Microbiological contribution to accelerated low water corrosion of support piles

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Introduction

Accelerated low water corrosion (ALWC) is a complex type of corrosion as it not only involves purely electrochemical factors, it also is greatly affected by microbiologically influenced corrosion (MIC). While some definitions of ALWC do consider MIC as an integral part of the definition, emphasising the importance of the role played by corrosion-enhancing bacteria, it is still open to discussion how MIC can enhance severity of this type of corrosion.

ALWC has been reported to cause severe corrosion of mainly steel piles in ports and jetty structures all around the world such as USA, Europe and Australia. In many cases of ALWC, microbial corrosion manifest itself as an orange mass known as 'orange bloom' that schematically can be shown in Figure 1. Figures 2a to 2d show real life examples of the orange blooms. Figures 3a and 3b show two more examples of orange blooms as appearing under-water with the deteriorating effects of orange blooms on the steel material of the piles. The metal underneath the orange blooms can be highly deteriorated. Figures 4a and 4b show such instances.

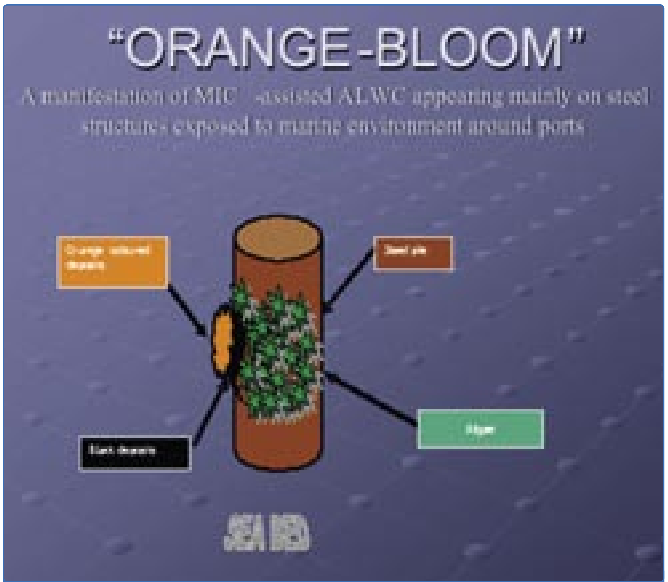

Figure 1. Schematic presentation of orange bloom on steel piles.

