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Pilot-scale landfill with leachate recirculation for enhanced stabilization

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ABSTRACT

A pilot-scale landfill and a two-phase (acidogenesis and methanogenesis) anaerobic sequencing batch reactor (anSBR) system was setup to treat leachate collected from the simulated landfill cell which had leachate recirculation (at <0.3% of total waste volume/day). It was noted there was already substantial acidogenic activity in the landfill cell before the acidogenic reactor. Development of the microbial communities in the two reactors was influenced by the acidogenesis in the landfill cell. A COD half-life of 10 weeks was achieved in the pilot-scale landfill system indicating very fast organics stabilization in the landfill. It was shown that with an ex-situ anSBR augmenting treatment of the landfill leachate, rapid landfill stabilization could be achieved even when leachate recirculation was at a relatively low rate.

Introduction

Sanitary landfilling is by far the most economic and common way for managing municipal solid wastes (MSWs) disposal around the globe. For big countries, such as China, US and Australia, sanitary landfilling makes up 50–90% of MSW disposal [1–3]; for smaller countries, like Japan and Singapore, landfilling contributes to only 2–5% of MSW disposal [4,5], due to land scarcity. After completion, landfill sites may be developed into parks, golf courses and even real estate [6], but such development typically cannot be done soon after landfill closure, because of the long duration necessary for landfill stabilization [7].

Leachate recirculation is a most widely used procedure to enhance landfill stabilization [3,8–12]. Leachate recirculation can help improve the attributes of a landfill in the following ways: increased moisture content, improved leachate quality, increased methane production, increased waste subsidence and lowered heavy metals concentration. To enhance landfill leachate quality and accelerate landfill stabilization, studies on leachate recirculation have often involved high recirculation rates (>10% of total waste volume/day) [8,13–15]. However, the large volume of leachate moved can impose difficulties such as increased risk of leakage and high costs of operation.

Another strategy to accelerate landfill stabilization is by biological treatment [13,16], among which anaerobic treatment is increasingly favored because of its low energy requirement. The advantages of anaerobic treatment (ex-situ) are: faster removal of organic acids from the landfill cell; higher buffer capacity for treated landfill leachate; and improved microbial community balance in both the landfill and anaerobic reactors. O'Keefe and Chynoweth [17] found that with leachate recirculation, anaerobic treatment of leachate could greatly improve the management of landfill in terms of methane production and volatile solids reduction. Two-phase anaerobic treatment, since first proposed by Pohland and Ghosh in 1971 [18], has aroused extensive researches and application of such technology. The idea was to physically separate the two main groups of microorganisms (i.e., acidogens and methanogens) into serial phases (reactors) so as to maximize the growth rate of each. This technology has been shown to be effective in establishing optimal microbial communities in the respective phases, improving process stability, increasing methane production and speeding up substrate turnover rate [19,20]. However, its feasibility in treating landfill leachate was seldom investigated [21],

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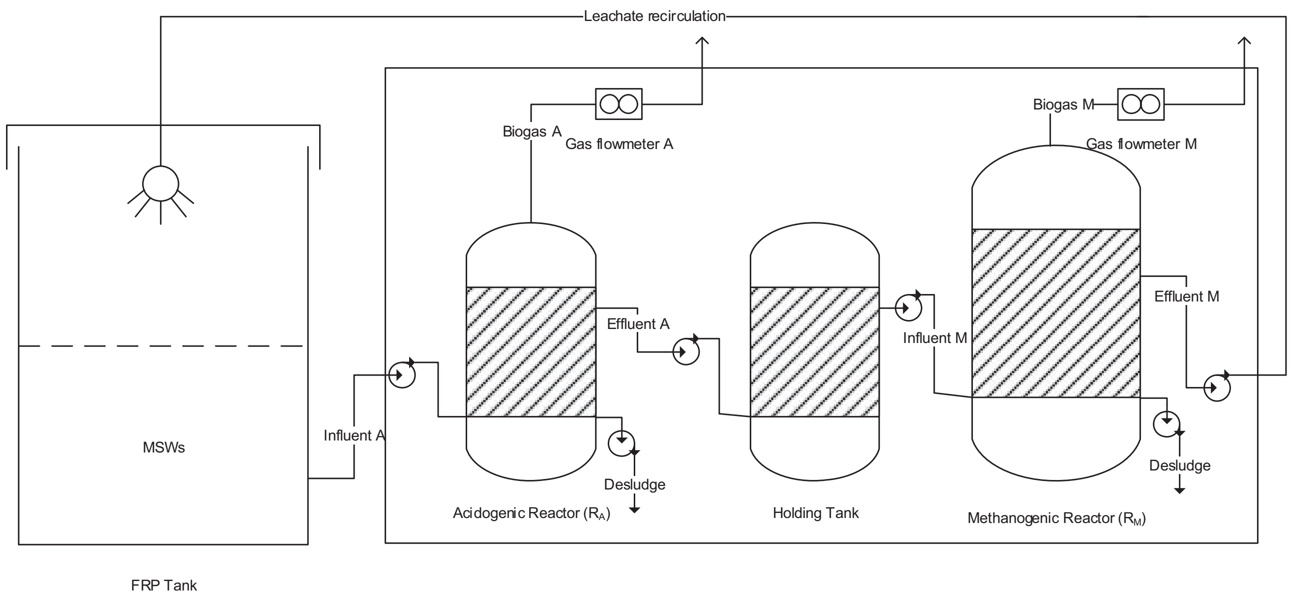

