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# Earth Surface Processes and Environmental Sustainability in China

# Performance of an intermediate soil cover for landfill sites

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ABSTRACT: This study aimed to improve the performance of an intermediate covering of soils in landfill sites by using agents such as calcined lime, sawdust and polyacrylamide (PAM). Compressive strength, permeability and water-holding capacity of modified soils were measured, and the effects of regulating pH and pollutant removal in leachate were also investigated in a leaching experiment. The results indicate that three modifying agents could improve the compressive strength of an intermediate soil cover. The permeability of lime-treated soil increased as the amount of lime increased, while that of sawdust- and PAM-modified soil declined. Results from a leaching experiment show that lime- and sawdust-modified soils could improve leachate quality. The pH value of leachate from 5% lime-modified soils was 7.78, which is suitable for the metabolism of anaerobic microorganisms. The removal efficiencies of chemical oxygen demand, total organic carbon, total nitrogen and volatile fatty acids in leachate permeating lime- and sawdust-modified intermediate cover was improved so that the pollution load of leachate was reduced. The water-holding capacities for 20% sawdust and 0.5% PAM-modified soils were 65.19% and 43.52%, respectively, which helps to maintain the optimum water content of landfill. The water-holding capacity of PAM-modified samples declined in alkaline soil. It is concluded that the combination of 5% sawdust, 5% lime and 90% soil would be optimal for an intermediate covering layer.

KEY WORDS: bioreactor landfill, compressive strength, intermediate cover, leachate pollutants, permeability coefficient, water-holding capacity.

Several methods are used in China to dispose of municipal solid waste (MSW), with landfill being the dominant one (Zhang *et al*. 2010). The Chinese standard for pollution control of MSW landfill sites (GB16889-2008) stipulates that MSW should be covered by soil to prevent pollution as soil provides microorganisms and assists with soil water distribution. Suzuki *et al*. (2008) report that the concentrations of heavy metals (e.g., nickel, manganese, copper, zinc, lead and cadmium) in leachates with a soil cover were less than those without one.

The intermediate cover is used to cover the MSW in multiple layers. This is to avoid direct contact between the MSW and the environment, the spread of odour and the infiltration of rain water into the landfill. Generally, intermediate cover is created by using soils from adjacent areas for cost and convenience reasons. However, the quality of natural intermediate covers differs from one place to another. The permeability coefficient for intermediate covering should be neither too great nor too small. Studies have shown that poor permeability and low porosity make soils very unfavourable to microorganisms (Chugh *et al*. 1998). Therefore, the intermediate covering of soils needs to be modified to improve their performance for sanitary landfill.

Often, several substances are added to intermediate covers. The blending of soils and lime can adjust the pH of leachate *in situ*, to increase the removal efficiency of heavy metals (Safari & Bidhendi 2007) and to reduce $H_2S$ emissions (Plaza *et al*. 2007). Polyacrylamide (PAM) has a significant effect on stabilising the structure of soils through improving moisture content and reducing fertiliser loss (Lu *et al*. 2010). A PAM ratio of soil 0.1% could increase the moisture content in landfill by 12%, promote microbial activities by 3.3 times and reduce leachate by 75.6% (Lu *et al*. 2012). The combined use of PAM and lime can promote the effect of coagulants for increasing the precipitation of phosphorus, carbonates and sulphates. Jiang *et al*. (2010) point out that the phosphorus adsorption capacity of PAM- and lime-treated soils is greater than that of PAM- and humus-treated soils. Furthermore, sawdust is a natural water-retention agent because it contains fibre and has many capillaries, a large surface area and good water absorption. There is a large amount of lignin in the organic fractions, which are recalcitrant during fermentation, with greater compressive capacity and water retention (Bramryd & Binder 2001). In fermentation, lignin has no adverse effects on soil microorganisms, and its larger surface area can speed up the activities of microorganisms (Perdikea *et al*. 2008).

Because traditional landfill usually has slow degradation of MSW, bioreactor landfill technology is proposed as a way of

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**Table 1** Physical and chemical parameters of landfill leachate used in the experiments ('–' indicates that the elements have not been detected). Abbreviations: $\mathrm{COD}_{\mathrm{Cr}}$ = chemical oxygen demand by potassium dichromate method; Zn = zinc; Mn = manganese; Cr = chromium; Cu = copper; Cd = cadmium; Ni = nickel; Pb = lead.

| Component | Value | Component | Value |
|---|---|---|---|
| Colour | Black and grey | Cd (mg $\mathrm{L}^{-1}$) | – |
| pH | 5.52–7.50 | Ni (mg $\mathrm{L}^{-1}$) | – |
| CODcr (mg $\mathrm{L}^{-1}$) | 13,094–19,717 | Pb (mg $\mathrm{L}^{-1}$) | – |
| TOC (mg $\mathrm{L}^{-1}$) | 7780 | Acetic acid (mg $\mathrm{L}^{-1}$) | 4567.30 |
| TN (mg $\mathrm{L}^{-1}$) | 1177 | Propionic acid (mg $\mathrm{L}^{-1}$) | 452.52 |
| Zn (mg $\mathrm{L}^{-1}$) | 4.06 | Isobutyric acid (mg $\mathrm{L}^{-1}$) | 520.16 |
| Mn(mg $\mathrm{L}^{-1}$) | 2.73 | Butyric acid (mg $\mathrm{L}^{-1}$) | 264.33 |
| Cr (mg $\mathrm{L}^{-1}$) | 1.31 | Isovaleric acid (mg $\mathrm{L}^{-1}$) | 478.07 |

