A REVIEW OF GENERAL ASPECTS OF MICROORGANISMS INVOLVED IN THE CORROSION PROCESS

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Abstract. The microbial corrosion process is the deterioration of metals under the influence of microbial metabolism. Due to the negative effects that resulted in massive economic losses and environmental pollution, studies on this complex phenomenon have developed during the last 80 years. All this resulted in an understanding of corrosion microbial organisms involved in this process and, not least, the key role of bacterial biofilm in biocorrosion. Thus, in this analysis we aim to highlight some aspects related to the involvement of microorganisms in the corrosion process.

Keywords: bacterial strains, corrosion process, biofilms.

Rezumat. O revizuire a aspectelor generale ale microorganismelor implicate în procesul de coroziune. Procesul de coroziune microbiană reprezintă deteriorarea metalelor sub influenţa metabolismului microbian. Datorită efectelor negative soldate cu masive pierderi economice, dar şi cu poluarea mediului, au condus la intensifcarea studiilor, pe durata a 80 de ani, asupra acestui fenomen complex. Toate aceste aspecte au avut drept rezultat înțelegerea fenomenului de coroziune microbiană, implicarea microorganismelor în acest proces şi nu în ultimul rând rolul cheie deţinut de biofilmul bacterian în biocoroziune. Astfel, prin prezenta analiză ne propunem să punctăm unele aspecte legate de implicarea microorganismelor în procesul de coroziune.

Cuvinte cheie: tulpini bacteriene, proces de coroziune, biofilm.

INTRODUCTION

Corrosion is a natural process, which converts fine metal to its oxide or hydroxide or another compound in a more stable form (MANSOUR & ELSHAFEIA, 2016). Different types of corrosion were reported such as galvanic, pitting, uniform, erosion, lamellar, crevice and microbial corrosions (RASHIDI et al., 2007; MANSOUR & ELSHAFEIA, 2016).

Microbial corrosion or biocorrosion refers to the accelerated deterioration of metals owing to the presence of biofilms on their surfaces (BEECH & SUNNER, 2004), biocorrosion is a importants category of the corrosion process, leading to important economic losses in many industries (WARSCHEID & BRAAMS, 2000; DALL'AGNOL & MOURA, 2014; USHER et al., 2014), including in the oil fild, offshore, pipelines, armaments, etc. (GU et al., 2000; MARTIN-GIL et al., 2004), potentially leading to environmental pollution (MANSOUR & ELSHAFEIA, 2016). KOCH et al., 2002 has estimated that the microbial corrosion process is responsible for 20% of the total damage to the corrosion process.

The involvement of microorganisms in the process of corrosion was observed since the 19^{th} century, when in 1830 De la Rive suggested the existence of microcells on the surface of zinc (MANSOUR & ELSHAFEIA, 2016). Approximately 80 years ago von Wolzogen Kurh and Vander Vlugt identified sulphur reducing bacteria as responsible for metal corrosion under anaerobic conditions. The corrosion process is caused or promoted by microorganisms, usually chemoautotrophs, indicated as belonging to the genera: *Desulfovibrio, Pelobacter*, *Pseudomonas*, *Firmicutes*, *Archaeoglobales*, *Shewanella,* methanogenic archaea, etc.

MICROORGANISMS INVOLVED IN THE CORROSION PROCESS

Microorganisms which have been associated with corrosion involve many genera and species. They may be divided into three groups: bacteria, fungi, and algae (WARREN, 1987). EMDE et al., 1992 signalled a heterogeneous population of potentially corrosive microorganisms present in untreated water supply, treated water and corrosion tubercles, so we can talk about a corrosion consortium. Several groups of microorganisms are recognized for their role in corrosion, including the: sulphite-reducing bacteria (*Clostridium* sp.) (ENNING et al., 2012; ENNING et al., 2016), iron-reducing bacteria (*Bacillus* sp., *Clostridium* sp., *Escherichia coli, Enterobacter aerogenes, Klebsiella oxytoca, K. pneumoniae, Pseudomonas aeruginosa, P. cepecia, P. fluorescens*) (HERRERA & VIDELA, 2009), exopolymer producing bacteria (FORD et al., 1991; ZUO, 2007), sulphur-oxidizing bacteria (*Thiobacillus thiooxidans, Th. thioparus*) (LI et al., 2008), iron-oxidizing bacteria, fungi (*Penicillium, Rhizopus, Aspergillus*) (VIDELA, 1996).

Scientific works on the direct corrosion process by algae are quite scarce. They would to have the potential for inducing corrosion by their role in the ecosystem in the production of oxygen, nutrients, organic acids (PRESCOTT, 1969; WARREN, 1987).

Moreover, VERMA and KHAN, 2016 reported that green algae *Spirogyra* are used as an inexpensive and efficient mild steel corrosion inhibitor. However, some algae species are directly involved in the corrosion process as well, such as *Nostoc* sp., *Spirulina* sp. (MERT et al., 2011). From a biological corrosion viewpoint, significant fungi are

Cladosporium resinee, Penicillum sp., *Fusarium* sp., *Aspergillus* sp., *Hormoconis* sp., acid producing fungi (LITTLE et al., 2001; ROVETTA et al., 2013).

The microorganisms most commonly associated with the corrosion process are bacteria. Most of the time microorganisms implicated in biocorrosion are classified by the type of breathing respiration techniques (Table 1). Two types of single-celled bacteria exist, namely aerobic and anaerobic bacteria. The aerobic bacteria have the ability to use and detoxify oxygen, whereas anaerobic bacteria can survive without the presence of oxygen (MANSOUR & ELSHAFEIA, 2016).

