EXPERIMENTAL STUDY ON PERMEABILITY AND ITS CHANGING REGULATION OF DRAINAGE LAYER IN WASTE SANITARY LANDFILL

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ABSTRACT

As landfill site working, biochemical process and seepage of leachate always influence on and change the permeability of drainage layer. By means of laboratory experiments, selecting and using 8 kinds of granulometric composition sands and gravels as drainage material of dairage layer, permeability and its changing regulation of drainage layer in waste sanitary landfill were deeply studied. The experimental researches show the following: Effective particle size has important influence on the changing rate of permeability coefficient and drainage porosity Leachate water quality and ions content change greatly when leachate seeps though the drainage layer consisting of sands and gravels, that is, all parameters of effluent leachate, including COD, Ca^{2+}, Mg^{2+}, TVFA, total rigidity , total alcolinity, NH_4^+-N, TSS as well as VSS and so on, decrease in some extent and present similar variation tendency with time, except for pH values increasing a little; Meanwhile, changing regulation of leachate water quality proves to be irrelevant with granulometric composition of drainage media during seeping; Calcium carbonate and silicon dioxide are of major compounds of the clogging matter generated by leachate seeping in soil pores, and Ca, Si, Fe, Mn, Zn, Mg are of main elements; The components and their relative contents of the clogging matter are independent of granulometric composition of the drainage media, but the larger effective particle size is, the more generation gross and uniformity of distribution of the clogging matter are; It is the main reason for deducing permeability of drainage layer that mineral salts and biomembrane are generated in drainage media pore from chemical process of leachate, biomembrane growth and solid suspended sedimentation. Based on the result of laboratory experiments, The clogging model reflecting leachate water quality parameter (COD_r) influencing on drainage layer permeability and drainage porosity, as well as the function concerning drainage layer permeability coefficient, drainage porosity and effective particle size, were set up.

Keywords: leachate, drainage layer, permeability, chemical process.

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INTRODUCTION

Since the 1970’s, the disposal of solid waste had gradrually developed from simple dump to sanitary landfill with engineering preventive measure[1]. Liner systems consisting of drainage and mineral layer are essential engineered components of modern municipal solid waste landfills which were designed to keep landfills safe during their operation. Due to the chemical and biological nature of the leachate when discharging in a drainage layer, there is potential for changing permeability of drainage layer, enhancing the height of leachate mounding above the liner systems, thereby, increasing containment transportion through the liner systems and improving the polluted probability to groundwater and surface water nearby induced by clogging of the drainage layer. There were clogging phenomena in some foreign waste landfills, for example, the permeability of drainage layer in Keele Valley Landfill and Toronto landfill had reduced greatly about 4 years and 16 years after landfillling commenced. The leachate mound was about 23 m above the base of the landfill and the drainage layer only collected about 6% of the estimated fluid [2-4].Permeability deducing phenomena were observed in and the vicinity of the leachate collecting pipe[5,6]. By means of man-made synthetic leachate and taking glass beads as drainage media, the work by some researchers outlines a leachate mass loading and temperate influence on the rate and composition of clogging matter[5,7-14].The clogging in other drainage materials such as tyre broken piece, gravels and dolomite was also been touched on [15-17].The relationship between the accumulating rate of clogging matter and VFA biological ferment had been studied too[18-21]. The former research work mainly focused on labortary simulating, meanwhile, taking glass bead as drainage media and permeating with man-made synthetic leachate. But there exist obvious difference between man-made synthetic and on-the-spot leachate in their ion species, content as well as biological activity. And, the waste ingredient and the leachate composition of China are distinguished from those of foreign countries. In June 1995, it was discovered that there were sewage accumulated in the bottom of of Asuwei Landfill in Beijing because leachate collecting pipe maybe clogged[22]. Except for this, any other relative reports and reseach informations about permeability changing regulation of drainage layer in waste sanitary landfill of China haven’t yet been found.

It would be highly desirable to have experimental evidence to study the clogging regulation reduced by on-the-spot leachate in China seeping in the drainage media consisting of sands and gravels. The primary objective, therefore, of the experimental study reported herein is to examine the changing regulation of drainage layer and the relationship between drainage layer permeability and leachate water quality. The MSW leachate used in the test was mainly collected from Yanqun landfill, in Xuzhou, Jiangsu, China. 8 kinds of granulometric composition sands and gravels were selected and used as drainage material of dairage layer.

