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Deterioration of Welded Tubes by Bacterium

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Abstract: It is widely recognized that microorganisms promote the degradation of most of the materials in their natural environment, including metallic materials. In the latter case, the presence of bacterial colonies in the form of a biofilm influences the initiation and spread of most attacks corrosion commonly encountered. In other words, biocorrosion is not a form of corrosion, but a change in the kinetics under the influence of the presence of bacteria and products of their metabolism. Among industrial risks necessary to control, the phenomena of biodegradation represent a real danger, which is essential to characterize. So far, the mechanisms leading to the deterioration of materials by the bacterial microflora are not all fully explained. Indeed, the spread of knowledge requires a sustained dialogue between metalworkers, microbiologists, biochemists, chemists and corrosionnistes. A second reason, no less important, is the lack of scientific studies from micro-organisms isolated from the industrial environment.

Key words: Biofilm, corrosion, degradation, Bacteria Sulphato Reducing (BSR)

INTRODUCTION

Corrosion is the phenomenon whereby metals tend, under the action of atmospheric agents or chemical reagents, to return to their original state oxide, sulphur, carbonate, are more stable compared to the mid considered and to undergo a deterioration of their properties.

The problem of corrosion took nowadays considerable importance given the use of increasingly large metals and alloys in modern life.

From an economic point of view, corrosion is a major problem, for example, it is estimated that each year the fourth production of steel is destroyed by this phenomenon (Abbassi, 2000).

The total cost of corrosion is about 4% of Gross National Product (GNP), this represents several billion dollars per year. These figures take into account: the direct losses, losses indirect measures of protection and prevention. The first words, which we believe are of course corrosion and degradation to discuss the deteriorating pipes. It is not always easy to differentiate the corrosion damage by abuse of language. However, the term corrosion is reserved for metals, while the term degradation is linked to other materials such as plastics, concrete and various mechanical effects that can endure the pipes. Among the various types of corrosion that attack metal, corrosion bacterial or microbiological or even biocorrosion.

Table 1: Chemical composition of steel E24 (Technique de l'ingénieur M4)

Chemical composition (%)					
C	Mn	Si	P	S	Al
0.10	0.40	0.02	0.003	0.007	0.042

Our aim is to highlight the mechanism such corrosion in the case of tubes/pipelines and the estimated annual losses of metal because ultimately it's the economic issue is important.

The material used for welding pipes is steel construction E24-2 (S235JR, in European norm EN 10025), whose chemical composition is given in Table 1. The nuance is indicated by a letter E followed by a number corresponding to the minimum yield strength in traction.

DEFINITION OF BACTERIAL CORROSION

The corrosion biological result of the action on the metallic material of bacteria or products from bacterial

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activity such as organic acids or gas CO_2, SO_2 and so on. The pipelines are buried prone to this type of corrosion (Pierre and Tissot, 1980).

This deterioration of materials directly or indirectly caused by bacteria, algae, mold or fungi; separately or association. The bacteria are present in all spheres:

- Water.
- Air.
- Earth.

and in all conditions of pH, temperature, oxygenation. The bacteria can drastically alter the conditions of physical and chemical environment in which they find themselves on the formation of bio film created by their metabolism to the surface of the material:

- Changing the pH (some leading to the formation of acid such as sulphuric acid).
- Changing the oxygen concentration.
- Production sulphide.

Different assumptions mechanisms described in literature are reviewed. Regardless of the physical-chemical role played by iron sulfide, not covering, good electrical conductors, it appears that the resulting acidification of cellular metabolism is a crucial factor, not only in terms of electrochemistry, but also in terms of growth microbial. Acidification metabolic probably explains the supply of ferrous ions for the micro organism in an environment charged ion sulphides and finally the persistence of its physiological activity in an environment rich in micro H_2S (Fig. 1) (Marchal, 1999).

