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Effects of influent DO/COD ratio on the performance of an anaerobic fluidized bed reactor fed low-strength synthetic wastewater

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ABSTRACT

The effect of influent DO/COD (dissolved oxygen/chemical oxygen demand) ratio on the performance of an anaerobic fluidized bed reactor (AFBR) containing GAC was studied. A high influent DO concentration was found to have adverse impacts on organic removal efficiency, methane production, and effluent suspended solids (SS) concentration. These problems resulted with a DO/COD ratio of 0.12, but not at a lower ratio of 0.05. At first organic removal appeared satisfactory at the higher DO/COD ratio at a hydraulic retention time of 0.30 h, but soon a rapid growth of oxygen-consuming zoogloeal-like organisms resulted, eventually causing high effluent SS concentrations. The influent DO also had an inhibitory effect, resulting in a long recovery time for adequate methanogenic activity to return after influent DO removal began. With the growing interest in anaerobic treatment of low COD wastewaters, the increased possibility of similar adverse DO effects occurring needs consideration.

1. Introduction

There is increasing interest in anaerobic as opposed to aerobic treatment in order to reduce energy consumption, a desired goal because of climate change concerns. Anaerobic treatment produces methane as a renewable energy source while conventional aerobic treatment consumes energy. A typical activated sludge treatment plant uses about 0.3 kWh/m^3 just for aeration, which represents nearly half of the plant's total energy needs (Owen, 1982; Park and Craggs, 2007). Thus, by adopting the anaerobic process for sewage treatment, reduction in greenhouse gas emissions associated with fossil fuel consumption as well as problems and costs involved in sludge management could be achieved. Toward this end, many studies have been conducted recently for the anaerobic treatment of low strength wastewaters such as domestic sewage. Improved anaerobic reactor designs better enable the maintenance of a long solids retention time (SRT) as needed for efficient treatment, while allowing operation at hydraulic retention times (HRT) of only a few hours (Speece, 1996). In lab-scale anaerobic treatment systems with low-strength wastewaters, COD removal efficiencies higher than 90% have been obtained at temperatures of 20 °C and lower (Dauge et al., 1998; Lettinga et al., 2001; Ndon and Dague, 1997; Barber and Stuckey, 1999).

The anaerobic fluidized bed bioreactor (AFBR) is one possible choice for the anaerobic treatment of low strength wastewater as it provides good mass transfer of substrate to the bioflim attached to the support medium, low clogging potential and short-circuiting of flow, and good potential for maintaining a high biomass concentration to yield a long SRT, even at high upflow rates and short HRT (Rittman and McCarty, 2001). In the classic first study of the AFBR, Swizenbaum and Jewell (1980) evaluated treatment efficiency over a temperature range of 10 to 30 °C with a dilute synthetic wastewater having a COD between 200 and 600 mg/L at HRT ranging from 0.33 to 6 h. COD removal efficiencies at 0.33 h HRT ranged from about 40% at 10 °C to about 50% at 30 °C, while at 6 h the respective efficiencies were about 75% and 95%. There are many other studies supporting the above findings for both synthetic and domestic sewage (De Oliveira et al., 2010; Tseng and Lin, 1994; Sanz and Fdz-Polanco, 1990; Maragno and Campos, 1992).

Although the AFBR appears to be a good alternative for dilute wastewater treatment, a possible problem is the effect of dissolved oxygen (DO) contained in the wastewater. As oxygen is toxic to methanogens (Whitman et al., 1992), its presence has been of concern. However, an apparent tolerance of methanogens toward oxygen under oxygen-limited conditions has been reported. Kato et al. (1994, 1997) indicated that an influent DO of 3.8 mg O_2/L to both an upflow anaerobic sludge blanket (UASB) and an expanded granular sludge bed (EGSB) reactor treating synthetic wastewater with COD of 200–400 mg/L produced no detrimental effects on the processes. Stephenson et al. (1999) introduced oxygen into the recycle line of an anaerobic reactor treating a synthetic waste with COD of 3000 mg/L to evaluate the effect on treatment effectiveness. While decreasing methane production, the amount of oxygen introduced

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with air did not otherwise harm anaerobic treatment, although a greater amount introduced with pure oxygen did have an adverse effect. Not provided was information on the oxygen to COD ratios involved, which might give a better quantitative idea of how much oxygen is required to harm the process. Shen and Guiot (1996) investigated the impact of DO concentrations on the characteristics of anaerobic granular sludge by controlling the DO in the recirculated flow between 0.0 and 8.1 mg/L (corresponding DO/COD ratios of 0–0.11). Although COD removal was not affected by the DO level, methane yield decreased as influent DO increased due to significant aerobic degradation of substrate. Slight decline on the acetoclastic activities of granules in the reactor receiving 8.1 mg/L DO was noted after 3 months of operation. For complete-mix, suspended growth cultures, Zitomer and Shrout (1998) concluded that overall COD removal efficiencies for oxygen-limited, strictly anaerobic, and strictly aerobic cultures were comparable. Some negative effects of DO were also reported. Kato et al. (1993) reported that 50% of the methanogenic activity was inhibited after the granular sludge was exposed for 3 days to a headspace gas containing up to 41% O_2 (equivalent to 6 mg/L DO in the bulk liquid phase). Leitao (2004) found effluent volatile fatty acid (VFA) concentration increased following a hydraulic shock load during anaerobic treatment of sewage and speculated that this might have resulted because the influent DO might then have exceeded the ability of the facultative bacteria present to consume it. However, this was not proven to be the cause. Most of the above studies were conducted with high influent COD and mainly focused on organic removal rather than methane production. These limited studies have not provided an adequate quantitative understanding of possible DO effects when treating very dilute wastewaters, which was the objective of this study.