Table 1. Bacteria involved in the corrosion process.

		Electon acceptor	**Microorganisms**
Respiration	**Aerobic respiration** (**have the ability to use oxygen)**	O_2	*Pseudomonas aeruginosa, Escherichia coli*, these bacterial strains can be all strictly or facultative aerobic organisms, corrode the carbon steel (JAYARAMAN et al., 1997; KIP & VAV VEEN, 2015)
	Anaerobic respiration (**have the ability to use S, CO_2, etc. like electron acceptor)**	NO_3^-	Denitrification: *Paracoccus denitrificans, Pseudomonas stutzeri*
		CO_2	Acetogenic bacteria: *Clostridium aceticum, Clostridium* sp. Methanogenicbacteria : *Methanobacterium* sp., *Methanosarcina* sp. (USHER et al., 2014)
		S	Sulphur respiration: facultative and obligate anaerobe bacteria *Thiobacillus thioparus,* acid producing (LI et al. 2008), *Desulfuromonas* sp.
		S^{2-}	Sulphate respiration: obligate anaerobe bacteria *Desulfovibrio desulfuricans* (VOICU et al., 2005), *Desulfovibrio vulgaris* (XU & GU, 2014)
		Fe^{3+}	Iron respiration: *Gallionella* sp., *Leptothrix* sp., *Clonothrix* sp., *Sphaerotilus* sp., etc. (VOICU et al., 2005)
		MnO_2	Manganese respirations: *Shewanella putrfaciens* (MARTIN-GIL et al., 2004)
		Fumarate	Fumarate respiration: *E. colli*

The groups of bacteria responsible for the corrosion process most frequently studied were: sulphate-reducing bacteria, sulphur-oxidizing bacteria, iron bacteria.

Sulphate-reducing bacteria, strictly anaerobic, are commonly considered to be the main originators of this microbiologically influenced corrosion (VOICU et al., 2005), including *Desulfuromonas* sp., *Desulfobacter* sp. and *Desulfococcus* sp. Sulphate-reducing bacteria gain their biochemical energy for growth by reducing sulphate to sulphide (HAMILTON, 1985).

Sulphur-oxidizing bacteria are primarily of the genus *Thiobacillus*, aerobic chemolithoautotrophs bacteria. These organisms notably form sulphuric acid during oxidation, and are capable of oxidizing both sulphur and ferrous iron, at a very low pH (WARREN, 1987).

Aerobic iron bacteria have also been associated with biocorrosion; this group of microorganisms is divided into two types: stalked (*Gallionella* sp.) and filamentous (*Leptothrix* sp., *Clonothrix* sp., *Sphaerotilus* sp.). These bacteria primarily oxidize or reduce iron species during respiration (WARREN, 1987).

BIOFILMS

Studies conducted over time on microbial corrosion have not fully disclosed mechanisms (KIP & VAV VEN, 2015) the underlying mechanism of microbial corrosion remains an open question. The mechanisms by which microorganisms induce corrosion essentially involve the basic electrochemical mechanisms of corrosion, based on the removal of electrons via oxygen or hydrogen ions (WARREN, 1987). We are focusing on biofilm and its role in microbial corrosion.

A biofilm is a complex structure (BEECH & SUNNER, 2004), and an essential part of the degradation process. Many elements of these processes are still unknown. In general, the process involves such mechanisms as: acidic degradation, electron movement, metal depolarization, polymerization and attachment of biofilms.

The biofilm involved in the corrosion process consists of a microbial consortium, a unique composition, influenced by environmental conditions: salinity, temperature, pH, biocide treatment, oil composition, nitrate, nutrient availability, surface of the substratum (VINGERON et al., 2016; 2018).

According to DONLAN 2002, biofilm is an assembly of surface-associated microbial cells that is enclosed in an extracellular polymeric, substance matrix, biofilm frequently enhances corrosion, facilitates exchange between metal and environment, and leads to deterioration of the metal (XU et al., 2014).

The origin of biofilm formation is attributed to indigenous microorganisms in the environment where this process takes place (LENHART et al., 2014). The microbial consortium may express different metabolic characteristics depending on the physico-chemical properties of the biofilm (VIGNERON et al., 2018). Within biofilm, interactions, cooperation, competition, intra and interspecific are established (ANDERSSON et al. 2008; VIGNERON et al., 2016). Thus, it can be concluded that the corrosion rate can be correlated with increasing biofilm.

The growth of biofilm is considered to be a result of complex processes involving the transport of organic and inorganic molecules and microbial cells to the surface, the adsorption of molecules to the surface and the initial attachment of microbial cells followed by their irreversible adhesion facilitated by the production of extracellular polymeric substances (BEECH et al., 2005).

Extracellular polymeric substances are molecules of different sizes, conformations and physical/chemical properties; they can be: polysaccharides, proteins, lipids, and even nucleic acids are actively secreted components (DECHO & GUTIERREZ, 2017).

CONCLUSIONS

Reducing microbial corrosion process involves understanding complex phenomena that take place within it. Also, it is necessary to study the microbiotic zone so as to evaluate the corrosion potential of the microorganisms present in the environment. An essential role in the corrosion process is played by biofilm. Therefore, taking measures to limit the formation of biofilm will lead to the reduction of microbial corrosion and less economic damages.

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