Modelling of a falling sludge bed reactor using AQUASIM

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Abstract

The falling sludge bed reactor (FSBR) allows for increased solids retention time, resulting in greater substrate conversion for all particulate degradation and biological reactions. The purpose of the FSBR is to hydrolyse primary settled sewage (PSS). Soluble products are then used for the biological treatment of acid mine drainage. A mathematical model has been developed that describes the anaerobic digestion of PSS and biological sulphate reduction in the FSBR. The hydrodynamic processes taking place in the FSBR have been simulated using a system of mixed reactors connected by water flow and mass flux streams. Trends obtained from varying the hydraulic retention time, the sludge recycle ratio, and the feed COD: SO_4^{2-} ratio allow for identification of the critical biological processes taking place in the FSBR, as well as the influence of the operating parameters. Areas where there is a lack of understanding in the mechanism and kinetics have been identified, and these include the influence of sulphate reduction on the hydrolysis of particulate organic matter, as well as the mathematical influence of sulphide inhibition on the various biological groups. A sensitivity analysis shows that hydrolysis is the rate-limiting process, while sulphide inhibition is of importance when sulphate conversion increases.

Introduction

Acid mine drainage (AMD) characteristically consists of high concentrations of heavy metals (Al = 50 to 2000 mg·ℓ^{-1}; Fe = 10 to 6 700 mg·ℓ^{-1}; Zn = 10 to 100 mg·ℓ^{-1}), sulphate (3 000 to 30 000 mg·ℓ^{-1}) and total dissolved solids (1 800 to 45 000 mg·ℓ^{-1}), coupled with a low pH (2 to 3) (Christensen et al., 1996). Biological sulphate reduction is an attractive option for the treatment of AMD. Sulphate reduction directly reduces salinity and protons, producing alkalinity in the form of sulphide, and allowing the precipitation of the heavy metals as metal sulphides or hydroxides. Organic electron donors that have been tested for sulphate reduction include producer gas (Du Preez et al., 1992; Van Houten et al., 1994), intermediate-length carbon chain compounds like ethanol and methanol (Postgate, 1984; Braun and Stolp, 1985; Szewzyk and Pfennig, 1990) and complex compounds such as sewage sludge (Butlin et al., 1956; Pipes, 1960; Burgess and Wood, 1961; Conradie and Grutz, 1973), animal waste slurries (Ueki et al., 1988), lactate and cheese whey (Oleszkiewicz and Hilton, 1986) and molasses (Maree and Hill, 1989).

The Rhodes BioSURE Process used primary settled sewage (PSS) as the electron donor. The AMD was blended with the PSS at a fixed COD: SO_4^{2-} ratio, before being fed to the falling sludge bed reactor (FSBR) which had been seeded with sulphate-reducing bacteria (SRB). The aim of the FSBR was to hydrolyse the particulate organic matter, producing volatile fatty acids (VFAs). The soluble products and sulphate then entered a baffled reactor, where the majority of the sulphate reduction took place. The effluent from the baffled reactor went into an algal-ponding system as a polishing step. Before integration of the process could be performed to include recycling of the alkalinity that is generated, mathematical modelling of the individual unit operations was required. This study focused specifically on the FSBR.

Sulphate-reducing bacteria cannot use particulate or complex soluble organic matter directly. Therefore, they rely on acidogenic bacteria to reduce the long-chain organics to short-chain volatile fatty acids and alcohols. These acidogenic bacteria hydrolyse the particulate organics extracellularly, taking up complex soluble organics and producing short-chain organics. The rate of hydrolysis is dependent on the concentration of this group of bacteria as well as the particulate organic concentration. Therefore, by designing a bioreactor in which a high solids retention time is possible, coupled with a low hydraulic retention time, the conversion of particulates to soluble products can be maximised. The FSBR allows for the internal recycle of settled particulates, uncoupling the solids and hydraulic retention times. This takes place by the settling of the solid matter into three valleys inside the reactor, as opposed to an external settling unit with sludge recycle.

Khan and Trottier (1978) concluded that the presence of reduced sulphur species is essential for the degradation of cellulose. Laboratory studies have also shown an increase in hydrolysis conversion of PSS in the presence of sulphate-reducing bacteria (Wittington-Jones, 1999). Pareek et al. (1998) showed an increase in the conversion of cellulosic materials under sulphate-reducing conditions. By operating the hydrolysis reactor in the presence of biological sulphate reduction, an increased rate of hydrolysis was expected.

Modelling of the biological reactions and the hydrodynamic variations in the FSBR would identify the critical processes taking place within the reactor, as well as highlight areas where further experimentation on this system is required. The kinetic model was developed from a combination of existing models from the literature. A computer program called AQUASIM was used to integrate the rate equations for the various biological and chemical processes. AQUASIM was designed for the identification and simulation of aquatic systems in the laboratory, in technical plants and in nature (Reichert, 1994). It has been applied to a number of biological systems, the majority of these involving nutrient removal by activated sludge. In this study, AQUASIM was applied to a biological sulphate-reduction process.

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