**Table 2** Evaluation criteria of the intermediate covering soil in landfills. Abbreviation: VS = volatile solids.

| Index | Water content % | Compact density kg $\mathrm{m}^{-3}$ | VS % | Permeability coefficient cm $\mathrm{s}^{-1}$ | Compressive strength kPa |
|---|---|---|---|---|---|
| Evaluation criteria | <40 | >600 | <50 | $10^{-4} \sim 10^{-5}$ | >50 |

accelerating waste degradation by injecting a liquid, adding nutrition, regulating temperature, adjusting pH and inoculating microorganisms (Wang & Pelkonen 2009). Some reports propose water addition or leachate recirculation to obtain optimal pH and moisture content in bioreactors (Townsend *et al.* 1996; Yang *et al.* 2006; Mali *et al.* 2012; Aguilar-Virgen *et al.* 2014). Guérin *et al.* (2004) conclude that maintaining the moisture content between 40 and 70 % by leachate recirculation promotes microbial activities.

Although there have been many studies on the effects of the intermediate covering of soils, there is still a need to improve knowledge on the impacts on soils associated with bioreactor landfill. Water-retention agents are often employed to reduce water loss in agriculture, but are seldom used for landfill sites. Timber processing produces considerable amounts of waste in China every year, so that recycling waste as sawdust in landfill has much potential. This study was designed to improve the performances of intermediate covering of soils in bioreactor landfill sites by employing such modifying agents as calcined lime, sawdust and PAM. Compressive strength, permeability and water-holding capacity of modified soils were measured. The effects of regulating pH and pollutant removal in leachate were also studied in a leaching experiment.

## 1. Material and methods

### 1.1. Source and characteristics of materials

The sampled soils were from construction waste materials and had a heavy loam texture with a volatile content of 13.5 %. The lime was calcium limestone and the sawdust was pure pine sawdust with a moisture content of *ca.*17 %. PAM is a material containing anions with a very large molecular weight. Leachate was collected from the Chongqing Jiang-jin landfill, and the physical and chemical characteristics of the leachate are presented in Table 1.

### 1.2. Preparation of modified soil samples

The mass ratios of lime to soil are 0, 5, 10, 20 and 30 %, respectively. The results show that the pH value of leachate with 5 % lime-modified soils was 7.78, which was suitable for anaerobic microorganism metabolism. Sawdust and PAM were then added to the samples with 5 % lime. The addition of sawdust and PAM to 5 % lime-modified soils was to further improve the water-retention capacity and reduce the pollution load of leachate. The mass ratios of sawdust were 0, 1, 5, 10, 20 %. The mass ratios of PAM were 0.1, 0.5, 1.0, 5.0, 10 % in PAM-modified samples. The ratio of the water content of each modified soil sample was 35 ± 3 %.

### 1.3. Determination of compressive strength

Modified soil samples were compressed into cylindrical specimens (diameter = 39 mm; height = 80 mm), with a compaction density of 1500 kg $\mathrm{m}^{-3}$.

### 1.4. Determination of the permeability coefficient

Modified soil samples were inserted into cutting rings (diameter = 61.8 mm; height = 40.0 mm) with a compaction density of 1500 kg $\mathrm{m}^{-3}$. The permeability coefficient of samples was measured using a falling head permeameter (State Environmental Protection Administration of China 2004).

### 1.5. Leaching experiment

The leaching experiment was carried out with two sets of five columns filled with the sampled soil with varying lime contents (0, 5, 10, 20 and 30 % by dry weight) and sawdust (0, 1, 5, 10 and 20 % by dry weight). The lime- and sawdust-modified soil samples were put into cutting rings, and the thickness of the samples was 20 mm with a compaction density of 1500 kg $\mathrm{m}^{-3}$. There was a bottom covering under the cutting rings with uniform circular holes. The joint at the bottom cover and cutting rings was sealed with Vaseline. Cutting rings were placed in a 100 ml beaker. Fresh leachate with a low pH was added to the cutting rings on the modified soil samples. Concentrations of chemical oxygen demand (COD), total organic carbon (TOC), total nitrogen (TN) and volatile fatty acids (VFAs) in the influent and effluent were measured when leachate infiltrated into the beaker.

### 1.6. Determination of water-holding capacity

The water-holding capacities of sawdust- and PAM-modified soil samples were determined by the interior cutting ring method (Xin *et al.* 2010).

