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Effect of increasing salinity on biogas production in waste landfills with leachate recirculation: A lab-scale model study

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ABSTRACT

The effects of salinity on anaerobic waste degradation and microbial communities were investigated, in order to propose an appropriate leachate recirculation process in a waste landfill in a tropical region. A salt concentration of 21 mS cm^{-1} of electrical conductivity (EC) did not affect waste degradation, but a salt concentration of 35 mS cm^{-1} of EC inhibited CH_4 generation. A higher salt concentration of 80 mS cm^{-1} of EC inhibited not only CH_4 and CO_2 generation, but also degradation of organic compounds. The bacterial and archaeal community compositions were affected by high salinity. High salinity can exert selective pressure on bacterial communities, resulting in a change in bacterial community structure. Ammonium caused strong, dominant inhibition of biogas production in the salt concentration range of this study. Quality control, especially of ammonium levels, will be essential for the promotion of waste biodegradation in landfills with leachate recirculation.

1. Introduction

Appropriate management of waste landfills is required worldwide, including in developing countries. Early stabilization of landfills and reduction of environmental pollution by leachate is recognized as an important issue [1]. In most developing countries, landfill leachate is treated in stabilization ponds [2]. Leakage or overflow of untreated leachate to the surrounding environment is a concern, with large volumes of landfill leachate being produced by extensive landfill areas with high seasonal rainfall. Leachate recirculation in landfill bodies is an attractive technology that can reduce the volume of leachate and attenuate pollutants in the leachate by degradation in the landfill body [3,4]. Leachate recirculation is a process known to enhance the biodegradation of organics in waste and leachate, especially in arid regions, since it contributes moisture and extends the retention time [1,5–7]. Recently, a decrease in the biodegradation rate in the dry season in the tropics was reported [8], and Sanphoti et al. [9] reported that leachate recirculation with supplemental water enhanced stabilization in a simulated landfill reactor in a tropical region. In this context, leachate recirculation in waste landfills in tropical regions might improve both the handling of leachate in the rainy season and enhance the degradation of wastes in the dry season.

Landfill leachate typically contains not only a high concentration of organic matter but also salts, ammonium, and metals [10–14]. Sodium, potassium, and ammonium are often detected as major inorganic components in landfill leachate (sodium, up to 10,930 mg L^{-1}; potassium, up to 2243 mg L^{-1}; ammonium, up to 13,000 mg L^{-1}; electrical conductivity (EC), 3–41 mS cm^{-1}) [10–14]. Salt accumulation in landfill bodies can result from repeated leachate recirculation [15], and high salinity and ammonium are known to affect biological processes, including anaerobic digestion [16–19]. However, there are only a few reports on the effect of salinity on waste biodegradation with leachate recirculation [20,21]. To the best of our knowledge, this is the first report on the effect of the accumulation of complex inorganic matter, including salts, ammonium, and metals, on anaerobic waste degradation and microbial communities, as a possible result of leachate recirculation. An evaluation of the impact of salt concentration on microbial activity and community composition should lead to a greater understanding of biogas generation as an end-point reaction.

The purpose of this study was to evaluate the influence of salt accumulation on biogas production and microbial communities with the application of leachate recirculation technology to tropical developing countries in mind.

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2. Materials and methods

2.1. Waste extract and culture media

Organic waste is major component (41–63%) of municipal solid waste (MSW) in tropical developing countries [22,23]. Currently, the most common MSW disposal method in tropical sites is direct landfilling. Degradation of organic wastes in landfills is primarily a result of anaerobic biodegradation processes. Therefore, an anaerobic degradation test using synthetic organic waste was conducted. Synthetic organic waste was made of mixed dog food, rice, and compost (7:7:6 [wet weight]). The synthetic organic waste was mixed at a solid-liquid ratio of 9 by blender and then centrifuged twice (10,000*g*, 4 °C, 20 min). The supernatant was used as the waste extract. Characteristics of the waste extract are shown in Table 1. Culture medium was added to each test system to provide essential elements for bacterial reactions. The composition of the culture medium was as follows [(final concentration, mg L^{-1}): KH_2PO_4 (270), K_2PO_4 (1120), EDTA (EDTA·2Na) (1), $MgCl_2{\cdot}6H_2O$ (100), NH_4Cl (530), $FeCl_2{\cdot}4H_2O$ (10), $CoCl_2{\cdot}6H_2O$ (2), $MnCl_2{\cdot}4H_2O$ (0.5), $NiCl_2{\cdot}6H_2O$ (0.14), Na_2SeO_3 (0.12), $AlCl_3{\cdot}6H_2O$ (0.09), H_3BO_3 (0.05), $(NH_4)6Mo_7O_{24}{\cdot}4H_2O$ (0.05), $CaCl_2{\cdot}2H_2O$ (0.04) and HCl (37.7%) 0.001 mL].

