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Laboratory assessment of bioproducts for sulphide and methane control in sewer systems

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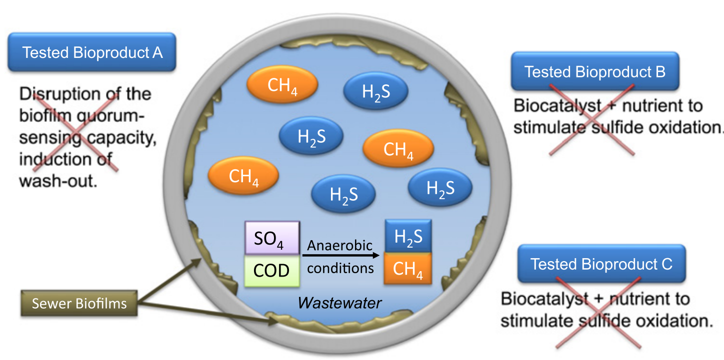
HIGHLIGHTS

- ► Effectiveness of three bioproducts for H_2S and CH_4 control in sewers is tested in a laboratory system.
- ► None of the bioproducts tested showed any significant effects.
- ► Their field application/trials are not recommended.
- ► All bioproducts should be subject to rigorous laboratory tests prior to dosage in real sewers.

GRAPHICAL ABSTRACT



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ABSTRACT

The effectiveness of three bioproducts (also known as biomaterials) for liquid-phase biological treatment (LPBT) of sewer biofilms to control detrimental build-up of sulphide (H_2S) and methane (CH_4) in sewers was tested in a laboratory system mimicking a rising/force main sewer pipe. Bioproduct A claims to disrupt cell-to-cell communication of sewer anaerobic biofilms while Bioproducts B and C claim to enhance sulphidotrophic (sulphide-oxidising) capacity of the sewer biofilm, to avoid sulphide accumulation. The results demonstrated that all three bioproducts tested had no or negligible impact on sulphide or methane control, as opposed to traditional sulphide-controlling chemicals widely used by the wastewater industry such as oxygen, nitrate, iron salts and magnesium hydroxide. Those had previously been demonstrated to be effective using the same laboratory system with the same testing protocol. The implications of the findings are discussed. It is concluded that field application/trials of these three bioproducts are not warranted. It is recommended that other bioproducts should be subject to similar rigorous tests prior to being taken up by the water industry for field trials/application.

1. Introduction

Raw wastewater in most towns and cities is collected and transferred to a central treatment plant via a network of fully surcharged, pressurised rising mains and/or through partially filled gravity sewers. The retention of nutrient-rich wastewater under different conditions

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in sewers allows for significant microbial activity, which impacts on the wastewater characteristics and the environment. Anaerobic conditions in rising mains result in the production of sulphide (H_2S) by sulphate reducing bacteria (SRB). The build-up of H_2S in sewer atmosphere causes detrimental effects such as odour nuisance, health hazards and corrosion of pipes (Thistlethwayte, 1972; USEPA, 1974; Boon et al., 1998; Hvitved-Jacobsen, 2002; Vollertsen et al., 2008). An estimated US$14B is spent on sewer corrosion every year in the US (Brongers, 2001). In addition, recent studies revealed that significant amounts of methane (CH_4) are formed and emitted from sewers, particularly from rising mains (Guisasola et al., 2008; Foley et al., 2009). Methane is a potent greenhouse gas (GHG), with a lifespan of about 12 years and a global warming potential of 21–23 times higher than that of carbon dioxide (IPCC et al., 2006). Uncontrolled CH_4 release is also potentially unsafe since it forms an explosive mixture in air at low concentrations (down to approx. 5%) and therefore poses occupational health and safety risks (Spencer et al., 2006).

Amongst different mitigation strategies to reduce H_2S and CH_4 production in sewers, the addition of chemicals to liquid phase is the most commonly used by water utilities. According to WERF (2007), the large number of products available with claimed H_2S-controlling capabilities can be divided into two main classes: liquid phase chemical treatments (LPCT) and liquid phase biological treatments (LPBT). The LPCT products rely on the chemical reactions between the chemicals dosed and sulphide in the liquid phase to convert it to harmless non-odorous species. They include the injection of oxidising agents like oxygen or nitrate (Hvitved-Jacobsen, 2002; Bachmann et al., 2007; Gutierrez et al., 2008; Zhang et al., 2008) to induce sulphide oxidation, dosage of iron salts that convert dissolved sulphide to FeS precipitates (Firer et al., 2008; Nielsen et al., 2008; Zhang et al., 2009), and the addition of alkali that shifts the sulphide speciation to the harmless HS^- form (Hvitved-Jacobsen, 2002; Gutierrez et al., 2009). In contrast, the LPBT products, also known as bioproducts or biomaterials, aim to alter the community or the metabolism of the microorganisms responsible for generating sulphide and odours in wastewater collection systems. Enzymes to block metabolic pathways of sulphate reducing bacteria (SRB) or addition of specially-breed sulphide-consuming bacteria are examples of the LPBT methods (WERF, 2007). Although the LPCT products are still most commonly used by utilities (Jefferson et al., 2002; Ganigue et al., 2011), there is an increasing number of LPBT products appearing in the market with claimed control capacities, some of them with proven effectiveness in anaerobic biofilm control, for instance free nitrous acid (FNA), which is a biocide at concentrations at sub-ppm levels (Jiang et al., 2011a, 2011b). Unfortunately the effectiveness of majority of the bioproducts commercially available is still far from being established. While some of these products have been tested in real sewers, the results are typically inclusive and difficult to extrapolate. The main difficulty is related to the lack of a ‘control’ system in tests, which would form the basis for an objective comparison. Consequently, testing results have to be compared to historical data, which were obtained under different weather and wastewater conditions. It is known that sulphide production is largely affected by temperature, wastewater flow (or wastewater hydraulic condition) and wastewater composition (Hvitved-Jacobsen, 2002).