### 1.7. Evaluation criteria

The evaluation criteria were selected according to Chinese standards (Ministry of Construction of the PRC 2009) and the results from other research (Zhang *et al.* 2004; Zhao *et al.* 2010; He 2013). The evaluation criteria for the intermediate covering soil are shown in Table 2.

**Table 3** Test items and methods of modified samples.

| Test items | Instrument model | Test methods |
|---|---|---|
| Moisture content | Balance | Specification of soil test (SL237-1999) |
| Permeability coefficient | TST-55 variable head permeability tester | |
| Compressive strength | YYW-2 Strain controlled unconfined pressure gauge | |
| Organic matter | Muffle furnace | Municipal domestic refuse. Determination of organic matter. Ignition method (CJ/T 96-1999) |
| Water-holding capacity | $61.8 \times 40\,\text{mm}^2$ ring cutter, bottom cover | Cutting ring method for determination of field water-holding capacity in soil |

**Table 4** Monitoring items and method of leachate.

| Test items | Instrument model | Test methods |
|---|---|---|
| pH | pH meter | Glass electrode method |
| TOC | SHIMADZU TOC-L CPH TOC analyser | Instrument measurement |
| TN | SHIMADZU TNM-L type TN analyser | |
| COD | Burette | Dichromate method (GB11914-89) |
| VFAs | Gas chromatograph GC-2010 Plus | Instrument measurement |

### 1.8. Analytical methods

Modified samples were collected for analysing moisture content, permeability, compressive strength, organic matter and water-holding capacity. Leachate was collected for determining pH, COD, TOC, TN and VFAs. The tests are presented in Tables 3, 4.

## 2. Results and discussion

### 2.1. Compressive strength of modified soils

The relationships between compressive strength and modified soils with different ratios of lime, sawdust and PAM are shown in Figure 1. The compressive strength was 43.25 kPa, indicating that construction waste soil was not suitable for intermediate covering of landfill. The maximum compressive strength of the sample (20% lime) was 67.83 kPa. Calcium oxide in the lime, aluminium oxide and silicon dioxide in the soil could be combined to form hydrated calcium aluminosilicate fibrous material (Zheng *et al.* 2012; Bouhadja *et al.* 2013), which could together form aggregate cement and improve the soil's physical properties. The resultant process of lime slaking releasing large amounts of heat energy would also promote the gelation reaction. However, the compressive strength of the specimen (30% lime) was less than that of the specimen (20% lime), which could have been due to excessive lime. The heat from lime slaking made some soil vaporise to thus increase porosity and also lead to a decrease in strength. In general, the compressive strength of the lime-modified specimen was >50 kPa in order to meet the basic strength requirements for landfill covering materials.

The compressive strength of the sawdust-modified sample was greater than that of the blank control group. The maximum compressive strength (10% sawdust) was 100.91 kPa, 72.6% greater than that of the blank control group, as sawdust has a relatively high compressive capacity (Perdikea *et al.* 2008). Wood fibre can further enhance compressive strength. The experimental results were similar to the results from studies using construction materials; the addition of hemp fibre can also improve the compressive strength of soils. Similar research shows that the compressive strength of soil with the addition of 0.5% hemp fibre increased by 93% compared with pure soils (Wu 2013).

The compressive strength of the sample with 0.5% PAM was 83.64 kPa. The PAM amide group and a variety of adsorbed material formed hydrogen bonds between the particles (Johansson *et al.* 1974), thus enhancing the compressive performance of modified samples. In addition, PAM could increase the soil cohesion strength and the mechanical stability by improving the soil cracking pressure, tensile strength and crack coefficient (Su 2013). Results indicate that the compressive strength did not always increase when adding more PAM. The compressive strength of the sample with 10% PAM was only 31.08 kPa because of the marked swelling ability of PAM to expand after adsorbing water. PAM and adjacent soil could form aggregates, which were hard to compress. Surrounding soils and uneven mixing samples sharply reduced the compressive strength. When the addition ratio of PAM was 5%, PAM in soil aggregates would swell and generate gels.

### 2.2. Permeability coefficients of modified soils

The permeability coefficients of modified soils with different ratios of lime, sawdust and PAM are presented in Figure 2. The maximum permeability coefficient (20% lime) was $2.18 \times 10^{-4}\ \text{cm s}^{-1}$. The results show that swelling of the lime could increase porosity and enhance permeability. The lime treatment significantly increased soil porosity and permeability (Grieve *et al.* 2005). Omidi *et al.* (1996) found that adding 4% lime might increase montmorillonite and illite, which were the main mineral constituents. However, gelation gradually increased with increasing lime contents, which reduced the permeability of the sample. Jiao (2007) points out that quicklime slaking could change the gel effect of samples, which might decrease pores and thus reduce permeability.

