Internal Memo

To	Glenn Toogood Team Leader Water and Environment Santos - Energy NSW	Date	28 November 2012
From	Richard Cresswell	Project No	GENV17062
Subject	**Sulphate-reducing bacteria**		

What are sulfate-reducing bacteria?

Sulfate-reducing bacteria (SRB) are anaerobic microorganisms that can obtain energy by oxidizing organic compounds (CH_2O) or molecular hydrogen (H_2) in the presence of sulfate (SO_2^{-4}). This process generates dissolved sulfide (HS-) at pH > 7, or hydrogen sulfide gas (H_2S) at pH < 7and bicarbonate (HCO_3^-). These organisms may be thought of as "breathing" sulfate rather than oxygen, in a form of anaerobic respiration.

Sulfate-reducing bacteria can be traced back over 3.5 billion years and are considered to be among the oldest forms of microorganisms, having contributed to the sulfur cycle soon after life emerged on Earth. It is now appreciated that SRBs also play a significant role in the carbon cycle.

Many bacteria will reduce small amounts of sulfates in order to synthesize sulfur-containing cell components; this is known as assimilatory sulfate reduction. In contrast, the sulfate-reducing bacteria reduce sulfate in large amounts to obtain energy and they expel the resulting sulfide as waste; this is known as dissimilatory sulfate reduction. Most of them are anaerobes, that is, they live in oxygen-deficient environments, though a few can tolerate oxic (oxygen-rich) conditions and even thrive long enough to generate an anoxic (oxygen-deficient) environment for other SRBs to thrive. Some SRBs can also use nitrate, iron and other compounds (including oxygen) instead of, or as well as, sulfate to generate the energy they need to survive. There are over 220 species of SRB and the ecology of most is still poorly known or unknown (e.g. Muyzer & Stams, 2008).

Health effects

The Australian Drinking Water Guidelines (ADWG, 2011) do not have guidance on acceptable levels of SRB as there are no known direct health implications, though the presence may be indicative of faecal contamination. The US EPA also states that SRB pose no known health risks. Based on aesthetic considerations the ADWG suggest the concentration of H_2S should not exceed 0.05 mg/L.

SRB generate hydrogen sulfide (H_2S) (rotten egg smell) as a product of the sulfate reduction process, although the extent is dependent on the pH of the system. In NSW the EPA set odour impact assessment criteria for H_2S in air, ranging between 1 ppb and 3 ppb with the lower value applying in densely populated areas and the higher value applying for a single receiver, for example and isolated rural property. Health impacts from exposure to H_2S in air occur at much higher concentrations, with permissible exposure levels typically set at 10 ppm. H_2S odour increases as the gas becomes more concentrated, with the strong rotten egg smell recognisable up to 30 ppm. Above this level, the gas has a sickeningly sweet odour up to around 100 ppm. However, at concentrations above 100 ppm, a person's ability to detect the gas is affected by rapid temporary paralysis of the olfactory nerves in the nose, leading to a loss of the sense of smell. This means that the gas can be present at dangerously high concentrations, with no perceivable odour. Prolonged exposure to lower concentrations can also result in similar effects of olfactory fatigue. This unusual property of H_2S makes it extremely dangerous to rely totally on the sense of smell to warn of the presence of the gas.

SRB may be present in the human gut and elevated levels (>1,000,000 per g of faeces) has been reported in some individuals. While this does not, in itself, have health effects, the production of excess H_2S may have links to gastrointestinal diseases, but this does not affect all individuals (Christophersen, et al., 2011).

