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INVESTIGATION INTO MUNICIPAL WASTE LEACHATE IN THE UNSATURATED ZONE OF RED SOIL

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There are many organic pollutants in the monitoring wells at Taichung sanitary landfill. The objectives of this study were to understand the leachate transport phenomena in this specific site, to identify the parameters, and to simulate the mathematical transport model of organic matters of leachate plume by SEFTRAN. The model uses the Galerkin's finite element method and its mechanism includes convection, dispersion, retardation, and biological decay. Consequently, this study investigated not only on the parameters of convection but also on the parameters of dispersion, retardation, and decay. In the laboratory, several significant pre-tests and filter selections were performed to standardize the testing process. The results show chloride is a good tracer and mercuric chloride is an excellent inhibitor for decay study in this case. The equilibrium time of soil organic matter's adsorption is less than 12 h. The half life of chemical oxygen demand for this methane phase leachate is 46 d. In the lysimetric study, the experiments simulated field conditions such as soil characteristics and groundwater temperature. The results show that the mean retardation coefficient is 2.05, and the dispersivity of the column is between 0.17 and 0.35 cm. In addition to the sensitivity study, parameter comparison was made to show Darcy's velocity is the most sensitive parameter.

INTRODUCTION

Landfills of municipal solid waste are a significant source of groundwater contamination. A leachate leakage has been discovered in the Taichung sanitary landfill, and the pollution is obvious (Chen and Wang 1990). Because the cost of drilling a well is high, an investigation of the whole area cannot be completed. Also, polluted groundwater is hard to clean, and the cost of the control is huge. If the transport phenomena of leachate plume in the region could be predicted by a model, extension of the pollution would be more controllable. A method to treat the contaminated aquifer could be arrived at to ensure cleaning of the groundwater. Therefore, the objectives of this study were to understand the leachate transport phenomena of the Taichung sanitary landfill. The tasks included the choice of tracers, tests of inhibitors, identification of the parameters, and the practice of the simplified SEFTRAN model.

Papers on transport models for organic matter in leachate leakage with parameter identification are not found in the literature. The dirty water in municipal landfill flow is called "leachate" and the leachate contaminated groundwater is called "leaking leachate", which is leakage from the landfill sealing, the so-called

NOTATION LIST

AL	: dispersion coefficient
AL'	: 0.73 dispersion coefficient
D_x	: longitudinal dispersion coefficient in SEFTRAN
K	: biological decay coefficient
K'	: 0.73 biological decay coefficient
P	: effective porosity
P'	: 0.73 effective porosity
R	: retardation coefficient
R'	: 0.73 retardation coefficient
V	: Darcy velocity
V'	: 0.73 Darcy velocity
V_x	: longitudinal Darcy velocity in SEFTRAN
Φ	: effective porosity in SEFTRAN
λ	: biological decay coefficient in SEFTRAN

"leachate plume" (Freeze and Cherry 1979). The leaking leachate will affect the quality of groundwater (Griffin et al. 1976).

Kjeldsen and Christensen (1984) investigated the transport property of acid phase leachate, in which fatty acid is the primary component to chemical oxygen demand (COD) and the biochemical oxygen demand/chemical oxygen demand (BOD/COD) ratio is higher than the methane phase leachate's. Although acid phase leachate is easily decomposed by bacteria in nature, Kjeldsen and Christensen found that the COD of the acid phase leachate adsorbed by earth is low and its anaerobic decay phenomenon is slow in Denmark because of low temperatures. Kjeldsen (1986) reported that COD adsorbed by earth in the methane phase is low, but higher than in the acid phase. The quantity of COD adsorbed by earth is mainly related to the water quality of the groundwater, and soil characteristics. The decay rate of COD is mainly related to the temperature of the groundwater and whether it's anaerobic or not. Chloride was used as a tracer and Brenner's method (Brenner 1962) was used to determine the dispersion coefficient. The half life of COD was determined in the laboratory.

Using the leaking leachate from Taichung sanitary landfill, Chen (1986) found adsorption or a biological effect in the lysimeter's column. Wen and Fu (1985) used the finite difference method to solve the transport equation. The transport mechanics include velocity, dispersion, and first-order decay without adsorption.