A substantial decrease in the permeability coefficient was found after the addition of sawdust and PAM. The permeability coefficient of modified soil (5% sawdust) was $9.89 \times 10^{-6}\ \text{cm s}^{-1}$, and the permeability coefficient of modified soil (0.1% PAM) was $9.02 \times 10^{-6}\ \text{cm s}^{-1}$, which accords with the requirement for landfill intermediate cover materials. Sawdust rich in lignin and cellulose has a large surface area and freely absorbs water. The bonding between fibre or between fibre and soil would cause the fusion of particles to decrease permeability. PAM is hydrophobic and cohesive, causing the formation of a hydrophobic layer. The application of PAM decreases saturated

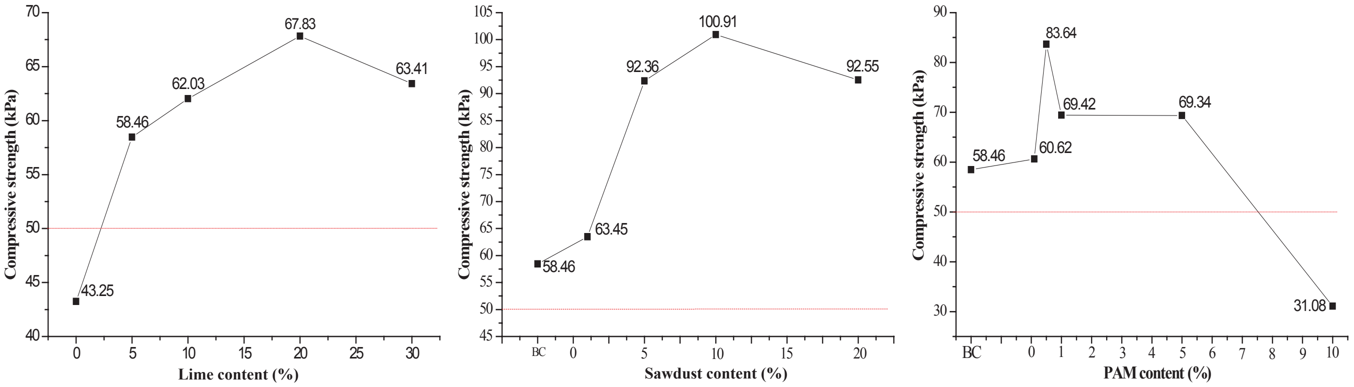

**Figure 1** Impact on the compressive strength of modified soil with different ratios of lime, sawdust and PAM. Abbreviation: BC = blank control group.

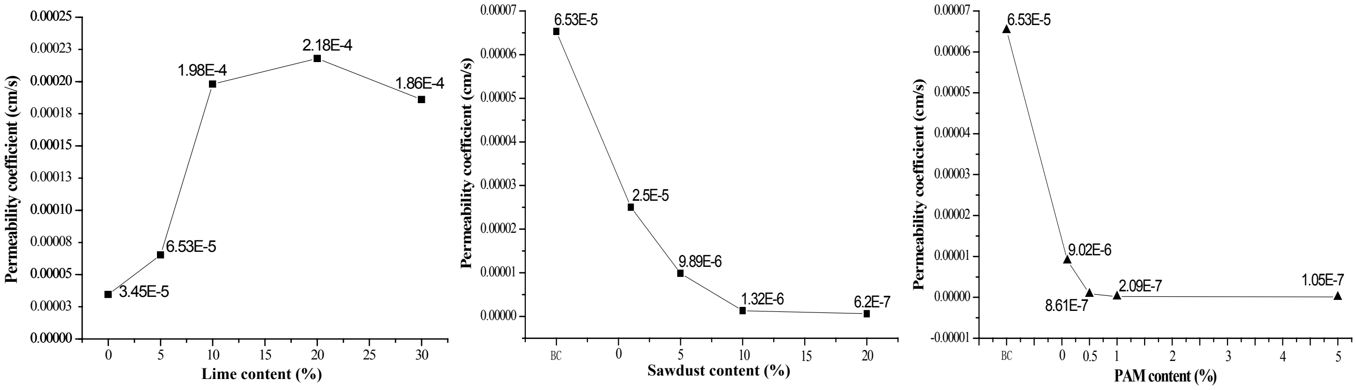

**Figure 2** Permeability coefficient of modified soil with different ratios of lime, sawdust and PAM.

hydraulic conductivity; however, the opposite has also been reported. Green *et al.* (2000) found that PAM could improve the infiltration rates of different soil textures. Al-Abed *et al.* (2003) also report that PAM could increase soil porosity, water-holding capacity and hydraulic conductivity.

### 2.3. Leaching experiment with lime- and sawdust-modified soils

The leachate properties of lime-modified groups are shown in Figure 3. The concentration changes in VFAs in the leachate are shown in Figure 4.

