Technical Note 99

Sulfate Reducing Bacteria on Steel Structures

November 2015

Queensland Government

Copyright

Feedback: Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

1 Types and characteristics

(Holt *et al*. 1994)

In Bergey's Manual of *Determinative Bacteriology* (Holt *et al*. 1994), several genera of bacteria are classified as group seven: *Dissimilatory Sulfate-or Sulfur-Reducing Bacteria* (SRB). Dissimilatory sulphate reduction occurs when byproducts of sulphate reduction, such as H_2S, are excreted. During assimilatory sulfate reductions, reduction products are used to produce components required by the bacterium, such as sulfur containing amino acids. Another group of SRB, classified in group 32 in Bergey's Manual, are the Archaeal Sulfate Reducers. However, as these bacteria grow best at temperatures >45˚C, they are not discussed here.

The *Dissimilatory Sulfate-or Sulfur-Reducing Bacteria* are ***strict anaerobes***. This means that they are incapable of oxygen-dependent growth and cannot grow in the presence of an oxygen concentration equivalent to that present in an air atmosphere (21% O_2). Sulphate reducing bacteria (SRB) reduce sulphate and in a few cases also sulphur to H_2S. Hydrogen or organic compounds serve as electron donors; oxidation of organic compounds is either incomplete, leading to acetate as an end product, or complete, leading to CO_2, as is shown in the following two reactions, where lactate is used as a substrate.

$$2CH_3\text{-}CHOH\text{-}COOH + 2H_2O \rightarrow 2CH_3\text{-}COOH + 2CO_2 + 8H$$

$$SO_4^{2-} + 8H \rightarrow S^{2-} + 4H_2O$$ (Gottschalk, 1979).

The *Dissimilatory Sulfate-or Sulfur-Reducing Bacteria* comprise both mesophilic and thermophilic species. ***Mesophiles*** are bacteria which grow best at a moderate temperature range of between 25 – 40˚C; **thermophiles** grow best at high temperatures > 45˚C.

The SRB of group seven are differentiated into four subgroups, subgroups one to four. Consideration is given only those genera which have been found in oxygen-depleted (anoxic) marine and freshwater sediments.

Subgroup one consists of the one genus *Desulfotomaculum* which comprises all spore forming SRB. Spore formation is a distinctive property possessed by only a few genera of bacteria, and in the case of SRB, only by the genus *Desulfotomaculum*. The trigger for spore formation occurs when the bacteria is stressed by environmental factors such as heat and desiccation. In the spore form, cells become resistant to these stresses. One reason for this is that bacterial cells do not grow or exhibit any metabolic activity when in spore form. That is, *Desulfotomaculum* cannot participate in corrosion when present as spores. Once the environmental stress is removed, then spores will germinate into actively growing cells.

Desulfotomaculum reduces sulphate, and in some cases also sulfite or thiosulphate, to H_2S. Organic substrates are either incompletely oxidised to acetate or completely oxidised to CO_2. Some species require only H_2 (electron acceptor), inorganic compounds (for nutrients) and CO_2 (carbon source) for growth; for other species, acetate must also be available to enable them to grow. The optimum pH range is 6.6 – 7.4. The optimum temperature range is between 25 – 40˚C, although some species can grow at higher temperatures between 40 – 65˚C.

Subgroups two and three comprise sulphate reducing bacteria, whilst Subgroup four contains sulphur reducing bacteria, and will not be further discussed. Subgroups two and three are differentiated on the basis of whether organic compounds are incompletely oxidised to acetate (subgroup two), or completely oxidised to CO_2 (subgroup three).

Subgroup two contains three genera *Desulfobulbus, Desulfomicrobium, Desulfovibrio*, which have been found in anoxic freshwater and marine sediments. They share the properties listed above for *Desulfotomaculum* with two exceptions:

- they do not produce spores
- they will only grow if a carbon source, other than CO_2, is available.

Subgroup three contains three genera of interest: *Desulfotobacter, Desulfobacterium*, and *Desulfosarcina*. Again they are very similar to *Desulfotomaculum* with three practical exceptions:

- they do not produce spores
- *Desulfosarcina* has a slightly high optimum pH than the other SRB: 7.2 – 7.6
- the optimum temperature range for these genera is between 20 – 33˚C; i.e. their growth rate may be reduced in tropical climates.

2 Mechanism for corrosion by SRB

The formation of biofilms may enable the establishment of SRB populations in an aerobic environment, because anaerobic conditions may be established inside the biofilm as a result of oxygen scavenging by aerobic microorganisms. The practical problem created by biofilm creation is that it protects cells from adverse environmental conditions, such as extremes in pH or the presence of biocide (Boothroyd & Bolton, 1998).