SEFTRAN was used in this study to simulate the transport of organic matter in the leachate contaminated groundwater zone. SEFTRAN is a three-dimensional transport model. The equation can be simplified (in one dimension) as follows:

$$\Phi R \frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) - V_x \frac{\partial C}{\partial x} - \lambda \Phi \quad (1)$$

where,
Φ = effective porosity;
D_x = longitudinal dispersion coefficient;
V_x = longitudinal Darcy velocity;
λ = biological decay coefficient; and,
R = retardation coefficient.

Φ and V_x can be measured in the laboratory. D_x, λ, and R are unknown parameters. When the tracer takes action, any biological reaction or soil adsorption is excluded. Therefore, $\lambda = 0$ and $R = 1$. The governing Eq. 1 becomes:

$$\Phi \frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) - V_x \frac{\partial C}{\partial x} \quad (2)$$

Now, D_x is the only unknown variable in Eq. 2. The dispersion coefficient D_x can be obtained by running the lysimeter.

If the experiment is conducted with a biological inhibitor in the lysimeter, biological activity is restrained, $\lambda = 0$, and the COD of the leachate plume will be affected by soil only. Consequently, the governing Eq. 1 can be rewritten as follows:

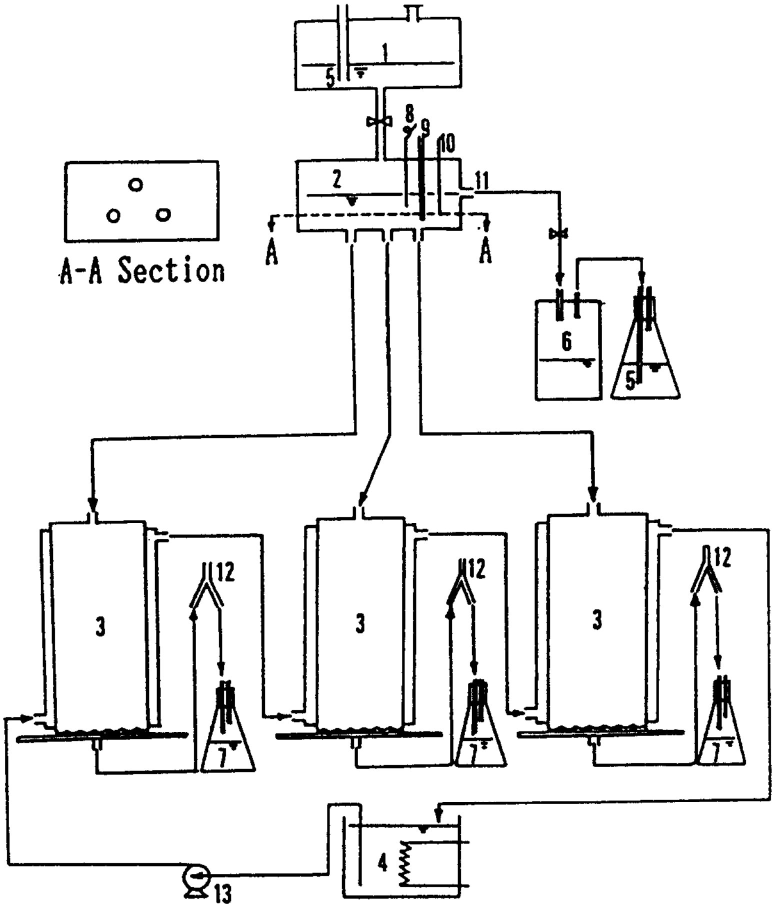

Fig. 1. Continuous experimental system.

$$\Phi R \frac{\partial C}{\partial t} = \frac{\partial}{\partial x}(D_x \frac{\partial C}{\partial x}) - X_x \frac{\partial C}{\partial x} \quad (3)$$

where R is the only variable which can be identified in the laboratory.

