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Research article

Control of dissolved CH_4 in a municipal UASB reactor effluent by means of a desorption – Biofiltration arrangement

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ABSTRACT

The direct anaerobic treatment of municipal wastewater represents an adapted technology to the conditions of developing countries. In order to get an increased acceptance of this technology, a proper control of dissolved methane in the anaerobic effluents should be considered, as methane is a potent greenhouse gas. In this study, a pilot-scale system was operated for 168 days to recover dissolved methane from an effluent of an upflow anaerobic sludge blanket reactor and then oxidize it in a compost biofilter. The system operated at a constant air (0.9 m^3/h ±0.09) and two air-to anaerobic effluent ratio (1:1 and 1:2). In both conditions (CH_4 concentration of 2.7 ± 0.87 and 4.3% ± 1.14, respectively) the desorption column recovered 99% of the dissolved CH_4 and approximately 30% ± 8.5 of H_2S, whose desorption was limited due to the high pH (>8) of the effluent. The biofilter removed 70% ± 8 of the average CH_4 load (60 gCH_4/m^3h ± 13) and 100% of the H_2S load at an empty bed retention time of 23 min. The average temperature inside the biofilter was 42 ± 9 °C due to the CH_4 oxidation reaction, indicating that temperature and moisture control is particularly important for CH_4 removal in compost biofilters. The system may achieve a 54% reduction of greenhouse gas emissions from dissolved CH_4 in this particular case.

1. Introduction

The anaerobic treatment of municipal wastewater in Mexico and the majority of Latin American countries represents a viable technology due to its low operational costs. This technology shows great potential for application in developing countries of intertropical regions. Although, several factors have limited its application including the generation of odors, the accumulation of floating material inside gas separators and the presence of dissolved methane, a potent greenhouse gas, in the treated effluent which is subsequently released to the environment (Noyola et al., 2006; Chernicharo et al., 2015). Overall, the quantity of CH_4 generated by municipal wastewater systems is limited due to the low concentration of organic matter. In this sense, the production of energy from the anaerobic treatment of municipal sewage is not feasible for small treatment facilities (Noyola et al., 2012).

In Latin America, the majority of small anaerobic wastewater treatment plants (flow < 25 L/s) that treat municipal wastewater do not adequately manage the produced biogas, which is often released to the atmosphere instead of being recovered or burned (Noyola et al., 2012). Notably, during the anaerobic treatment of municipal wastewater, between 30 and 60% of the total CH_4 generated is dissolved in the effluent (Noyola et al., 1988; Souza et al., 2011; Heffernan et al., 2012). Once outside the reactor, the dissolved CH_4 is desorbed due to the turbulence or agitation in the effluent weirs and piping, contributing to the emission of CH_4 to the atmosphere. This gas has a global warming potential up to 34 times greater than that of CO_2 (Myhre et al., 2013) and represents approximately 23% of total greenhouse gas emissions worldwide. The concentration of CH_4 in the atmosphere has reportedly increased at two times the rate of CO_2 (USEPA, 2006). Thus, the recovery of methane produced by wastewater treatment systems is an important strategy for limiting global warming (Nikiema et al., 2005; Noyola et al., 2006). In this regard, the dissolved CH_4 may be stripped using an air flow, resulting in a dilute stream that cannot be flared, or may be used as carbon source for a downstream nitrification-denitrification process (Modin et al., 2007). In the case of small municipal wastewater treatment facilities, the anaerobic

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reactor is usually followed by some simple post-treatment processes, such as ponds, wetlands and trickling filters (Chernicharo, 2006). In such arrangements, the aim is to remove organic matter, not considering nitrogen removal due to cost and complexity considerations. Consequently, the most suitable option for managing dissolved CH_4 in such small treatment facilities is to desorb and then oxidize this gas in a biofilter.

The objective of this study was to evaluate a pilot scale system for controlling CH_4 emissions from municipal anaerobic effluents. The system, intended for small treatment facilities, contained a methane desorption column followed by a compost biofilter for its biological oxidation.

2. Materials and methods

The experimental study was carried out at the wastewater treatment plant of the Acatlan campus, National Autonomous University of Mexico (UNAM), State of Mexico. The installation comprises an upflow anaerobic sludge blanket reactor (UASB) followed by an activated sludge process, disinfection (sodium hypochlorite) and filtration (sand and anthracite) units, with a treatment capacity of 5 L/s. The pilot scale system consisted of a desorption column and a biofilter (Fig. 1a). A schematic diagram is presented in Fig. 1b.