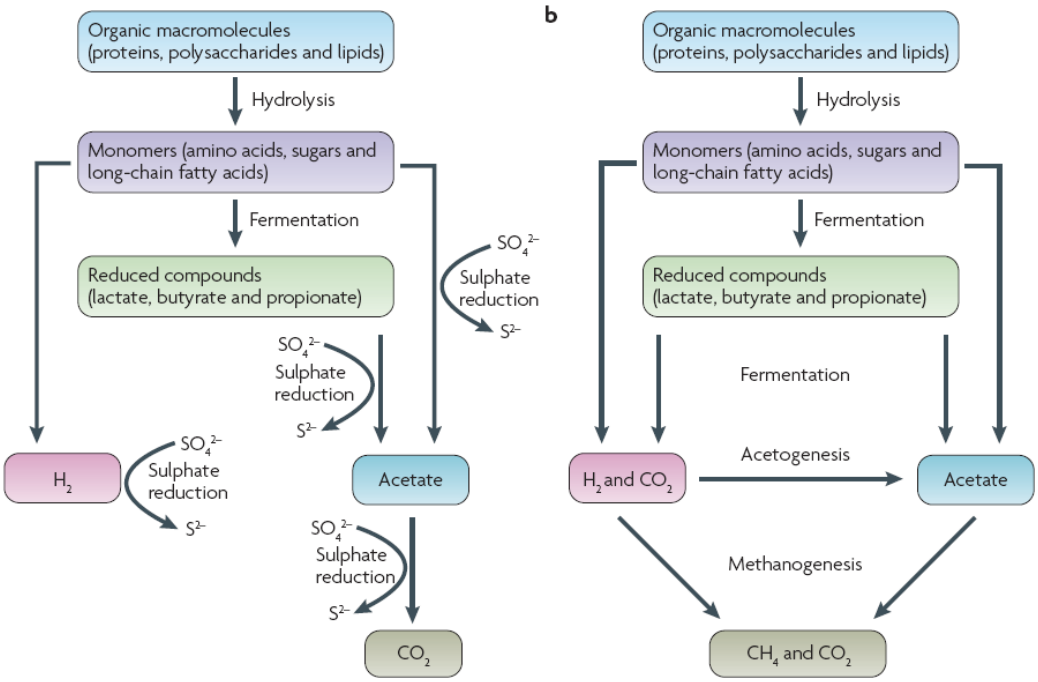
Water with hydrogen sulfide alone (not sewage) does not cause disease; however, sulfate-reducing bacteria can negatively impact the water industry because of their primary role in the anaerobic corrosion of iron in pipelines, heating systems, and other structures. However, these organisms can also be beneficial by removing sulfate and heavy metals from waste streams and are commonly used in the coal and metal mine industry to remediate leachate from acid-waste tailings and abandoned mines

Where do you find SRBs?

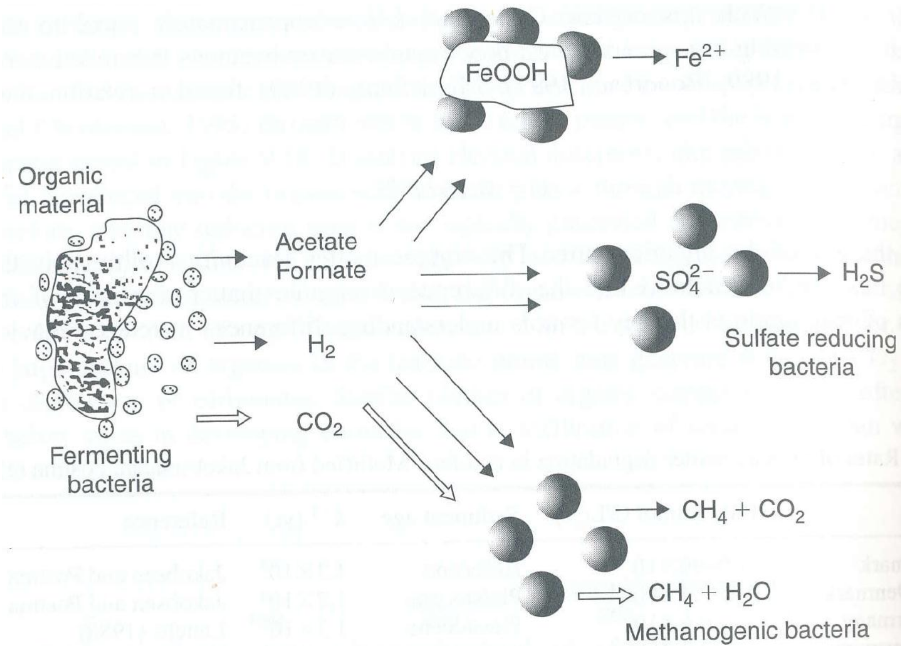
SRB are ubiquitous and can be found in many natural and engineered environments where sulfate is present. Most commonly where anoxic conditions exist, but they have been found in oxic environments. SRB live in environments such as deep wells, plumbing systems, water softeners, and water heaters. These bacteria usually flourish on the hot water side of a water distribution system. Sulfate reduction can occur over a wide range of pH, pressure, temperature, and salinity conditions. Indeed, SRBs are commonly found in surface waters and seawater. Often sulfate and sulfur reduction is apparent from the smell of hydrogen sulfide (similar to rotten eggs) and the blackening of water and sediment by iron sulfide. Scrape the heel of your shoe along the sand at the waters edged of the beach front and the blackened sand is a result of naturally occurring SRB activity.

Organic degradation pathways in anoxic environments

The commonest occurrence of SRB is in organic, anoxic environments. In these environments a distinction can be made between those that also have sulfate present and those that do not. Where sulfate is present, SRB thrive and the degradation process results in generation of H_2S together with carbon dioxide and bicarbonate. Where sulfate is absent the methanogenic bacteria dominate and methane and carbon dioxide is produced. This is outlined in Figure 1 and shown schematically in Figure 2.