At last λ, the final remaining unknown in governing Eq. 1, can be calculated from the results of lysimetric study without inhibitor and all other coefficients found in the aforementioned method. By eliminating the need to identify two parameters simultaneously, the use of a tracer and inhibitor can help to determine the coefficients of dispersion, decay, and retardation separately.

METHODS AND EQUIPMENTS

Preparations of soil and leachate

Taken from Taichung sanitary landfill, the earth for the experiment was red soil of 20-40 cm depth. After air drying, granulating, and filtrating through 2 mm filter paper, it was stored for use. Leachate was also taken from Taichung sanitary landfill from the sump of the leachate collection system. Filtered through 0.45 µm filter paper to remove the earth of the fill-well and analyzed, the leachate was stored in a refrigerator at 4°C.

Choices and tests of tracers and inhibitors

Chloride (Cl^-) was chosen as a tracer because it is not easily adsorbed by earth, is difficult to decompose, and is easy to measure (Kjeldsen 1986; Lin 1989). Besides, the leachate has a high chloride concentration, so the self-contained chloride could be used as a tracer and did not change the original property of the leachate. In some special cases, it could be adsorbed by certain soil (Hung 1988), therefore, it needed to be verified that the red soil doesn't adsorb it. An inhibitor which does not affect the adsorption process in the lysimetric study had to be identified. Different dosage levels of inhibitors were tested with BOD bottles in 20°C for 5 d to restrain the biological interactions. A study was carried to determine whether the inhibitor would affect the adsorption. All the previous studies were carried out with blanks to avoid any disturbance.

Table 1. Results of the red soil analysis.

Category		Sandy soil
Density (g/cm^3)		1.631
Porosity (%)		39.14
Water content (%)		10.18
pH value		4.48
Organic content (%)		0.82
Specific density		2.68
	Sand	59.95
Gradients (%)	Silt	24.70
	Clay	18.38
Hydraulic conductivity (cm/s)		$2.1 \cdot 10^{-5}$

Note: Mean hydraulic conductivity measured by 4 columns at indoor 25°C constant head.

Batch experiments

To find soil adsorption characteristics such as equilibrium time and unit adsorption rate, 12 g of the well-prepared red soil and 120 mL leachate were placed in a closed flask kept in the anaerobic condition. The experimental conditions were as follows: 1) constant temperature at 25°C simulated to the field temperature; 2) phase separation with centrifugation at 6000 rpm for 10 min and filtration of 0.45 μm filter paper; 3) pH adjustment with NaOH and $NaHClO_4$; 4) mixing with roller at 160 rpm; and, 5) ratio of soil and solution = 1:10.

Dynamic experiments

Lysimeters as in Fig. 1 were kept anaerobic and at a constant temperature (25°C). The flux overflows to keep a constant head to stabilize the flow velocity in the system. The cylinder is 12 cm long and 10 cm diameter. The column media, earth, compacts in the same density as in the field, fed by four levels. To keep air out of the media, an inverse flow of cooled-down boiled water was carried out until the water level over the soil level was at least one pore volume (Kjeldsen 1986) for one week. The experimental system included two sets of columns to compare the inhibition dose addition (B set) and the blank (A set). There were three columns in each set; one was not fed with soil to observe the water-quality changes of influent. The chloride break through experiment and biological inhibition study were carried out until chloride or COD broke through.

Table 2. Results of the on-site underground leachate analysis.

Items	Ranges	Means
Temp. (°C)	25.1 - 26.8	25.8
pH	7.20 - 7.43	7.32
SS[a] (mg/L)	48 - 344	151
COD (mg/L)	335 - 1996	1014
BOD (mg/L)	15.8 - 50.7	30.6
Cl^- (mg/L)	720 - 878	805
DO (mg/L)	0.04 - 0.10	0.07
Water level (m)	27.11 - 31.05	29.54

[a] SS: Total suspended solids.

RESULTS AND DISCUSSIONS

Analysis of earth and leachate

The earth, as in Table 1, was sandy soil where hydraulic conductivity is near the region of clay. The water quality of the seepage leachate is shown in Table 2. The temperature of the groundwater was near 25°C, pH-value was near 7 and the ratio of BOD and COD was less than 0.1. There was seepage of methane phase leachate from the sanitary landfill. Chloride content was about 800 mg/L, and dissolved oxygen (DO) was near 0.

