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Microbiologically Influenced Corrosion: An Unexplored, Green Filed for Research and Development

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Editorial

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Corrosion, by itself, can be regarded as a thermodynamically favourable reaction. This means that it is as natural as breathing. Being as such, corrosion can only be “controlled” and not as many, even professionals, believe, “prevented”: Metals, when in their ores, are co-existing with non-metallic compounds such as their sulphate, oxides etc. In their ores, metals are at minimum level of Gibbs free energy. That is why metals have to be “extracted” from their ores and they just do not ooze out of it. The minimum level of free energy associated makes them stay where they are.

However, we have to extract metals out of their ores for our needs. Upon this, we crush them and we subject them to a series of reactions collectively referred to as “extractive metallurgy reactions”. It is during these reactions that metals are extracted out of their ores with industrially achievable high purities. It is also during these reactions (processes) that electrons are injected into metals, making them a host to extra electrons that can be otherwise called as “uninvited guests”.

Corrosion, then, can simply be defined as the process by which these extra electrons are being sent off from metal. These electrons that are subjected to being taken out of the metal are in fact the main reason for establishing anodic and cathodic reactions and thus, establishing electrochemical corrosion.

Corrosion by itself is a very serious matter: normally around 5% of the Gross Domestic Product (GDP) of a country is consumed by corrosion. This is an indeed a very significant figure given that many countries around the globe do suffer from the aftermath of the economical meltdown. However it is not all: corrosion by itself costs human society more than all natural disasters. In 2012, the cost of all natural disasters around the world, including earthquakes, floods, tsunamis, etc. was in the order of US$ b 157. The same year the estimated global cost of corrosion was in the order of US$ b 5000, roughly 32 times of what cost us as imposed by natural disasters.

Any factor that can affect corrosion will be of significance for us then. Organisms, both macro- and micro-organisms, are amongst factors that do contribute to the intensity of corrosion, as measured by corrosion monitoring techniques.

Microbiologically influenced corrosion (MIC) can be defined as an electrochemical corrosions process in which organisms, such as but not limited to bacteria, can affect corrosion either by initiating, enhancing and even inhibiting it. To continue with our model of expressing the importance in terms of money, the minimum direct cost of MIC will be about 20% of the economical cost of corrosion. To make this statement make more sense, if we take the GDP of India as of 2013 being US$ 1.877 trillion. Therefore, the minimum annual cost of microbial corrosion (another abbreviated form to address MIC) will be more than US$ b 18.

There are a variety of both bacteria and archaea that can influence corrosion **(Table 1):**

Table 1. The following table shows just a group of these microorganisms known for having corrosive effects.

General Hetrotrophic Bacteria/ Archea	Thiosulphate Oxidising Bacteria (TOB)	Acetogenic Bacteria	Slime-Forming Bacteria
Acid-producing Bacteria/Archea	Metanogens	Nitrate reducing Bacteria/Archea	Sulphate oxidising Bacteria/ Archea
Sulphate reducing Bacteria/ Archea	Nitrate reducing Sulphate oxidising Bacteria/Archea (NR-SOB)	Thiosulphate reducing Bacteria (TOB)	Thiosulphate reducing Archea (TRA)

As seen, while one could have corrosion-related bacteria (CRB) such as sulphate reducing bacteria, it is quite possible to also have corrosion–related archea (CRA) such as sulphate reducing archaea: while SRB can thrive and be proactive within a certain temperature range, making them mesophilic, SRA can easily become active at temperatures above 60˚C.

CRB/A can be found everywhere, in soil, water and even air. It has recently been shown that especially in highly polluted industrial areas, under the corrosive impact of sulphur oxidising bacteria present in such atmospheres the rate of concrete deterioration/corrosion is enhanced.

The ways by which bacteria can contribute to corrosion can either be by producing by-products that will act as cathode to metallic substrates of engineering structures and thus making them anode and corrode (such as production of FeS by sulpahte reducing bacteria where the iron sulphide film produced as a result of the bacterial activity will act like cathode to the underlying steel and thus will enhance corrosion), or making the environment corrosive (like the highly acidic sulphuric acid produced by sulphur oxidising bacteria or organic acids produced by *Clostridia*) or contributing to damaging the protective chemistry by which metals can protect themselves against corrosion (for example like the way iron reducing bacteria reduce protective ferric ions into soluble ferrous ions). One should also not forget that many bacteria can take other bacteria roles in contributing to corrosion: some species of bacteria-other than iron reducing bacteria- such as some *Clostridia*- can also reduce iron. In addition to producing organic acids and the capability of reducing iron, Clostridia are also known for producing relatively huge amounts of hydrogen. This hydrogen can serve to initiate hydrogen induced cracking (HIC) in steel pipelines which will fail under service within a time frame much shorter than originally designed for.

Microbiologically influenced corrosion is a multidisciplinary research and development area, a Greenfield for more research and there are many aspects of it we still don't know. For example, we now know that many bacteria such as some sulphate reducing bacteria, iron reducing bacteria and methanegense actually contribute to MIC by direct electron take from the metallic surfaces via developing nano-sized tubes. Based on such observations, a new look at MIC mechanisms have been developed called "EMIC"- Electrical microbiologically influenced corrosion. What could be the possible impact of EMIC on routine industrial practices such as use of "Intelligent pigs" in pipeline industry? Another subject: we know that magnetotactic bacteria have nano-sized magnets called magnetosomes within their bodies. These nano-sized magnets are made up of magnetite-a magnetic iron oxide. But what could possibly be the source of the iron required by the bacteria to make magnetosomes? Could it be because of the iron ions produced as a result of corrosion? Ho come cathodic protection which is of highly intensive use in industry sometimes fails to treat MIC by SRB? This author have developed a theory based on both electrostatic and chemical factors to explain it but this is a very serious matter for all industries, including oil, gas and petrochemical industries as well as water treatment.

MIC continues to amaze generations of scientists and engineers, not only because of the complex electrochemistry which is involved in it but also because we often forget a simple fact: microbes are mush smarter than what we may think!