Figure 3a shows that the pH value of the leachate permeating soil was 6.07, which was greater than that of the original (pH 5.52). This suggests that the construction waste soil contained a small amount of alkaline substances, which could have neutralised the acid in the leachate. The pH of leachate in lime-modified groups was greater than that in the soil group. The leachate pH values of lime-modified samples (lime proportion $<10\%$) were highly variable. The leachate pH value of the sample (5% lime) was 7.78, which was suitable for anaerobic bacteria. Neutral pH seems to foster physical, chemical and biological processes to thus contribute to waste stabilisation (Valencia *et al.* 2009). The leachate pH value (lime proportion $>10\%$) was almost 9.5, showing that the leachate pH of the lime-modified sample had reached saturation. As shown in Figures 3b–d, the COD, TOC and TN in the leachate permeating soil (0% lime) were reduced and the removal efficiencies were 34.39, 19.15 and 53.44%, respectively. These show the ability of soil cover and soil microorganisms to inhibit and buffer contaminants. The result indicates a substantial increase in the removal efficiency through the addition of lime to the soil. With the increase in the lime content in the leached layer, the removal efficiencies of COD, TOC and TN were improved. The removal efficiencies of COD, TOC and TN in the leachate permeating the modified sample (5% lime) were 40.36, 24.51 and 58.71%, respectively. The removal efficiencies increased by 5.96, 5.36 and 5.27%, respectively, compared to the soil with no lime addition. The lime-modified groups could reduce the pollution load of the leachate. The pollution load of leachates consisted of suspended particles, organic pollutants and heavy metals. Lime could be used to dispose of municipal wastewater and acid industrial wastewater as antalkali and coagulants (Cáceres & Contreras 1995). Treatment with lime alone proved to be very effective in removing the part of the COD (50-60%) from the textile wastewater (Georgiou *et al.* 2003). The addition of lime to the covering layer in landfill caused precipitating, adsorbing and intercepting organic pollutants, thus reducing the pollution load of leachates. Adjusting the pH of covering soils to be alkaline is a suitable approach for encouraging microorganisms, the formation of an active intermediate layer for biochemical degradation of organic matter and improving the efficiency of gas production. The modified sample (5% lime) had the obvious effect of removing TN, with a removal efficiency of TN 58.71%. TN removal can be explained because ammonium nitrogen in the leachate could be converted into ammonia nitrogen with the neutralisation of alkaline substances, and then volatilised from the leachate. Lime could effectively regulate the pH of the reactor to maintain an optimal environment for anaerobic digestion, nitrification, denitrification and other biological reaction processes (He *et al.* 2012a, b; Rathnayake *et al.* 2015), therefore increasing the degradation efficiencies of COD and TN. Similarly, the column reactor with sulphur and limestone was introduced to treat sewage