Choice and test of tracer and inhibitor

In Table 3, the experimental results indicate that adsorption of the earth to chloride is negligible; therefore, chloride is a non-reactive material and can be used as a tracer for red soil in saturated aquifer. The inhibitor experiments (Figs. 2a and 2b) show that, although both $HgCl_2$ and NaN_3 are excellent, $HgCl_2$ requires a dosage as low as 5 mg/L, compared to hundreds of mg/L NaN_3. The effect of inhibitors on red soil adsorption is shown in Table 4. Figure 3 indicates that NaN_3 produces COD. Consequently, $HgCl_2$ (5 mg/L) was taken as an inhibitor in the later experiments.

Batch experiments

Figure 4 shows that most of the adsorptable organic matter (COD) was adsorbed within 1 h. The adsorption equilibrium time is conservatively estimated at 12 h.

Table 3. Results of chloride adsorption experiments.

Reaction time (h)	Soil-water ratio	Initial conc. (mg/L)	Final conc. (mg/L)	pH[a]
12	1 : 10	865 ± 4	870 ± 3	7.56
24	1 : 10	843 ± 8	845 ± 4	7.43
24	1 : 10	717 ± 4	716 ± 8	7.61
48	1 : 1	789 ± 1	793 ± 3	6.83

[a] Measure at the end of reaction time.

Table 4. Results of inhibitor selection experiments.

1) Test 1.

Chemical	Specific adsorption (mg COD/g soil)	Ratio of specific adsorption[a]
Blank	1.18	1.00
$HgCl_2$ 5 mg/L	1.19	1.01
$HgCl_2$ 10 mg/L	1.17	0.99
$HgCl_2$ 70 mg/L	1.37	1.16
NaN_3 400 mg/L	1.03	0.87
NaN_3 600 mg/L	0.99	0.84

2) Test 2.

Chemical	Specific adsorption (mg COD/g soil)	Ratio of specific adsorption
Blank	1.09	1.00
$HgCl_2$ 5 mg/L	1.08	0.99
$HgCl_2$ 10 mg/L	1.09	1.00
$HgCl_2$ 15 mg/L	1.11	1.02
$HgCl_2$ 70 mg/L	1.20	1.10

[a] The ratio of the experimental sample's specific adsorption to that of the blank.

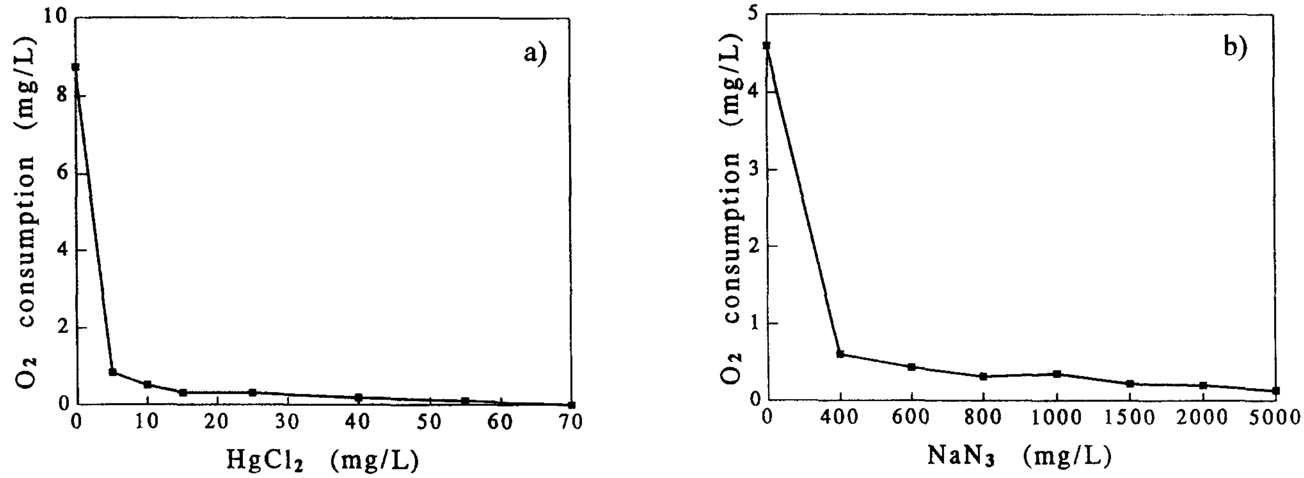

Fig. 2. Inhibitor experiments: a) $HgCl_2$; b) NaN_3.