Desorption column. The design of the countercurrent desorption column was based on simulations performed with the software Berkeley Madonna (University of California, USA) using the Onda model (Onda et al., 1968) to determine the mass transfer coefficients. The column was constructed with PVC material and had a diameter of 0.15 m and a packed height of 1 m. The packing material consisted of Pall plastic rings (diameter and height of 2.5 cm, specific area of 280 m^2/m^3 and void fraction of 90%). The wastewater (effluent of the UASB reactor) was fed through a centrifugal pump to the upper part of the column and the air, supply by the post-treatment aeration system, to the bottom, where a differential manometer for pressure drop measurements was installed. The column operated under two wastewater flow conditions (air-to-water ratios of 1:1 and 1:2), with a constant air flow of 0.9 m^3/h (15 L/min) and the corresponding anaerobic effluent flows (0.9 and 1.8 m^3/h). These conditions were selected in order to obtain CH_4 concentrations in the desorbed gas lower than 5%, the lower explosion limit of CH_4. The initial air-to-water ratio (1:1) was determined by the above mentioned software considering 3% CH_4 content in the stripping stream and 95% CH_4 desorption efficiency (resulting in experimental values of 2.7% and 99% respectively). The second operating condition (1:2 ratio) was applied by doubling the water flow to the column, obtaining 4.3% CH_4 content and a similar desorption efficiency. The operating conditions of the desorption column are presented in Table 1.

2.1. Biofilter

For the biofiltration system, a polyethylene recipient 1 m in height with a diameter of 0.85 m was used; the filtration material was a mix of 338 kg of fresh compost and 127 kg of acclimatized compost from another biofilter used for odor control in a wastewater treatment plant in the main campus of the National Autonomous University of Mexico (Ciudad Universitaria, UNAM), Mexico City. The filtering material had a volume of 0.340 m^3, resulting in a packed bed height of 0.60 m. The biofilter had four sampling ports, spaced 15 cm apart along the height of the filter media. A differential manometer was installed at the entrance of the biofilter and a temperature sensor was placed 60 cm inside the media through the second sampling port for continuous monitoring. Considering the air flow fed to the biofilter (0.9 m^3/h), the empty bed retention time (EBRT) was 23 min. Under condition I, the resulting mean concentration of CH_4 was 2.7% ± 0.87 v/v and 4.3% ± 1.14 for condition II. The feeding loads were 35 and 56 gCH_4/m^3h, respectively. The average ambient temperature at the site was 25 °C (max: 31 °C in summer; min: 2 °C in winter).

2.2. Monitoring

The experiment had a duration of 168 days (48 days under condition I and 120 days under condition II). The concentrations of different gases (CH_4, H_2S, CO_2, O_2) in the inlet (after the desorption column) and the outlet of the biofilter were measured with a portable device (BIOGAS 5000, Geotech, USA). The air flow supplied to the column was measured with a calibrated rotameter (Cole-Parmer), and the wastewater flow was determined by means of a graduated cylinder. The concentration of dissolved CH_4 in the liquid influent and effluent of the desorption column were determined according to the method proposed by Souza et al. (2011) and Martí et al. (2012). A pH meter (Orion 4 Start 9157BNMD, Thermo Scientific, USA) was used to measure the pH of the influent and effluent of the desorption column and in the biofilter (filtering media); the moisture content was determined by gravimetric analysis.

3. Results and discussion

3.1. Desorption of dissolved CH_4

Fig. 2 shows the behavior of the CH_4 concentration at the water influent and gas outlet of the column for the duration of the experiment. The percentage of CH_4 in the desorbed gas was related to its concentration in the liquid effluent. Under condition I during the first 48 days of operation, the average concentration of dissolved CH_4 was 12.5 mg/L ± 3.52 (average temperature 19.7 °C ± 1.9). However, based on Henry's law, the equilibrium concentration of CH_4 in water at 20 °C, 0.76 atm (atmospheric pressure at Mexico City) and a biogas with 80% CH_4 is 11 mg CH_4/L, indicating oversaturation in the anaerobic effluent. The concentration of CH_4 in the desorbed gas was 2.7% ± 0.87 for an air to water ratio of 1:1, while it increased to 4.3% ± 1.14 for a ratio of 1:2. The higher concentration obtained under condition II is due to the higher amount of water (and methane) that is fed to the desorption column while maintaining the air flow constant. In both conditions, 99% of the dissolved CH_4 was desorbed and carried to the biofilter.

It should be mentioned that in several occasions under condition II, the concentration of CH_4 in the desorbed gas was greater than 5% (Fig. 2). As mentioned, these variations were related to changes in the dissolved CH_4 concentration entering the desorption column. Considering that the lower explosive limit (LEL) of CH_4 is 5%, these conditions represent an unsafe operation, which may be controlled by dilution, increasing the air flow during those periods.

3.2. Desorption of H_2S

The concentrations of S^{2-} in the column influent and of H_2S in the desorbed gas were 15 mg/L ± 2.68 and 419 ppmv ±75.74, respectively, corresponding to the first set of operating conditions and representing an average desorption efficiency of 28% ± 8. For the second set of conditions, 15 mg/L ± 3.24 and 422 ppmv ±160 were obtained for an average efficiency of 32% ± 8.4. In contrast to CH_4, the desorbed H_2S did not follow the variations of the S^{2-} dissolved in the anaerobic effluent, as this gas is dissociated in water as a function of pH. Fig. 3 shows that the concentration of H_2S in the gaseous stream varied with the pH of the anaerobic effluent.

Based on the H_2S dissociation equilibria (pKa1 = 7.04,

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