Ilhan-Sungur et al. (2007) showed that planktonic cells of *Desulfovibrio* attached and formed a biofilm layer on galvanised steel surfaces. These cells produced Extracellular Polymeric Substances (EPS) which are an important component of biofilms. Their results suggested that *Desulfovibiro* was responsible for the corrosion of galvanised steel

Cathodic depolarisation is one explanation for the corrosion of steel in anaerobic environments by SRB. When iron or steel is placed in contact with soil water, iron atoms from the metal lattice, particularly from the more negative (anodic) areas, tend to go into solution as positive ions (Fe^{2+}). The free electrons remaining in the metal migrate to the more positive (cathodic) areas where they attract and neutralise hydrogen ions. The process is driven when SRB utilise H_2 as they metabolise sulfates in the soil to H^2S or S^{2-} ions. The sulphides combine with the released Fe^{2+} ions, to form black ferrous sulphide (Jacobsen, 1996; King & Miller, 1971).

Jacobsen (1996) postulates that over time there is a build-up of hydroxyl ions (OH^-) in the soil water, left as excess because ferrous ions combine with sulphide ions instead of hydroxyl ions, causing it to become more alkaline and eventually inhibitory to SRB growth (pH ≥ 8.4). The accumulation of H^2S may also be inhibitory (Holt et al. 1994; Ilhan-Sangur, 2007). However, water movement in pervious soils may flush away both hydroxyl ions and H_2S, allowing SRB induced corrosion to continue. *Cathodic protection* works by maintaining a negative charge on the steel, causing the build-up of hydroxyl ions on the steel surface and the consequent increase in pH.

3 Inhibition of SRB growth

Favourable conditions for SRB growth include oxygen-depleted, marine or freshwater pervious soils (sediments) containing sulfates at neutral pH. In order for microbially induced corrosion to proceed to a significant extent, the anodic and cathodic reactions must remain in balance, and the electrolytic cell must continue to function over prolonged periods.

According to Boothroyd & Bolton (1998), cathodic protection, together with protective coatings, may offer very effective corrosion protection. However very alkaline pHs may cause problems such as cracking, and may be difficult to achieve in acid soils. Under adverse pH, *Desulfotomaculum* will form spores. In this form, it will not grow (and therefore cannot cause corrosion), but will germinate to actively growing cells should the pH become favourable.

SRB in biofilms will be protected from the action of biocides. Biocides may not give lasting activity against *Desulfotomaculum*, as once the biocide has washed away or degraded, spores may be able to germinate.

Jacobsen (1996) recommends that where the presence of conditions favourable to the action of SRB is suspected, then a few test piles should be left in place for withdrawal and examination after some years.

Boothroyd & Bolton (1998) noted that corrosion due to SRB had been observed in condenser pipes made from Grade 304 stainless steel. Nickel sulphide was a corrosion product as well as Iron sulphide. Ilhan-Sungur et al. (2007) found that galvanized steel also suffered from SRB attack.

4 Summary

There are several genera of Sulphate Reducing Bacteria having different characteristics. However, all are strict anaerobes which reduce sulphates in the soil to H_2S and OH^- ions. Although SRB can be destroyed in upper stratum there appears to be no reliable way to destroy the bacteria or arrest corrosion at depth. However, for soils with very low permeability the ability of the bacteria to access fresh supplies of sulphates is limited. This and the build-up of OH^- ions and consequent increase in pH limits the rate of corrosion by SRB.

5 References:

A.Boothroyd & L.H.Boulton, *Microbiologically Influenced Corrosion, Causes, Cases and Control*, ACA Conference Corrosion & Prevention-98, Paper No. 19, Hobart, Tasmania, 1998.

G. Gottschalk, Bacterial Metabolism, pp. 210-211, Springer Verlag, New York, 1979

J. G. Holt, N. R. Krieg, P. A. Sneath, J. Staley & S. T. Williams, *Dissimilatory Sulfate- or Sulfur-Reducing Bacteria*, pp. 336-342 In: Bergey's Manual of *Determinative Bacteriology* 9th Ed., 1994

E.Ilhan-Sungur, N.Cansever & A.Cotuk, *Microbial corrosion of galvanized steel by a freshwater strain of sulphate reducing bacteria* (Desulfovibrio sp.), Corrosion Science 49 (2007) 1097-1109.

R.C. Jacobsen, *Bacterial corrosion of underground metals*, Ontario Hydro Research Quarterly, Vol. 18 No. 3, 1996.

R. A. King & J. D. A. Miller, *Corrosion by the Sulphate-reducing Bacteria*, Nature 293 (1971) 491-492.

Authors:

Robyn Shaw, Consulting Microbiologist

Ross Pritchard, Deputy Chief Engineer (Structures), Transport and Main Roads: ross.w.pritchard@tmr.qld.gov.au

Peter Shaw, Associate Director, AECOM, Brisbane.