Chapter 7
Examples of Some Systems Vulnerable to MIC

Abstract It may come to mind that different systems will have different patterns for MIC. While this is true for many systems , there is a general pattern for MIC that can repeat itself in seeming far different industrial systems. This chapter describes some of these systems.

Keywords Pipeline · Jetty · Offshore platforms · Firewater system

7.1 Introduction

It is not a rare accident to meet people who, despite having no blood connection, look so similar to each other.

R. Javaherdashti, *Microbiologically Influenced Corrosion*,
Engineering Materials and Processes, DOI 10.1007/978-3-319-44306-5_7

How two different individuals may look alike![1]

No matter how different such individuals may be in other details of their lives, the most interesting features are that they look so much like each other. These "similar, yet, different" characteristics can also be seen in many industrial systems and their problems, especially if MIC is the problem.

As we shall see, the proposed cyclic mechanisms of MIC are very similar in a buried pipeline to accelerated low water corrosion of steel piles of a jetty or wharf. Although there are many aspects of biocorrosion not yet clear, some "rules of thumb" can still be developed to allow estimating the vulnerability of a system to MIC, as stated in details in Chap. 5. Despite the limitations and related uncertainties, it is still possible to come up with some patterns that repeat themselves in systems where corrosion is enhanced by microbial corrosion mechanisms. It is these general patterns and global features that we are trying to address in this chapter for some industrial systems as diverse as fire water lines, offshore platforms, buried metallic pipelines and immersed piles.

7.2 Buried Metallic Pipelines

According to the principles of CKM, as discussed earlier in Chap. 3, the first step in understanding corrosion is to be able to define the system in which one is interested to detect, define and mitigate corrosion or more specifically as the topic of this book is concerned, microbial corrosion. As Fig. 7.1 suggests, the following corrosion systems can be defined in a buried pipe:

1. External corrosion system that includes corrosion problems such as those occurring in the soil surrounding the buried pipe, the coating, the cathodic protection system, …
2. Internal corrosion system, including corrosion problems that are likely to occur with regard to the fluid (water, gas, oil, its temperature and pH, its velocity, its TDS, …), the lining, …
3. The corrosion system itself, the pipe, where corrosion can be the result of wrong/incomplete hydrotesting, the steel characteristics (physical, chemical, metallurgical), …

As far as corrosion-related bacteria are concerned, in this chapter we will focus on both external and internal corrosion systems of a buried metallic pipeline in this chapter.

A very important point, however, is the appearing discrepancy between our use of "external corrosion" and the way that it is addressed in corrosion literature: most of the time, when external corrosion of buried pipes is mentioned in the literature, the damage to the coating and the "exterior" wall of the pipe is meant. As the reader can easily understand, our use of the term external corrosion includes this type of

[1]Source: www.marshal-modern.org.

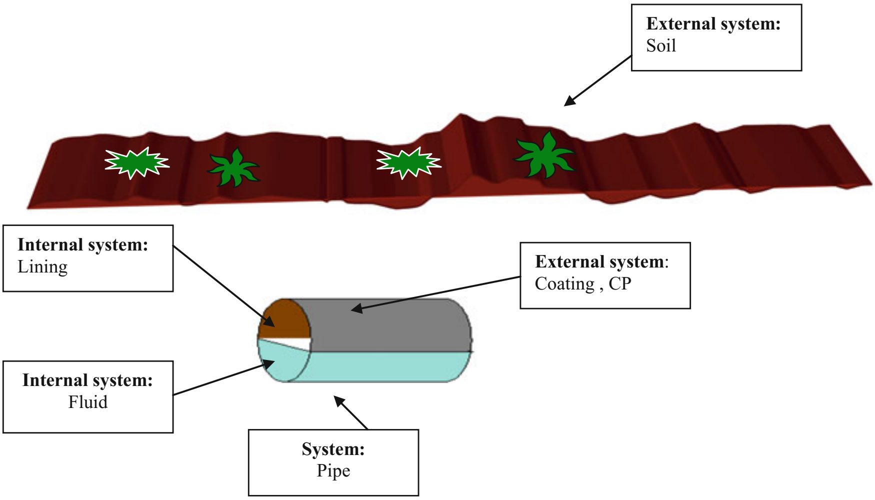

Fig. 7.1 Corrosion systems and subsystems in a buried pipe (Javaherdashti R, Marhamati EG (2005) A computerised model incorporating MIC factors to assess corrosion in pipelines. Mater Performance (MP) 44(1):56–59, Jan 2005.)

corrosion classification too. Therefore, we may use these terminologies interchangeably, bearing in mind that defining the surroundings of a buried pipe as the external system of corrosion, will define a wider domain than just addressing what happens on the exterior wall of the pipe.