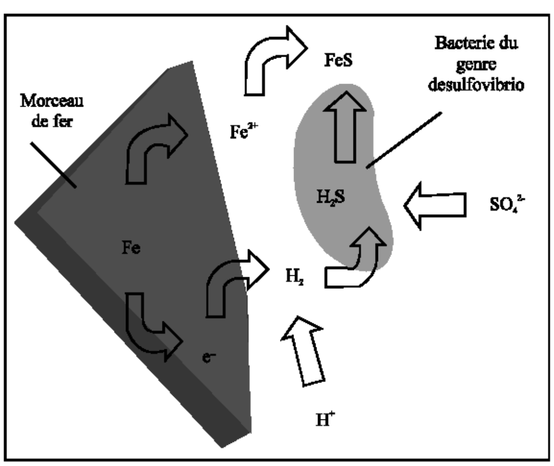

Fig. 1: Metabolism deterioration of materials (Wikpedia, 2008)

HISTORY OF THE BIOCORROSION

The idea that micro-organisms may be involved in metal corrosion is first issued by Garret (1891). A little later, GAINES discusses the role of bacteria sulfate-reducing bacteria and sulfur oxidizing bacteria ferruginous during this phenomenon. However, this is between the years 1925-1935, von Wolzogen Kuhr and van der Vlugt offer a genuine biological theory of corrosion, based on the intervention of sulfate-reducing bacteria. In a general review of the problem, Postgate fact the work of von Wolzogen Kuhr (Perrin and Schareff, 2006).

THE MICRO-ORGANISM

The term micro-organism means of living organisms, animals and microscopic plants, unicellular and viruses. The bacteria are organisms morphology of a simple, small size (of agenda Î¼ m), discovered only through the invention of the microscope. The bacteria is currently regarded as the most aggressive opposite the metallic material are bacteria sulfurogènes:

- Bacteria Sulphato Reducing (BSR).
- Bacteria Thiosulphato Reducing (BTR).

These bacteria cause corrosion localized (pitting until 1 cm an^{-1}) (Fig. 2) by:

- Acidification.
- Creating niches anoxic (oxygen-free) to the surface of the material.

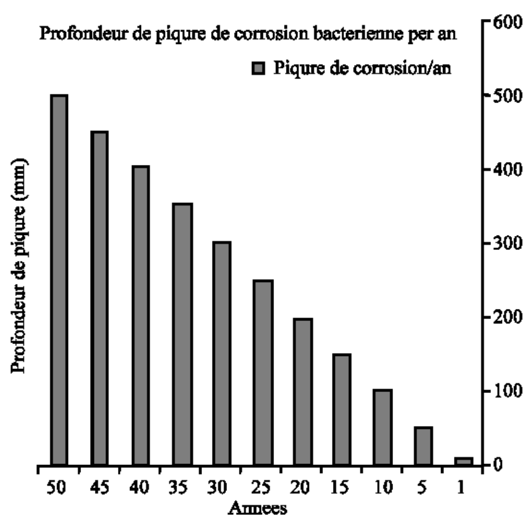

Fig. 2: Depth of corrosion pit bacterial estimated for 50 years

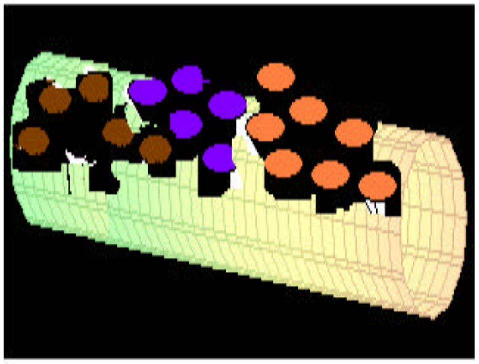

Fig. 3: Three classes of bacteria

The bacteria are organisms morphology of a simple, small size (of agenda Î¼ m), discovered only through the invention of the microscope.

It should take account of bacterial effects in any study of corrosion or protection. Three classes of bacteria are to be used (Fig. 3).

- The ferro bacteria.
- The sulfate-reducing.
- The thiobacilles.

MECHANISM BIOCORROSION

In anaerobic conditions, as may occur in soils compact clay, corrosion can be stimulated by the activity of micro-organisms such as bacteria reduction for example (desulfuricans of desulfovibrio).

The bacterial corrosion is possible in aerobic conditions. In this situation, corrosion is often the result of producing a metabolite such as a corrosive acid (), or can be caused by bacteria such as ferro-oxidants (Fig. 4 and 5).

At the anode the ferrobacteria, drawing its energy from the transformation of salts ferrous iron salts, produce accelerated training of rust continually break the balance by depolarization simultaneous anode and cathode (Fig. 6).

