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Psychrophilic and mesophilic anaerobic digestion of brewery effluent: A comparative study

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ABSTRACT

Two expanded granular sludge bed-anaerobic filter (EGSB-AF) bioreactors (3.38 l active volume) were used to directly compare psychrophilic (15 °C), anaerobic digestion (PAD) to mesophilic (37 °C) anaerobic digestion (MAD) for the treatment of a brewery wastewater (chemical oxygen demand (COD) concentration of $3136 \pm 891\,\mathrm{mg\,l^{-1}}$). Bioreactor performance was evaluated by COD removal efficiency and biogas yields at a range of hydraulic and organic loading rates. Specific methanogenic activity (SMA) assays were also employed to investigate the activity of the biomass in the bioreactors. No significant difference in the COD removal efficiencies (which ranged from 85–93%) were recorded between PAD and MAD during the 194-d trial at maximum organic and hydraulic loading rates of $4.47\,\mathrm{kg\,m^{-3}\,day^{-1}}$ and $1.33\,\mathrm{m^3\,m^{-3}\,day^{-1}}$, respectively. In addition, the methane content (%) of the biogas was very similar. The volumetric biogas yield from the PAD bioreactor was approximately 50% of that from the MAD bioreactor at an organic loading rate of $4.47\,\mathrm{kg\,COD\,m^{-3}\,day^{-3}}$ and an applied liquid up-flow velocity (V_{up}) of $2.5\,\mathrm{m\,h^{-1}}$. Increasing the V_{up} in the PAD bioreactor to $5\,\mathrm{m\,h^{-1}}$ resulted in a volumetric biogas production rate of approximately $4.1\,\mathrm{l\,d^{-1}}$ and a methane yield of $0.28\,\mathrm{l\,CH_4\,g^{-1}\,COD\,d^{-1}}$, which were very similar to the MAD bioreactor. Significant and negligible biomass washout was observed in the mesophilic and psychrophilic systems, respectively, thus increasing the sludge loading rate applied to the former and underlining the robustness of the latter, which appeared underloaded. A psychrotolerant mesophilic, but not truly psychrophilic, biomass developed in the PAD bioreactor biomass, with comparable maximum SMA values to the MAD bioreactor biomass. PAD, therefore, was shown to be favourably comparable to MAD for brewery wastewater treatment and biogas generation.

1. Introduction

Anaerobic digestion (AD) is now an established and proven technology for the effective treatment of a multitude of industrial wastewater categories (Driessen and Yspeert, 1999; Macarie, 2000; Elmitwalli et al., 2001; Bouallagui et al., 2005; Rincon et al., 2006). However, the majority of full-scale applications and research effort, until recently, has been concentrated on AD within the mesophilic (25–45 °C) or thermophilic (45–65 °C) temperature ranges. This was largely due to the belief that sub-ambient or psychrophilic (<20 °C) AD (PAD) was not viable because of low microbial activity and biogas production rates under low-temperature conditions (Lin et al., 1987; Lettinga et al., 2001). Despite this, the majority of industrial effluents are discharged at low-ambient temperatures (Lettinga et al., 2001). As a consequence, one of the

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main advantages of psychrophilic anaerobic wastewater treatment would be increased cost-efficiency, as the need to heat influent wastewaters or to direct AD-produced energy back into system maintenance (e.g. bioreactor heating) is reduced or eliminated. The use of new or modified bioreactor designs, such as various versions of the up-flow anaerobic sludge bed (UASB), internal circulation (IC), expanded granular sludge bed (EGSB) and EGSB-anaerobic filter (EGSB-AF) bioreactors, has, in part, facilitated the successful demonstration of PAD at laboratory scale for the treatment of a wide variety of wastewater categories (Rebac et al., 1995; Lettinga, 1999a; Collins et al., 2003; McHugh et al., 2004; Enright et al., 2005).

