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Research article

Leachate/domestic wastewater aerobic co-treatment: A pilot-scale study using multivariate analysis

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ABSTRACT

Multivariate analysis was used to identify the variables affecting the performance of pilot-scale activated sludge (AS) reactors treating old leachate from a landfill and from domestic wastewater. Raw leachate was pre-treated using air stripping to partially remove the total ammoniacal nitrogen (TAN). The control AS reactor (AS-0%) was loaded only with domestic wastewater, whereas the other reactor was loaded with mixtures containing leachate at volumetric ratios of 2 and 5%. The best removal efficiencies were obtained for a ratio of 2%, as follows: 70 ± 4% for total suspended solids (TSS), 70 ± 3% for soluble chemical oxygen demand (SCOD), 70 ± 4% for dissolved organic carbon (DOC), and 51 ± 9% for the leachate slowly biodegradable organic matter (SBOM). Fourier transform infrared (FTIR) spectroscopic analysis confirmed that most of the SBOM was removed by partial biodegradation rather than dilution or adsorption of organics in the sludge. Nitrification was approximately 80% in the AS-0% and AS-2% reactors. No significant accumulation of heavy metals was observed for any of the tested volumetric ratios. Principal component analysis (PCA) and partial least squares (PLS) indicated that the data dimension could be reduced and that TAN, SCOD, DOC and nitrification efficiency were the main variables that affected the performance of the AS reactors.

1. Introduction

Landfilling is a well-established, safe solution for waste management. The environmental effects of landfilling primarily result from greenhouse gas and leachate emissions. Leachate is a dark-colour of wastewater that contains inorganic salts, heavy metals, total ammoniacal nitrogen (TAN), and biodegradable and refractory organic matter (Contrera et al., 2013; Moravia et al., 2013).

Leachate may be classified as young or old according to its physicochemical characteristics. Young leachate is mostly (80%) made of easily biodegradable organic matter, and it has been successfully treated by biological processes. In contrast, old leachate presents two important factors that limit the feasibility of biological treatment processes: high concentrations of TAN and refractory organic matter (Renou et al., 2008; Zhang et al., 2009).

The limitations of biological processes for old leachate treatment can be overcome by its co-treatment with other wastewaters. Co-treatment of leachate and domestic wastewater has been adopted extensively worldwide and presents economic advantages for using existing wastewater treatment plants (WWTP) (Renou et al., 2008).

Leachate co-treatment with domestic wastewater has been tested primarily in bench-scale aerobic systems, and chemical oxygen demand (COD) removals as high as 90% have been reported for leachate volumetric ratios up to 5% (Capodici et al., 2014; Çeçen and Aktas, 2004; Fudala-Ksiazek et al., 2014). Nonetheless, those reports did not clarify whether the leachate slowly biodegradable organic matter (SBOM) was effectively biodegraded by the aerobic microorganisms or simply diluted in domestic wastewater and erroneously included in COD removals.

The current research aimed to verify the behaviour of old leachate SBOM when it was aerobically co-treated with domestic wastewater. For a better assessment of the organic matter and nitrogen removal mechanisms, the experiments were performed in pilot-scale AS reactors operated under a continuous-flow regime, whereas most previous studies were based on lab-scale batch

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experiments. Another innovative aspect of the current research relies on the use of multivariate analysis (PLS and PCA) for the assessment of organic matter and nitrogen removal.

2. Materials and methods

2.1. Leachate, domestic wastewater and mixture of wastewaters

Leachate was collected at the treatment pond of a sanitary landfill located in the Brazilian city of São Carlos-SP. The landfill was closed in 2011 after 21 years of receiving municipal solid waste from São Carlos-SP.

To reduce the TAN from raw leachate to the range of 100–150 mg L^{-1}, air stripping was performed prior to the aerobic co-treatment, according to Ferraz et al. (2013).

Based on previous studies (Campos et al., 2014; Ferraz et al., 2014), the selected volumetric ratios of leachate were 2% and 5%. A sewer system near the campus of the University of Sao Paulo (EESC/USP) provided the domestic wastewater used in this study.

2.2. Activated sludge (AS) reactors

Two identical 95-L aeration tank (rectangular shape) reactors, each with a 30-L clarifier, were used in the experiments. The aeration tanks were provided with air diffusers to maintain the dissolved oxygen (DO) concentration at a minimum of 2 mg L^{-1}.

The inoculum of each AS reactor consisted of 40 L of return activated sludge collected from a municipal WWTP. One reactor was loaded with domestic wastewater (AS-0%), whereas the other was loaded with a mixture of leachate and domestic wastewater at volumetric ratios of 2% (AS-2%) and 5% (AS-5%). Prior to the operation, the reactors were adapted for two weeks at each tested volumetric ratio. Operational conditions included a hydraulic retention time (HRT) of 24 h and a 20-d solid retention time (SRT). The experiments were performed at room temperature (20 °C).

