC, Souza MC, Martins CA, et al. *Corynebacterium pseudodiphtheriticum* isolated from relevant clinical sites of infection: a human pathogen overlooked in emerging countries. *Lett Appl Microbiol*. 2009;48(4):458–64.
20. Washburn BK, Levin AE, Hennessy K, Miller MR. Identification of bacteria in scuba divers' rinse tanks. *Undersea Hyperb Med*. 2010;37(4):233–40.
21. Yang SS, Lin JY, Lin YT. Microbiologically induced corrosion of aluminum alloys in fuel-oil/aqueous system. *J Microbiol Immunol Infect*. 1998;31(3):151–64.
22. Ooi EH, Psaltis AJ, Witterick IJ, Wormald PJ. Innate immunity. *Otolaryngol Clin North Am*. 2010;43(3):473–87, vii.
23. Yuan SJ, Pehkonen SO, Ting YP, Neoh KG, Kang ET. Inorganic-organic hybrid coatings on stainless steel by layer-by-layer deposition and surface-initiated atom-transfer-radical polymerization for combating biocorrosion. *ACS Appl Mater Interfaces*. 2009;1(3):640–52.
24. Haferburg G, Kothe E. Microbes and metals: interactions in the environment. *J Basic Microbiol*. 2007;47(6):453–67. <http://www.v-brazil.com/tourism/amapa/map-amapa.html>. Accessed 2010 Oct 22.
25. Vartoukian SR, Palmer RM, Wade WG. Strategies for culture of 'unculturable' bacteria. *FEMS Microbiol Lett*. 2010;309(1):1–7.
26. Duncan KE, Gieg LM, Parisi VA, et al. Biocorrosive thermophilic microbial communities in Alaskan North Slope oil facilities. *Environ Sci Technol*. 2009;43(20):7977–84.
27. Zhu XY, Lubeck J, Kilbane JJ. Characterization of microbial communities in gas industry pipelines. *Appl Environ Microbiol*. 2003;69(9):5354–63.
28. Correia AF, Segovia JFO, Gonçalves MCA, et al. Amazonian plant crude extract screening for activity against multidrug-resistant bacteria. *Eur Rev Med Pharmacol Sci*. 2008;12(6):369–80.

**Publish with Libertas Academica and every scientist working in your field can read your article**

*"I would like to say that this is the most author-friendly editing process I have experienced in over 150 publications. Thank you most sincerely."*

*"The communication between your staff and me has been terrific. Whenever progress is made with the manuscript, I receive notice. Quite honestly, I've never had such complete communication with a journal."*

*"LA is different, and hopefully represents a kind of scientific publication machinery that removes the hurdles from free flow of scientific thought."*

**Your paper will be:**

- Available to your entire community free of charge
- Fairly and quickly peer reviewed
- Yours! You retain copyright

**<http://www.la-press.com>**