

Development of a kinetic model for biological sulphate reduction with primary sewage sludge as substrate

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Abstract

The Rhodes BioSURE® Process is a low-cost active treatment system for acid mine drainage (AMD) waters. Central to this process is biological sulphate reduction (BSR) using primary sewage sludge (PSS) as the electron donor and organic carbon source, with the concomitant reduction of sulphate to sulphide and production of alkalinity. To optimise the design, operation and control of (and research into) BSR with PSS, a mathematical kinetic model would be an invaluable aid. This study describes the development of such a kinetic model. A two-phase (aqueous/gas) physical, biological and chemical processes kinetic model for the methanogenic anaerobic digestion of sewage sludges has been proposed (UCTADM1). This model incorporates biological processes for sewage sludge hydrolysis/solubilisation (usually the rate-limiting step) and acidification, acetogenesis, and acetotrophic (clastic) and hydrogenotrophic methanogenesis. Additionally, the background weak acid/base chemistry for water, carbonate, acetate, propionate, ammonium and phosphate species have been included, as well as the physical gas exchanges for carbon dioxide and ammonia. The compound H^+ is explicitly included in the model as a predictive parameter, with corresponding pH inhibition of the methanogenic bioprocesses. Using this model as a basis, it is extended to incorporate BSR. The stoichiometry and kinetics for the bioprocesses (growth and death) mediated by the propionate degrading, acetotrophic and hydrogenotrophic sulphate-reducing bacteria are formulated, including sulphide and pH inhibition. These bioprocesses produce and consume inter alia sulphate and sulphide acid/base species which are not present in the original UCTADM1 model. Accordingly, following the approach in the UCTADM1 model, chemical processes for these are included. Further, in the BSR model the end-product sulphide has a gaseous equilibrium not in the UCTADM1 model, and hence the physical gas exchange for sulphide is included. The BSR biological, chemical and physical processes are integrated with those of the UCTADM1 model, to give a complete kinetic model for competitive methanogenic and sulphidogenic anaerobic digestion with PSS as substrate. This model currently is being evaluated, by application to a series of experimental systems fed a mixture of PSS and sulphate, operated over a range of retention times and pHs.

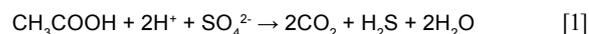
Keywords: biological sulphate reduction, primary sewage sludge, kinetic model

Introduction

Pollution of surface and groundwater resources as a result of mining activities is not unique to South Africa, but occurs in most countries where mining plays a crucial role in the economy. This pollution emanates mainly through the discharge, intentionally (e.g. pumping) or unintentionally (e.g. seepages), of acid mine drainage (AMD) waters to the environment. AMD waters arise from the biological oxidation of pyrite exposed in mining operations, and are characterised by low pH (2 to 3), high iron (10 to 6 700 mg/l) and sulphate (3 000 to 30 000 mg/l) (salinity) concentrations, and varying non-ferrous (usually heavy) metal (e.g. Al 50 to 2 000 mg/l) and TDS (1 800 to 45 000 mg/l) concentrations (Christensen et al., 1996). Accordingly, treatment of AMD prior to discharge, to lessen the environmental impact, has received increasing attention, particularly in South Africa (Holtzhausen, 2005). This treatment requires neutralisation of the pH and removal of the metals (ferrous and non-ferrous) and sulphate.

Most conventional methods for AMD treatment include chemical and/or physical processes, such as precipitation (e.g. as barium sulphate, gypsum, Hammack et al., 1994) and/or membrane filtration, which tend to be expensive and require skilled

operators for the installation and maintenance of the various unit processes and their elements (Furter, 2005). Biological sulphate reduction (BSR) is an attractive alternative or supplement to these processes. In BSR, sulphate is reduced biologically to produce sulphide, consuming protons which neutralises the pH. The produced sulphide forms insoluble precipitates with the metals ions, removing these from solution (Ristow and Hansford, 2001). BSR requires an organic substrate to act as an electron and carbon source; with acetic acid, the reaction is:



Various organic substrates for BSR have been evaluated, such as producer gas, ethanol, methanol and lactate (Dill et al., 2001; Greben and Maree, 2000; Ristow and Hansford, 2001). The pure substrates have proven effective, but are costly. As a lower cost alternative, in the Rhodes BioSURE® process (Rose et al., 2002) for the active treatment for AMD waters, primary sewage sludge (PSS) has been proposed as substrate (electron donor and carbon source) for the central BSR unit process (Furter, 2005).

For this and similar treatment schemes, a kinetic model describing BSR with PSS would be a valuable aid for design, operation and control. Further, the model would be a valuable research tool, to improve understanding of the underlying fundamental processes and their interactions. Such a model would need to incorporate the kinetics and stoichiometry for the two-phase (aqueous/gas, solid to be considered in the future) chemical, physical and biological processes of importance in

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