This process leads to a dissolution of the metal continues until the puncture.

$$4Fe \rightarrow 4Fe^{2+} + 8\ e^{-} \text{ or}$$

$$4Fe + 8H^{+} \rightarrow 4Fe^{2+} + 8H$$

The corrosion ventilation differential: The mechanism that we have seen for soil and water can also be caused by micro-organisms. Indeed, the consumption of oxygen resulting from microbial metabolic activity creates a potential difference between the surfaces of poorly ventilated metal in the colony and more airy around. This type of aggression involves bacteria belonging to the genera Pseudomonas, Flavobacterium, Aerobacter Gallionella. They are the cause corrosion stick or pitting in English up to perforation of the pipe (Vrignaud, 1998). The anode effects of microbial corrosion due to:

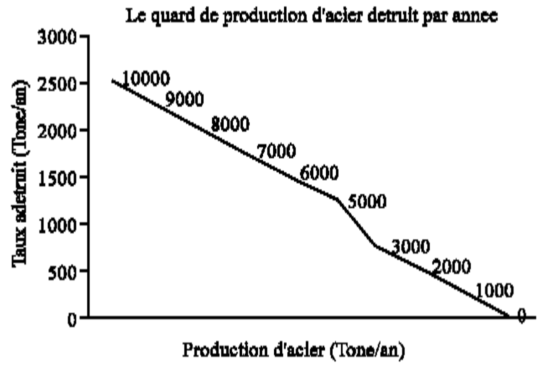

Fig. 4: Loss of metal by the effect of corrosion

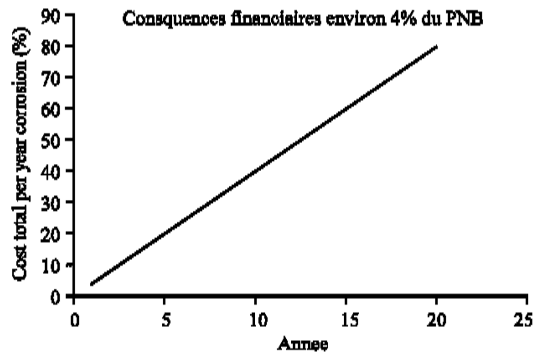

Fig. 5: Evolution of the total cost per year to corrosion of pipes

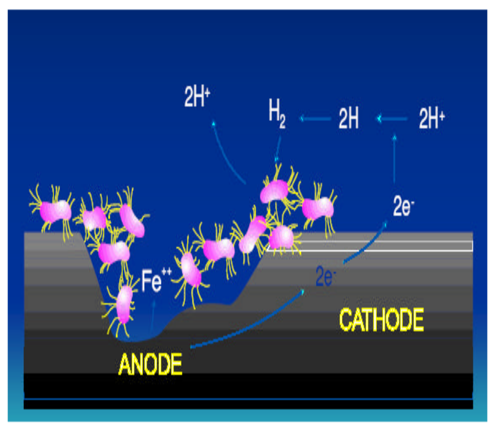

Fig. 6: Depolarization anodic

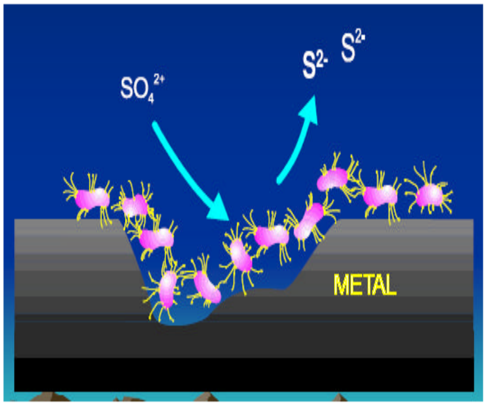

Fig. 7: The sulfate-reducing

- Production of metabolites corrosive.
- Production of metabolites that exalt the power of corrosive chemical entities present in the environment.
- Degradation or complexation of corrosion inhibitors.

The effects could come from cathode:

- Production of cathode reagents.
- Complexion or degradation of these reagents cathode.
- The indirect acceleration of the catholic reaction.

However, the "myth of ventilation differential." It would show that this is not the main reason for corrosion but this is a process of initiation.

At the cathode sulfate-reducing bacteria mobilize hydrogen and leads a cathode. The reduction in sulphate (Fig. 7):

$$SO_4^{2-} + 8H \rightarrow S^{2-} + 4H_2O$$

and the dissolution of electrolytic water

$$8\ H_2O \rightleftarrows 8H^+ + 8OH^-$$

The formation of degradation by acid: The minerals and organic acids from microbial metabolism may play a role in the degradation process. Many bacteria are capable by fermentation or oxidation, give metabolites acids.