A study about failures of on-land oil and gas pipelines from 1970 to 1984 has shown that more than 16 % of the damage was due to corrosion with 40 % of it being external corrosion, and 17 % internal corrosion.[2] Jack et al.[3] have also reported that the primary mechanism of deteriorating pipeline integrity was external corrosion of the buried pipes. It is a common practice to address coating and CP as measures of protecting underground pipelines from "the effects of the environment".[4] However, while external corrosion has been reported to be the main cause of underground pipe failures, a study[5] regarding the share of contribution of chemical, microbial and cathodic protection factors (such as the pipe-to-soil

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[2]Eiber RJ, Jones DJ, Kramer GS (1992) Analysis of DOT-OPSR data from 20-day incident reports, 1970–1984 as quoted in Potts, A.E Accident analysis and reliability of offshore pipelines. Monash University, Offshore Engineering Program, June 1992.

[3]Jack TR, Van Boven G, Wilmott M, Sutherby RL, Worthingham RG (1994) Cathodic protection potential penetration under disbonded pipeline coating. Mater Performance (MP) 33(8):17–21.

[4]Touzet M, Lopez N, Puiggali M (1999) Effect of applied potential on cracking of low-alloyed pipeline steekl in low pH soil environment. In: Jackman PS, Smith LM (eds) Advances in corrosion control and materials in oil and gas production (EFC 26). Woodhead Publishing.

[5]Li SY, Kim YG, Kho YT (2003) Corrosion behaviour of carbon steel influenced by sulphate-reducing bacteria in soil environments, Paper No. 03549, CORROSION 2003, NACE International, USA.

potential) to the underground corrosion of steel in anaerobic environments, concluded that the microbial factor was the most important element.

Biofilms are reported to mainly form on the bottom of the internal surface of pipelines (over a sector of approximately 30° angle[6]), making them different from scale and corrosion products that are, for instance, generated over the whole surface in injection water pipelines.[7]

Figurer 7.2 summarises some of the most well-known failure mechanisms in buried pipelines. Some of these mechanisms have been explained and discussed in previous chapters in this book such as the effect of hydrotesting on MIC (Chap. 5)

It must be noted, however, that while MIC could be an initiator of corrosion, it could well be a result as well. For instance, as shown in Fig. 7.2, if the line is passing through different soils where the difference in the average diameter of the soil particles will allow different oxygen ingress gradients to be formed, this may increase the possibility of having differential aeration cells formed on the exterior wall of the underground pipeline. If, also, the coating is performing poorly, then, due to coating disbonding some areas with poor or no coating cover (holidays) are formed. Chances are that these holidays will be the best spots at which electrochemical corrosion starts. Being exposed to the community of the soil micro-organisms, including SRB and SOB, a "sulphureta"[8] may be created, depending on many factors including weather conditions, as will be addressed later in this chapter.

When condensed moisture and water are collected under disbonded coatings, at least two scenarios can occur:

1. The collected water is quite conductive
2. The collected water is not very conductive.

If the trapped water has good conductivity and the pipeline is under CP, this will allow the current to pass and the required potential to be established so that the steel under the disbanded coat may be protected.[9] However, one should not forget that this water with relatively good conductivity is also a good electrolyte thus raising the possibility of electrochemical corrosion under the disbonded area. On the other hand, if the trapped water is not a good conductor, the CP criteria will not have the

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[6]King RA (2007a) Trends and developments in microbiologically induced corrosion in the oil and gas industry. In: MIC—an international perspective symposium, Extrin Corrosion Consultants-Curtin University, Perth-Australia, 14–15 Feb 2007.

[7]King RA (2007b) Microbiologically induecd Corrosion and biofilm interactions. In: MIC—an international perspective symposium, Extrin Corrosion Consultants-Curtin University, Perth-Australia, 14–15 Feb 2007.

[8]Sulphureta is a term used to address alternating oxidised and reduced sulphur environments, such as a bacterial consortia containing SRB (that reduce sulphur compounds) and SOB (that oxidise sulphur compounds). See footnote 18.