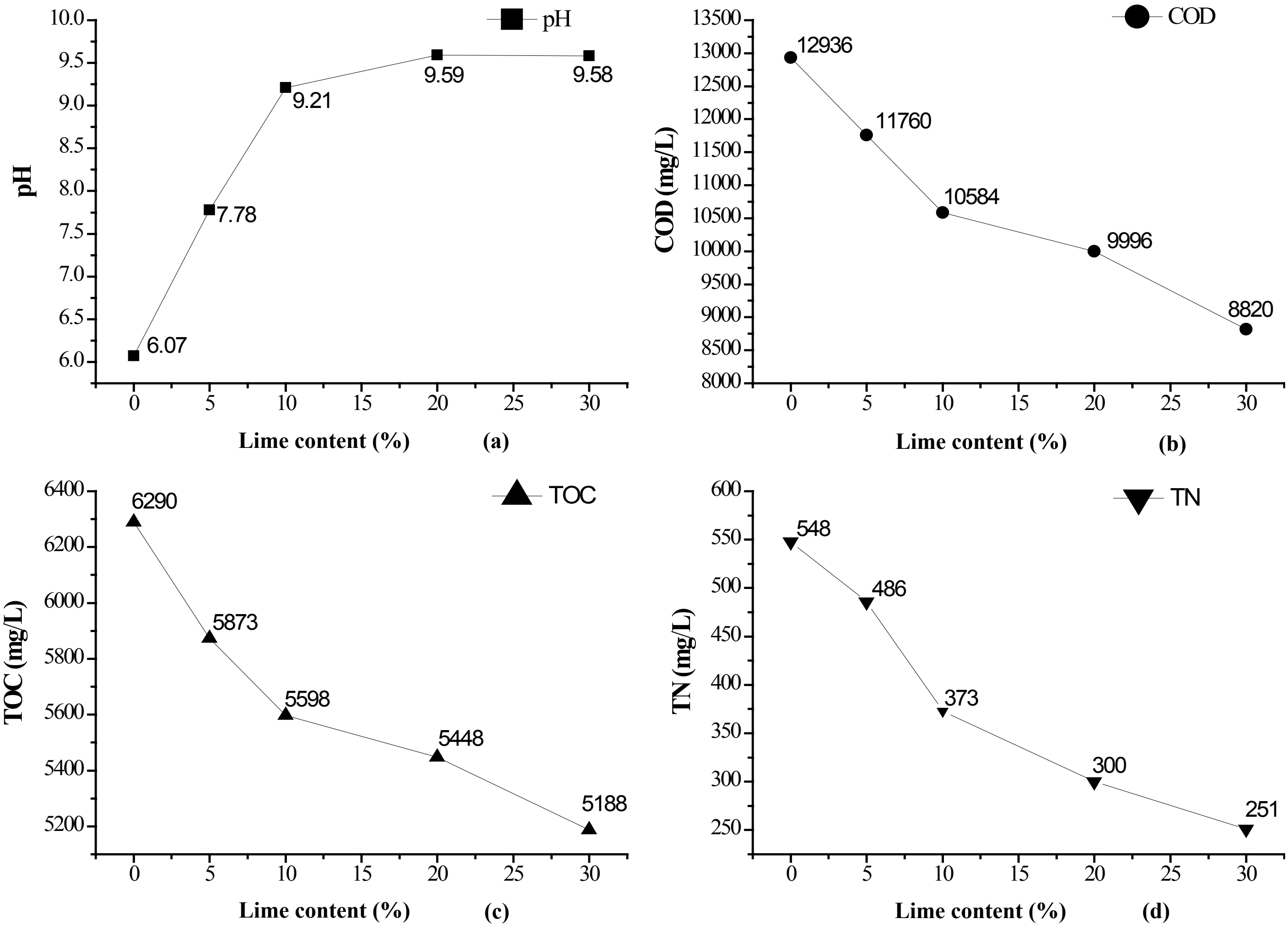

**Figure 3** Leachate water-quality variables for modified soil with different ratios of lime. (a) pH. (b) COD. (c) TOC. (d) TN.

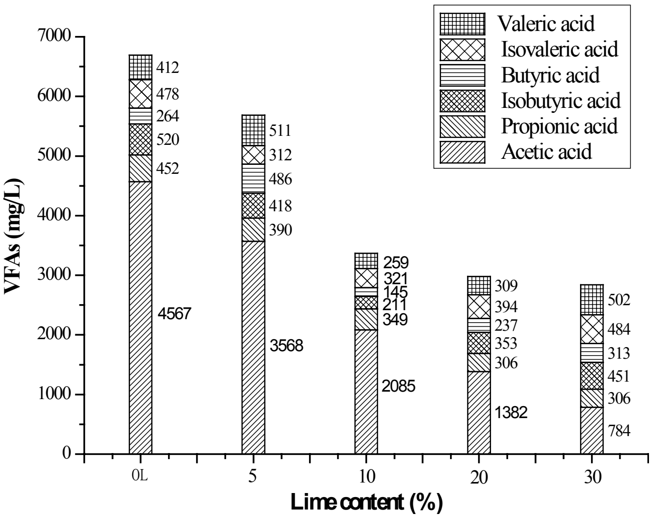

**Figure 4** VFA variables in leachate for modified soil with lime. Abbreviation: OL = original leachate.

rich in nitrogen. When the lime proportion was >10%, the downward trend in pollutant concentration was relatively flat and paralleled the pH trend, which showed the close relationship between pH and the removal efficiency of pollutants in the covering layer.

As shown in Figure 4, in the leachate of modified samples with varying lime contents (5, 10, 20 and 30%), total VFAs removal efficiencies were 15.06, 49.65, 55.46, and 49.65%, respectively. Figure 4 also shows a substantial increase in the removal efficiency of acetic acid through the addition of lime. Concentrations of acetic acid in the leachate of lime-modified samples were 3568, 2085, 1382, and 784 mg $L^{-1}$, respectively. However, several other VFA concentrations did not significantly decrease. The acetic acid reacted with the alkalinity, resulting in a greater removal efficiency. When the lime proportion was >10%, concentrations of isobutyric acid, butyric acid, isovaleric acid and valeric acid increased with the increasing lime ratio. The results indicate that acetic acid could be converted into a complex fatty acid under highly alkaline conditions. The leachate properties of the sawdust-modified group are shown in Figure 5. Concentration changes in VFAs in the leachate are shown in Figure 6.

Figure 5a shows that the leachate pH of the sawdust groups was greater than that of the blank control group, and the pH continued to increase with increases in the proportion of sawdust. The leachate pH value of the sample (20% sawdust) was 10.1. Sawdust-modified samples contained 5% lime, which could reduce the permeability of the sample, retard the leachate from passing through the sample layer and increase the pH of the leachate. As shown in Figure 5b–d, interactions between chemistry and physics in sawdust-modified samples became more complex. The COD and TOC in the leachate of sawdust groups had obvious fluctuations, ranging from 6547 to 11,784 mg $L^{-1}$ and from 4519.5 to 5185 mg $L^{-1}$, respectively. Overall, the COD, TOC and TN of the sawdust groups were less than those of the blank control group. The smallest COD