EXPERIMENTAL MATERIALS AND EXPERIMENTAL DEVICES

The extablishment of experimental devices

By means of basic differential equation of saturated vadose zone[23] and integral analogy method, seepage similarity criterion of landfill leachate seeping through drainage layer was calculated, and formula 1 is the seepage similarity criterion obtained. This seepage similarity criterion is taken as a foundation to design the laboratory simulating experiment devices as well as a theorical base to analyze experiment result.

$$\pi = \frac{a_v \rho g l^2}{k(1+e)t} = cons\tan t \quad (1)$$

Where, a_v is the vertical compressive coefficient, k is hydraulic conductivity, e is void ratio, t is seeping time, ρ is the density of drainage layer, l is the length of seeping path.

According to the structure of on-the-spot waste sanitary landfill and seepage similarity criterion, the laboratory simulating experimental devices were established as showing Figure 1a. and 1b. Experimental device group A consisting of 4 columns is the drainage layer reappear of on-the-spot landfill, with 2100-mm-long, 500-mm- diameter. However, Experimental device group B consists of 8 columns and every 2 columns have indentiful drainage material and structure. The column of the group B is 700-mm-long and 80-mm-diameter. Anaerobic conditions with the columns were maintained at all times by thin membrane, which can only penetrate gas but water, air pressure gage and ball valve.

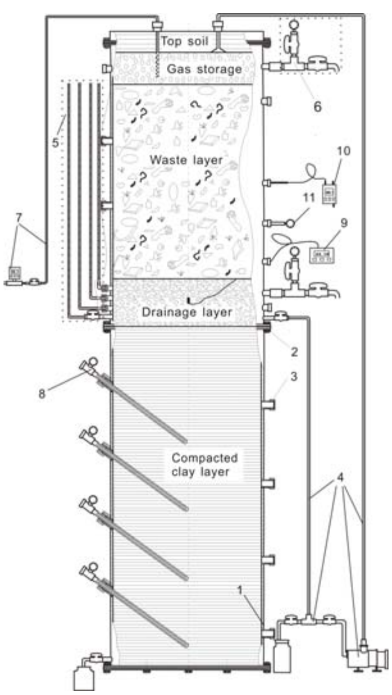

Figure 1a.: Experimental device Group A sketch of the laboratory simulating landfill

1—Landfill column 2—Flanged shaft 3—Sampling hole 4—Leachate circulating system 5—Piezometer system 6—Landfill gas pressure measure syetem 7—Landfill gas flow volume measure system 8—The water content measure system of compacted clay 9—Pore water pressure sensor 10—Redox potentiometer 11—Thermometor

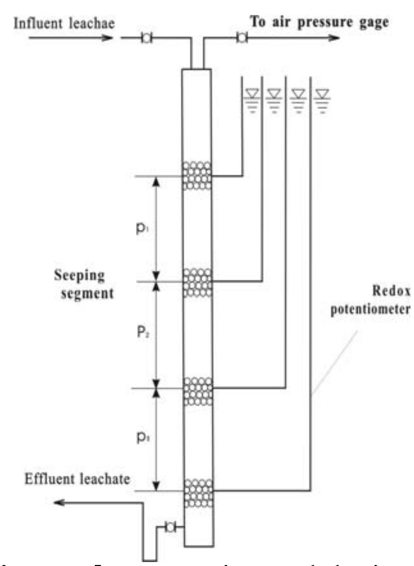

Figure 1b.: Experimental device Group B sketch of the laboratory simulating drainage layer

The selection of drainage media

8 kinds of sands and gravels were selected and packed as drainage material whose grain size distrutes from fine sand to cobble. Granulometric composition and their general properties are showed in Table 1.

Table 1.: Granulometric composition and general properties of drainage media.