2. Methods

2.1. Anaerobic fluidized bed reactor (AFBR)

The AFBR used (Fig. 1) consisted of a reactor and two settlers, as described in detail elsewhere (Kim et al., 2011). The 3.93 L reactor column (2 m long and 50 mm diameter) contained 450 g of 10 × 30 mesh GAC (MRX-M, Calgon Carbon Corp., Pittsburgh, USA) as support medium for bacterial growth. The height of the GAC without fluidization was 50 cm. A magnet pump (Pan World, NH-100PX-Z, Korea) was used to circulate reactor fluid in order to maintain GAC fluidization. The first of the two identical settlers (2.35 L) connected to the reactor was used to prevent the loss of GAC from the reactor column and the second to prevent possible GAC migration into the recirculation pump. The effluent flowed out through a U-shaped trap. The AFBR was operated in a 35 °C constant-temperature chamber.

Table 1 contains a summary of the AFBR operating conditions during different stages. Each stage is classified according to reactor HRT and influent DO. The influent DO was higher than 6.3 mg/L for Stages I, II-1, and II-3, and was lower than 1 mg/L for the rest of the experiments. The organic loading rate (OLR) was set to 4.2 kg COD/m^3-d for all stages by controlling the amount of stock solution fed to the reactor. HRT was varied between 0.27 and 1.33 h through changes in influent flow rate between 71 and 349 L/d. In order to keep the OLR constant, the influent COD was varied between 47 and 266 mg/L. The GAC bed-expansion was maintained between 240% and 400% by adjusting the recirculation flow between 1010 and 3020 L/day. During stage IV, no recirculation was needed for GAC bed-expansion as the specific gravity of the GAC by then had decreased with increase in biofilm concentration.

The AFBR influent was a mixture of stock feed solution and tap water, each of which was fed separately. The stock feed solution,

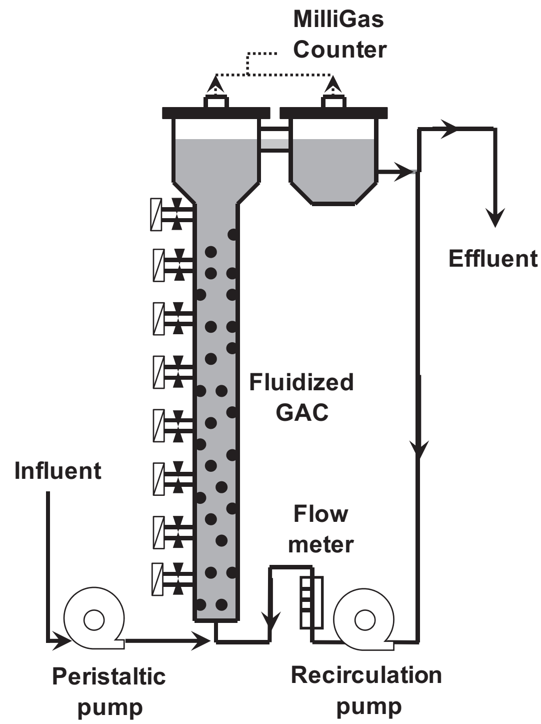

Fig. 1. Schematic diagram of the anaerobic fluidized bed reactor.

kept in a 4 °C refrigerator, was supplied to the recirculation line by a peristaltic pump (Masterflex, Model No. 7520-57, USA). When a low DO influent was desired, the tap water feed was heated to 90 °C, purged with nitrogen gas in a closed water tank and then cooled down to 35 °C. With this pretreatment, influent DO was controlled to <1 mg/L (Table 1). In studies without such pretreatment, the tap water was fed just after heating to 35 °C and contained DO above 6.3 mg/L. The tap water was added separately by a peristaltic pump (Masterflex, Model No. 77521-47, USA) with flow adjusted to provide the desired HRT and substrate concentration.

Before this study began, the AFBR had been acclimated for 96 days after inoculating with 500 mL of anaerobic sludge from a lab-scale CSTR treating primary sewage sludge. During this acclimation period, a variable mixture consisting as COD of methanol (20–50%), sodium acetate (40–50%), and sodium propionate (0–40%) was fed. Following 21 days of batch feeding, continuous feed was begun with an influent COD of 1500–3000 mg/L for about 75 days at OLR of 3.2–6.5 kg COD/m^3-d using an equal COD mixture of acetate, propionate and methanol. Then, the FBR was fed with an equal COD mixture of acetate and propionate for 110 days. Although influent COD was decreased during this time from 2100 to 540 mg/L, OLR was kept in a similar range of 4.3–4.6 kg COD/m^3-d by decreasing HRT from 11.6 to 2.9 h. Following this, the operating conditions listed in Table 1 were begun.

2.2. Analyses

COD and total and volatile suspended solids (TSS and VSS) were analyzed according to Standard Methods (APHA, 1998). For soluble COD, samples were first filtered through 1.2 μm Whatman GF/C filter paper. Alkalinity was measured by the titration method (APHA, 1998) using an end point pH of 3.8. pH was measured immediately after sampling with a pH-meter (Orion A plus portable, USA). VFA were analyzed with an HP 6890 series Gas Chromatograph with flame ionization detector (FID), a 0.5 mm ID graphite column