[9]Jack TR, Wilmott MJ, Sutherby RL (1995) Indicator minerals formed during external corrosion of line pipe. Mater Performance (MP) 35(11):19–22.

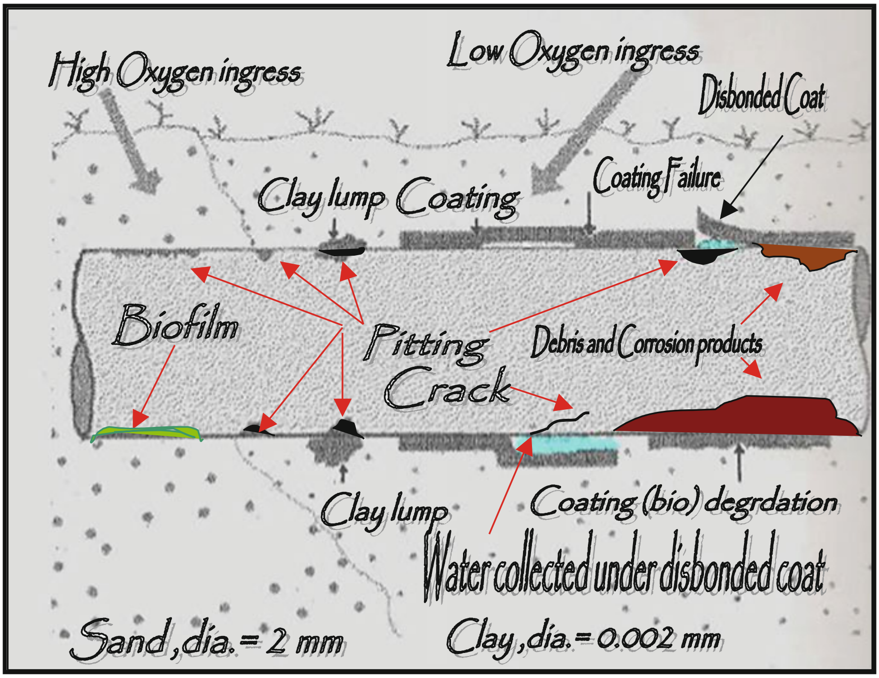

Fig. 7.2 A review of some of the factors contributing to corrosion and particularly, MIC (Javaherdashti R (2000) A review of microbiologically influenced corrosion of buried, cathodically protected, coated gas pipe lines, in Persian, Department of Technical Education, Iranian National Gas Company, Tehran, Iran, Winter 2000)

opportunity of being maintained. If the water trapped under the coat is saturated with cations such as calcium or carbonate ions, making it quite alkaline, scaling may occur and this plus an elevated pH may protect the underlying steel (see footnote 3).

It may also be interesting to know that if the soil around the pipe contains SRB and SOB, as these two almost always accompany each other,[10] they can work in "shifts" so that when the environmental conditions are suitable for the aerobic SOB-such as dry soil where interparticle spaces and cavities are filled with oxygen-The SRB will wait, for example, until in the wet soil resulting from a rainy day, the oxygen trapped in the interparticle spaces is expelled. This makes the environment so low in oxygen that the SRB can start to proliferate. This coexistence can enhance the corrosion even further.

[10]Tatnall RE (1993) Introduction. In: Kobrin G (ed) A practical manual on microbiologically influenced corrosion. NACE, Houston, TX, USA.

7.3 Maritime Piled Structures (Jetty and Wharves)

A commonly seen problem with steel piles in ports and jetty structures is a type of electrochemical corrosion called "Accelerated Low Water Corrosion" or ALWC for short. An integral part of ALWC could be MIC.[11] In fact, some definitions of ALWC do consider MIC as an integral part of the definition.[12] This type of corrosion has been observed and reported in ports all around the world, including the USA,[13] Europe (see footnote 12) and Australia.[14] In many cases of ALWC, microbial corrosion manifests itself as a mass which is orange in colour and collectively referred to as "orange bloom", Fig. 7.3a–d.

In essence, orange bloom can be regarded as a microbial community where SRB are definitely a part, due to the black iron sulphide mass associated with the orange bloom, Fig. 7.4. Upon removal of the orange bloom, the liberated hydrogen sulphide produced by the SRB and the remaining black iron sulphide products can be detected. Orange bloom is capable of flagging very serious pitting of the steel piles and thus endangering their mechanical integrities, Fig. 7.5.