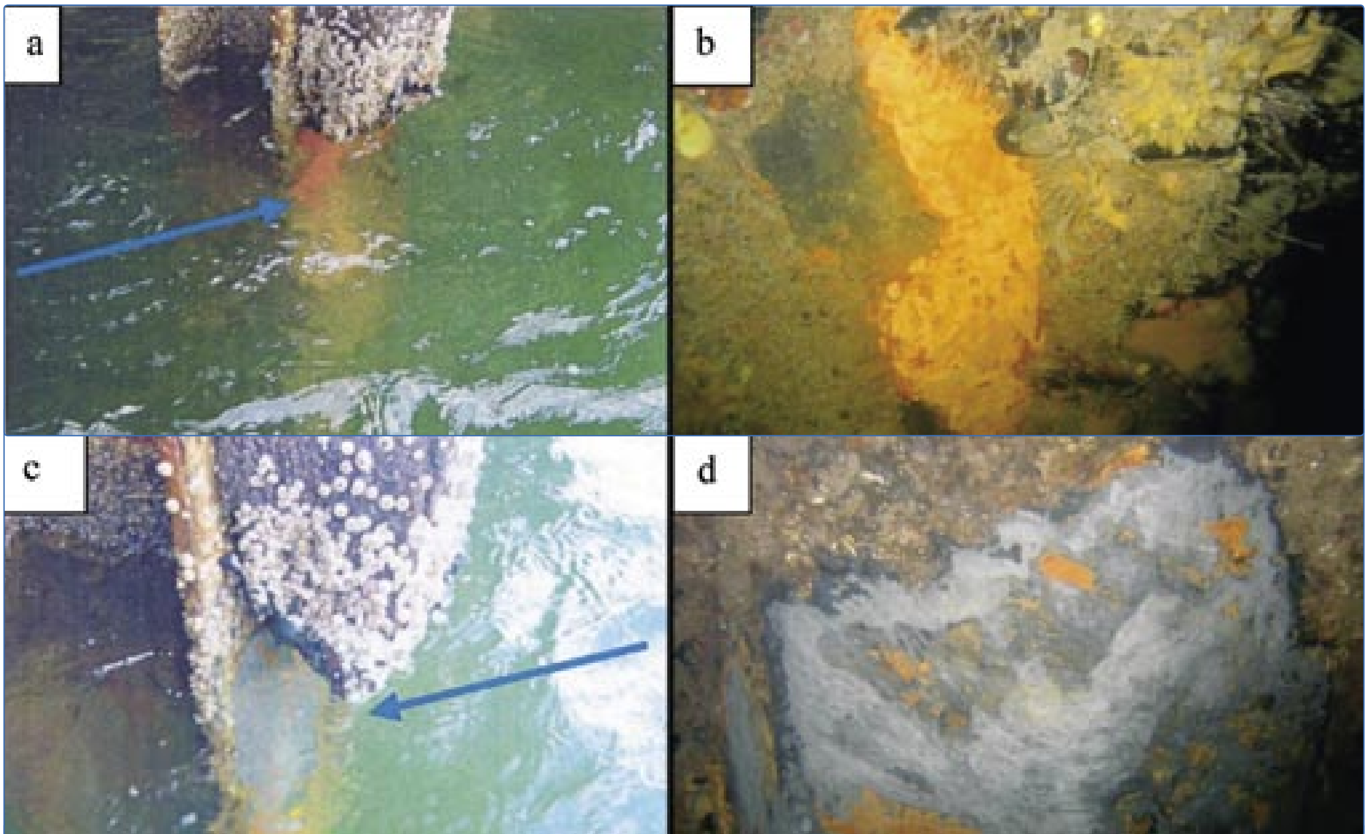

Figure 2. (a) a case of orange bloom (arrow), (b) the same case under water, (c) the metal underneath of the orange bloom after removal (d) a closer look, under water, at the metal surface after the orange bloom has been removed.

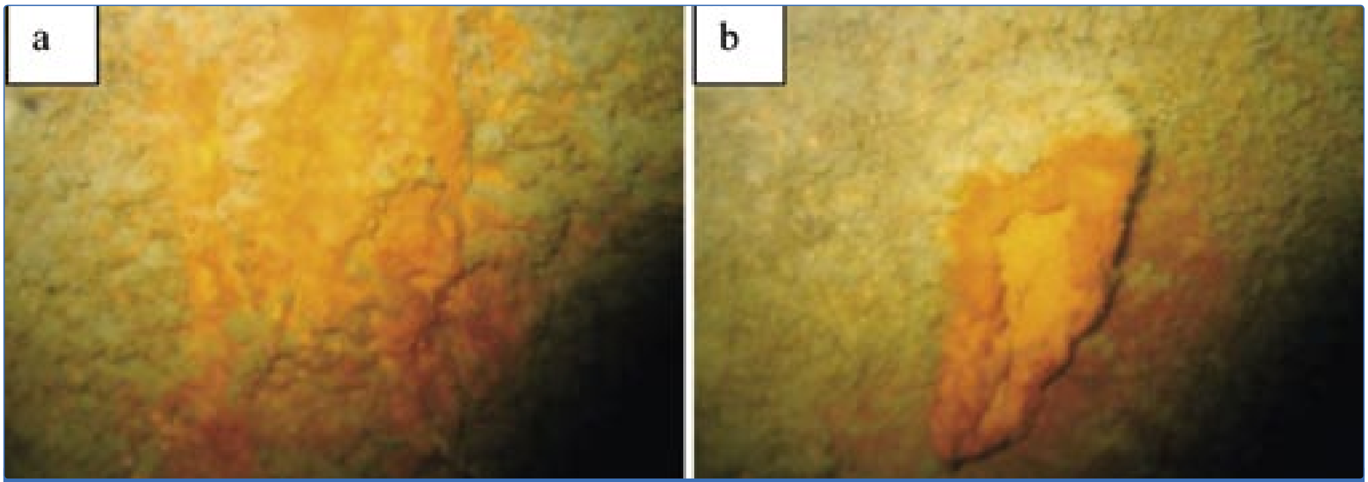

Figure 3. (a) and (b) examples of orange blooms as found on steel piles under water level.