- **Figure 1. The sequential pattern of microbial degradation of complex organic matter in anoxic environments in the presence (a) and absence (b) of sulfate (Muyzer & Stams, 2008).**

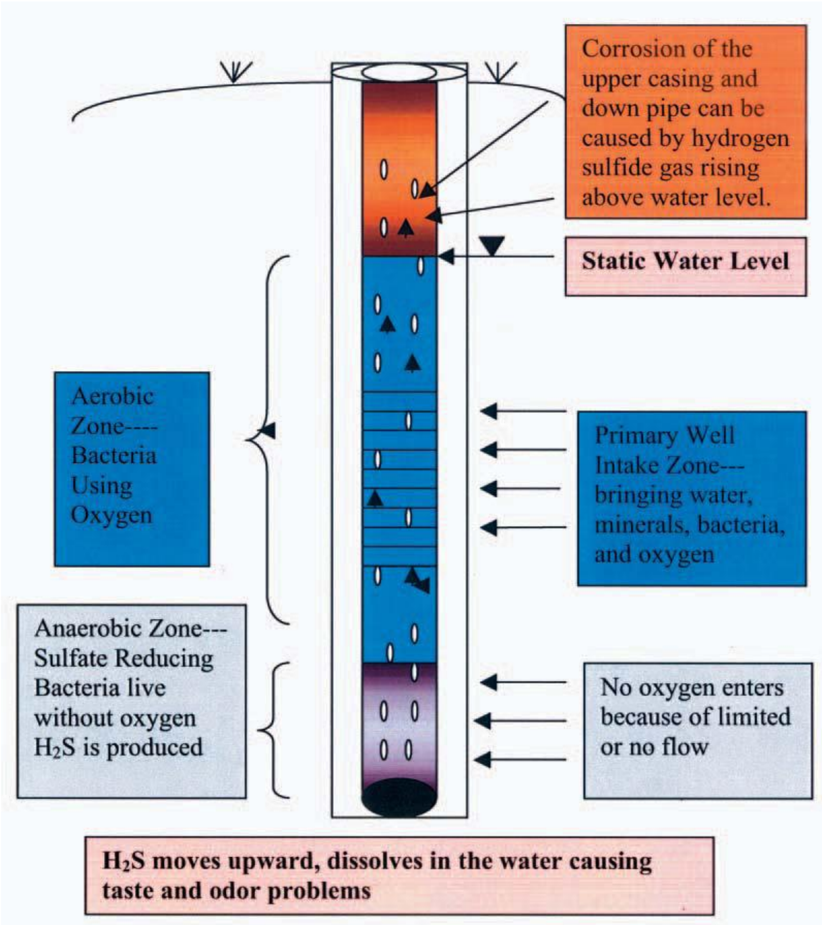


- **Figure 2. Schematic pathway of organic matter decomposition under anaerobic conditions (Appelo & Postma, 2005).**

SRB in water wells

SRB occur in any environment where oxygen levels are low and sulfate levels are significant (not necessarily high). Such conditions invariably exist in wells below the intake zone for pumps or where the water in the well has been allowed to stand for a period of time (Figure 3).

Bacteria reproduce rapidly, doubling every 20 minutes. Wells left standing for even a month will develop communities of anaerobic bacteria and, if there is any sulfate dissolved in the groundwater, then SRB will flourish.



- **Figure 3. Typical water well conditions (Schneiders, 2008)**

In wells that are in constant use, the oxidising effect of continual flushing reduces the levels of SRB as they do not survive in highly oxic environments. There is usually a sump beneath the intake slots, however, and this bottom zone may remain stagnant and therefore provide good conditions for bacterial growth.

SRB generate H_2S, and this is a corrosive gas that will pit and corrode any steel-cased well. These corrosion zones may also provide anoxic conditions (behind the scale) for bacteria to thrive.

Remediation involves thorough cleaning of the pump and removal of any organic material in the bottom of the well and oxidation of the well using chlorine and agitation (Schneiders, 2005). Maintaining a non-acidic environment in the well is also important, particularly in regions where groundwaters have a naturally low pH.

SRBs and CSG

SRB will out-compete methanogenic bacteria if any sulfate is present in the groundwater system. Methane is therefore not produced with coalbed waters that contain significant concentrations of sulfate (>500 mg/L)(e.g. Van Voast, 2003). Fortunately, the geochemical evolution of groundwaters recharged in coal-bearing beds results in rapid biochemical reduction of any sulfate present, precipitating sulfides, thereby depleting the sulfate. Methanogenic bacteria are then free to consume the organic material and produce methane.

There is thus generally exclusivity between CSG wells and wells where SRB may exist.

Yours sincerely

Dr Richard Cresswell

Senior Hydrogeologist

Phone: (02) 9032 1700
Fax: (02) 9928 2224
E-mail: rcresswell@globalskm.com

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