There are still debates about the exact mechanisms that could be operative in ALWC. However, the involvement of bacterial species such as SRB and SOB has always been reported.[15] Figure 7.6 shows the factors that are important in ALWC and its occurrence.

An accepted scenario on the effect of SRB and SOB[16] can schematically be shown in Fig. 7.7. As it is seen in the figure, when there is high tide and thus limited or no oxygen available, the anaerobic SRB will be able to use the anaerobic environment thus produced and reduce sulphates to sulphide that, when taken into consideration with the anodic reaction of dissolving iron and availability of iron ions, iron sulphides will be produced (thus the black colour of the "orange" bloom,

[11]Javaherdashti R (2006) Microbiological contribution to accelerated low water corrosion of support piles. Port Technol Int 59–61, 29th Edition, Spring 2006. At a conference on Durability of Steel Pilings in Soil and Marine Environments in 1984, it was reported that "bacterial corrosion of steel piling in marine environments was not significant and… marine fouling appeared to be mostly beneficial". See footnote 15 for more details.

[12]Gehrke T, Sand W (2003) Interactions between micro-organisms and physicochemical factors cause MIC of steel pilings in harbours (ALWC), Paper No. 03557, CORROSION-2003, NACE International, Houston, Texas, USA, 2003.

[13]Hannam MJ, Clubb DL (2002) Experince and considerations on the corrosion protection of harbour steel sheet piling. In: The institute of corrosion conference, Cardiff, UK, 23rd Oct 2002.

[14]Hutchinson CPA, Vallini FD (2004) The effectiveness of petrolatum tapes and wraps on corrosion rates in a marine service environment, Paper 033, Corrosion and Prevention 2004 (CAP04), Perth, Australia, 21–24 Nov 2004.

[15]Gubner R, Beech I (1999) Statistical assessment of the risk of the accelerated low water corrosion in the marine environment, Paper No. 318, CORROSION-99, NACE International, USA.

[16]Little BJ, Lee J, Ray R (2007) How marine condition affect severity of MIC of steels. In: MIC—an international perspective symposium. Extrin Corrosion Consultants-Curtin University, Perth-Australia, 14–15 Feb 2007.

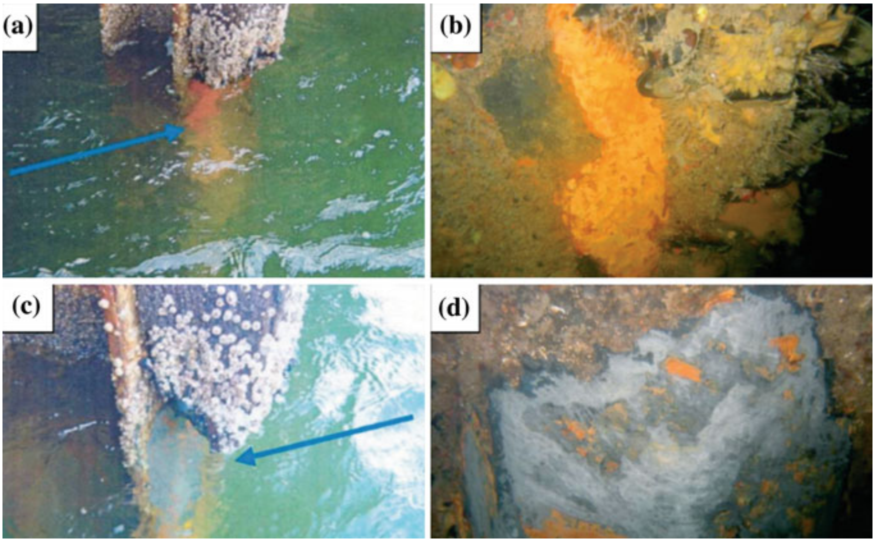

Fig. 7.3 **a** "*Orange bloom*" (*arrowed*) as seen from above the water level, **b** close up of the same mass under water, **c** the steel underneath the *orange bloom* and **d** its close up after removal of the *orange bloom* (All images Courtesy of Extrin Consultants)

