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The function of sulfate-reducing bacteria in corrosion of potable water mains

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Abstract

Growing awareness of the detrimental effect of corrosion in conjunction with bacterial activity in potable drinking water systems has led to an increase in research sponsored by water companies. In particular, sulfate-reducing bacteria (SRB), found in anaerobic conditions underneath the main corrosion shell, are noted for their effects in promoting localized corrosion. This study investigates the presence of sulfate-reducing bacteria in sampled water mains, in a region that would otherwise be expected to be stable, both by direct sampling, by using coupons in a Robbins device installed in the distribution network, and by sampling from laboratory tanks. Samples of pipes of various materials show a high frequency of SRB. Cast iron coupons from the Robbins device gave positive results for SRB after only 1 month in the distribution system, though negative for total viable count and coliforms. Corrosion rates of the coupons in the Robbins device increased in the presence of sulfate-reducing bacteria, indicating microbially induced corrosion. Laboratory coupon tests indicated no sulfate-reducing bacteria present.

Keywords: Corrosion; Sulfate-reducing bacteria; Drinking water

1. Introduction

The incidence of sulfate-reducing bacteria (SRB) colonizing ferrous water mains has been reported for many years (Butlin, 1949; Tuovinen et al., 1980; Beech et al., 1994). These bacteria are generally associated with the area underneath the main corrosion shell since they require anaerobic conditions (Butlin, 1949; Beech et al., 1994). However, anaerobic conditions may also occur on the corrosion surface due to the presence of other aerobic bacteria producing anoxic pockets (Spencer, 1971; Gaylarde, 1989; Jain, 1995). Once colonization has begun, bacterial growth is further promoted due the spread of reducing conditions (Starkey, 1958).

SRB are particularly unwanted in ferrous mains because of their notable effect in promoting corrosion by reducing sulfate to sulfide, which may in turn oxidize hydrogen to give hydrogen sulfide, and this may react further to produce ferrous sulfides or sulfuric acid, which also contributes acid corrosion (Starkey, 1958; Gaylarde, 1992). In addition, the undesirable "rotten egg" smells of hydrogen sulfide, and the possibility of sloughing of the black slime, can lead to consumer complaints and increased health risks. Microbial corrosion by SRB results in severe graphitization of cast iron, leaving a soft surface liable to collapse (Butlin, 1949; Starkey, 1958).

The work reported here forms part of a study to assess the frequency of SRB occurring in the water distribution system (WDS) and their effect on corrosion. Sections of mains pipe were removed from a distribution system and examined directly; a Robbins device was used to assess colonization and corrosion rates of the inner pipe surface by exposing coupons to normal network conditions. Coupons were also immersed in water tanks in the laboratory, to assess whether SRB favour certain conditions.

2. Materials and methods

2.1. Pipe sampling

Sections of drinking water pipes were removed from the distribution system and immediately swabbed. Cast iron samples could then be cut into

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sections for cross-sectional analyses using scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS) and elemental analysis.

2.2. Coupon design and preparation

Two types of cast iron coupons were made—new cast iron (BS 1452) and old cast iron (taken from an original water main). Cast iron (CI) coupons were immersed in two static tanks: one aerobic, where water was changed daily; and one anaerobic with unchanged stagnant water. Coupons were also used in a Robbins device installed in a ductile iron section of the distribution system, where the coupon surface was flush with the inner pipe surface.

Coupon preparation and weight loss measurement was carried out according to ASTM D2688-94.

2.3. Bacterial enumeration

All coupons and pipe samples were immediately swabbed on removal for the presence of sulfate-reducing bacteria, indicator bacteria (total and fecal coliforms), and non-lactose-fermenting (NLF) bacteria. Swabs for SRB were dipped directly into a glass vial containing Postgate E Agar, quickly sealed, and stored in an oven at 25 °C. Other bacterial swabs were sent directly to an independent laboratory for analysis using the membrane filtration method (HMSO, 1994). For pipe samples, an area of approximately 1 cm^2 was swabbed from between the pipe surface and corrosion interface; from the Robbins, 2 coupons of each type of cast iron were swabbed—half the coupon area (approximately 140 mm^2) for SRB, half for indicator bacteria; for static tanks 1 cm^2 was swabbed for both.

2.4. Elemental analysis

Corrosion products were removed from pipe samples and coupons and pre-treated with acid for elemental analysis by ICP-MS and ICP-OES.

SEM-EDS was used to identify structures through the scale, and locations of elements with atomic weight greater than 16 g/mol. In preparation, the samples were embedded with epoxy resin (Struers Epofix®). The samples were then cut to size and the through wall surface was polished with silicon carbide paper of decreasing grit size (120, 240, 400, 800, 1200), followed by diamond polishing (6 and 1 μm). For SEM, the edges and back of the samples are painted with silver electrodag, and subsequently carbon coated. Samples were analyzed using a JEOL JSM 6400 scanning electron microscope coupled to EDS.

3. Results and discussion

3.1. Pipe samples

Table 1 summarizes the bacterial enumeration results of the pipe samples. In total, 10 samples of varying materials—cast iron (CI), ductile iron (DI), and concrete lined (CL) pipes—were all swabbed for SRB and bacteria. For SRB, seven of the samples were positive, thus highlighting the frequency of SRB in the WDS. However, it should also be noted that none of the pipes when sampled had a notable ‘‘rotten egg’’ smell or the black slime that is associated with high levels of SRB. It is unexpected for SRB to be colonizing concrete lined pipes, as they are expected to be found in areas of depleted oxygen, i.e. under corrosion tubercles; however, it has been shown that SRB can become dormant in aerobic areas (Hamilton, 1985) or may colonize anaerobic pockets created by aerobic bacteria (Videla and Herrera, 2005).

The results also show high total viable counts (TVC) with the exception of 6628. It is usually expected that 3 day TVC associated with flora are higher than 2 day TVC that may be associated with fecal contamination. High counts were indicated for sample 5661, which was negative for SRB. No results were available for samples 4900, 5841, and 5848. It should be noted that none of these results are high enough to give concern about the potability of the water.

Due to sample preparation it was not expected to see bacteria directly using the SEM-EDS; however, it was expected that, where SRB were detected, some iron sulfides would be observed. Cast iron samples were analyzed using SEM-EDS, where for all samples, trace amounts of sulfur were detected as well as phosphorous, calcium, and silicon, which are associated with bacterial action (Beech et al., 1994) as well as the base metal suffering heavily from graphitization. For samples 6106, 6626, 5665, and 5481 ratios of iron to sulfur were found to vary—4Fe:1S, 4Fe:3S, 3Fe:1S and 3Fe:4S, indicating the presence of different types of iron sulfides, where the presence of greigite (Fe_3S_4) is indicative of biological activity (McNeil and Little, 1990); an example is given in Fig. 1.

Table 1
Results of bacterial enumeration of pipes sampled from the distribution system

Sample no.	Pipe material	Faecal coliforms	TVC 2 days at 37 °C	TVC 3 days at 22 °C	Coliform	SRB
4900	Ductile iron					Negative
5481	Cast iron					Positive
5484	Cast iron					Negative
5661	Cast iron	0	100	440	0	Negative
5665	Cast iron	0	28	33	0	Positive
6106	Cast iron	0	76	27	0	Positive
6625	Concrete lined	0	13	30	0	Positive
6626	Cast iron	0	40	14	0	Positive
6627	Concrete lined	0	48	20	0	Positive
6628	Concrete lined	0	16	6	0	Positive

Note: TVC is the total viable count.