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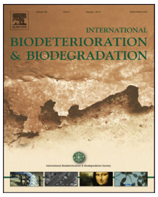

Review

Critical review: Microbially influenced corrosion of buried carbon steel pipes

K.M. Usher [a], [*], A.H. Kaksonen [a], I. Cole [b], D. Marney [c]

[a] CSIRO Land and Water, Private Bag No. 5, Wembley, Western Australia 6913, Australia
[b] CSIRO Materials Science and Engineering, Private Bag 33, Clayton South, Victoria 3169, Australia
[c] CSIRO Land and Water, PO Box 56, Highett, Victoria 3190, Australia

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ABSTRACT

External corrosion of buried carbon steel pipes is a problem of global proportions, affecting a wide range of industries and services. Many factors affect corrosion rates. Biofilms may secrete enzymes and compounds that attack metal, alter local acidity and create differential aeration and galvanic cells. An important consideration is that biofilm metabolisms and enzymatic reactions are constantly in flux, altering the impact of microorganisms on corrosion rates, and thermodynamic equilibrium is not reached. Recent research demonstrates that some anaerobic microorganisms catalyse the oxidation of metallic iron and directly consume the electrons, with serious consequences for corrosion. This review examines relationships between soil characteristics, microbiology and corrosion processes, focussing on the impacts of microorganisms on external corrosion of buried carbon steel pipes. Techniques for improving the understanding of microbially influenced corrosion are considered and critiqued, with the aim of assisting those who work in the area of corrosion mitigation.

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[*] Corresponding author. Tel.: +61 8 9333 6270; fax: +61 8 9333 6211.
E-mail address: Kayley.Usher@csiro.au (K.M. Usher).

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1. Introduction

Carbon steel is one of the most widely used materials for the transmission of water, petroleum products and chemicals (Baboian, 2005), and external corrosion of buried pipes is a major problem for these transmission pipeline systems (Jack et al., 1996). The consequences of pipe failure are borne by a wide range of industries and utilities and can include the costly loss of production, contamination of the environment, expensive and difficult repairs, suspension of critical services such as water supplies and serious safety hazards including public health risks due to contamination of water that can occur during a failure event.

Corrosion is often considered an abiotic process controlled by physico-chemical/electrochemical processes (Little et al., 1991). This approach has largely determined both corrosion management and research, while microbiological contributions to the corrosion rates of buried pipes have often been overlooked. This perhaps is the reason that correlations between corrosion rates and soil characteristics have remained poor (Cole and Marney, 2012).

Recently, increases in the rates of corrosion have been reported (Ringas and Robinson, 1987; Boothroyd and Boulton, 1998; Melchers, 2005, 2007), affecting buried steel and marine structures. However, this has not been quantified under controlled conditions. Higher corrosion rates may be caused by increases in the concentrations of nutrients from fertilisers such as nitrates (NO_3^-) and ammonium (NH_4^+), which can increase microbial growth rates (Little et al., 1991; Melchers, 2007), although NO_3^- is also involved in ferrous iron oxidation (*discussed later*). Restrictions in the biocides that can be applied to infrastructure have been blamed by some for increased corrosion rates (Boothroyd and Boulton, 1998).

Higher temperatures, for example during warmer summer months, are also known to increase biofilm growth rates, particularly when nutrient levels are high (Little et al., 1991). Future extreme weather events such as high temperatures and floods that are expected with climate change, together with greater nutrient availability from increased urban populations, are likely to result in further increases in microbially influenced corrosion (MIC) problems.

Today, MIC, or biocorrosion, is an established field of research, but this has taken many years. In 1963 it was suggested that microbes might affect corrosion rates when corroded pipes were observed in what was considered to be mildly corrosive soils (Fitzgerald, 1989). However, the significance of MIC was not widely recognised at this time. We now know that the involvement of microorganisms can increase corrosion rates by several orders of magnitude (Beech and Coutinho, 2003), and the understanding of the impacts of specific microorganisms on their environments, the interconnected functioning of natural microbial communities and the physical and chemical characteristics of biofilms has advanced significantly.

Assisting this process are powerful new tools, such as advanced microscopy, spectroscopy and surface-analysis techniques, that have changed perceptions regarding the impact of microorganisms on materials (Beech et al., 2005). It is now accepted that microbial activities strongly influence iron redox chemistry in most environments (McLean et al., 2002; Weber et al., 2006; Gadd, 2010). Advances in the understanding of MIC from the increasing use of these tools, together with molecular identification and analytical techniques, were identified as one of the major reasons for the establishment of BIOCOR ITN, the European Union biocorrosion training network, in 2009.

Despite progress there remain few studies of MIC of buried pipes that have been conducted in natural environments. Important challenges that have been identified in understanding MIC include the significance of different microbial populations for MIC, how enzymes within a biofilm affect corrosion and the transfer of electrons from zero valent metals to electron acceptors by metals trapped within biofilms (Beech and Sunner, 2004). There is an understanding that MIC can lead to severe damage through pitting, crevice corrosion and blistering (Mansfeld and Little, 1991; Campaignolle, 1997; Little et al., 2000) and MIC is thought to be a major cause of external corrosion of pipes in soil (Jack et al., 1996; Li et al., 2001).

Despite protective coatings and cathodic protection buried pipes can fail prematurely (Jack et al., 1996; Li et al., 2001) and in some cases protective measures may promote MIC, for example, where protective tape forms an anaerobic environment in which sulphate reducing bacteria can grow (Hutchinson et al., 2004). MIC is thought to be responsible for at least 20% of the $276b annual corrosion costs experienced in the US, that is, about $55b annually (Corrosion costs and preventive strategies in the United States,

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