The sulphurs compounds: It is difficult to dissociate the action of hydrogen sulfide and sulfuric acid. However, we can attribute a substantial quantity of sulphuric acid activity Thiobacillus. These micro-organisms, usually autotrophic acidophilous and draw the necessary energy to the fixing of carbon dioxide or the degradation of organic substrates from the oxidation of sulfur from hydrogen sulfide.

These sulphur-oxidizing bacteria could have metabolic reactions following:

$$H_2S + 2\ O_2 \rightarrow H_2SO_4$$

$$4\ S + 6\ O_2 + 4\ H_2O \rightarrow 4\ H_2SO_4$$

$$2S + 3\ O_2 + 2\ H_2O \rightarrow 2\ H_2SO_4$$

Other bacteria such as sulfate-reducing bacteria in anaerobic environment can produce hydrogen sulfide, which is also corrosive.

These reactions are mostly located in the exits of pipelines. The degradation that we face is of two kinds: Degradation direct H_2S solubilised on the walls. He will attack the lime cement;

$$2\ H_2S + Ca\ (OH)_2 \rightarrow 2\ H_2O + Ca\ (SH)_2$$

Degradation indirectly: Hydrogen sulphide can also oxidize in the presence of sulphur-oxidizing bacteria or oxygen H_2SO_4 sulphuric acid.

The free lime form with sulfuric acid and formed calcium sulfate, which precipitates. The aluminates react with the calcium sulfate to form complex sulfo-aluminates strongly hydrated, it causes swelling first, then expansion and finally a burst of concrete.

$$H_2SO_4 + Ca\ (OH)_2 \rightarrow CaSO_4 + 2\ H_2O \text{ (calcium sulfate)}$$

The deterioration of concrete takes place exclusively in the emerged part of the pipe and unevenly. This uneven distribution of the degradation is due to the presence of air flow in pipelines. In a sewage pipe, there is a temperature difference between water and the wall of the pipe, causing air circulation. It is characterized by a downward movement of air cooled and the rise of warmer air). Hence, the supply of hydrogen sulfide is more intense at the crest of the pipe. Another cause of concrete deterioration uneven lies in the disposal of acid solution on the walls alternately dumped or not.

The metal pipes are not spared. The reactions of attack on iron and some of these compounds are

$$H_2S + Fe \rightarrow FeS + H_2\ (g)$$

$$H_2S + FeCO_3 \rightarrow FeS + CO_2 + H_2O$$

$$H_2S + Fe(OH)_2 \rightarrow FeS + 2\ H_2O$$

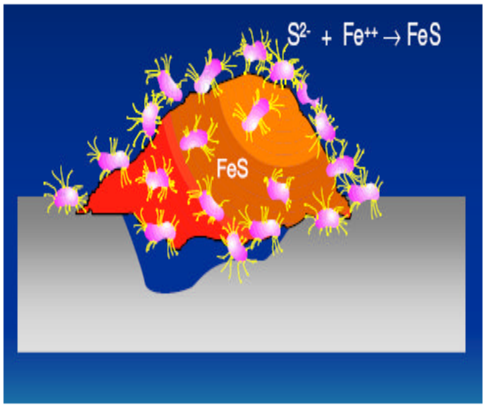

Fig. 8: The iron sulphides

The iron sulfide and formed (Fig. 8) is very responsive and will react with oxygen to give the iron oxide, Fe_3O_4, which will turn into red iron oxide and restore of hydrogen sulfide. There is the formation of an endless cycle as long as there is iron.

$$6FeS + O_2 + 6H_2O \rightarrow 2Fe_3O_4 + 6H_2S$$

$$4\ Fe_3O_4 + O_2 + 18\ H_2O \rightarrow 6(Fe_2O_3{,}3H_2O)$$

Remarks: Stainless steel has good resistance to corrosion by hydrogen sulfide. The plastic compounds such as Polyvinyl Chloride (PVC), Polyethylene (PE), are widely used to replace conventional materials destroyed by hydrogen sulphide. They seem inert hydrogen sulfide.

Nitric acid: Nitrifying bacteria could also be involved in the phenomena of biocorrosion because they are the source of nitric acid production.

The ferrobacteria: The ferrobacteria derive the energy required for their synthesis of the transformation of salts ferrous iron salts. But in the ferrous metal pipes, there is still training at a point unprotected or altered the surface of a mild attack of metal in contact with water to form ferrous hydroxide. This ferrous hydroxide, under normal conditions, turns quickly to iron hydroxide and carbonate through oxygen and carbon dioxide dissolved. In general, the phenomenon stops there. The presence of Ferro bacteria the point of attack will lead to the mobilization of ferrous ions and their transformation into ferric salts and this quickly as the middle contain ferrous ions. Then there is formation of large clusters of "rust" containing the bacterial body followed by a continuous dissolution of the metal.