Experimental group and its serial number		Properties					
		Fraction (mm)	Density ($kN \cdot m^{-3}$)	*Gs*	$k_0/(\times 10^{-2} cm \cdot s^{-1})$	d_{10}	*e*
Group A	TMZT-I	5 ~ 10	14.8620	2.6724	0.9821	7.27	0.8392
	TMZT-II	10 ~ 20	16.2468	2.6919	1.0016	14.53	0.7404
	TMZT-III	2 ~ 10	14.2087	2.6478	0.8450	3.70	0.9653
	TMZT-VI	2 ~ 20	17.3512	2.5319	0.9303	4.23	0.5557
Group B	BLZT-I	0.5 ~ 2	15.8599	2.6568	1.0123	0.475	0.9899
	BLZT-II	0.25 ~ 0.5	14.0140	2.6568	1.1323	0.278	1.1008
	BLZT-III	0.5 ~ 5	16.4627	2.6568	3.1068	1.000	0.8177
	BLZT-VI	0.074 ~ 20	17.9286	2.6849	0.3020	0.275	0.6959

The selection and conservation of leachate

Leachate used in experiment device Group A came from the waste biodegradation which is filled above the drainage layer in the device. Meanwhile, continuous flow of leachate in the drainage layer was operated in recirculation mode. Leachate seeping in the device Group B was collected from Yanqun landfill, in Xuzhou, Jiangsu, China. The leachate was transported to the laboratory in sealed HDPE tanks. At the laboratory, the leachate was stored at 0 ~ 28°C. Leachate was fed into each pair of columns in pour into and discharging mode by manual work. The average seepage quantity is 0.585L/d, and the temperature of the test is 6 ~ 37°C. A number of the influent leachate characteristics are summerised in Table 2.

Table 2.: Water quality of influent leachate in experiment

COD ($mg \cdot L^{-1}$)	Ca^{2+} ($mg \cdot L^{-1}$)	Mg^{2+} ($mg \cdot L^{-1}$)	Total rigidity ($CaCO_3$)/($mg \cdot L^{-1}$)	Total alkalinity (CO_3^{2-})/($mg \cdot L^{-1}$)	Temperature (°C)	pH

13000 □ 899	122 .256 □ 272 .544	369.4 36□ 49 5.822	1396.5517□ 94 13.7931	2820.47□ 12 242.04	1 0□ 30	6. 52 □ 7. 54

PERMEABILITY AND PORE CHARACTER OF DRAINAGE LAYER

The changing feature of permeability

The feature of drainage porosity

Drainage porosity is the discharge rate of unit cross sectional area in column, that is, the volume which flow across the experiment drainage media divided by total volume of drainage media. Drainage porosity represents the pore space which can discharge free water, and its value is smaller than porosity. During the test, the measurement period is 24 day.

The experimental results show the following: 1) The larger effective particle size is, the larger drainage porosity is, and the more evenly change of drainage porosity along column is, in identify seeping condition. The reason of the former phenomenon is, the experiment column with larger effective particle size having more pore space and smaller surface area, and providing more space for clogging matter accumulation, then clogging matter can distribute more evenly in the tested column. 2) The decrease in drainage porosity is greatest at the influent end of the columns and gradrually decreases with distance from this influent end. Average $CaCO_3$/ $MgCO_3$ generating from per litre leachate was measured and calculated after the test columns disassembled. When the experiments were operated until 168 days, $CaCO_3$ deposition from per litre leachate in BLZT-Ⅰ(BLZT-Ⅱ)BLZT-Ⅲ and BLZT-Ⅳ is 0.484g□ 0.461g□ 0.534g□ 0.467g separately, while, $MgCO_3$ deposition is 0.035g□ 0.032g□ 0.035g,0.034g respectively.It can been seen that the larger effective particle size of the columns is, the more generation gross and uniformity of distribution of $CaCO_3$□ $MgCO_3$ are, and $CaCO_3$ generation gross is greater than that of $MgCO_3$.

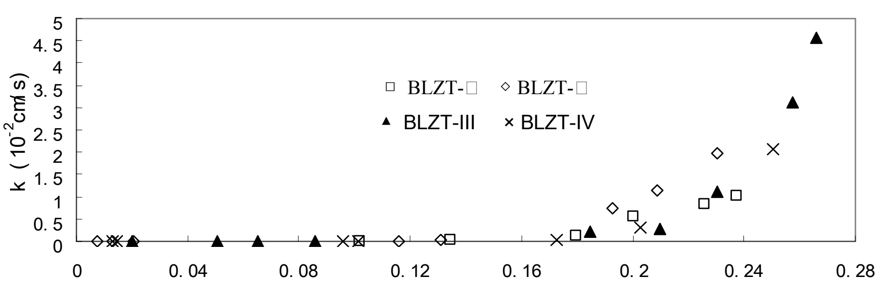

Figure 2.: Changing of *k* and n_d with time in Group B.