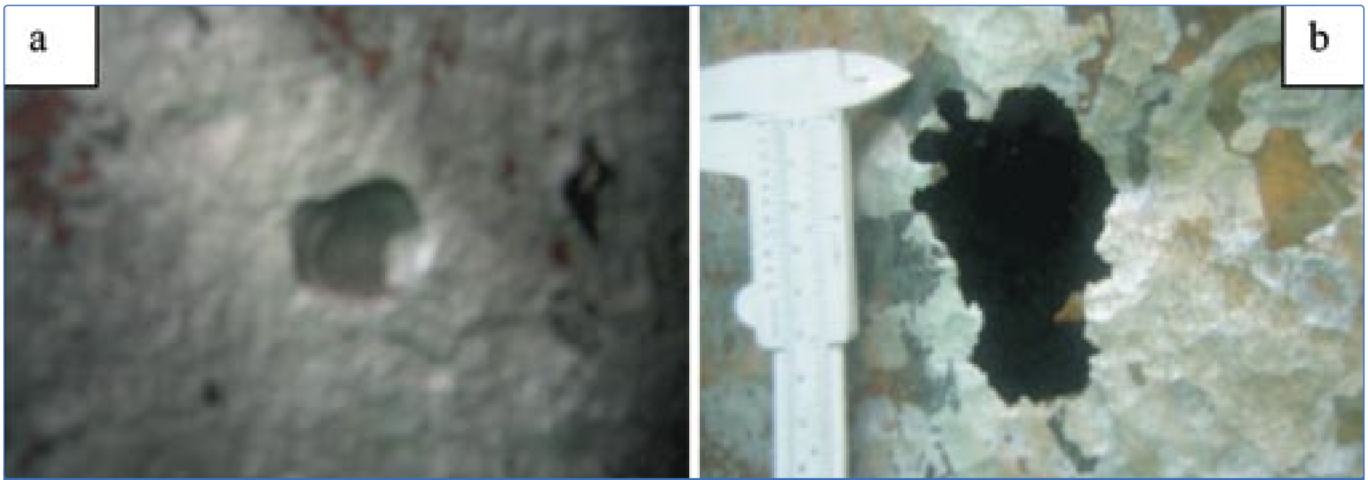

Figure 4. (a) A large pit formed as a result of orange bloom formed on the steel; (b) a serous deterioration of the steel material under the orange bloom.

It has been suggested that some groups of corrosion-enhancing bacteria such as sulphate reducing bacteria (SRB) and Iron reducing bacteria (IRB) may play an important role in ALWC problems, Figure 5.

However, there are some issues that when taken to consideration, may further increase the complexity that MIC can induce to ALWC. Of these issues is possible involvement of other types of corrosion-enhancing bacteria such as iron bacteria (IB) as their growth and corrosion activity can be supported by biochemical nature of seawater. The other issue is the rather false reputation that routine laboratory-based methods for investigation of numbers and intensities of corrosion-enhancing bacteria have created among professionals who have little hands-on experience on MIC-assisted issues.

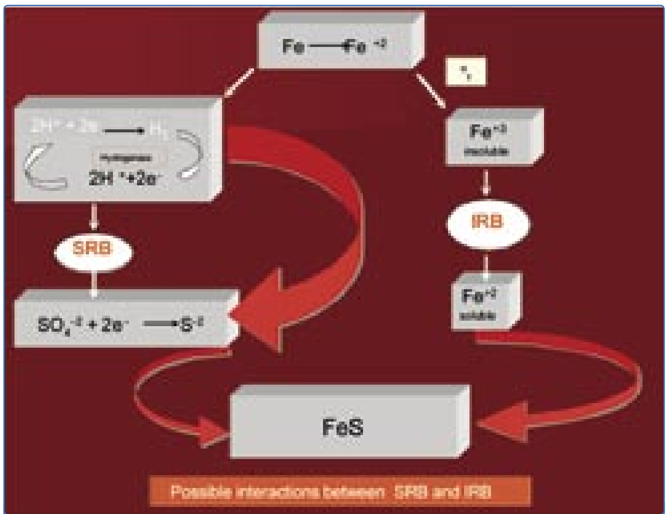

Figure 5. An example of possible microbial consortia contributing to MIC-assisted ALWC.

This 'over-relying' on these methods may bring about technical misunderstandings and 'myths' that would result in misinterpretations and thus wrong synopsis of the corrosion-case.

Regarding the professional importance of the above-mentioned shortcomings of approaches towards MIC-component of ALWC, this paper will introduce the proposed mechanisms by which these bacterial species can enhance corrosion. Also, some of pros and cons of routine microbiological processes, such as culturing method, that are used for showing the presence of some corrosion-enhancing bacteria will also be addressed.