2.3. Analytical procedures

2.3.1. Analytical determinations

The AS reactors were monitored for the following parameters by subsequent analyses conducted in accordance with APHA et al. (2012): biochemical oxygen demand (BOD_5) (Hach BODTrakII respirometric apparatus, method 5210 B); COD (Hach COD reactor 45600-00/Hach DR 2010 spectrophotometer, colorimetric method 5220 D); conductivity (method 2510 B); DO (method 4500 − G); dissolved organic carbon (DOC) (Shimadzu TOC 5000 A Analyser, method 5310 B); nitrate (Shimadzu UV-160A spectrophotometer, method 4500 C − NO_3^-); pH (Digimed DM-22, method 4500 − H^+); solid content (method 2540); total alkalinity (method 2320 B); TAN (Büchi distillation unit B-339, method 4500 C − NH_3 Nitrogen); total heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) (Varian AA240 FS atomic absorption spectrophotometer, methods 3111 B and D); and total Kjeldahl nitrogen (TKN) (Büchi digestion unit B-426, method 4500 C − Norg Nitrogen).

For the spectroscopic monitoring, KBr pellets containing 1 mg of a lyophilised sample and 100 mg of KBr (Ferraz et al., 2014) were used. The FTIR spectra were recorded by a Bomem B-102 FTIR spectrometer. This instrument collected 16 scans over a wavenumber range of 4000 to 400 cm^{-1} at a resolution of 4 cm^{-1}. Origin 8.0 software (OriginLab) was used to plot the spectra.

2.3.2. Evaluation of the leachate slowly biodegradable organic matter (SBOM)removal

A crucial concern in leachate co-treatment is whether the SBOM is biodegraded or diluted. There is no model to accurately address this concern.

A previous study (Ferraz et al., 2014) proposed a tentative method called "equivalent in humic acid" (Eq.HA) with the aim of correlating DOC measurements with equivalent concentrations of humic acid. Although other constituents of leachates SBOM include fulvic acid and humin, humic acid was selected as a representative compound.

It must be emphasised that the Eq.HA is not a precise method: it consists of an analytical tool to estimate the behaviour of the leachate SBOM during co-treatment with domestic wastewater. To determine the equivalent concentration of humic acid in DOC measurements, Ferraz et al. (2014) constructed a calibration curve using different concentrations (5–300 mg L^{-1}) of humic acid (Sigma–Aldrich). The resulting linear regression (Equation (1)) had a R^2 of 0.999 (Ferraz et al., 2014):

$$Eq.HA = -11.37 + 2.7*DOC \quad (1)$$

The leachate SBOM was obtained by discounting the domestic wastewater "COD Eq.HA" from the mixture of leachate/domestic wastewater "COD Eq.HA". This procedure was applied to raw and treated samples, which were compared to assess the percentage of leachate SBOM removal (Ferraz et al., 2014).

2.4. Statistical analyses

The results were evaluated using PCA and PLS multivariate methods while focussing on identifying the physicochemical parameters affecting the performance of the AS reactors regarding organic matter and nitrogen removal. Pirouette 4.5 software was used for both multivariate methods.

Next, PCA was performed on auto-escalated data organised in a matrix of 42 samples and 4 variables while focussing on the similarities among the samples. The variables included DOC, soluble chemical oxygen demand (SCOD), nitrification efficiency (Nitrif) and TAN. Free-ammonia nitrogen (FAN) may be toxic to aerobic biomass as a function of its concentration (Vadivelu et al., 2007). Therefore, the following class variables were selected for PCA: 0–0.04 mg FAN L^{-1}, class 1; 0.04–0.25 mg FAN L^{-1}, class 2; 0.25–1 mg FAN L^{-1}, class 3; 1–1.72 mg FAN L^{-1}, class 4; and 1.72–3.70 mg FAN L^{-1}, class 5. The FAN concentration was calculated as a function of the equilibrium constants, pH and temperature, as described by Anthonisen et al. (1976).

PLS analysis was used to validate the models (Ferreira et al., 1999). FAN was selected as a dependent variable. The contributions of the independent variables (DOC, SCOD, Nitrif and TAN) to the FAN vector were evaluated. The model was validated by leave-one-out to leave-n-out cross-validations, where n corresponded to 10% of the data after the exclusion of outliers. The correlation (R^2) and validation (Q^2) coefficients and the calibration (RMSEC) and validation (RMSEV) errors given compared the statistical relationships, characterised by $R^2 > Q^2$ and RMSEC < RMSEV (Ferreira et al., 1999).

In addition, an analysis of variance (ANOVA) was applied to compare the organic matter and nitrogen removal performance of the aerobic reactors.

3. Results and discussion

3.1. Wastewater characteristics

The physicochemical characterization of wastewaters can be found in the study of Ferraz et al. (2014).The raw leachate presented typical characteristics of old leachates, including alkaline pH, high TAN concentrations (corresponding to an average of 85% of the