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Performance of leaching bed reactor converting the organic fraction of municipal solid waste to organic acids and alcohols

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ABSTRACT

A lab-scale leaching bed reactor (LBR) was operated to (1) investigate the potential of in-vessel solid-state anaerobic digestion of the organic fraction of municipal solid waste (MSW) and (2) examine the feasibility of using LBRs for hydrolysis/liquefaction and acidification of organic fraction of MSW for maximum total volatile fatty acid (tVFA) and alcohol production. A hydrolysis efficiency of 60% was achieved in the LBR, which was mainly affected by the solids content of organic fraction of MSW, the amount of water addition into the LBR and the channeling through the waste bed. The net mass of tVFA produced was 7000 mg at the end of 80 d. The main individual VFAs produced were acetic and butyric acids and the main alcohol was ethanol. The variations in the by-products of acidification were mainly due to the nature of feed and pH variations in the LBR. LBRs achieved rapid hydrolysis and acidification of organic fraction of MSW, consequently, high hydrolysis yield, chemical oxygen demand removal and tVFA production.

1. Introduction

The management of municipal solid wastes (MSW) may create serious environmental and economic problems. In the developed countries, the trend is to divert a large part of urban refuse away from landfills to controlled bioreactors, providing improved control over operating conditions and allowing the process to be manipulated to achieve more efficient digestion of waste. The concerns on the long term management issues of landfills favor bioreactor practices, which promote short stabilization times and minimize environmental impact (Chugh et al., 1999; O'Keefe and Chynoweth, 2000).

Organic fraction of MSW has high energy content. Due to its composition, organic fraction of MSW can also be considered as an optimal substrate for acidogenic fermentation (Traverso et al., 2000). In general, the beneficial product formation through anaerobic digestion (AD) has been focused on methane only, which is the final product in the methanogenic anaerobic process (Hwang et al., 2004). However, AD must not be seen solely as a biogas production process. In addition to biogas, AD may generate other intermediary and valuable products, such as solvents and volatile fatty acids (VFAs), which can be marketed along with methane. Furthermore, earlier reports indicated that conversion of the MSW can be achieved as VFA production by acidogenic step of AD. The VFA would be extracted and converted to products, such as methyl or ethyl esters for commercial purposes (Ten Brummeler et al., 1991; D'Addario et al., 1993). The aim would be to obtain the maximum concentration of VFA in the liquid phase (Argelier et al., 1998). Using organic fraction of MSW acidogenic fermentation, the yields obtainable in terms of VFA and light alcohols, are up to the 40% of the influent total chemical oxygen demand (tCOD) which is a promising result (Traverso et al., 2000).

Leaching bed reactors (LBRs) were designed mainly to treat the high-solids organic wastes and to recover biogas at high rates. LBRs also constitute a promising option for dry AD of organic fraction of MSW. The results of the organic fraction of MSW studies resulted in the development of two-phase processes including LBRs (Ghosh, 1985; Chugh et al., 1999; Vieitez et al., 2000). The concept of an LBR (also known as percolating anaerobic or dry AD) is basically a one-stage column reactor operated in batch mode, through which leachate (or liquor) is collected at the bottom of the reactor. The solubilisation of complex solid-state organic wastes to simple organic compounds (known as liquefaction/hydrolysis) by hydrolytic microorganisms and their acidification to VFAs and alcohols efficiently by acidogens take place in LBRs.

The concept of a two-stage leaching bed and methanogenic reactor has been used effectively for AD of organic fraction of MSW (Chugh et al., 1999; Vieitez et al., 2000), fruit and vegetable wastes (Mtz-Viturtia et al., 1995), food wastes (Ghanem et al., 2001; Han et al., 2002), animal manure (Demirer and Chen, 2008) as well as biohydrogen production by anaerobic fermentation of food waste (Han and Shin, 2004). However, to the author's best knowledge no study is cited in the literature for the hydrolysis/acidification of

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organic fraction of MSW using LBRs in order to produce organic acids and alcohols. Compared with other biological technologies, LBRs have advantages, including simple operation, low water, energy, and temperature requirements, as well as bioenergy and bioproduct formation.

The annual MSW generation in Turkey is significant which was 16.4 Mt in 2004 accounting for 65.5% of MSW (TURKSTAT, 2006). Therefore, this study was conducted considering the need for an effective MSW management option in terms of both environmental and economical concerns, and the lack of information on acidification of organic fraction of MSW in the LBRs. The objectives were set as to evaluate the performance of LBR for the hydrolysis/liquefaction and acidification of organic fraction of MSW and to attain high-rate anaerobic biodegradation of high-solids (25–30%) organic fraction of MSW. Besides, the individual VFA production was specifically investigated for the potential recovery of these bio-products. The feasibility of using LBR in order to recover maximum total VFA (tVFA) as a result of acidification (fermentation) of high-solids organic fraction of MSW was the main objective of this study.