Some examples of corrosion-enhancing bacteria

Sulphate reducing bacteria

Sulphate-reducing bacteria (SRB) has been so much of interest that it has become one of the myths of MIC as being that SRB is the most important corrosion-enhancing bacteria. The fact is that SRB is just one of the many types of microorganisms that are enhancing bacteria.

SRB derive their energy from organic nutrients. They are anaerobic and, as an alternative to oxygen, use sulphate with the consequent production of sulphide. SRB grow in the pH range between 5 to 10 and the temperature range of 5 to 50°C, and

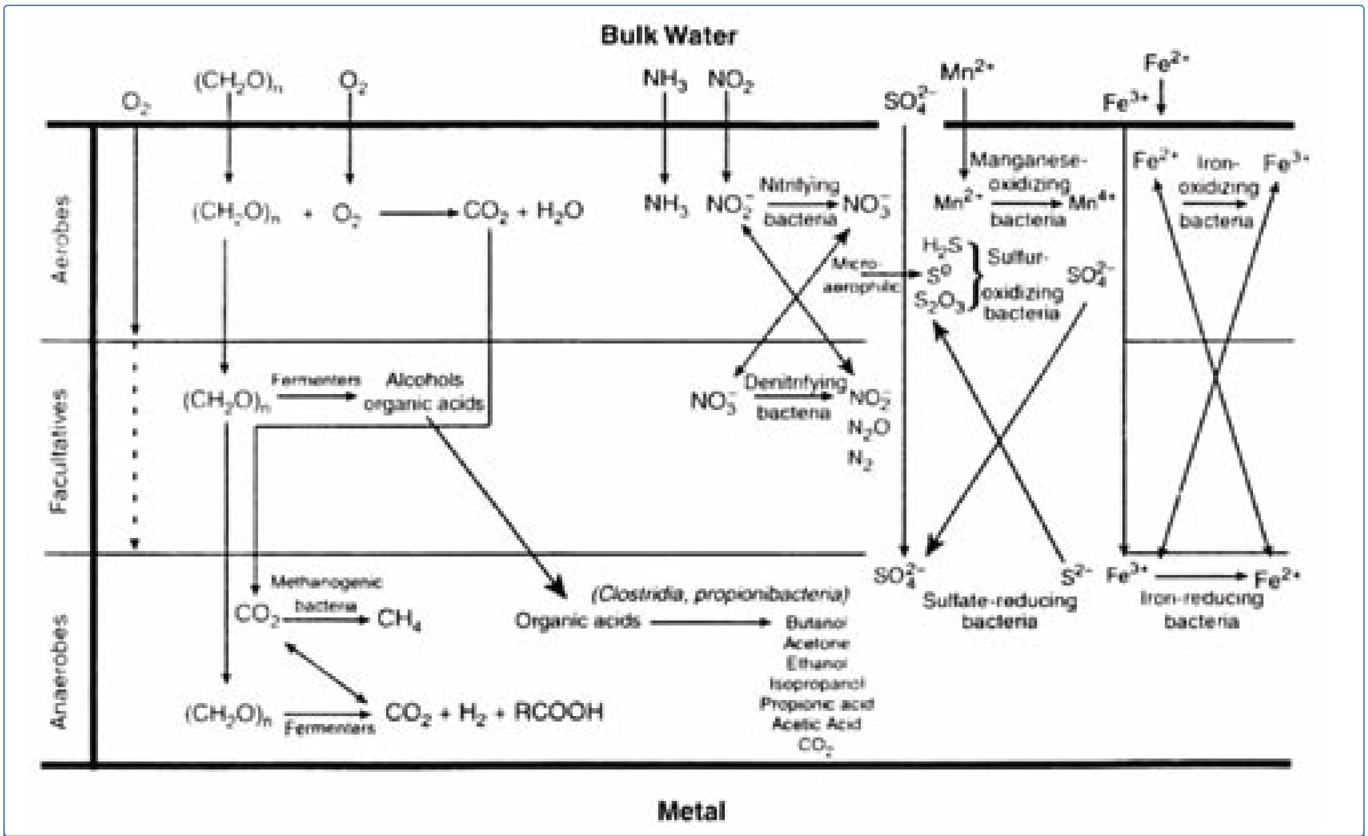

Figure 6. Possible reactions in a biofilm.

at pressures up to 500 atmospheres. For such bacteria to grow, the environment must contain no oxygen, and hence they are classified as anaerobic. SRB can be found everywhere, from more than 70 metres deep in clay to seawater. The colour of the black sea is believed to be the result of the activity of these bacteria as the sulphide produced is black in colour.