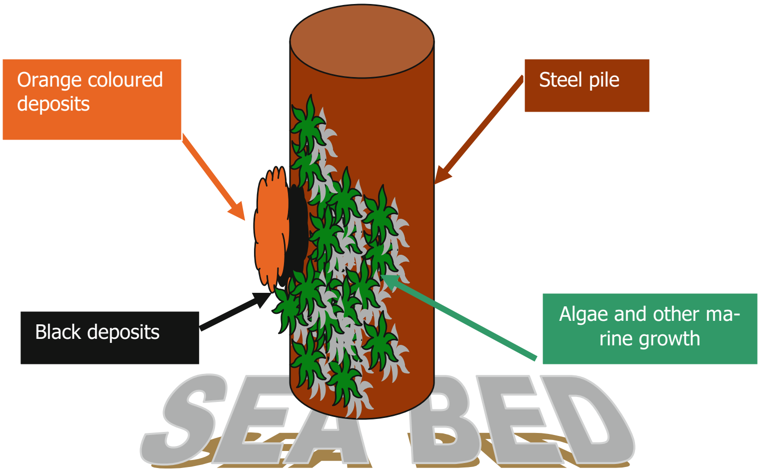

Fig. 7.4 Schematic presentation of *orange bloom* on a steel pile (Javaherdashti R (2005) Microbiological contributions to accelerated low water corrosion (ALWC) of steel—piled structure: a review. In: Proceedings of corrosion and prevention 2005 (CAP05), Gold Coast, Australia, November 2005.) (Not to scale)

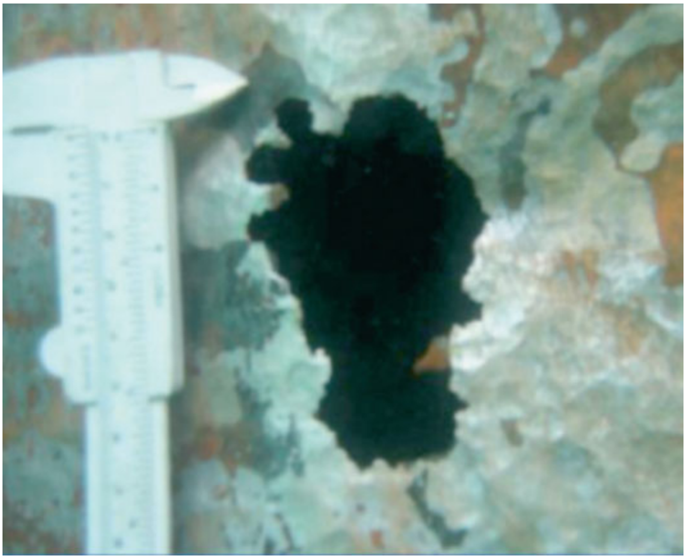

Fig. 7.5 Perforation on the steel under the *orange bloom* (Courtesy of Extrin Consultants)

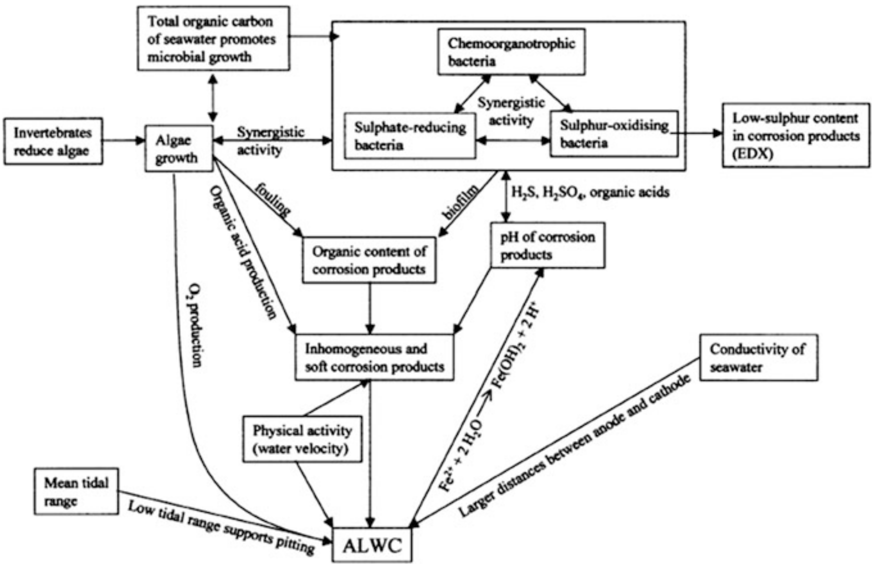

Fig. 7.6 A presentation of factors that can be important in ALWC (see footnote 15)

see Fig. 7.4). When, however, there is a low tide, oxygen becomes available to the sulphur oxidising bacteria (SOB) where these bacteria are capable of using the situation to produce acidic conditions and very low pH.