Fig. 1. Schematic diagram of pilot-scale plant set-up.

Table 1
The composition of waste inside the landfill tanks.

Waste type	Weight (ton)	Ratio (%)
Gravel	1.38	17.6
Paper	1.93	24.6
Horticulture	0.38	4.9
Food waste	1.72	21.8
Plastics	2	25.5
Sludge	0.44	5.6
Total	7.85	100

especially at scales larger than laboratory-size and over longer time spans.

In the present study, a Fiber glass Reinforced Plastic (FRP) tank containing MSW was fabricated to simulate a landfill cell. A pilot-scale two-phase anaerobic sequencing batch reactor (anSBR) system was setup to treat the leachate collected from the FRP tank with low leachate recirculation rate (<0.3% of total waste volume/day). The objectives of the study were to: (1) evaluate the effectiveness of low-rate leachate recirculation and two-phase anaerobic treatment in enhancing landfill stabilization; and (2) investigate the development of microbial communities within the two-phase anSBR system.

2. Materials and methods

2.1. Feedstock

The MSW used in the simulated landfill was configured to simulate the composition of MSW in Singapore [4]. Detailed composition of the MSW is as listed in Table 1. The simulated MSWs had 68% (w/w) of the material such as paper, cardboard, plastic, and gravel collected from residential areas, 22% comprising food waste from a local food court, 4.9% of horticultural waste collected from a university campus and the remaining 5.6% would be dewatered sludge collected from Ulu Pandan water reclamation plant, respectively.

2.2. Pilot plant design and operation

The schematic diagram of the pilot plant is shown in Fig. 1. A FRP tank with a diameter of 2 m and height of 4 m was constructed to simulate landfill cell. The FRP tank was placed on a concrete platform and sheltered from rain and direct sunshine. Three vessels comprised the two-phase anaerobic system, and these were placed in a small container. The two reactors [i.e., acidogenic reactor (R_A) and methanogenic reactor (R_M)] were constructed using stainless steel while the holding tank was constructed using FRP. The working volumes of R_A and R_M were 100 L and 200 L, respectively, and that of the holding tank was 100 L. The reactors were jacketed with heating tapes and the temperature controlled at $40 \pm 1\,^{\circ}C$. The pH control, feeding, mixing, desludging, settling and decanting of the two-phase anSBR system together with the simulated landfill were implemented using a programmable logic controller (PLC). pH was controlled by the PLC system with 1 mol/L sodium hydroxide solution and 1 mol/L hydrochloric acid solution. Cycle time was 12 h with feeding (while mixing, 10 min), mixing (10 h 35–40 min depending on desludging time), desludging (while mixing, 0–5 min depending on SS in the reactors and effluent SS), settling (1 h) and decanting (10 min). The control panels used Schneider automation and controller units.

The bottom of the simulated landfill cell was first paved with gravel to ensure better collection and subsequent circulation of the leachate. The seed sludge for R_A and R_M was obtained from an anaerobic digester at a water reclamation plant in Singapore. After collection, the seed sludge was filtered through a 600 μm sieve. R_A was removed from the system in Week 18 to investigate the performance of R_M on its own. Detailed operating parameters are shown in Table 2.

2.3. Analytical methods

Influent and effluent samples were collected from feed tanks and reactors routinely for chemical analysis. Volatile fatty acids (VFAs, C_2–C_8) were measured using gas chromatography (Agilent Technologies 7890A GC system, US) with a Zebron ZB-FFAP 30 m × 320 μm × 0.5 μm column and a flame ionization detector (FID). Prior to analysis, 0.1 mL of 10% formic acid was added to each 0.9 mL of samples and standards for sample acidification. COD, MLSS, and MLVSS were determined in accordance with Standard Methods [22]. MLSS and MLVSS inside the reactors and in the discharge were tracked in order to monitor the SRT.