The associations bacterial: But his pile of "rust" can also be called vesicles gelatinous when they are at the origin of association with the sulfate-reducing bacteria. The latter are in the area of internal blisters, while ferrobacteria fall in the surface area. The presence of sulfate-reducing bacteria can be explained by the fact that oxygen will be increasingly difficult to penetrate into the interior of the gallbladder established by ferrobacteria. This process will then create a layer underlying conditions of strict anaerobic promoting the development of sulfate-reducing bacteria. They reduce sulphate hydrogen sulfur inside the gallbladder, it can produce 2 kinds of reactions:

$$2Fe\ (OH)_3 + 3H_2S \rightarrow 2FeS + S + 6H_2O$$

$$Fe\ (OH)_2 + H_2S \rightarrow FeS + 2H_2O$$

These reactions allow the continuation of puncturing pipelines.

Biofilm formation and enumeration of bacteria: The surface of a steel immersed in sea water is naturally colonized by bacteria: Is the formation of a biofilm. The electrochemical consequences are well known. In the development of biofilm, is linked to an increase in speed of reaction cathode, which leads to an increased potential for corrosion free (Ecorr) sample of stainless steel. This increase is bad for passivity alloys, because the potential critical pick likely to be exceeded and corrosion initiated.

The biodegradation of materials affects all sectors of industry where materials are in contact with wetlands (Fig. 9).

If corrosion or biocorrosion immediately evokes metallic materials, carbon steel, stainless steel, copper-nickel alloys, we must not forget the concrete, resins and other composite materials.

Counting bacterial: Figure 10 shows that UFC: Colony Forming Unit. Based on these results, it is noteworthy that the microbial load in the middle is low. The temperature seems conducive to bacterial growth: overall, bacteria are more numerous in summer and winter. The flores total aerobic and anaerobic (Fig. 11) and the number of BTR rose with the temperature. Only BSR do not follow this trend. In addition, as so often in natural conditions, BTR are significantly outnumber BSR (Fig. 12) (Centre Corrosion, 2008).

Environments biocorrosion

Seawater: The seawater is a complex environment, aggressive opposite materials, which are immersed (Fig. 13). You can define the aggressiveness of the marine environment as the set of parameters, which determine the

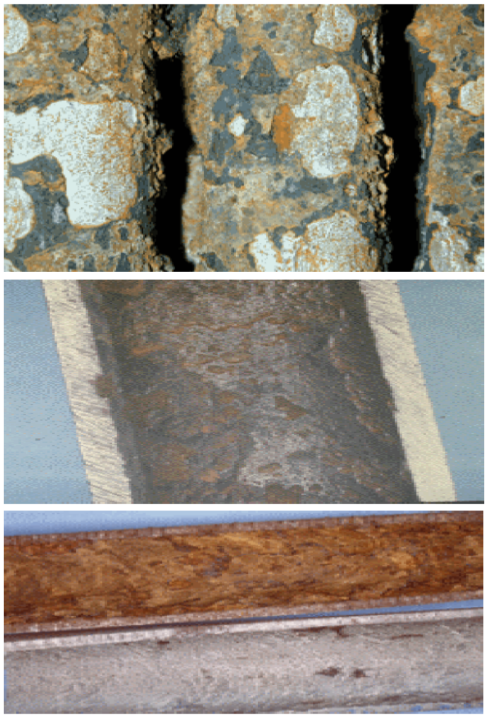

Fig. 9: Samples of surface and inside the corroded pipes biologically

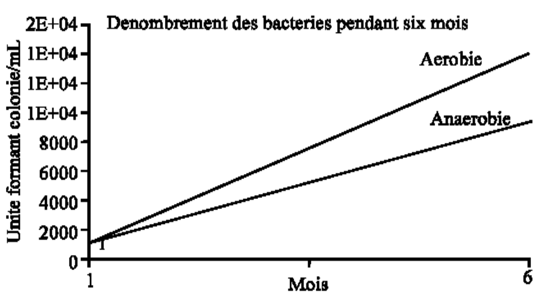

Fig. 10: Comparative increase in aerobic and anaerobic bacteria

degradation of mechanical, physical, chemical, biological or electrochemical. The seawater is characterized by its salinity, which is defined as weight in grams of electrolytes contained in one kilogram of water.