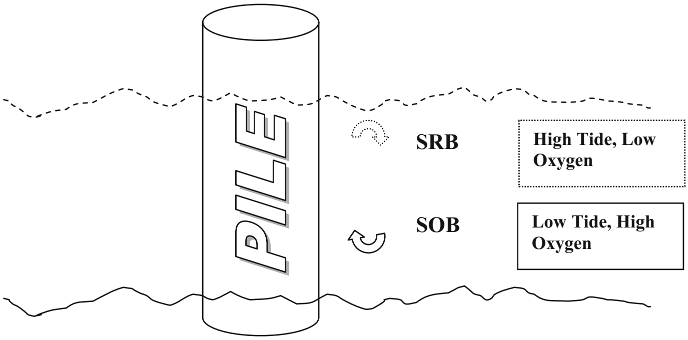

Fig. 7.7 Possible cyclic effect of SRB and SOB on ALWC of steel piles

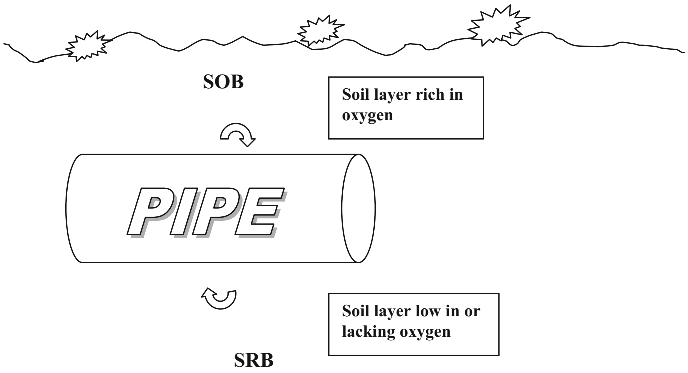

Fig. 7.8 Possible cyclic effect of SRB and SOB on a buried pipe

By comparing Fig. 7.7 with Fig. 7.8, a general pattern may be reached: a cyclic corrosion effect of which SRB are an important part helps in intensifying corrosion in an environment that also contains SOB.

To prevent f ALWC, use of coatings such as coal tar epoxy or glass flake composite along with application of CP have been recommended (see footnote 15). While replacing the piles which are beyond economic repair can always be an option, the repair techniques that can normally be applied are one or a combination of the following.[17]

[17]Christie J (2007) Dealing with MIC on maritime piled structures. In: MIC—an international perspective symposium. Extrin Corrosion Consultants-Curtin University, Perth-Australia, 14–15 Feb 2007.

- Welding patch plates (for small areas showing sign of MIC)
- Welding strengthening plates (for areas where the effect of corrosion is more extensive, either U-plates or profiled plates can be used for the damaged areas)
- Plating with reinforced concrete infill (especially in Z sections)
- Concrete as in-situ collars or reinforced concrete plugging (e.g. as encasement on H piles)
- Splicing, it may be possible to cut out damaged sections of single piles (H, box or tubular) and joining the replacement sections.

7.4 Offshore Platforms

Offshore platforms are, in essence, similar to buried pipelines as in both of them external and internal surfaces are exposed to corroding environments: in buried pipelines the external surface of the pipe is exposed to the soil which is a corrosive environment and its internal surface is under the corrosive impact of the fluid that is going through, either water, oil or the like. In case of offshore platforms, the whole immersed structure is exposed to the seawater (a corrosive medium) and the internal surfaces of the systems such as seawater injection systems or oil storage facilities can be considered as locations at which corrosion is occurring internally.

While there could be many ways to classify offshore platforms and structures, one approach to address the basic types of offshore platforms (or, alternatively within the context of this book, offshore drilling units) is as follows:

1. Fixed platforms;
2. Submersibles;
3. Semi-submersibles;
4. Jack-ups;
5. Drilling ships;
6. Tension-legs platforms.

In an offshore platform most of the MIC problems may happen in the following spots[18] some of which have been shown in Fig. 7.9:

- Marine fouling
- Drill cuttings around the platform legs
- Oil storage and transport
- Water-filled legs
- Production system
- Seawater injection system
- Downhole pipework
- Reservoir problems.