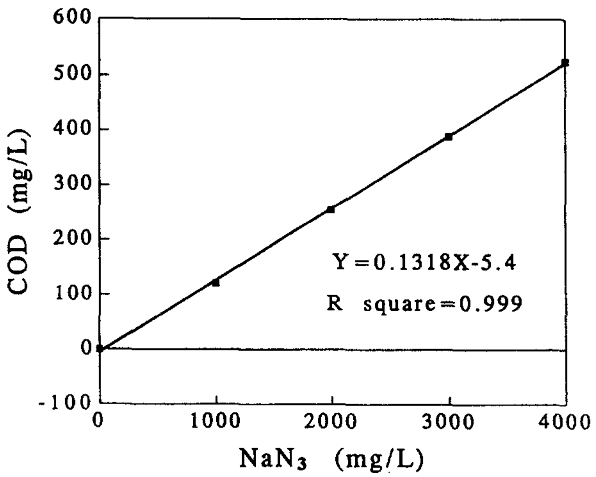

Fig. 3. Relationship between COD and NaN_3 dosage.

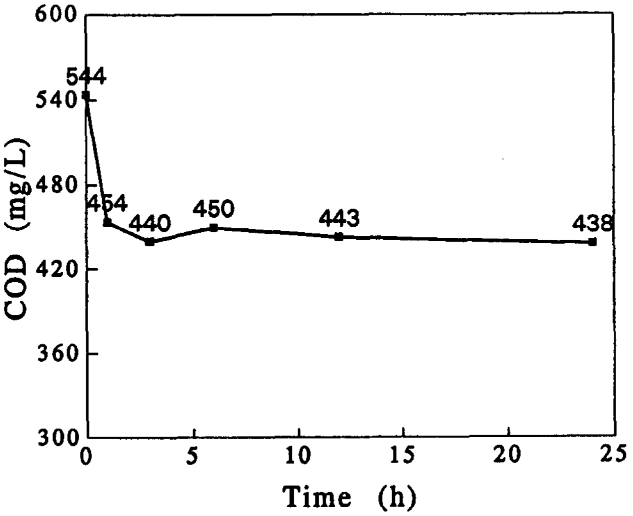

Fig. 4. Soil adsorption to COD of leaking leachate with time.

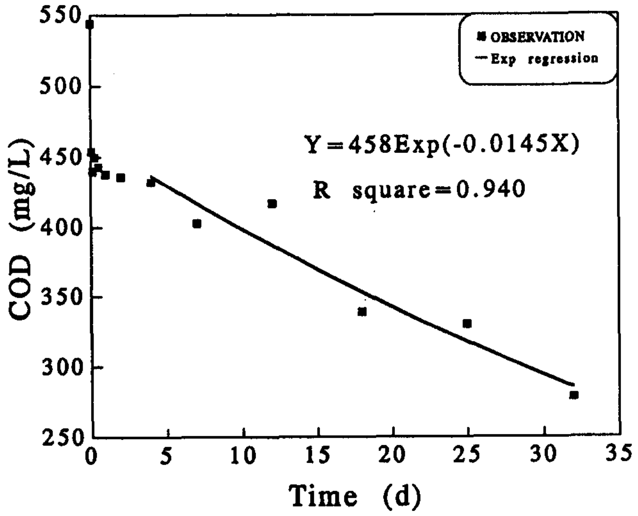

Fig. 5. Batch experiment for COD decay.

