Preliminary analysis of the bio-mechanical characteristics for High-kitchen Municipal Solid Waste

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Abstract: Degradation of Municipal Solid Wastes (MSW) results in a change in solid skeleton, particle size and pore structure, inducing an alteration of compressibility and liquid/gas conductivity of the wastes. To investigate the complicated biological, hydraulic and mechanical coupled processes of the MSWs, a pilot-scale experimental device which is consist of waste column container, environment regulation system, vertical loading system and measuring system for liquid/gas conductivity is built. With the experimental systems, long-term tests were set up to investigate the biological, hydraulic and mechanical behaviour of the High-kitchen Municipal solid waste with high organic content and high water content. Different values of vertical stress and different degradation conditions (micro-aerobic and anaerobic) were simulated. Throughout the experiments, the changes in total volume, degree of saturation, leachate quantity and chemistry, LFG generation and composition, liquid and gas conductivity were measured. The experimental results will provide solid data for a development of the Bio-Hydro-Mechanical coupled characteristics for High-kitchen Municipal solid waste.

1. Introduction
Municipal Solid Wastes (MSWs) contain biodegradable component, which results in the difference in engineering property between MSWs and traditional soil (Chen, 2013). The biodegradation of MSW is a complicated Bio-Hydro-Mechanical coupled process, which results in the decrease of solid phase and the variation on skeleton, particle size and pore structure of the MSWs.

Lots of experiment devices imitating the soil test apparatus have been designed to study the geotechnical properties for MSW with different degradation degree (Landva and Clark, 1990; Wall and Zeiss, 1995; Hossain, 2003; Reddy et al., 2009a,b; Bareither, 2012). The scale effect has an important influence on the mechanical and biodegraded properties of MSW (Hossain et al., 2009; Bareither et al., 2012), so the measured results by imitating-soil-test device can not be used to accurately estimate the behavior of the field-scale landfill. Currently, there was only a few equipments with large dimension (diameter is more than 30 cm) and bioreactor functions which can measure the variation of geotechnical properties for MSW during bio-degradation process (Beaven, 2000; Ivanova, 2007; Olivier et al., 2007; Reddy et al., 2009c).

In this paper, a pilot-scale experiment apparatus is developed, which can simulate the complicated landfill environment (different buried depth and varied liquid-gas pressure) and measured the geotechnical and biochemical parameters (compression, water content, leachate production and chemistry, LFG generation and composition, liquid and gas conductivity) of the MSWs. The objective...
of the study based on the pilot-scale experimental apparatus is to analyze the changes in MSWs geotechnical properties with waste decomposition and provide reliable data for development of mathematic relationship between time-dependent model property parameters and the degree of degradation (C/L) to describing the coupled behaviour of the MSWs.

2. Pilot-scale experiment apparatus and landfilled waste

The pilot-scale experiment apparatus is consist of waste column container, hydraulic loading system, heating device, measuring system for liquid/gas conductivity and monitoring system.

Synthetic MSW sample was prepared according to the reported composition of fresh MSW by World Bank (2005) for China. As shown in Table 1, degradable matter in MSW is mainly food waste, accounted for 50.0% (wet basis), which has a water content of more than 90%. High water content and high organic matter were the impressive characteristics for the MSW generated in China. The initial physical parameter for landfilled waste is given by Table 2. The experiment was conducted for 200 days.

| Component       | Food waste | Dust, Cinder | Paper | Textile | Plastics | Metal | Glass | Wood | Total |
|-----------------|------------|--------------|-------|---------|----------|-------|-------|------|-------|
| Data(%)         | 50.0       | 15.5         | 13.0  | 2.0     | 14.0     | 1.5   | 2.0   | 2.0  | 100   |

Table 2. Characteristic parameter of MSW sample

| Parameter          | Cell 1 |
|--------------------|--------|
| Total weight(t)    | 0.200  |
| Initial Water Content(%) | 66.5   |
| Height (m)         | 1.12   |
| Density (t/m3)     | 0.725  |

3. Results and discussion

The variation of cumulative LFG production for Cell 1 in 200 days was shown in Figure 1(a). Cell 1 was sealed at the 11d after landfilling finished, so there was no data for LFG production in the first 10 days. The largest LFG production rate appeared between 10 d and 30 d, with the value of 16.83 L/d (0.250Ld⁻¹kg⁻¹-dry-waste). Then the LFG production rate decreased from 4.70L/d (0.070 Ld⁻¹kg⁻¹-dry-waste) to 3.00L/d (0.045 Ld⁻¹kg⁻¹-dry-waste) during 30 d to 180 d. 180 days later, the LFG production rate ceased gradually and the average value was only 0.94 L/d (0.014 Ld⁻¹kg⁻¹-dry-waste). The total LFG production was 735 L (10.97 L/kg-dry-waste).

The variation of the LFG composition (CO₂ and CH₄) was given by Figure 1(b). After sealed at 11 d, the relative concentration of CO₂ reached peak value of 79.0%. Then the relative concentration of CO₂ decreased to 27.15% quickly at 47 d. Between 47 d and 105 d, the relative concentration of CO₂ increased from 27.15% to 42.0%. The relative concentration of CO₂ dropped to 18% at 200 d. The production of CH₄ was firstly observed at 8 d and the relative concentration was 1.43%. Then the relative concentration of CH₄ went up to 36.86% with the degradation process during 8 to 105 d. At the end of the stage-A (200 d), the relative concentration of CH₄ increased to more than 40.0%.