[18] Edyvean RG, Dexter SC (1993) MIC in marine industries. In: Kobrin G (ed) A practical manual on microbiologically influenced corrosion. NACE, Houston, TX, USA.

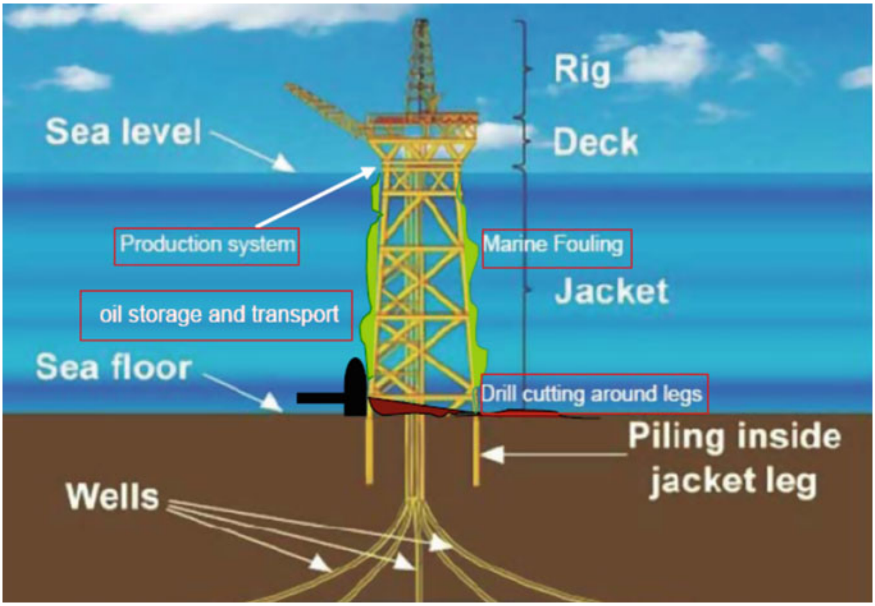

Fig. 7.9 Some locations vulnerable to MIC in offshore platforms (The figure has been taken from www.consrv.ca.gov/dog/picture_a_well/offshore_platform.htm with some modifications for our purpose here)

In addition to a series of problems,[19] two main problems resulting from bacterial growth in offshore structures are[20] (1) hydrogen sulphide production (generated, for example, by SRB) that besides being volatile and toxic, thus serious to the personnel safety, causes corrosion and souring of the products (crude oil, for instance) which ultimately affects the quality and final price[21] and (2) the production of bacterial metabolites which could give rise to accelerated materials deterioration.

The effects on offshore structures can be categorised as external (such as environmental effects on external surfaces of these structures) and internal effects (such as MIC problems in water handling system and oil production system).

[19]Some of such problems are reservoir souring and/or filter blockages in diesel systems (Communication with Dr. A. MOrshed, Production Services Network, Aberdeen, UK, 01/June/07).

[20]Wilkinson TG (1983) Offshore monitoring. In: Microbial corrosion: proceedings of the conference d sponsored and organised jointly by The National Physical Laboratory and The Metals Society, 8–10 March 1983. The Metals Society, London, UK, 1983.

[21]Evans P, Dunsmore B (2006) Reservoir simulation of sulphate-reducing bacteria activity in the deep sub-surface, Paper No. 06664, CORROSION-2006, NACE International, USA, 2006.

Fig. 7.10 A semi-submersible offshore platform (*Source* http://www.rigjobs.co.uk/oil/semisub.shtml)

The impact of MIC on the internal systems is more apparent and immediate than those on the external surfaces. Careful monitoring, regular maintenance, and prudent use of biocides (such as chlorine and chlorine-releasing compounds, phenolics, aldehydes and quaternary ammonium compounds) are some of practices that can be recommended.

The type of MIC-related problems that may be expected in, for example, submersible and semi-submersible platforms are, more or less, similar to stagnant water problems caused in firewater lines or pipelines. Such platforms have pontoons and columns that, when flooded with seawater, cause the pontoons to submerge to a predetermined depth. Figure 7.10 shows an example of a semi-submersible offshore platform.

