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Effective anaerobic biodegradation of municipal solid waste fresh leachate using a novel pilot-scale reactor: Comparison under different seeding granular sludge

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HIGHLIGHTS

- A novel IIEC reactor was developed with integration of EGSB and IC construction.
- The pilot-scale (10–15 m^3/d) reactor could effectively treat MSW leachate.
- The OLR was 23.0–40.5 kg COD/m^3 d, much higher than others' results.
- Granular sludge derived from leachate-like-wastewater performed better.

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ABSTRACT

A novel integrated internal and external circulation (IIEC) reactor was developed for anaerobic biodegradation of municipal solid waste (MSW) fresh leachate with chemical oxygen demand (COD) between 40,000 and 60,000 mg/l. The pilot-scale IIEC reactor was inoculated with two kinds of granular sludge from paper mill (S_{PM}) and from citric acid factory (S_{CF}), respectively. The bio-treating capacity in contaminant removal and biogas production performed much superior to others' results, principally attributed to appropriate configuration modification. Compared to S_{CF}, much higher organic loading rate (40.5 vs 23.0 kg COD/m^3 d) and COD removal efficiency (>80% vs 60–75%) were achieved for the reactor with S_{PM}. For methane production, 11.77 or ~6 m^3_{STP}/m^3 d of rate and 66–85% of content were observed with S_{PM} or S_{CF}, respectively. Due to better sludge concentrations and methanogenic activity, these findings indicate the anaerobic reactor could effectively bio-treat MSW leachate for methane generation, especially inoculated with granular sludge derived from leachate-like-wastewater.

1. Introduction

Continuing industrial and commercial growth, increasingly affluent lifestyles, coupled with accelerated product obsolescence and ubiquitous wastefulness tendency, all contribute to the drastically increasing generation of municipal solid waste (MSW) (Ahmed and Lan, 2012). Accompanying with staggering amounts of MSW, leachate, always characteristically rich in organic species, ammonium, heavy metals and other contaminants (Renou et al., 2008), has also become one of the most concerned issues in solid waste management. If simply discharged, MSW leachate will often severely cause destruction to its receiving medium (Sanphoti et al., 2006; Oman and Junestedt, 2008). Thus the effective treatment of MSW leachate has been drawing more and more attentions worldwide, particularly for the fresh leachate generated during the early stage of solid wastes dumping or fermentation.

Among various alternatives, anaerobic digestion not only removes most pollutants without massive sludge production, but also produces bio-methane for renewable energy (Zhou et al., 2007; Trzcinski and Stuckey, 2010), serving as a cost-effective technology for the treatment of such high-strength organic wastewater. Several anaerobic processes, such as up-flow anaerobic sludge blanket (UASB) reactor (Peng et al., 2008; Ye et al., 2011) and anaerobic moving-bed biofilm reactor (MBBR) (Chen et al., 2008), have been demonstrated effective (chemical oxygen demand (COD) removal efficiency >80% and average methane yield >0.3 m^3/kg $COD_{removed}$ under organic loading rates (OLRs) between 10 and 20 kg COD/m^3 d) when treating MSW leachate with COD concentrations higher than 10,000 mg/l. Furthermore, under pilot-scale studies, Turan et al. (2005) and Zayen et al. (2010) also achieved similar favorable results when employing anaerobic

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fluidized bed reactor (AFBR) and anaerobic membrane bioreactor (AnMBR), respectively. Recently, the third generation of anaerobic reactors (e.g., expanded granular sludge bed (EGSB) reactor or internal circulation (IC) reactor with an elevated height/diameter ratio and a recirculation unit for much higher up-flow velocity), modified from the former UASB construction, have received more concerns. Higher OLR of ~20 kg COD/m^3 d and COD removal efficiency of ~90% were reported with bench-scale EGSB reactor treating fresh leachate up to ~70,000 mg COD/l (Liu et al., 2010; Dang et al., 2013). However, there have hardly been studies using this kind of pilot-scale reactor to treat MSW leachate, although some on-site UASB reactors fed with only low-concentration leachate (<3200 mg COD/l) were successfully operated at low temperature (Kettunen and Rintala, 1998; Pelkonen et al., 1999), or a pilot EGSB one with synthetic wastewater was arranged to analyze heavy metals inhibition on methanogenic activity (Colussi et al., 2009). Thus, the effectiveness of the reactor should be further studied especially when fed directly with high-strength fresh leachate without any dilution even at the initial start-up stage. Here, a pilot-scale reactor (so-called integrated internal and external circulation (IIEC) reactor, modified from EGSB and IC construction) was developed to possibly improve the efficiency of anaerobic biodegradation for fresh leachate.