Figure 1(c) and 1(d) provided the change on the concentration of the pH and COD measured in effluent leachate. The pH value remained between 5.26–6.26, that indicated the MSW cell was in acid environment. The COD concentration increased gradually from 18.31 g/L to maximum value of 47.75 g/L, due to rapid release and hydrolysis of complex organics from solid waste to the leachate, and then remained at a high level due to the accumulation of volatile fatty acid (VFA).

The bio-degradation process of MSW can be seperated into 5 stages (Ivanova, 2007): aerobic degradation, acidogenesis, acetogenesis, methanogenesis, aerobic. Referring to Olivier (2007), three successive stages of bio-degradation can be observed for stage-A: aerobic (0–11 d, not sealed for Cell 1), acidogenesis (12–105 d, with pH≥6.0, CO₂≥25%, CH₄≤40%), acetogenesis (105 ~200 d, with pH↑,
45% \ (>\ CO_2 \ >\ 20\%\ ,\ 60\% \ (>\ CH_4 \ >\ 40\%\ ).\ The\ duration\ of\ stages\ 1\sim3\ was\ almost\ same\ as\ that\ described\ by\ Olivier\ (2007)\ (203\ days).

Figure\ 1(f)\ showed\ the\ surface\ settlement\ of\ Cell\ 1.\ 5\ days\ after\ landfilling,\ the\ accumulated\ settlement\ was\ 11\ cm\ (corresponding\ strain\ is\ 0.098).\ At\ 61\ d\ the\ settlement\ was\ developed\ to\ 14.2\ (corresponding\ strain\ is\ 0.126).\ During\ 62\ to\ 200d\ the\ settlement\ can\ be\ neglected,\ which\ was\ less\ than\ 1\ mm.

![Figure 1](image1.png)

**Figure 1.** Characteristics of effluent leachate, LFG and settlement

There\ was\ no\ vertical\ load\ applied\ on\ the\ MSW\ cell\ at\ the\ stage-A\ of\ experiment,\ so\ the\ settlement\ can\ be\ thought\ as\ the\ time-dependent\ biocompression\ induced\ by\ the\ rapid\ hydrolysis\ of\ the\ food\ waste\ and\ the\ release\ of\ the\ intracellular\ water.\ According\ to\ the\ $C'_{\alpha}$\ model\ (Hossain\ and\ Gabr,\ 2005),\ the\ $C'_{\alpha}$\ obtained\ for\ the\ biocompression\ in\ stage-A\ of\ Cell\ 1\ was\ 0.054,\ that\ was\ close\ to\ the\ $C'_{\alpha,M}$\ (0.020\sim0.056)\ calculated\ by\ Bareither\ (2012)\ based\ on\ laboratory\ compression\ experiments\ with\ different\ type\ MSWs.

The\ leachate\ production\ of\ MSW\ in\ Cell\ 1\ was\ shown\ in\ Figure\ 1(e).\ From\ 0\ to\ 60\ day,\ the\ accumulated\ leachate\ production\ accounted\ for\ 87.33\%\ of\ the\ total\ leachate\ production\ (56.472\ L).\ It\ indicated\ that\ at\ the\ beginning\ of\ degradation\ the\ settlement\ was\ affected\ directly\ by\ the\ leachate\ production.

The\ measured\ saturated\ permeability\ was\ shown\ in\ Figure\ 2.\ By\ immersion/drawdown\ cycles,\ the\ effective\ porosities\ for\ Cell\ 1\ at\ different\ time\ were\ 0.427,\ 0.476\ and\ 0.442\ respectively.\ The\ saturated\ permeabilities\ were\ 1.67\times10^{-4}\ m/s,\ 3.18\times10^{-4}\ m/s\ and\ 2.15\times10^{-4}\ m/s\ respectively.\ The\ gas\ permeability\ decreased\ from\ 5.06\times10^{-11}\ m^2\ to\ 6.04\times10^{-12}\ m^2,\ while\ the\ degree\ of\ saturation\ varied\ from\ 38\%\ to\ 66\%.

![Figure 2](image2.png)

**Figure 2.** Saturated permeability and gas permeability
4. Conclusions
In pilot-scale MSW model experiments, the following observations were found:

1) Under anaerobic environment without vertical additional stress, three successive stages of biodegradation for Cell 1 can be observed during the first 200 days: aerobic (0~11 d, not sealed for Cell 1), acidogenesis (12~105 d, with pH≈6.0, CO$_2$≥25%, CH$_4$≤40%), acetogenesis (105 ~200 d, with pH↑, 45% > CO$_2$ > 20%, 60% > CH$_4$ > 40%).

2) It indicated that at the beginning of degradation the settlement was affected directly by the leachate production;

3) The saturated permeabilities for Cell 1 ~ 3 were 1.67×10$^{-4}$ m/s, 3.18×10$^{-4}$ m/s and 2.15×10$^{-4}$ m/s respectively with the method of constant head test. The gas permeability decreased from 5.06×10$^{-11}$ m$^2$ to 6.04×10$^{-12}$ m$^2$, while the degree of saturation varied from 38% to 66%.

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