Organic materials: Low concentrations of organic matter in sea water (0.5 mg L^{-1}) make their chemical analysis very difficult. Among the dissolved organic matter, there are chlorophylls, carotenoids, monosaccharides, polysaccharides, amino acids, organic acids, fatty acids. Organic materials are mainly particulate debris animals or plants.

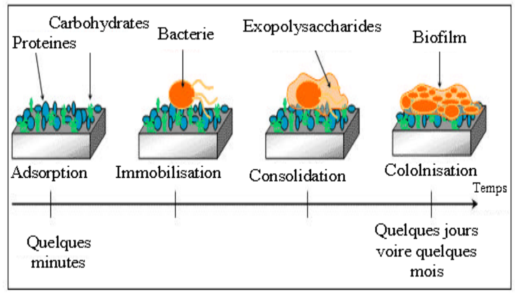

Fig. 11: Multiplication bacteria as a function of time (Centre Corrosion, 2008)

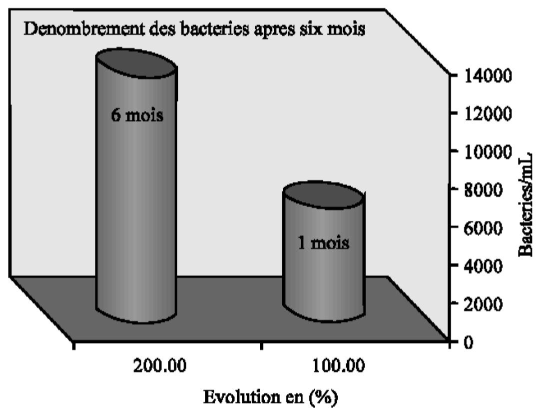

Fig. 12: Bacterial counts done on samples of the water

Fig. 13: The aggressiveness and high salinity of the sea

Variations pH: Sea water is slightly alkaline pH and its average is 8.2 with variations between 7 and 8.4. Changes in pH can be linked to those of dissolved oxygen. This is considering the photosynthetic activity of certain bodies: a strong production of oxygen is accompanied by a decrease in carbon dioxide and therefore an increase in the pH; oxidation of organic matter reduces oxygen content of water, producing carbon dioxide and thus, lowers the pH. The pH of the water decreases with increasing temperature.

Dissolved gas: The gases are dissolved in seawater and are primarily original atmosphere. These gases dissolve in seawater under the law of Henry. The dissolution of carbon dioxide is more complicated because it reacts with water to form carbonate and bicarbonate ions and participates in the regulation of pH. As is the case for all atmospheric gases, the solubility of oxygen varies with temperature and salinity of water.

Fight against this type of corrosion: The protection against corrosion may also have a negative impact on the environment, releasing toxic substances. Thus, anti-rust paint at least have been abandoned. The zinc due to the dissolution of sacrificial anode can also be problematic, that is why we are working more and more towards protection solutions cathode current imposed.

The protection cathodic is a technique to control corrosion of a metal surface by transforming the surface of the cathode an electrochemical cell. The CP is used to protect metal structures from corrosion, including steel, water pipes, pipelines, reservoirs, metallic pillars of jetties, ships and oil platforms, reinforced concrete structures.

It is absolutely necessary to avoid stagnation of water at the bottom of reservoirs. The recommended treatment is effective use of biocides like (chlorine, hypochlorite, a sometimes, it is necessary to carry out the operation surfaces scraping or stripping before treatment. The use of suitable inhibitors is necessary.

CONCLUSION

In this study, we tried to discover bacterial corrosion, with a minimum of synthesis, although the subject is vast growth of knowledge requires a sustained dialogue between metalworkers, microbiologists, biochemists, chemists and corrosians. A second reason, no less significant is the lack of scientific studies from micro-organisms isolated from the industrial environment.

The choice of materials used to make a play is generally based on a set of criteria metallurgical and mechanical, but also corrosion and the ability to receive effective protection against corrosion.

Many are industrial sectors concerned, the very ones where micro-organisms have been identified as carriers of degradation:

- The oil industry affected the level of extraction wells, pipelines and o the shipbuilding industry, fisheries.
- Geothermal.
- Aerospace, particularly for microbial corrosion problems in tanks of kerosene.
- The nuclear industry for the storage of waste, either surface or deep site.
- The food industry.
- Industry water treatment.
- Nuclear power plants on the seafront.

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