Mechanisms by which SRB can contribute to corrosion have been the concept of many experiments and researches for more than half a century so that almost any paper regarding MIC has a section about SRB and their probable mechanisms.

Sulphur oxidising bacteria

Sulphur oxidising bacteria (SOB) that are a family of bacteria that require oxygen for their growth (aerobic bacteria). SOB can produce sulphuric acid with very low pH values even down to 1. A type of these bacteria known as Colourless SOB produces sulphuric acid by either of the reactions given below:

$$H_2S + 2O_2 \longrightarrow H_2SO_4$$

Or

$$2S^D + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4$$

Colourless SOB can be found everywhere in nature and be isolated from almost every aquatic system. A genus of SOB known as Thiobacillus Ferrooxidan is capable of producing 10% concentrated sulphuric acid with pH less than 2.5.

Iron oxidising and iron reducing bacteria:

Iron oxidising bacteria

The term iron bacteria (IB) is mainly used for what that can be more precisely described as iron-oxidising bacteria (IOB); for example, ASTM D 932-85 defines iron bacteria as a general classification for micro-organisms that utilise ferrous iron as a source of energy, and are characterised by the deposition of ferric hydroxide. A common example of IOB is Gallionella sp.

Corrosion of an AISI 304 stainless steel in chlorine treated hydro test water and penetration of an AISI 304L stainless steel in brackish water primed with untreated well water has been attributed to corrosive effect of Gallionella. Two recent case studies on corrosive effects of IOB on a carbon steel heat exchanger and pipe weld joints in a power plant have also shown the corrosive effect of IB, especially Gallionella, in enhancing pitting. In both instances, evidence of IOB-assisted pitting include the presence of black slimy deposits containing high numbers of the bacteria and high concentration of iron and also the attack morphology (pits with very small entry and exit holes with massive subsurface cavities).

Iron reducing bacteria

In comparison with SRB or IOB, iron-reducing bacteria have been studied to a lesser extent. A recent work shows that reducing effects of IRB on metals such as copper, nickel, gold and silver have been known for nearly 50 years.

Iron-reducing bacteria (IRB) act by reduction of the generally insoluble ferric compounds to the soluble ferrous, exposing the metal beneath a ferric oxide protective layer to the corrosive environment have corrosive effects. However, it is interesting to know that some experimental works have reported that two strains of IRB, called shewanella algae and shewanella ana, were able to significantly reduce corrosion of mild steel and brass. The work postulates that the bacterial strains are capable of reducing the rate of both the oxygen reduction and anodic reactions. A recent research on MIC of mild steel by iron reducing bacteria has also suggested that this type of bacteria may decrease rather than accelerate corrosion of steel due to reduction of ferric ions to ferrous ions and increased consumption of oxygen. Most important aspect is that ferrous ions produced by the bacteria prevent oxygen from attacking the steel surface. This aspect of IRB is certainly a new area of investigation as so far any bacterial species associated with MIC has been assumed to accelerate corrosion.