2. Materials and methods

2.1. Organic fraction of MSW and acidogenic seed culture

The organic fraction of solid waste free of glass, plastic materials and other inorganic materials was collected from the houses of students and supermarkets and stored at 4 °C prior to use. To ensure minimal variations, the collected organic fraction of MSW used in the LBR was apportioned from a total of 6 kg of solid waste that was mainly composed of fruit, vegetable and kitchen wastes (3:2:1 by weight, respectively). The collected organic fraction of MSW was coarsely shredded by meat mincer to an average particle size of about 4 mm and well mixed manually. The characteristics of organic fraction of MSW that was used as feedstock in the LBR are presented in Table 1. The parameters used in the characterization of the organic fraction of MSW were analyzed in three replicates and reported as mean ± standard deviation of three replicates. When the standard deviation values obtained are considered (Table 1), it is seen that the range of standard deviation values were 0.8–1.5%. This range can be considered to be acceptable especially due to the heterogeneous nature of the substrate.

Acidogenic culture was used as seed in the LBR. The mixed anaerobic culture fed with alkalonoid wastewater at a hydraulic retention time and solids retention time of 2 d in a 2 L fed-batch reactor was initially discarded and maintained on acidogenic culture development study in a continuous reactor. Glucose was used as substrate and reactor pH was maintained at 5–5.5 by a pH-controller for 25 d. The developed cultures were periodically sampled for maximum specific acidogenic activity analyses (data not shown) (Soto et al., 1993; Punal et al., 1999). At the end of 25 d, the developed cultures displayed maximum specific acidogenic activity of 22.6 g COD $d^{-1} g^{-1}$ VSS, which was comparable to the literature values stated as 24 g COD $d^{-1} g^{-1}$ VSS (Soto et al., 1993) and 38.1 g COD $d^{-1} g^{-1}$ VSS (Punal et al., 1999). The developed acidogenic cultures were then concentrated by settling before being used as inoculum in the LBR. The suspended solids (SS) and volatile suspended solids (VSS) concentrations of the concentrated seed cultures were 4230 ± 141 mg L^{-1} and 3680 ± 165 mg L^{-1}, respectively.

Table 1
Characteristics of organic fraction of MSW.

Parameter	Value[a]
Real density (kg m^{-3})	1084 ± 9
Bulk density (kg m^{-3})	938 ± 5
Porosity (%)	13.5 ± 0.5
Total solids (g kg^{-1})	248 ± 4
Volatile solids (g kg^{-1})	212 ± 4
Total COD (g kg^{-1})	97 ± 2
Total N (g kg^{-1})	2 ± 0.1
Total P (g kg^{-1})	3 ± 0.2
pH	3.85–4.05

[a] Values were expressed in terms of mean ± standard deviation of three replicates.

2.2. Experimental set-up

Experiments were conducted in a laboratory-scale LBR made of cylindrical PVC column with a volume of 5 L. A sprinkler was placed at the top of the LBR in order to distribute the water homogenously over the bed. A stainless steel mesh (screen) with a pore size of 155 μm was placed at the bottom of the LBR over the leachate collection system (with conical shape) to prevent the mixing of organic solid waste particulates to the leachate. The volume of the sprinkler and the leachate collection system at the bottom of the LBR provided an effective volume of 4 L. The corresponding inner diameter and height were 12.4 cm and 33 cm, respectively.

The LBR was packed with a mixture of acidogenic seed culture, organic fraction of MSW and tap water with volumes of 250, 2500 and 1200 mL, respectively. For the first two d of the operation, tap water was not added to the LBR, except for the initially added water amount of 1200 mL and no leachate was collected from the LBR to achieve saturation of the waste and its full contact with water. After the first 2 d, operation of LBR was performed by daily addition of tap water to the LBR through the sprinkler by using a peristaltic pump and daily collection of the produced leachate throughout 80 d. During the operation time, the volume of water in the LBR was kept at a level of 1.2 L by keeping the water level above the bed at a constant value via manually control. No digested feedstock was removed from the LBR during the operation period. LBR was maintained in a constant room temperature at 35 ± 2 °C.

The volume of the leachate produced was monitored daily and analyzed for its tCOD and soluble oxygen demand (sCOD), TS and volatile solids (VS), VFA contents and pH values.

2.3. Analytical methods

TS, VS and pH analyses of leachate were performed as described in Standard Methods 2540B, 2540E and 4500H, respectively (APHA, 1995). All tCOD and sCOD analyses of leachate were carried out using the spectroquant analysis system, on Aqualytic PC Multidirect Autotest photometer and Aqualytic PC COD vials for COD 0–15 000 ppm (for high medium range – COD values) and COD 0–1500 ppm (for low medium range – COD values). The leachate samples were filtered from 0.45 μm Millipore filter papers before sCOD analysis.

TS and VS analyses of solid waste were performed as described in Standard Methods 2540B and 2540E and TP and TKN analyses of solid waste were measured using Standard Methods 4500-P B-E and 4500-N_{org} B, respectively. SS and VSS values of seed culture were determined by using Standard Methods 2540 D-E (APHA, 1995).

VFAs were determined by a Trace Gas Chromatograph (GC) Ultra (Thermo Co.) device with a flame ionisation detector (FID) fitted with a Zebron ZB-FFAP column, with a length of 30 m, internal diameter of 0.32 mm and film thickness of 0.25 μm. Operating conditions were: injector temperature, 250 °C; FID temperature, 350 °C; oven temperature program: 100–250 °C (8 °C min^{-1}); duration, 2 min. Helium was used as a carrier gas. The leachate samples were initially centrifuged for 10 min at 4000 rpm and then they were stored frozen at a temperature of about −20 °C till the GC analyses. Before the analyses, samples were filtered through