The aim of this study is to rigorously assess the effectiveness of three widely available commercial bioproducts for H_2S and CH_4 control in sewers. The work was carried out under well-controlled conditions in a sewer laboratory by means of the previously proposed SCORe-CT method (Gutierrez et al., 2011). The testing involved the use of two specially designed laboratory scale systems able to mimic sulphide and methane production in real rising main sewers, one of which was used as the experimental system while the other was used as a control. The SCORe-CT method has previously been successfully applied to the testing of a number of sulphide-control products including oxygen (Gutierrez et al., 2008), nitrate (Mohanakrishnan et al., 2009), nitrite/free nitrous acid (Mohanakrishnan et al., 2008; Jiang et al., 2011a), magnesium hydroxide (Gutierrez et al., 2009) and iron salts (Zhang et al., 2009). In addition to establishing the effectiveness of a product, the SCORe-CT method also helps to reveal the controlling mechanism for an effective product. Such information is critically important for the development of suitable dosage strategies. A survey of the Australian water utilities and the bioproduct market was undertaken, and the bioproducts tested were selected based on the biological mechanisms claimed by the suppliers, and the effectiveness reported/claimed.

2. Material and methods

2.1. Bioproduct selection

A comprehensive compilation of bioproducts information was performed based on three sources: a national survey of the current practice in the Australian water industry (Ganigue et al., 2011), a review of LPBT literature and direct communication with bioproduct manufacturers. Thirty-three different bioproducts were identified worldwide and classified into 6 different categories based on claimed working mechanisms. These included: enzymatic enhancement, bioaugmentation, bioaugmentation + enzymatic enhancement, breed of bacteria stimulation by trace chemicals, and breed of bacteria inhibition by trace chemicals and masking agents. A shortlist of three bioproducts, named as A, B and C, were selected based on claimed effectiveness in previous field trials, different biological mechanisms and commercial availability in Australia. Bioproduct A claims to disrupt the quorum-sensing capacity (cell-to-cell communication) of the sewer-anaerobic bacteria, thus slowing down its metabolic and reproduction rates. This down-regulation of the bacteria metabolism would weaken the biofilm, which would then be removed from the pipe by the shear stress imposed by the flowing sewage. Bioproducts B and C claim to stimulate the microbial activity of microbes that oxidise sulphide by the addition of biocatalyst and nutrients, into sewers. The enhanced sulphidotrophic capacity of the biofilm would consume the H_2S before it is released to the atmosphere and causes any detrimental effect. Due to a confidentiality agreement, the commercial names and compositions of the bioproducts tested could not be released. However, the results obtained and the discussion carried out on the claimed mechanisms of these products are still highly valuable for the water industry, which is constantly in the search for novel products for sulphide control in sewers.

2.2. Laboratory setup

The laboratory setup used was designed and validated to mimic the main features of anaerobic sewer rising mains including (i) hydraulic features: hydraulic retention times (HRT), turbulence and area-to-volume ratio (A/V), and (ii) wastewater characteristics: sulphate concentration, biodegradable organic matter concentration, pH and temperature (Gutierrez et al., 2011). The system consists of a two lab-scale rising main sewers (control and experimental) operated in parallel (Fig. 1). Each line has 2 completely sealed reactors, connected in series to reproduce upstream and downstream sections of a rising main. Each reactor has a volume of 0.75 L, an inner diameter of 80 mm and an inner height of 150 mm corresponding to an inner surface area of 0.06 m^2. Plastic Kaldnes carriers (circular, 1 cm diameter; Anox Kaldnes, Norway) are distributed on 3 separated rods inside the reactors in order to obtain easily extractable biofilm samples for further detailed microbial and micro-scale analyses. Anaerobic biofilms grew simultaneously in the reactor walls (0.05 m^2) and the surface of the plastic carriers (0.01 m^2). The biofilm area to volume (A/V) ratio is estimated to be 66 m^2/m^3. The system is operated at 20 °C ± 1 °C. Full description of the SCORe-CT setup can be found in Gutierrez et al. (2011).