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First-order kinetics of landfill leachate treatment in a pilot-scale anaerobic sequence batch biofilm reactor

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A B S T R A C T

This paper reports the kinetics evaluation of landfill leachate anaerobic treatment in a pilot-scale Anaerobic Sequence Batch Biofilm Reactor (AnSBBR). The experiment was carried out at room temperature (23.8 ± 2.1 °C) in the landfill area in São Carlos-SP, Brazil. Biomass from the bottom of a local landfill leachate stabilization pond was used as inoculum. After acclimated and utilizing leachate directly from the landfill, the AnSBBR presented efficiency over 70%, in terms of COD removal, with influent COD ranging from 4825 mg L^{-1} to 12,330 mg L^{-1}. To evaluate the kinetics of landfill leachate treatment, temporal profiles of $COD_{Filt.}$ concentration were performed and a first-order kinetics model was adjusted for substrate consumption, obtaining an average $k_1 = 4.40 \times 10^{-5}$ L $mgTVS^{-1}$ d^{-1}, corrected to 25 °C. Considering the temperature variations, a temperature–activity coefficient $\theta = 1.07$ was obtained. Statistical "Randomness" and "F" tests were used to successfully validate the model considered. Thus, the results demonstrate that the first-order kinetic model is adequate to model the anaerobic treatment of the landfill leachate in the AnSBBR.

1. Introduction

The production of leachate from municipal sanitary landfills is a critical environmental problem due to its chemical characteristics. In Brazil, many cities have problems with the management and treatment of landfill leachate. Anaerobic and aerobic stabilization ponds have demonstrated in practice not to be proper for landfill leachate treatment. In Brazil, a very common solution found was a combined treatment with sewage in municipal wastewater treatment plants, transporting the leachate to be treated from the landfill to an existing wastewater treatment plant, but most of systems were not designed for this combined treatment, presenting inefficiency or imbalances.

Leachate characteristics change from site to site, seasonally, and also over the life of a landfill, with constant changes in flow-generated, chemical composition and concentration. Furthermore, the philosophy of leachate treatment has changed in recent decades. Today, many leachate treatment plants are combinations of different treatment steps for biodegradable and non-biodegradable substances (Ehirir and Robinson, 2011).

The methods applicable to leachate treatment are biological, physicochemical, a combination of these processes, or combined municipal wastewater treatment (Qasim and Chiang, 1994). Biological aerobic and anaerobic treatment of leachate has been extensively researched as pre-treatment for physicochemical treatments. Among the main aerobic treatments, we can highlight sequencing batch and continuous activated sludge (Sun et al., 2010; Kheradmand et al., 2010; Klimiuk and Kulikowska, 2006), biofilters (Xie et al., 2010; Li et al., 2010; Jokela et al., 2002) and rotating biological contactors (Castillo et al., 2007; Kulikowska et al., 2010). Among the anaerobic systems, we can highlight the Upflow Anaerobic Sludge Blanquet (UASB) reactors (Castillo et al., 2007;

