ELSEVIER
Water Research 39 (2005) 1614–1620
WATER RESEARCH
www.elsevier.com/locate/watres

Anaerobic biological treatment of phenolic wastewater at 15–18 °C

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Received 24 November 2004; received in revised form 20 January 2005; accepted 25 January 2005
Available online 17 March 2005

Abstract

Low-temperature, or psychrophilic (<20 °C) anaerobic digestion has been proven feasible for the mineralisation of simple wastewaters. In this study, hybrid expanded granular sludge bed-anaerobic filter (EGSB-AF) bioreactors were used to evaluate the feasibility of psychrophilic digestion for the treatment of phenol-containing wastewater. Efficient chemical oxygen demand and phenol removal were observed at organic and phenol loading rates of 5 kg COD $m^{-3}\,d^{-1}$ and 0.4–1.2 kg phenol $m^{-3}\,d^{-1}$ (400–1200 mg phenol [l wastewater]$^{-1}$), respectively. There was no long-term accumulation of volatile fatty acids in the reactor systems. Methanogenic activity was developed under psychrophilic conditions but anaerobic methane-producing populations remained mesophilic throughout the trial of 415 days.

Keywords: Psychrophilic anaerobic digestion; Phenol; EGSB; Specific methanogenic activity.

1. Introduction

Phenolic compounds are present in the liquid effluent of coal gasification plants, coking plants, petroleum refineries, pharmaceutical, fertiliser and dye manufacturing plants, as well as degreasing and paint stripping operations (Khan et al., 1981) and fibreboard manufacturing (Eroglu et al., 1994). Although not found to be bioaccumulative (Loehr and Krishnamoorthy, 1988), humans exposed to phenol in well water at concentrations of 1300 mg l^{-1} exhibited a statistically significant increase in diarrhoea, mouth sores, dark urine and burning of the mouth (US EPA, 1980).

Anaerobic digestion of phenolic wastewaters enjoys increasing application, and upflow anaerobic sludge blanket (UASB) and expanded granular sludge bed (EGSB) reactor configurations have been successfully demonstrated for the remediation of this category of effluent (Chang et al., 1995; Li et al., 1996).

Continued advances in this field, however, are dependent on concerted efforts to improve and amend existing reactor configurations to design next generation technologies. In this context, the application of EGSB-based state-of-the-art reactor designs currently plays a significant role in the search for broader and newer applications of anaerobic digestion, and the successful widespread adoption of anaerobic reactors for the treatment of the vast and important range of phenolic

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0043-1354/$ - see front matter
doi:10.1016/j.watres.2005.01.017

discharges is strongly dependant on the bioengineering ingenuity required to provide increasingly efficient and versatile technology. Further, and in parallel to this, there is growing interest in maximising methane extraction for energy recovery from anaerobic treatment processes. As the popularity of anaerobic digestion increases, so too does the urgent demand for greater economic efficiency from these processes. This requirement has prompted recent study into the feasibility of low-temperature reactor operations (Rebac et al., 1995; Rebac et al., 1999; Collins et al., 2003).

One of the most important parameters for anaerobic treatment of wastewater is operating temperature. The mesophilic range is traditionally used since it is generally thought that maintaining a high (thermophilic) temperature is uneconomical for many wastestreams, whereas degradation within the psychrophilic range is too slow. However, efficient degradation, which was comparable to that from mesophilic trials, has been demonstrated for a range of wastewater types (Rebac et al., 1995; Lettinga et al., 1999; Rebac et al., 1999; Nozhevnikova et al., 2000; Collins et al., 2003; McHugh et al., 2004). Furthermore, the majority of industrial effluents released for treatment in temperate climates are below 20 °C. It follows, therefore, that psychrophilic anaerobic treatment, which returns satisfactory methane production, presents these countries with an attractive and economically sound option for sustainable remediation regimes. The aim of this study was to evaluate the feasibility of anaerobic biological treatment of phenolic wastewaters under ambient conditions (15–18 °C).

2. Materials and methods

2.1. Biomass

A mesophilic, anaerobic granular sludge was obtained from a full-scale (1500 m^3) internal circulation (IC) reactor, at Carbery Milk Products, Ballineen, Co. Cork, Ireland. The small (Ø, 0.4–0.8 mm), black and grey granules were of a regular form and settled well in liquid phase.

2.2. Reactor set-up and operation

Two 3.5 l glass laboratory-scale expanded granular sludge bed (EGSB)-based reactors (R1 and R2), which were of the same design as that described by Colleran and Pender (2002), with the addition of an upper fixed-film section, which was randomly packed with polyethylene rings of 1 cm diameter each, were used here. These hybrid expanded granular sludge bed-anaerobic filter (EGSB-AF) reactors were each inoculated with 70 g volatile suspended solids (VSS) of the seed sludge. The reactors were used for the stabilisation of a volatile fatty acid (VFA)-based, industrial wastewater (pH 7.5 ± 0.2) consisting of ethanol, butyrate, propionate and acetate, in the COD ratio of 1:1:1:1, to a total of 10 g COD l^{-1}. The influent was buffered with $NaHCO_3$ and fortified, as described by Shelton and Tiedje (1984), with macro- (10 ml l^{-1}) and micro- (1 ml l^{-1}) nutrients. The trial period was divided into six operational phases as detailed in Table 1. A loading rate of 10 kg COD m^{-3} d^{-1} was applied to each reactor, with a hydraulic retention time (HRT) of 24 h, and effluent was recycled at a rate of 5 m h^{-1}. The loading rate was reduced to 5 kg COD m^{-3} d^{-1}, on day 70, when the COD concentration of the influent was decreased to 5 g COD l^{-1}, in order to advance the start-up period of the reactors. The liquid upflow velocity applied through the recirculation facility was increased to 7.5 m h^{-1} and to 10 m h^{-1}, on days 34 and 98, respectively. The operational temperature was maintained at 18 °C until day 395 and at 15 °C for the remainder of the 415-day trial period. R2 influent was supplemented with phenol (Sigma), to a final concentration of 400 mg l^{-1}, on day 138 (Table 1). Phenol was not added to R1, thereby maintaining this reactor as an experimental control. Phenol concentration in R2 influent was increased to 800 mg l^{-1} and 1200 mg l^{-1}, on days 246 and 354, respectively.

Table 1
Particulars of wastewater components

Phase/day		Phenol (mg l^{-1})		COD (g l^{-1})					
				Phenol		VFA		Total	
		R1	R2	R1	R2	R1	R2	R1	R2
I	0–69	0	0	0	0	10	10	10	10
II	70–138	0	0	0	0	5	5	5	5
III	139–246	0	400	0	0.96	5	4.04	5	5
IV	247–354	0	800	0	1.92	5	3.08	5	5
V	355–395	0	1200	0	2.88	5	2.12	5	5
VI[a]	396–415	0	1200	0	2.88	5	2.12	5	5

[a]Phase VI was characterised by the reduction in reactor operating temperature from 18 to 15 °C

2.3. Biogas and effluent analysis

Samples of reactor effluent were taken for VFA and COD analysis and biogas was sampled for CH_4 determination (American Public Health Association (APHA), 1992). In addition, samples of reactor liquor were retrieved from a sampling port located mid-way up the reactor column for COD analysis. Effluent phenol concentrations were ascertained using a colorimetric spectrophotometer (Odyssey DR/2500, Hach) and the 4-aminoantipyrine technique (APHA, 1992). Briefly, this method involved the reaction of phenols with