The feature of hydraulic conducivity

During the test, the measurement period of hydraulic conducivity is 48 day. Fig 2 showed that the larger drainage porosity with larger discharge pore space has a larger hydraulic conductivity after a relatively equal period of time and equal volume of leachate passed through, that is, the hydraulic conductivity drops with decreasing drainage porosity in a similar manner for all particle diameters. Drainage porosity and hydraulic conductivity of drainage layer are decreasingly during seeping together with biological and chemical process of leachate. Under the same experiment condition, the smaller effective particle size is, the more decreasing rate of hydraulic conductivity is. For example, when hydraulic conductivity decreases to 10^{-6}cm/s order of magnitude, the column BLZT-Ⅳ needs about 200 days, while, BLZT-Ⅰ,BLZT-Ⅱ,BLZT-Ⅲ needs 250day,210 day and 288 days respectively. Based on drainage porosity and hydraulic conductivity measurements at different time as well as effective partical size, the following empirical relationship among drainage porosity, hydraulic conductivity and effective partical size for 0.275 mm to 14.53 mm sands and gravels is given:

$$\ln k = A \cdot n_d \cdot (d_{10})^{-\frac{1}{4}} - 15.0$$

Where, A is particle size parameter, $A=\begin{cases} 38.7 & (0.275 \le d_{10} \le 1.00) \\ 66.0 & (2.45 \le d_{10} \le 7.27) \\ 91.0 & (d_{10} \cong 14.53) \end{cases}$

The changing feature of drainage layer pore structure

The experiments were carried through until 168 days and until the column was defined as having "clogging" when it was not possible to transmit leachate under a head of 1.8 m. At the abovemetioned time, the columns of Group B were disassembled to measure and calculate the composition of clogging matter and pore structure parameter, such as the density of clogging matter, mass quality content of clogging matter, water content of clogging matter, volatile matter content, residual porosity, clogging matter volume attached per hektogram dry sand, pore space occupancy by clogging matter as well as porosity decrease value and so on. The relative data of BLZT-Ⅰwere given in Table 3. According to the test results, Calcium carbonate and silicon dioxide are of major compounds of the clogging matter generated by leachate seeping in soil pores, and the clogging matter distribution has the following regulation: 1) The clogging productive gross is greatest at the influent end of the columns and gradrually decreases with distance from this influent end. 2) The larger effective particle size of drainage media has a larger clogging generation gross and clogging matter volume attached per hektogram dry sand. For example, at the termination of experiment, clogging matter volume attached per hectogram dry sand of first segment in BLZT-Ⅳ(d_{10}=0.275mm) is 14.3526cm^3, whereas comparing with16.8762cm^3 for BLZT-Ⅲ (d_{10}=1.000mm). 3) Volatile matter content in clogging matter is large, generally exceed 60%. The data suggested that there were much thick biofilm generated. It properly relevanted to lower seeping rate during the test. 4) The smaller effective particle size with smaller initial porosity appears to allow a slightly small mass of clogging to develop and to promote a larger reduce in porosity, that is, the drainage media with smaller effective partical size columns may become blocked earlier than the larger effective partical size colomns.

Clogging matter composition showed that the components and their relative contents of the clogging matter are independent of granulometric composition of the drainage media. Ca、Si、Fe、Mn、Zn、Mg、Ba、Na、K、Pb、S、P、Cu、Ti、Ni、Al are of main elements of the clogging matter generated by leachate seeping in soil pores, and their content is from high to low. Calcium carbonate and silicon dioxide are of major compounds of the clogging matter. Among the inorganic element, the content of Ca is the highest. The probable reason is that $CaCO_3$ is more difficulty to dissolve than the other metal ion carbonate. The experimental foundings of this paper about the content sequence of clogging element is different from that of Armstrong M D（1998）[7],which maybe cause by different leachate water quality and experiment condition.

Table 3.: Clogging matter properties and drainable media porosity of BLZT-Ⅰ.