In such platforms, the stagnant water becomes deaerated and oxygen-free so it becomes a good place for SRB to become active. In addition, it has been investigated that[22] the decay of macro-organisms in sea water, in the presence of light, could encourage phototrophic sulphur bacteria's role in increasing anaerobic corrosion of metals. A routine countermeasure is the use of biocides. However, the biocide should not simply be introduced into the platform leg as it takes a

[22]Eashwar M, Maruthamthu S, Venkatakrishna Iyer S (2004) A possible role for phototrophic sulphur bacteria in the promotion of anaerobic metal corrosion. Curr Sci 86(5): 639–641, 10 March 2004.

substantial time (maybe many weeks) to distribute. Real life experiences have shown[23] that it will be necessary to overdose the biocide if a long life time is expected.

7.5 Fire Water Lines

At an emergency when water is required to extinguish a fire, having a reliable fire water system that can handle stagnant water is of vital importance. Figure 7.11a, b show two examples of MIC within such systems.

It has been reported[24] that the main cause of pitting in fire sprinkler systems is oxygen, as these systems use locally supplied potable water. This water, being rich in oxygen, can easily establish differential aeration cells along the piping. It is then possible for oxygen to diffuse out of the system; rendering it more anaerobic (see footnote 20). Interestingly, an investigation[25] has detected aerobic types of corrosion-enhancing bacteria, such as iron-oxidising bacteria (IOB), for example, *Gallionella* and *Siderophacus* which may also contribute to the corrosion seen in

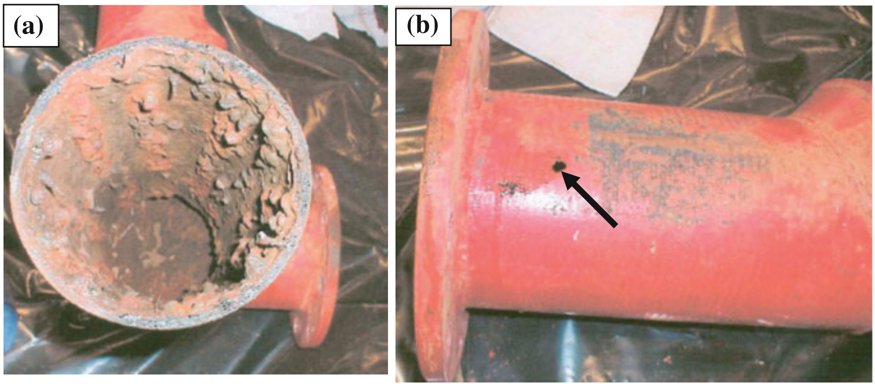

Fig. 7.11 **a** Internal wall of a fire water pipeline in which water has been stagnant and **b** observed perforation on the pipe (*arrowed*) (Fernance N, Farinha PA, Javaherdashti R (2007) SRB-assisted MIC of fire sprinkler piping. Mater Performance (MP) 46(2) Feb 2007.)

[23]NACE CORROSION NETWORK discussion group, "corrosion within Offshore jacket legs", November 2002.

[24]Brugman HH (2004) Corrosion and microbiological control in fire water sprinkler systems, Paper No. 04512, CORROSION-2004,NACE International, USA, 2004.

[25]Yee GG, Whitbeck MR (2004) A microbiologically influenced corrosion study in fire protection systems, Paper No. 04602, CORROSION-2004, NACE International, USA, 2004.

failed fire protection systems. Therefore, it may be assumed that a cyclic action of anaerobic SRB and aerobic IOB like anaerobic SRB and aerobic SOB in buried pipelines and steel piles (ALWC) could also be operational in fire water systems too.

7.6 Summary and Conclusions

No matter how different the two systems may seem at first sight, when it comes to MIC, some general patterns of corrosion can be recognised for both. These patterns such as those operative in a buried pipeline may well be similar to those of a submerged steel pipe and its ALWC problem. The stagnant water and the type of problems it produces have the same mechanisms for the involvement of MIC, whether in a firewater pipe or the water-filled legs of an offshore platform.

MIC may seem to be difficult to be explained but, if recognised promptly and accurately, could have simple general patterns to look at, both for mitigation and prevention.

An integral part of evaluation and assessment of the severity of MIC rests on the type of material that has been used. Examples of some materials that are frequently used in industry will be the topic of the next chapter.

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Yee GG, Whitbeck MR (2004) A microbiologically influenced corrosion study in fire protection systems, Paper No. 04602, CORROSION-2004, NACE International, USA