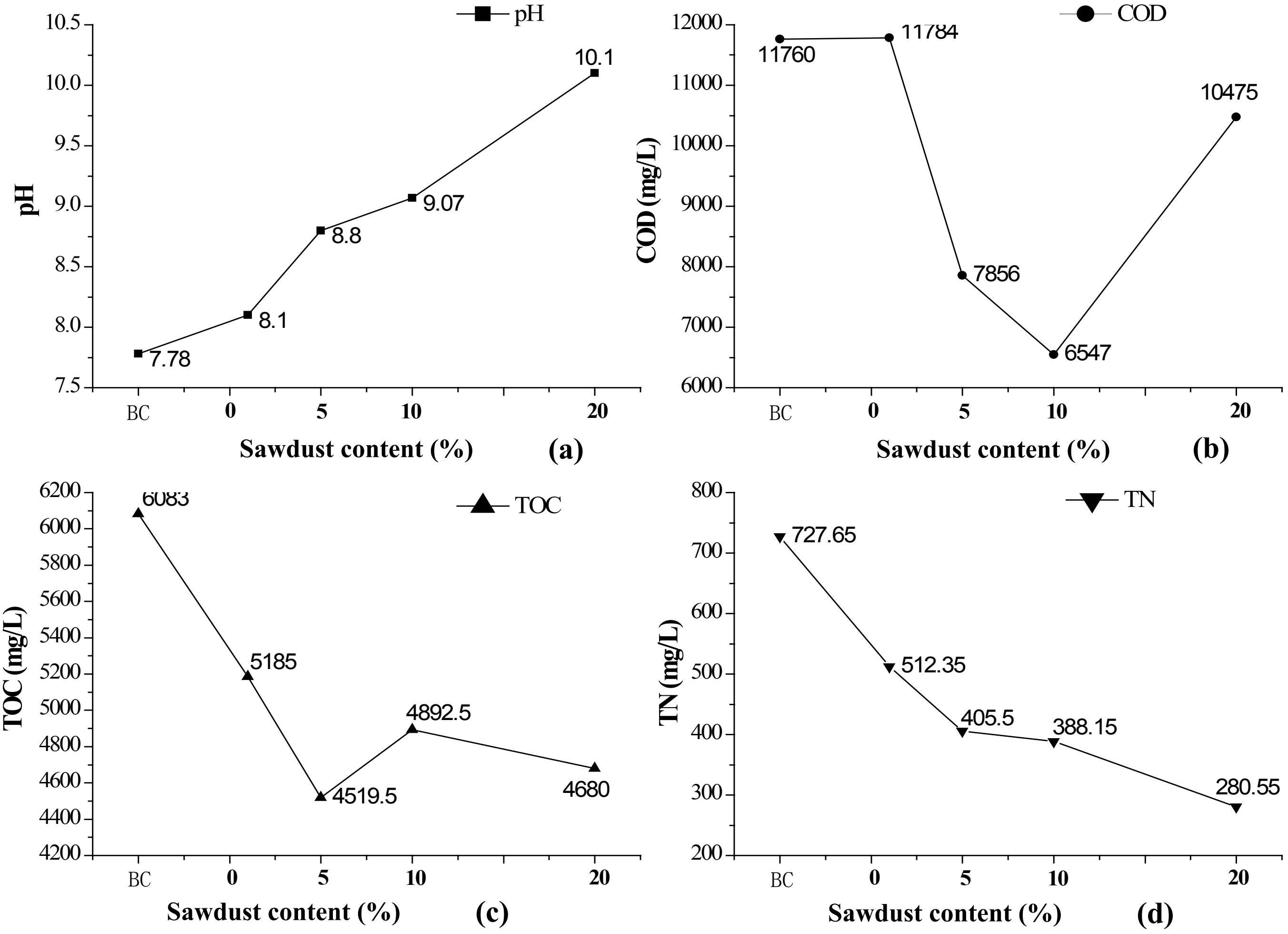

**Figure 5** Leachate water-quality variables for modified soil with different ratios of sawdust. (a) pH. (b) COD. (c) TOC. (d) TN.

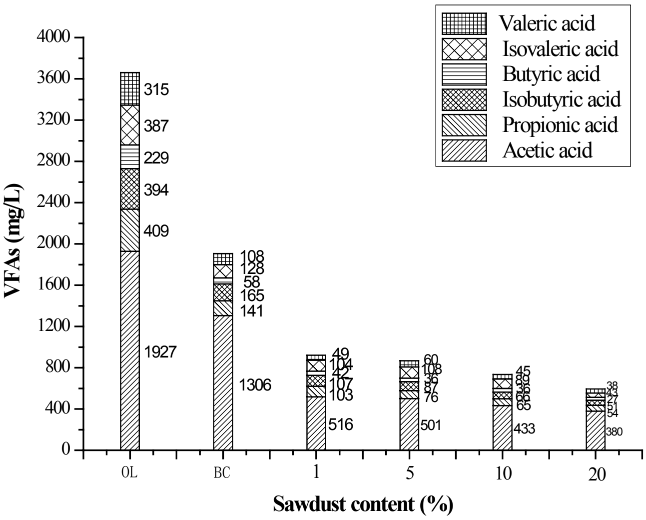

**Figure 6** VFA variables in leachate for modified soil with sawdust.

was 6547 mg $L^{-1}$ in the 10 % sawdust group and was reduced by 44.33 % compared with the blank control group. The minimum TOC in the leachate of the sample with 5 % sawdust was 4519.5 mg $L^{-1}$, reducing by 25.7 % compared with the control group. The TN in the sample with 20 % sawdust was the smallest (280.55 mg $L^{-1}$), which is 61.44 % lower than that in the control group. This indicates that sawdust can provide many more attachment points for soil organic pollutants, and thus promote the absorption of organic pollutants in the leachate. In addition, as the pH of the leachate increases, pollutants in the leachate can form hydroxide precipitates or flocculates more easily, and these can be adsorbed in the soil.