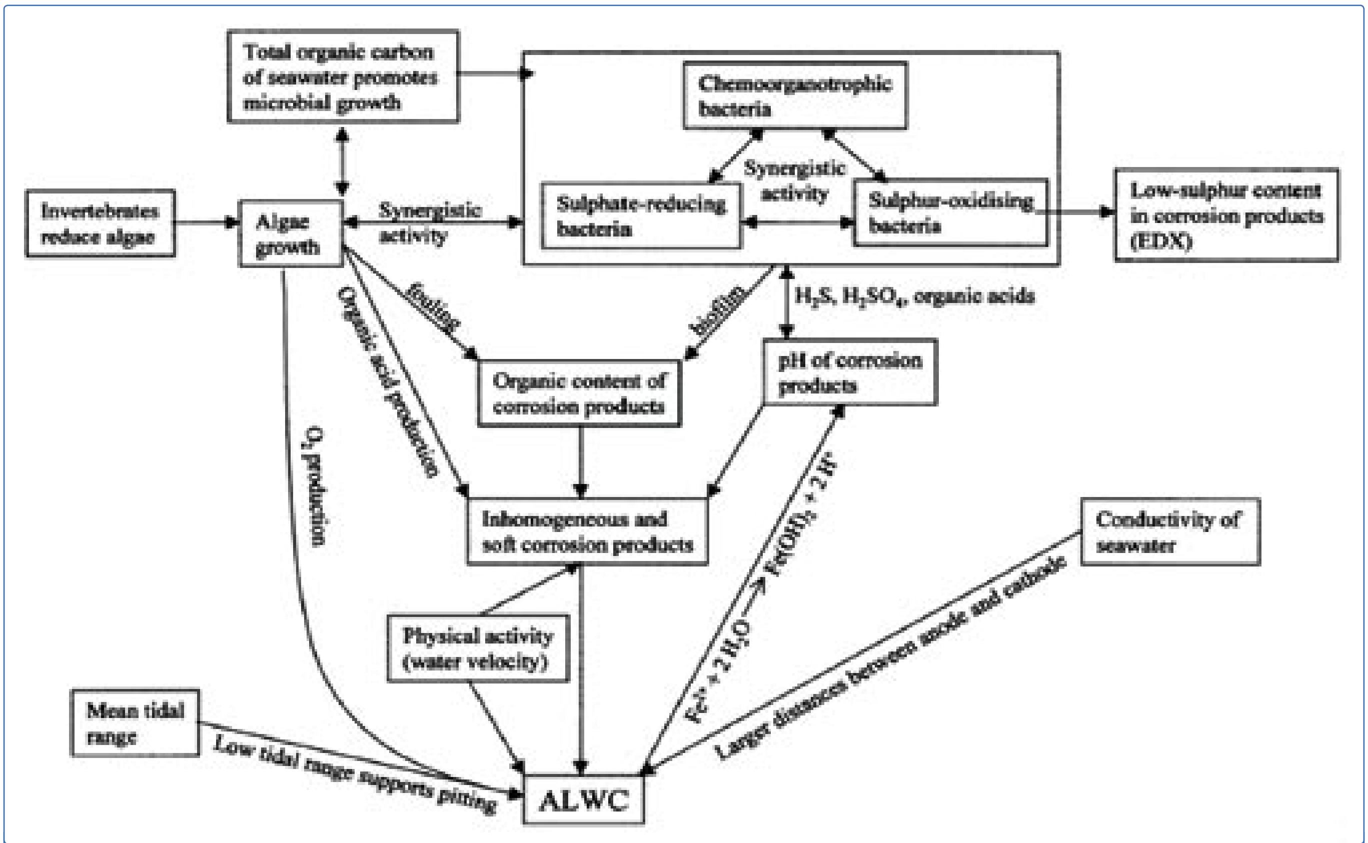

Figure 7. Factors that are important in ALWC.

Microbial consortia and its impact on corrosion

In nature, it is highly unlikely to find a 'single' type of microorganisms affect the severity of corrosion. What happens in reality is that several classes of bacteria together or one after the other help continue corrosion.

When SRB and SOB, for example, are both present in an environment, they usually act through a very interesting mechanism called 'sulphureta' where there is both oxidation and reduction of sulphur almost simultaneously.

Borenstein reports possible reactions that may take place in a biofilm, showing co-existence of SRB with IRB or IOB, forming a microbial consortium. These reactions have been shown in Figure 6, [B.J. Little, R.I. Ray, R.K. Pope, 'Relationship Between Corrosion and The Biological Sulfur Cycle: A Review', Corrosion, Vol.56, No.4, pp.434-443, 2000].

Another good example of sulphureta-assisted MIC can be seen in concrete sewage systems. Sewage contains water (typically 99.945%) along with chemicals such as ammonium and phosphorous that can be used as nutrients for bacteria such as SRB and SOB. SRB in absence of metallic ions such as iron, – that itself is highly corrosive – is also capable of producing hydrogen sulphide gas. The hydrogen sulphide gas thus produced by reducing action of SRB can then be used by SOB for production of sulphuric acid.

Mixed bacterial consortia may be effective on SCC of mild steel as reported by Javaherdashti et al. [R. K. Raman Singh, R. Javaherdashti, C. Panter, E.V. Pereloma, 'Role of Microbiological Environment in Chloride Stress Corrosion Cracking of Steels', to be published in Materials Science and Technology.]

