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Analysis of technical criteria for clay liner in China

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ABSTRACT: The impact of geoenvironmental characteristics of clay soil on landfill liner has been evaluated by 1-D convection-dispersion flow model, and three index, breakthrough time, leaching rate and leaching contaminant quantity, are used to analyse the effectiveness of the standard of landfill liner in China. Compared with other parameters, the effect of hydraulic conductivity on landfill liner is the biggest, but the effect of diffusion and adsorption of ion in clay cannot be ignored. Moreover, the Tung oil and the sticky rice juice added into clay under the best ratio of each material may improve the strength (increase by 40-50%), effectively decrease the permeability of clay (reduce two order of magnitude) and show strong absorbability.

1 INTRODUCTION

The sanitary landfill is one of the main methods to deal with the increasing Municipal Solid Waste in China. At present, the composite liner is widely adopted in Europe and America. And natural or compacted clay liners without geosynthetic materials are only used when leachate is little or no harmful. However, clay liner is still widely used in China for economic reason. “Technique code for MSW Sanitary landfill(CJJ17-2004)” made by the Ministry of National Construction of China requests that hydraulic conductivity of liner should not be larger than 10^{-7} cm/s and thickness of liner should not be thinner than 2m. This technique criterion is basically founded on the physical characteristics of clay. But clay liner also has high adsorption capacity against contaminant and retardation of contaminant transport besides of low hydraulic conductivity. Thus the main geoenvironmental characteristics of clay (absorbency, dispersion) should be considered in liner design.

The main content of Tung oil is elacostearin acid tristearin, with which it can prevent penetrating and has strong absorbability as well as acid/alkalescency-resistant, water-fast and sunproof property. Clay mixed with sticky rice juice can be found from the Great Walls to the walls of common houses in China. If the Tung oil and the sticky rice juice added into clay, they may improve the strength and reduce the permeability of clay.

2 MATHEMATICAL MODEL

Usually, convection-dispersion model in porous media is adopted to describe contaminant transport in clay. Convection transport is induced by hydraulic gradient in clay layers, while dispersion transport, including mechanical diffusion and molecular dispersion, is aroused by concentration gradient. Moreover, clayey material can absorb contaminant during the transport of leachate, which can be simply expressed by linear isotherm equation. On account that the area of bottom liner in landfill is much larger than its thickness, the contaminant transport in liner can be described with 1-D convection-dispersion model as following equation, and can be calculated by FDM:

$$R_d \frac{\partial C}{\partial t} = -\frac{q}{\theta}\frac{\partial C}{\partial z} + D_s \frac{\partial^2 C}{\partial z^2} \tag{1}$$

Where C = contaminant concentration of void solution with unit volume; q = flow quantity through unit area in unit time, which is content for Darcy’s law;θ = volumetric water content of clay; **D** = dynamical dispersion coefficient, including mechanical diffusion and molecular dispersion; **R** = retard factor of contaminant by clay; **D** and **R** mainly respond to the physical and chemical reaction between clay and contaminant, and can be regarded as constants for special clay and contaminant. (Sasaki 1996; Du et al. 2000).

3 ANALYSIS OF CHINESE CRITERION

To study the impact of geoenvironmental characteristics of clay, the clay liner in landfill is analyzed under different critical condition. According to "Technique Criterion of MSW Landfill" in China, the essential demand for clay liner is that the thickness is no less than 2m and the hydraulic conductivity is no larger than 10^{-7}cm/s. According to USEPA, the leachate collection system should be designed to keep the water level below 30cm. Here the basic water level is adopted as 30cm. But it hasn't confined water head of landfill in China. The phreatic line of landfill in China is usually high because of high water content of waste, rainfall and surface runoff. Thus the impact of high water head is considered. Assumed that the initial concentration in soil is 0mg/l and that in leachate C_0 is 1000mg/l (half of the highest) (Jiang et al., 2002), respectively. The retardation factor and the diffusion parameter are adopted with experiment result and adjusted with need of analysis. The breakthrough time T and the leaching contaminant quantity Q_{20} (total quantity during 20 years) under different cases are shown in Table 1, which is calculated using E_q. (1) by FDM. The leaching contaminant quantity is the integral of leaching rate, leachate concentration and time, where leaching rate v in unit area of clay liner is calculated by Darcy's law:

$$v = K_w \frac{H+L}{L} \tag{2}$$

Where K is hydraulic conductivity of clay; H is water level in landfill; L is thickness of clay liner. In Table 1, Case.1 is the basic case of clay liner.