As a bio-granulation technology, successful operation of these second or third generation of reactors greatly depends on their well-settleable and highly-active anaerobic granular sludge containing numerous microbial groups (Liu et al., 2006; Abreu et al., 2007). In order to avoid long-term granulation process and achieve rapid start-up, it is common to inoculate the bioreactor with available granular sludge from other anaerobic processes. The microbiological and physicochemical characteristics of the seeding granule for these reactors are consequently much vital and always strongly affected by the strength and composition of the original wastewater they have treated, showing significant differences (Pevere et al., 2007; van Hullebusch et al., 2007). Thus the relationship between running performances of the anaerobic bioreactor and the properties of its seeding granular sludge should be more studied.

Therefore, the objectives of this study were to evaluate the effectiveness of the novel pilot-scale IIEC reactor for the biodegradation of high-strength MSW fresh leachate, to observe the evolution of the anaerobic granule properties during the running process, and to understand the effect of the seeding sludge on the anaerobic performances.

2. Methods

2.1. MSW leachate

MSW leachate investigated in this study was generated during refuse temporary dumping from Shanghai Jiangqiao waste incineration plant, China. The acidic leachate (pH = 3.7–6.5) was characterized by high-strength organic pollutants (41,448–59,404 mg COD/l with a biochemical oxygen demand (BOD) concentration of 34,000–37,000 mg/l) with good biodegradability (~0.6 of BOD/COD ratio). Ammonium (809–1544 mg NH_3-N/l), sulfate (627–774 mg SO_4^{2-}/l), chloride (3245–3964 mg Cl^-/l) and various heavy metals (Ca 2327–4017 mg/l, Mg 552–914 mg/l, Fe 551–820 mg/l, Cr 0–2.19 mg/l, Cd 0.14–0.60 mg/l, Pb 0.06–0.95 mg/l) were also monitored.

2.2. Seeding granular sludge

Two kinds of anaerobic seeding granular sludge were taken from full-scale IC bioreactors in a paper mill (S_{PM}) and a citric acid factory (S_{CF}), respectively. Both spherical seeding sludge consisted of well-settled black granules and their main physicochemical characteristics are presented in Table 1. The bioreactor was each inoculated with 6 m^3 of these granular sludge to compare their crucial effect on anaerobic performances of the leachate treatment.

2.3. Bioreactor design and operation

MSW leachate biodegradation was continuously monitored using a stainless steel (coated with an anti-rot material) pilot-scale IIEC reactor with an internal diameter of 1.6 m and a height of 9 m (working volume = 18 m^3). As shown in Fig. 1, two pumps were employed to feed the raw leachate (influent) and circulate the mixed leachate, where the later comprised of influent and effluent mixed in a buffer unit to dilute hazardous substances. The produced biogas, treated leachate and granular sludge inside the reactor were duplicately separated through the lower and upper gas–liquid–solid separators, and the detached liquid was re-introduced to the sludge bed through internal circulator all by pressure differential. During the IIEC process herein, it is novel that there were simultaneous internal and external circulation to increase up-flow velocity and also two-stage gas–liquid–sludge separators to improve separating effectiveness, achieving much better hydraulic mixing and biomass accumulation. The temperature of the bioreactor was controlled with a thermostat and heating resistor around 35 °C. The influent flow rate, biogas production and pH were all on-line recorded. Herein, the uncontrolled pH in the buffer unit (i.e., the reacting pH between microbe and organics) varied in the range of 7–8 during the whole running process, owing to the mixture of raw leachate and the effluent.

The IIEC reactor was fed directly with raw leachate and the influent flow rate was gradually increased (i.e., the hydraulic retention time (HRT) reduced) to raise the OLR of the bioreactor under the identical external circulation induced up-flow velocity of 3 m/h. At the same time each day, the influent/effluent COD concentration and the CH_4/CO_2 content in the biogas were monitored. The granular sludge samples were withdrawn from the bioreactor at day 10, 20, 30, 40 and 50, after which the suspended solid (SS), volatile suspended solid (VSS) and specific methanogenic activity (SMA) were all analyzed.

2.4. Analytical methods

The determination of COD, BOD, ammonium, sulfate, chloride and various heavy metals (i.e., Ca, Mg, Fe, Cr, Cd, Pb) of the leachate, as well as SS and VSS of the granular sludge, was carried out according to the standard method (American Public Health Association, 2005). For COD and BOD, methods of titration with dichromate and dilution & inoculation for 5-days were employed, respectively. The CH_4/CO_2 content in the biogas was determined

Table 1
Comparison of physicochemical characteristics between two kinds of anaerobic seeding granular sludge investigated.

Parameter		S_{PM}	S_{CF}
Diameter distribution (%)	>2 mm	30.1	7.2
	1–2 mm	59.9	89.0
	0.5–1 mm	4.9	1.0
	0.1–0.5 mm	5.1	0.9
Settling velocity (m/h)	>2 mm	159	135
	1–2 mm	108	91
	0.5–1 mm	64	34
	0.1–0.5 mm	28	20
SS (mg/l)		116,478	57,050
VSS (mg/l)		86,844	53,683
VSS/SS (%)		74.6	94.1
SMA (ml CH_4/g VSS d)		38	50

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