Properties	Seeping time and seeping segment					
	Seeping until 168 days			Seeping until the termination of experiment		
	P_1	P_2	P_3	P_1	P_2	P_3
Water content of clogging matter (%)	92.6300	93.5789	91.1224	87.0905	89.7243	91.3294
Mass quality content of clogging matter (%)	9.9608	9.0597	6.7221	17.1401	13.7955	12.0129
Clogging mater density (g/cm^3)	1.1501	1.0218	0.9468	1.2212	1.1089	1.0468
The content of volatile matter (%)	75.9900	92.9900	75.1990	72.3615	82.1386	86.4763
Residual porosity	0.4862	0.4828	0.47369	0.4357	0.4449	0.4542
Clogging matter volume attached per hektogram dry sand (cm^3)	9.7837	9.9106	7.7314	15.4969	13.4321	12.3120
Pore space occupancy by clogging matter (%)	2.5858	3.5106	5.5183	12.4159	10.5652	8.7053
Porosity decrease value	0.0129	0.0175	0.0275	0.0618	0.0526	0.0433

THE CHANGING FEATURE OF LEACHATE WATER QUALITY

Leachate water quality of influent and effluent experiment columns were measured cyclically, and the period of measurement is 24 day.

pH value presents water quality environment of leachate, and different water environment can promote corresponding chemical reaction. The pH value changes greatly when leachate seeps through the drainage layer consisting of sands and gravels. pH value of influent columns leachate is 6.52～7.54, whereas, the effluent pH value is promoted to 7.06～8.02. The changing regulation of pH value proves to be irrelevant with granulometric composition of drainage media. During the seeping, volatile fatty acid in leachate ferment to generate carbonic acid, whose process will reduce the acid of leachate, then, pH value of leachate is to be increased.

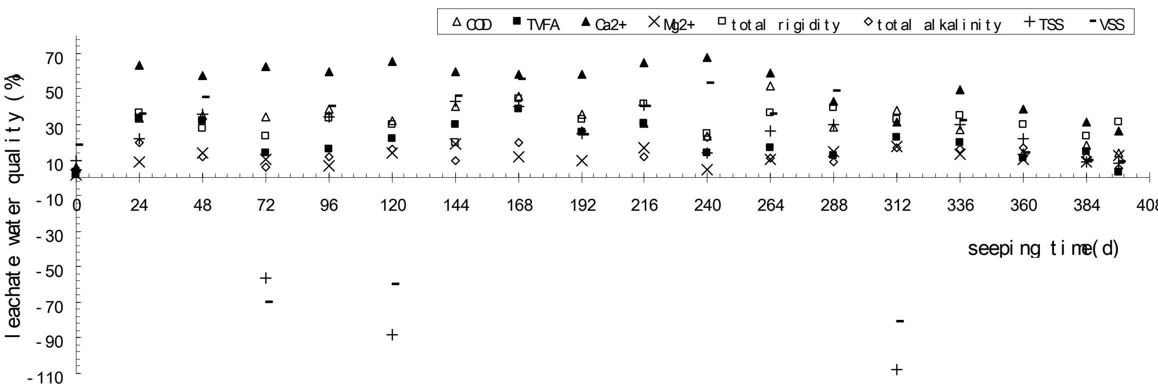

Figure 3.: Water quality of leachate changing with time in BLZT-Ⅰ.

Other parameters of effluent leachate, including COD, Ca^{2+}, Mg^{2+}, TVFA, total rigiditytotal alcolinity, NH_4^+-N, TSS as well as VSS and so on, decrease in some extent, suggesting that sands and gravels layer can remove the abovementioned leachate quality parameters at different extent. In order to describe the removal role of drainage layer exerting on leachate quality, removal ratio of leachate water quality was defined. Removal ratio of a certain leachate water quality was defined as (leachate water quality)$_r$=(influent value of this leachate water quality –effluent value of this leachate quality)/ influent value of this leachate quality. In the experiment, the removal ration of the above leachate quality present similar variation tendency with time. Now, take the experiment data of BLZT-Ⅰas an example to explain the leachate quality variation tendency with time (see Fig 3). There are three phases in leachate quality variation. First phase is an accretionary phase of COD_r and other parameter removal ration from the start of experiment to 36 days around; secondly, it is a stationary phase with going through a long term; the period of submergence is the last phase. Ca^{2+},COD show the highest removal ratio, but Total alkalinity removal ratio is the least. The experiment results suggested that the removal extent of Ca^{2+},COD by sands and gravels when leachate seeping in drainage layer is more higher than that of the other leachate quality parameters. Meanwhile, Ca^{2+}、Mg^{2+} exist and precipitate in soil pore by difficultly dissolved inorganic salt mode. Although the experiment data have a characteristic of scatter, leachate quality removal ratio appear to be similar variation tendency with seeping time, and the value of removal ratio have no appearently difference among the different test columns. Therefore, changing regulation and removal rate of leachate water quality prove to be irrelevant with granulometric composition of drainage media during seeping. $(NH_4^+\text{-}N)_r$ has uniform variation feature with $TVFA_r$, $Ca^{2+}{}_r$,$Mg^{2+}{}_r$ as well as COD_r and so on, but the value of $(NH_4^+\text{-}N)_r$ is small with 3%～8%. The effluent value of TSS and VSS are often smaller than that of influent, showing that some of suspended solid precipitate in soil pore during leachate seeping. The reason of TSS_r and VSS_r being smaller than zero accasionally is that biomembrane is split by random change of experimental condition.