The brewery industry consumes and produces significant volumes of process water and wastewater, respectively, resulting in water:beer:wastewater ratios ranging from 4–11:1:2–8 m^3 for each m^3 of beer produced (Driessen and Vereijken, 2003). To date, a number of laboratory and full-scale trials have been carried out with both synthetic and natural brewery effluents, which have concentrated on the applicability of AD to the biomethanation of brewery wastewater and on operational parameters, such as sludge-type employed, bioreactor configuration, hydraulic retention times and organic loading rates (Cronin and Lo, 1998; Ochieng et al., 2002; Driessen and Vereijken, 2003; Parawira et al., 2005). Some breweries that have set up in-house AD wastewater treatment processes have chosen either thermophilic or mesophilic operational temperatures (Harada et al., 1996; Leal et al., 1998; Parawira et al., 2005; Akarsubasi et al., 2006). However, some laboratory-scale work has also been carried out at ambient temperatures, which has illustrated that low-temperature AD of brewery effluents is feasible and can now be considered as an alternative to thermophilic or mesophilic AD (Yu and GU, 1996; Cronin and Lo, 1998). Despite the abundance of research into the stabilisation of brewery effluents, no data have yet been reported from a direct comparison between mesophilic and psychrophilic AD of brewery wastewater. Recently, Enright et al. (2005) recommended that research be carried out to directly compare mesophilic and psychrophilic AD treatment and, in particular, to evaluate the potential of PAD for bioenergy production. This research is imperative if PAD is to be established as a viable treatment alternative within the wider field of industrial wastewater treatment.

The study and data presented in this paper offer a comparison between mesophilic AD (MAD) and PAD. The aim of this study was to assess the process performance of two EGSB-AF bioreactors inoculated from the same seed sludge source and to treat a brewery wastewater. One of the bioreactors was operated at 37 °C, while the second was maintained at 15 °C.

2. Materials and methods

2.1. Source of biomass

A mesophilic anaerobic sludge was obtained from a full-scale, granular biomass nursery plant operated at 37 °C in the Netherlands (Paques B.V.). The sludge consisted of well-settling black granules ranging in size from 1–3 mm in diameter and had a volatile suspended solids (VSS) content of 73 g l^{-1}.

2.2. Bioreactor design and operation

Two identical 3.73 l (active liquid volume, 3.38 l) glass laboratory scale expanded granular sludge bed-anaerobic filter (EGSB-AF) bioreactors, B1 and B2, designed as described by Collins et al. (2005a), were each inoculated with 1.1 l of the granular sludge. This volume of seed sludge provided each bioreactor with 23.8 g VSS l^{-1}. The influent feed supplied to both bioreactors was procured from Beamish & Crawford, Cork, Ireland. This brewery has a production capacity of over 50,000 m^3 per annum, a beer to wastewater ratio of 1:6 and generates between 300,000–420,000 m^3 of process effluent annually. The effluent chemical oxygen demand (COD) discharged from this brewery ranges between 1000–6000 mg l^{-1} depending on product type and volume produced. However, for the period covered by this trial, the average COD concentration was 3136 ± 890.9 mg l^{-1} and the mean pH was 7.2 ± 0.45 (Figs. 1 and 2; Table 1). The treatment trial was divided into four different operational periods, P1–P4. Each period was characterised by a change in either the hydraulic retention time (HRT) or applied liquid up-flow velocity (V_{up}; Table 1). B1 and B2 were operated for a total trial period of 194 d at 37 °C and 15 °C $\pm$ 0.5 °C, respectively.

2.3. Specific methanogenic activity (SMA) assays

SMA assays were performed as described by Colleran et al. (1992) and Coates et al. (1996) using the seed inoculum and granular and fixed-film biomass samples recovered from the bioreactors at the conclusion of the trial (Table 2). The substrates tested, and the concentrations used, were acetate (30 mM), butyrate (15 mM), propionate (30 mM), ethanol (30 mM) and H_2/CO_2 (80:20 v/v) as described in greater detail by Collins et al. (2003).

2.4. Analytical techniques

Samples of bioreactor influent/effluent and biogas were routinely sampled for COD/pH and methane determinations, respectively, according to Standard Methods American Public Health Association (APHA, 1995). Biogas production volumes (biogas yield) were recorded using a wet-gas meter designed and manufactured by Centre Point Electronics, Galway, Ireland. Methane yield coefficient (MYC) values (expressed as l [CH_4 produced] g [COD removed]$^{-1}$) were calculated according to methods reported by Borja et al. (2004) and Rincon et al. (2006). Methane yield efficiency values were derived from the established stoichiometric value of 0.35 l [CH_4 produced] g [COD removed]$^{-1}$ equalling 100% efficiency as reported by Lawrence and McCarty (1969).