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Nomenclature

AnSBBR	Anaerobic Sequencing Batch Biofilm Reactor
AnSBR	Anaerobic Sequencing Batch Reactor
Cd	Cadmium, mg L^{-1}
COD	Chemical Oxygen Demand, mg L^{-1}
$COD_{Filt.}$	Chemical Oxygen Demand of filtered samples, mg L^{-1}
COD_{Total}	Chemical Oxygen Demand of unfiltered samples, mg L^{-1}
CO_2	Carbon dioxide
CH_4	Methane
Cr	Chrome, mg L^{-1}
C_S	Substrate concentration in the reactor, mgCOD L^{-1}
C_{Si}	Experimental value of substrate concentration in the reactor, mgCOD L^{-1}
C_{SR}	Residual substrate concentration in the reactor, mgCOD L^{-1}
C_{S0}	Initial substrate concentration in the reactor, mgCOD L^{-1}
Cu	Copper, mg L^{-1}
C_x	Biomass concentration in the reactor, mgTVS L^{-1}
Eq.	Equation
FAN	Free Ammonia Nitrogen, mgN L^{-1}
fca	Correction factor due to the recovery and conversion, mgHAc $mgCaCO_3^{-1}$
fcb	Correction factor due to interfering substances, mgHAc L^{-1}
F_{Calc}	Factor of F-test calculated
Fe	Iron, mg L^{-1}
$\overline{G}$	Velocity gradient, s^{-1}
HAc	Acetic Acid, mgHAc L^{-1}
H_2O	Water
k_T	Apparent first-order kinetic parameter at temperature *T*, L $mgTVS^{-1}$ d^{-1}
$k_{25°C}$	Apparent first-order kinetic parameter at 25 °C, L $mgTVS^{-1}$ d^{-1}
k_1	Apparent first-order kinetic parameter, L $mgTVS^{-1}$ d^{-1}
Mn	Manganese, mg L^{-1}
N	Nitrogen, mgN L^{-1}
Ni	Nickel, mg L^{-1}
P.	Profile
Pb	Lead, mg L^{-1}
PVC	Polyvinyl Chloride
$\overline{R}$	Mean of the distribution of variable '*R*'
r^2	Coefficient of determination (Pearson correlation coefficient squared)
r_S	Substrate uptake rate, mgCOD L^{-1} d^{-1}
r_x	Biomass growth rate, mgTVS L^{-1} d^{-1}
S	Substrate (organic matter), mg L^{-1}
S_E^2	Estimated variance of experimental error
S_c^2	Estimated variance of the model error
S_{CC}	Squared residuals
S_R	Residual substrate (recalcitrant organic matter)
t	Time, d
T	Temperature, °C
TA	Total Alkalinity, $mgCaCO_3$ L^{-1}
TAN	Total Ammonia Nitrogen, mgN L^{-1}
TFS	Total Fixed Solids, mg L^{-1}
TS	Total Solids, mg L^{-1}
TVA	Total Volatile Acids, mgHAc L^{-1}
TVAA	TVA Alkalinity by Dilallo and Albertson (1961) method, $mgCaCO_3$ L^{-1}
TVS	Total Volatile Solids, mg L^{-1}
VFA	Volatile Fatty Acids, mg L^{-1}
X	Biomass, mgTVS L^{-1}
Z	Standardized form of variable '*R*'
σ_R	Standard deviation of the distribution
Θ	Temperature–activity coefficient (dimensionless)
μ_S	Specific substrate removal reaction rate, mgCOD $mgTVS^{-1}$ d^{-1}
μ_x	Specific biomass growth rate, mgTVS $mgTVS^{-1}$ d^{-1}

Sun et al., 2010; Calli et al., 2006), sequencing batch reactors (Timur and Özturk, 1999; K.J. Kennedy and Lentz, 2000; Imen et al., 2009) and anaerobic filters (Calli et al., 2006).

Anaerobic treatment has been widely used in tropical countries as pre-treatment due to its advantages, especially related to low energy consumption, low sludge production and good performance treating high-strength wastewaters. However, the literature lacks kinetic parameters for the anaerobic treatment of landfill leachate.

In the last two decades, anaerobic sequencing batch reactors (AnSBR) have been researched and considered a potential alternative for treating several types of wastewater. The main advantages of AnSBR are the possibility of achieving high solids retention, high organic matter removal efficiency, providing better effluent quality control and the possibility of suitable process control (Dague et al., 1992). As biomass is not immobilized in fixed supports, this reactor configuration operates in four steps: feeding, reaction (with stirring or liquid recirculation), sludge settling, and effluent draw. Thus, the loss of biomass depends on the sedimentation step, the effectiveness of which depends on the formation of biomass with good settling characteristics (Sung and Dague, 1995).

In order to eliminate the sedimentation step and to minimize biomass loss, Ratusznei et al. (2000) proposed the anaerobic sequencing batch biofilm reactor (AnSBBR) which contains biomass immobilized in an inert support, confined in a basket-like container inside the reactor. As this configuration presented good results in treating synthetic wastewaters (COD about 485 mg L^{-1} and removal efficiency until 86%), the AnSBBR started to be studied, developed and evaluated, testing the feeding strategy influence (Ratusznei et al., 2003), the mechanical agitation rate (Rodrigues et al., 2003; Pinho et al., 2004), the liquid-phase mass transfer (Cubas et al., 2004) and the organic loading (Siman et al., 2004). The AnSBBR was also tested with several wastewaters reaching COD removal efficiencies over 80% by Damasceno et al. (2007) treating diluted whey (average influent COD concentration ranging from 976 to 5969 mg L^{-1}), by Oliveira et al. (2009) treating personal-care industry wastewater (average influent COD concentration ranging from 1035 to 5944 mg L^{-1}) and by Selma et al. (2010) treating biodiesel production effluent (influent COD concentration ranging from 500 to 3000 mg L^{-1}).

Although the results of bench-scale experiments with synthetic and real wastewaters indicate the application of AnSBBR as a promising alternative, pilot and full-scale studies are necessary to evaluate the viability of applying this technology. Sarti et al. (2007) utilized a pilot-scale AnSBBR to treat domestic sewage and, under stable operating conditions, after the start-up period, the average COD removal efficiency was 66%, which is a good performance for an anaerobic reactor treating domestic sewage.