It is shown that, in all parameters, the effect of hydraulic conductivity of clay liner is the most obvious. Compared Case 1 with Cases 2 and 3, it can be seen that if hydraulic conductivity adds an order of magnitude, the leaching contaminant quantity would increase hundreds times. On the contrary, it would decrease greatly. Thus, controlling hydraulic conductivity is obviously valid for decreasing leaching contaminant quantity through clay liner. It is feasible to adopt the hydraulic conductivity as the controlling index in the design of clay liner.

The diffusion parameter of contaminant ion also affects greatly on breakthrough time and leaching contaminant quantity (Cases 1, 4 and 5). The leaching quantity increases with the increasing of diffusion parameter, while breakthrough time is shorten. At present, only hydraulic conductivity and thickness are limited in China. But when the diffusion parameter is quite great, the leaching quantity will be very large, even if the water level and hydraulic conductivity are very low and meet the standard. Therefore, it is necessary to control diffusion parameter of ion through clay.

Compared Case 1 with Cases 6 and 7, it can be seen that the leaching quantity decreases with the increasing of retardation factor, while the breakthrough time is improved. The effect of retardation factor on breakthrough time is greatest. Even if a little variety of value, the breakthrough time is different in several years and leaching quantity is obviously lower. It is evident that the breakthrough time could be prolonged and leaching quantity could be decreased by improving the physical and chemical characteristics of clay in liner, strengthening the activity of clay and heightening ion adsorption capability of clay. Then the anti-pollutant capacity of liner is strengthen.

Compared Case 1 with Cases 8 and 9, the breakthrough time is shorten and the leaching quantity is increased with water level heightening. The leaching quality increased greatly during filling period. When the water level increased to 1m, the breakthrough time is shorten to 7.5 years, which is still in the filling period, and the leaching quantity increases quickly. When water level arrives at 10m, the breakthrough time is only 3.1 years, which is far less than the filling period of 10-20 years, and the total leaching quantity is great. Thus, the risk of water head to around circumstance can not be

Table 1 Breakthrough time and leaching contaminant quantity of clay liner

Case	K_w (10^{-7}cm/s)	D_s (10^{-6}cm^2/s)	R_d	H (cm)	L (m)	C_0 (mg/L)	v (m^3/m^2·s)	T (yrs)	Q_{20} (g/m^2)
1	1.0	2.0	1.1	30	2	1000	1.15×10-9	8.5	15.2
2	0.1	2.0	1.1	30	2	1000	1.15×10-10	15.2	0.0015
3	10	2.0	1.1	30	2	1000	1.15×10-8	1.9	6360.0
4	1.0	1.0	1.1	30	2	1000	1.15×10-9	11.8	3.58
5	1.0	20	1.1	30	2	1000	1.15×10-9	1.5	219.7
6	1.0	2.0	1.5	30	2	1000	1.15×10-9	11.6	1.2
7	1.0	2.0	2.0	30	2	1000	1.15×10-9	15.5	0.037
8	1.0	2.0	1.1	100	2	1000	1.5×10-9	7.5	271.0
9	1.0	2.0	1.1	1000	2	1000	6.0×10-9	3.1	700.0
10	1.0	2.0	1.1	30	2	200	1.15×10-9	9.4	3.1
11	1.0	2.0	1.1	30	2	2000	1.15×10-9	8.2	30.5

neglected. But in southern China, rain fall can arrive at 2000mm/year. So the quantity of water is high during the filling-time of landfill, which makes the water level reaches tens meters in landfill. For example, the highest water head in Tianziling Landfill of Hangzhou, Zhejiang Province has arrived 20 meters.

It can be seen that the initial contaminant concentration has little effect on breakthrough time, under the condition of low water level and low hydraulic conductivity, the leaching quantity is less, even if contaminant concentration is large. Thus it is no need to consider the effect of the initial contaminant concentration in liner design. But to organic compound in leachate, the effect of contaminant concentration should not be neglected for the very high concentration.

4 CLAY MIXED WITH TUNG OIL AND STICKY RICE JUICE

Clay is chosen from the Brick Factory of Xiaoshan in Hangzhou, named as Xiaoshan Clay in this paper, the Tung oil is used for industry and sticky rice is from northeast of China. Xiaoshan Clay is littoral facies deposit soil whose basic properties are shown in Table 2. Because it has strong absorbability, water-fast property and the coefficient of permeability is at approximately 10^{-7}cm/s, it can satisfy the Technical Code for MSW Sanitary Landfill (CJJ17-2004) and can be used directly as a compacted clay liner in landfill.