THE RESEARCH ON THE RELATIONSHIP BETWEEN DRAINAGE LAYER PERMEABILITY AND LEACHATE WATER QUALITY

Leachate water quality influencing on the pore of drainage media

It is the main reason for deducing permeability of drainage layer and clogging pore of drainage media that mineral salts are generated in drainage media pore from chemical process of leachate, biomembrane growing and solid suspended sedimentating.

Volatile fatty acid consists of acids with carbon atom number one to six in leachate. Two stages exist in the anaerobic ferment, the first stage is transformation from butyric and propionicacid acid to acetic, carbon acid and methane, another stage is the transformation from acetic acid to carbon acid and methane. Ca^{2+},Mg^{2+} ,Fe^{3+}(or Fe^{2+}) and other mental ion in the leachate take chemical reaction with CO_3^{2-} and generate such precipitation as calcium carbonate, magnesium carbonate and ferric carbonate which accumulate in drainage media pore to reduce the permeability of drainage layer. Some tests were been done to examine the main component of clogging matter, and found out that such carbonates as calcium carbonate are of major compounds. The results of the main component of clogging matter showed that chemical process in the leachate can generate inorganic salt precipitation in the pore and play an important role in decreasing drainage layer permeability.

During the seeping, there have continuous relative movement among leachate and drainage media surface, therefore, microbe, contaminant and solid suspended gradrually attach to the media surface. So biomembrane mainly made of microbiological cell were generated and suspended solid were accumulated in the drainage layer pore. Furthermore, drainage pore volumn and drainage layer permeability were lessened with seeping. The results of test showing that the volatile matter content is more than 60%, suggested that much thick biomembrance were generated in the drainage media pore.

The establishment of function concerning drainage layer permeability coefficient and leachate water quality

Based on the results of laboratory experiments, the clogging model showing relationship among drainage layer permeability coefficient, leachate water quality as well as drainage layer fabric($a_v \rho gl \cdot d_{10}$) and drainage porosity, was set up.

$$\frac{k}{k_0} = 0.6216 + 1.6367 a_v \rho gl \cdot d_{10} \cdot n_d^3 - 0.0169\mathrm{COD}_\mathrm{r}$$

Where, k is drainage layer permeability coefficient, k_0 is initial permeability coefficient of drainage layer, n_d is drainage porosity

The imitation clogging model function was got through by significance and parameter inspection (F and t inspection) respectively. But the clogging model needs to be further examined and corrected by sanitary landfill engineering practice.

CONCLUSION

By means of labortory simulating experiment, the changing regulation of drainage layer permeability and the relationship between permeability as well as leachate water quality were researched. The work delivered in this paper is a researching exploration and attempt on permeability changing regulation of drainage layer in waste sanitary landfill. The experimental results indicated the following: 1) Effective particle size has important influence on the changing rate of permeability coefficient and drainage porosity. The larger effective particle size is, the lower changing rate of permeanbility coefficient of drainage layer is, and the later blocking along column is. The analog function presenting relationship among effective particle size, drainage porosity and drainage layer permeability coefficient was set up. 2) Noted change was found in leachate water quality during leachate seeping though the drainage layer consisting of sands and gravels. All parameters of effluent leachate, including COD, Ca^{2+}, Mg^{2+}, TVFA, total rigidity, total alcolinity, NH_4^+-N, TSS as well as VSS and so on, decrease in some extent and present similar variation tendency with time, except for pH values increasing a little; Meanwhile, changing regulation of leachate water quality proves to be irrelevant with granulometric composition of drainage media during seeping. The clogging model which reflected leachate water quality parameter (COD_r) influencing on drainage layer permeability was established; 3) It is the main reason for decreasing permeability of drainage layer that such carbonates as calcium carbonate generation from ferment of volatile fatty acid in leachate, biomembrane growth and solid suspended sedimentation.

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