2.2. Anaerobic waste degradation test under different salt concentrations

Continuous leachate recirculation can cause an accumulation of high concentration of inorganic matter in a landfill. Five experimental conditions, A to E, included different salt concentrations. A salt mixture was used to simulate salt accumulation by leachate recirculation. The salt mixture was made based on the concentrations of inorganic matter in the waste extract ($NaHCO_3$, K_2CO_3, $CaCl_2{\cdot}2H_2O$, $FeSO_4{\cdot}7H_2O$, $MgSO_4{\cdot}7H_2O$, $ZnSO_4{\cdot}7H_2O$, $MnCl_2{\cdot}4H_2O$, and NH_4Cl) (Table 2). Condition A was prepared as a control, and the salt mixture was not added. Conditions B–E had concentrations of inorganic matter from the waste extract that were 1, 50, 100, and 200-fold as much as in condition A. Forty milliliters of the waste extract was combined with culture medium, and then the salt mixture was added to each of the conditions. Subsequently, anaerobic sludge (mixed liquor suspended solids [MLSS], 13.6 g L^{-1}) was inoculated into the mixture and the mixture was adjusted to a pH of 7.4–7.6 and a total volume of 80 mL. The sludge was taken from anaerobically digested food waste in a lab-scale reactor. The mixture was added to a 100-mL vial, flushed with nitrogen gas to provide anaerobic conditions, and incubated (100 rpm, 35 °C) for 28 days. The ECs in conditions A–E were 4, 5, 21, 35, and 80 mS cm^{-1}, respectively. Condition A was conducted in quadruplicate, and the other conditions were conducted in duplicate. A blank experiment of each condition using deionized water instead of the waste extract was also performed. The volume and composition of gas produced were measured periodically. Dissolved organic carbon (DOC) was measured on days 0 and 28. Net gas generation and DOC removal efficiency were calculated as follows:

Net gas generation (mL) = gas generation in each condition (mL) − gas generation in the blank of each condition (mL)

$$\text{DOC removal efficiency}(\%) = \frac{\text{DOCi} - \text{DOCe}}{\text{DOCi}} \times 100$$

where DOC_i = concentration of DOC on day 0, and DOC_e = concentration of DOC on day 28.

The specific gas generation rate was calculated using a modified Gompertz equation [24]. A statistical analysis was performed by ANOVA.

Table 1
Characteristics of the waste extract.

Parameter	Concentrations (mg L^{-1})
TS	8380
COD	10200
TOC	3550
TN	70
Calcium	22.4
Potassium	36.8
Sodium	45.9
Iron	0.8
Magnesium	7.5
Manganese	0.3
Zinc	0.5

Table 2
Salt mixture simulating salt accumulation by leachate recirculation (final concentration, mg L^{-1}).

	A	B	C	D	E
NH_4Cl	0	110	5500	11000	22000
$CaCl_2{\cdot}2H_2O$	0	40	2000	4000	8000
K_2CO_3	0	33	1700	3300	6600
$NaHCO_3$	0	85	4300	8500	17000
$FeSO_4{\cdot}7H_2O$	0	2.0	100	200	400
$MgSO_4{\cdot}7H_2O$	0	38	1900	3800	7600
$MnCl_2{\cdot}4H_2O$	0	0.50	25	50	100
$ZnSO_4{\cdot}7H_2O$	0	1.1	55	110	220

2.3. Anaerobic waste degradation test under different inorganic concentrations

The effects of various concentrations of inorganic matter (sodium, potassium, and ammonium) on biogas generation were evaluated. Six batch experiments were conducted with each salt ($NaHCO_3$, K_2CO_3, and NH_4Cl) in the same manner as described above. Conditions Na5, K5, and AM5 were prepared at a final concentration of 5000 mg L^{-1} of each ion (Na^+, K^+, and NH_4^+). Also, conditions Na8, K8, and AM8 were prepared to final concentration of 8000 mg L^{-1} of each ions. Forty milliliters of the waste extract was combined with culture medium, and then the each salt was added to each of the conditions. Subsequently, anaerobic sludge (MLSS, 13.6 g L^{-1}) was inoculated into the mixture and the mixture was adjusted to a pH of 7.4–7.8 and a total volume of 80 mL. The mixture was added to a 100-mL vial, flushed with nitrogen gas to provide anaerobic conditions, and incubated (100 rpm, 35 °C) for 28 days. The ECs in conditions Na5, Na8, K5, K8, AM5, and AM8 were 14, 28, 12, 20, 39, and 59 mS cm^{-1}, respectively. The ratio of free ammonia to total ammonium in conditions AM5 and AM8 (pH 7.4) were estimated to be 3% based on the equation described by Hansen et al. [25]. A blank experiment of each condition using deionized water instead of the waste extract was also performed. The volume and composition of gas produced were measured periodically. Net gas generation was calculated as described above.

2.4. Molecular analysis of microbial community structure

The effects of salt accumulation that can result from leachate recirculation on the community structure of bacteria and archaea were evaluated by comparing the communities in condition A (control) and condition E, which exhibited the strongest inhibition of biogas generation. Total DNA was extracted from 400 μL of the liquid sample in conditions A and E using an ISOIL kit (NIPPON GENE, Tokyo, Japan). The crude DNA extract was purified and concentrated by Montage PCR (Millipore, Bedford, MA, USA) and amplified by PCR using a primer set for the eubacterial 16S rRNA gene, 10F (5′-CAG AGT TTG ATC CTG GCT CAG-3′) and 1492R (5′-