Table 2 Properties of Xiaoshan Clay

Dry density	ρ(g·cm^{-3})	1.76
Nature water content	ω(%)	41.3
Specific gravity	d_s	2.72
Liquid limit	ω_L(%)	52.7
Plastic limit	ω_P(%)	26.3
Granulometric composition(%)	Sand grain	8
	Silt	35
	Clay particle	57
Organic content	(%)	0.6
pH		7.79
Clay minerals content (%)	Montmorillonite	10
	Illite	15
	Collyrium	10

The two parameters: the maximum dry density of 1.56g/cm^3 and the optimum water content of 24% are controlled. And for convenient comparison, sticky rice juice and Tung oil are regarded as addictives and the water content of the sticky rice juice is not calculated. The floating layer of juice is extracted by injector which is shown in Fig. 1.

Figure 1. Extraction sticky rice juice

Fig. 2 shows that, at the same mixture ratio, with water content increasing, the permeability decreases first and then increases. Obviously the tests support a mixture ratio of Xiaoshan Clay: sticky rice juice: Tung oil = 90:5:5 where the coefficient of permeability gets reduced by two orders of magnitude against that of original Xiaoshan Clay which holds an optimum water content. When the amount of sticky rice juice increases, the permeability coefficient has the same tendency.

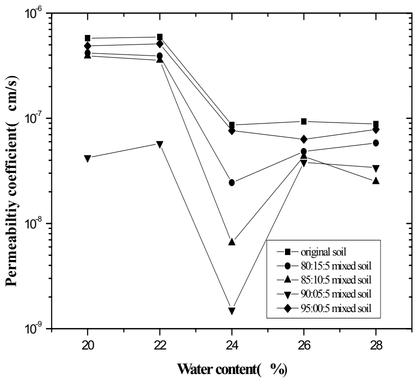

Figure 2. Permeability test under different water contents

From Table 3, under the best ratio (90:5:5), the cohesiveness and friction angle will improve greatly about 40-50%.

Table 3. Shearing test

Ratios	100: 0:0	95: 0:5	90: 5:5	88: 5:7	93: 5:2
Cohesiveness (kPa)	12	10	14.5	10	9
Friction angle(°)	18	20	28.5	23.5	27

Fig. 3 shows the mixed soil has better adsorption ability than original Xiaoshan clay, especially under high equilibrium concentration. Therefore, the mixed soil can serve as a soil barrier material in landfill.

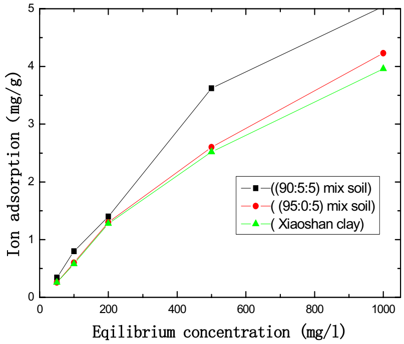

Figure 3. Ion absorbability

5 WETTING-DRYING TESTS

To see the durability of the Xiaoshan clay added the organic matters of the Tung oil and sticky rice juice, the wetting-drying tests about the ratio of (90:5:5) are done.

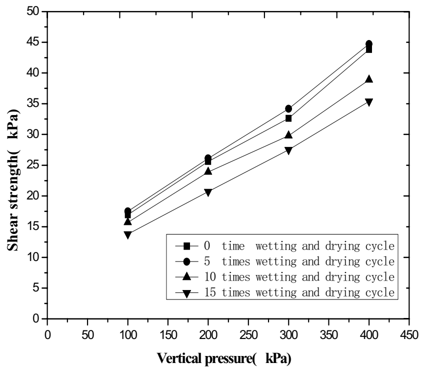

Figure 4. Wetting-drying test

From Fig. 4 when the soils are circulated for 5 times, the shear strength is maintained basically and increase a little, but for 10 times and 15 times, the shear strength will be dropped. But the friction angle changed little.

6 CONCLUSIONS

1) The request for clay liner of landfill standard (hydraulic conductivity <=10-7cm/s, thickness>= 2m) in China is basically feasible, especially in dry district. It is necessary to strengthen drainage measure in landfill to prevent the rain infiltration and restrict water level of landfill to reduce the risk on around circumstance.
2) Compared with other factors, the hydraulic conductivity on leaching contaminant quantity is greatest. It is feasible to adopt hydraulic conductivity as control index for landfill liner. But when the diffusion parameter of contaminant ion is great, the effect of diffusion parameter should be considered in liner design.
3) The mixed soil, with Tung oil and sticky rice juice, generally, has lower permeability coefficients and higher strength than the original soil. Under the best ratio (90:5:5) of each materials, it has better adsorption ability.

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