Some features of culturing

There are varieties of methods that can be applied to evaluate the presence, type and number of microorganisms. Some of these methods are, but not limited to, culturing, direct analysis methods using microscope (by applying especial dyes to differentiate certain micro-organisms), evaluation of ATP, fatty acids, DNA and anti-bodies. Pros and cons of these methods have been discussed in length elsewhere.

As of the above-mentioned methods, culturing is one of the mostly applied methods in most microbiology laboratories; we will briefly explain some of most important pros and cons of culturing.

Culturing is mainly used for its relatively simple approach towards the problem of evaluating the type of the bacteria. This method also allows having a back-up of the bacterial species found inn the specimen of question. It is possible to grow pure cultures where all the bacteria found are the 'same' either by morphology or by action.

For example, it is possible to establish a pure culture of SRB where all of them are desulphovibrio. However getting such a pure culture of a single type of bacteria could be mainly useful in studying the very features of that type of bacteria such as the way these bacteria are affecting corrosion. These results may or may not be applicable to many real-life examples where the bacterial community is rather mixed in terms of bacterial types and morphology and may be alternatively called a bacterial consortium. While culturing may be very useful in recognition of known bacterial species available in a given sample, it is ONLY useful for those known bacteria. In other words, due to rather artificial conditions established by culturing methods, only those species that can cope with those conditions can grow.

As certain bacteria are allowed to grow in a given medium, it is always possible 'to miss' the others. This in practical terms can be translated as lack of universality. In other words, while in the actual corroded sample, many bacterial species with known and unknown effects on corrosion may be present, by culturing, only a certain number of these micro-organisms can be revealed. Thus, to be on the safe side, in addition to examining culturing methods applicable for rather 'well-known' corrosion-enhancing bacteria such as SRB, other types of bacteria such as IRB must also be considered for investigation by culturing methods.

Therefore, although culturing is a simple technique that can be used to investigate type (s) of the bacteria present in a given sample, it must be noted that culturing methods all have their own disadvantages such as allowing the growth of certain types of bacteria that can be just a minor fraction of the whole micro-organisms actually present in the sample. It is then important to know what to expect and what not to expect from culturing methods. The best way is to verify the results of culturing methods by using other methods as well. This, although adds up to the cost, will result in more accurate results where a more realistic mitigation programme can be designed and applied.

Conclusion

ALWC is a very complicated kind of localised corrosion, and there are many factors involved in ALWC. These factors can schematically be shown as Figure 7. [R. Gubner, I. Beech, 'Statistical Assessment of the Risk of the Accelerated Low-Water Corrosion in the Marine Environment', Paper 318, CORROSION/99, NACE International, Houston, Texas, USA, 1999.]

Where the impact of corrosion-enhancing bacteria such as SRB and IRB have been reported, this paper emphasised the mixed culture nature of microbiological component of ALWC that would allow for contribution of other types of corrosion-enhancing bacteria such as IRB and/or IOB. In addition to that, this paper also briefly discussed the pros and cons of culturing methods as a rather simple, easy-to-apply laboratory method for the detection of the micro-organisms available in a given corrosion product-containing sample.

This paper mainly aimed at highlighting the possibility of existence of other types of corrosion-enhancing bacteria in corrosion by-products of ALWC that may not be detectable by routine culturing methods. It was suggested that to be on the safe side, in addition to examine culturing methods applicable for corrosion-enhancing bacteria other than SRB, other detection methods must also become available to verify the findings of culturing methods. The extra cost of these 'extra' investigation methods, could be justified by reducing the cost of mitigation programmes.

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ABOUT THE AUTHOR

Reza Javaherdashti is a Senior Corrosion Engineer at Extrin Consultants, Perth, Australia. He has extensive research and industrial expertise in MIC problems in various industries, including power generation, oil & gas and marine structures industries. He has also designed and implemented workshops on MIC.

ABOUT THE ORGANISATIONS

NACE International was originally known as 'The National Association of Corrosion Engineers' when it was established in 1943 by eleven corrosion engineers in the pipeline industry. These founding members were involved in a regional cathodic protection group formed in the 1930s, when the study of cathodic protection was introduced. With more than 60 years of experience in developing corrosion prevention and control standards, NACE International has become the largest organisation in the world committed to the study of corrosion.

Extrin Consultants is a unique specialist corrosion engineering consulting group established in Perth, Western Australia in 1991, initially to service an identified niche market in the mining industry. Extrin Consultants has addressed corrosion related issues in areas including: Over 50 mining sites worldwide, petrochemical, manufacturing, storage and handling, and port facilities.

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