Figure 6 shows that the total VFA concentrations of the sawdust-modified groups were less than that of the blank control group. In the experimental groups with sawdust contents of 1, 5, 10 and 20 %, the total VFA concentrations in leachate were 921, 868, 734 and 593 mg $L^{-1}$, respectively. The corresponding removal efficiencies were 74.84, 76.29, 79.95 and 76.92 %, respectively. The results indicate that the removal efficiency of VFA has a slight change with the increasing sawdust content. The sawdust-modified samples were helpful for removing acetic and valeric acids, while other types of fatty acids were not obviously removed.

## 2.4. Water-holding capacity of modified soils

The results of the water-holding capacities of modified soils are shown in Table 5. The water-holding capacities of four groups (SL5.0, SLS1.0, SP0.1, SLP0.1) were similar to those of the soil samples as divided into 39.32, 39.46, 39.12, 39.46 %. The water-holding capacity of the sawdust-modified samples increased with the addition of sawdust. The water-holding capacity of the sample with 20 % sawdust was 65.19 %, and this increased by 25.78 % compared with the blank control group. Sawdust has strong water absorption and water-retention properties. The addition of sawdust increased the effective porosity and soil capillarity, thereby improving the water-holding capacity of the soil. From comparing the data of

**Table 5** Water-holding capacity test for different modified intermediate cover materials.

| Sample number | Modified cover material composition | Water-holding capacity (%) |
|---|---|---|
| S | soil | 39.27 |
| SL5.0 | soil + 5%lime | 39.32 |
| SLS1.0 | soil + 5%lime + 1%sawdust | 39.46 |
| SLS5.0 | soil + 5%lime + 5%sawdust | 43.25 |
| SLS10 | soil + 5%lime + 10%sawdust | 48.74 |
| SLS20 | soil + 5%lime + 20%sawdust | 65.19 |
| SP0.1 | soil + 0.1%PAM | 39.12 |
| SP0.5 | soil + 0.5%PAM | 46.23 |
| SLP0.1 | soil + 5%lime + 0.1%PAM | 38.72 |
| SLP0.5 | soil + 5%lime + 0.5%PAM | 43.52 |
| SLP1.0 | soil + 5%lime + 1% PAM | 42.82 |
| SLP5.0 | soil + 5%lime + 5% PAM | 43.72 |

samples (SP0.1, SP0.5, SLP0.1 and SLP0.5), it was found that the water-holding capacity of samples with added lime and PAM was less than that of the samples with only PAM. This is because lime has an inhibitory effect on PAM water-retention (He *et al*. 2012a, b). In theory, the water-holding capacity was increased by adding PAM. However, the experimental data show that the water-holding capacity of the PAM-modified groups was 38.72, 43.52, 42.82 and 43.72%, respectively. When the ratio of PAM was >0.5%, the water-holding capacity of the PAM-modified samples was not significantly increased.

## 3. Conclusions

The main conclusions from this study are as follows:

(1) The compressive strength of 10% PAM-modified soils decreased to 31.08 kPa, while the compressive strength of other modified soils was >50 kPa, greater than that of the control group. The modified soil satisfied the basic strength requirement for landfill intermediate covering materials and improved the structural stability of the landfill site.

(2) The permeability coefficients of lime-modified soils were greater than for the soil sample. In contrast, the permeability coefficients of sawdust- and PAM-modified soils were significantly reduced. The permeability coefficients of modified soils (5% sawdust and 0.1% PAM) were $9.89 \times 10^{-6}$ cm s$^{-1}$ and $9.02 \times 10^{-6}$ cm s$^{-1}$, respectively, which met the requirements for landfill intermediate covering layers.

(3) The addition of lime to the intermediate covering layer could adjust the pH of the bioreactor. The leachate pH values of modified soils (5% lime and 5% sawdust) were 7.78 and 8.8, which would improve MSW degradation and stability of landfill. Concentrations of COD, TOC, TN and VFAs in modified group leachates were less than that of the control group. Modified intermediate covering soils had positive effects on reducing leachate pollution from landfill.

(4) The water-holding capacity of sawdust-modified soils increased with an increasing proportion of sawdust. The water-holding capacity of 20% sawdust-modified soils was 65.19%, and increased by 25.87% compared with the blank control group. Under alkaline conditions, the increase of PAM did not improve the water-holding capacity.

(5) Based on the evaluation criteria, the combination of 5% sawdust, 5% lime and 90% soil is optimal for an intermediate covering layer.

## 4. Acknowledgements

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