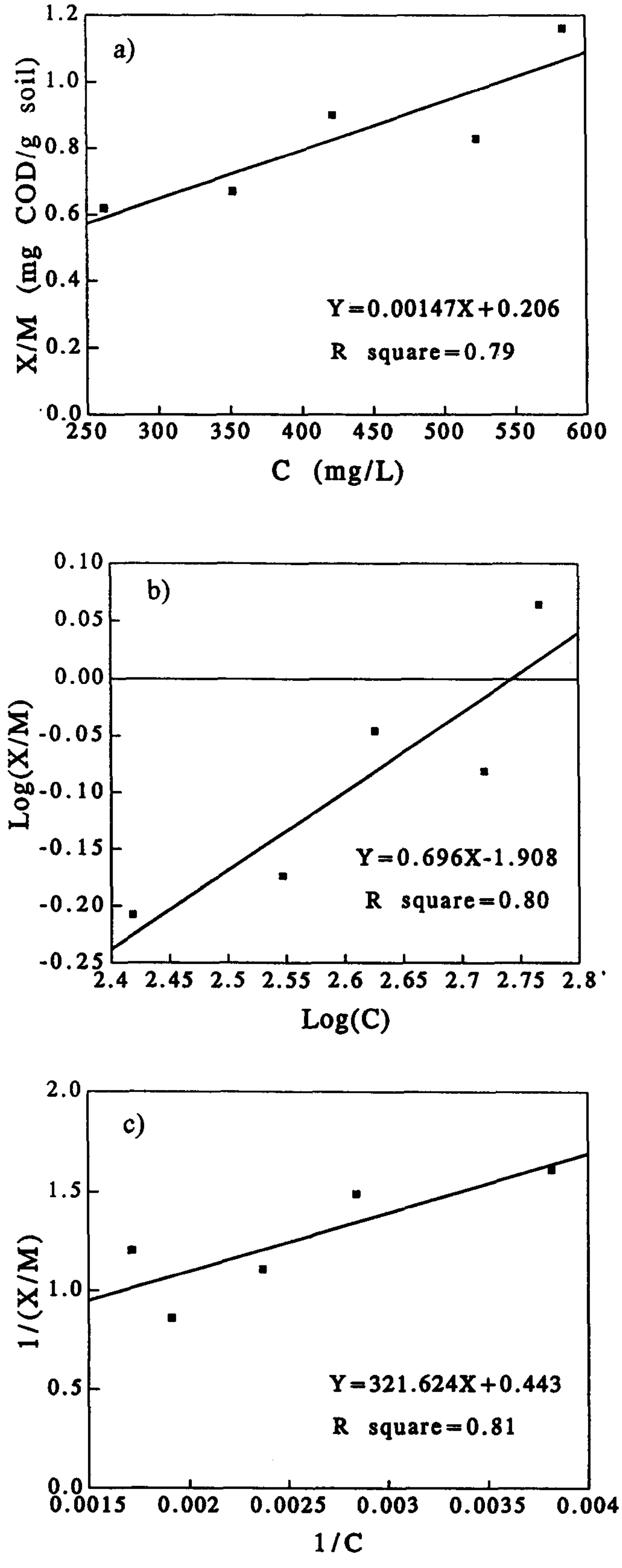

Fig. 6. Regression adsorption curve (note: X/M = unit adsorption, and C = equilibrium concentration of COD). a) Linear; b) Freundlich; c) Langmuir.

The biological decay experimental results show the biological decay coefficient is 0.0145/d (Fig. 5). The linear, Freundlich, and Langmuir models all show similar results; the R-square values are 0.79, 0.80, and 0.81 in Figs. 6a-6c, respectively.

Dynamic experiments and SEFTRAN simulation studies

Adequate numbers of elements and time steps were obtained by trial-and-error. Taking the soil background concentration as the initial conditions, Dirichlet boundary conditions as boundary conditions, and taking effective porosity and Darcy velocity into account, a dispersion coefficient (AL) of 0.24 ± 0.11 cm was obtained. Dispersion coefficients of 0.35, 0.25, 0.17, and 0.20 cm were obtained for columns A1, A2, B1, and

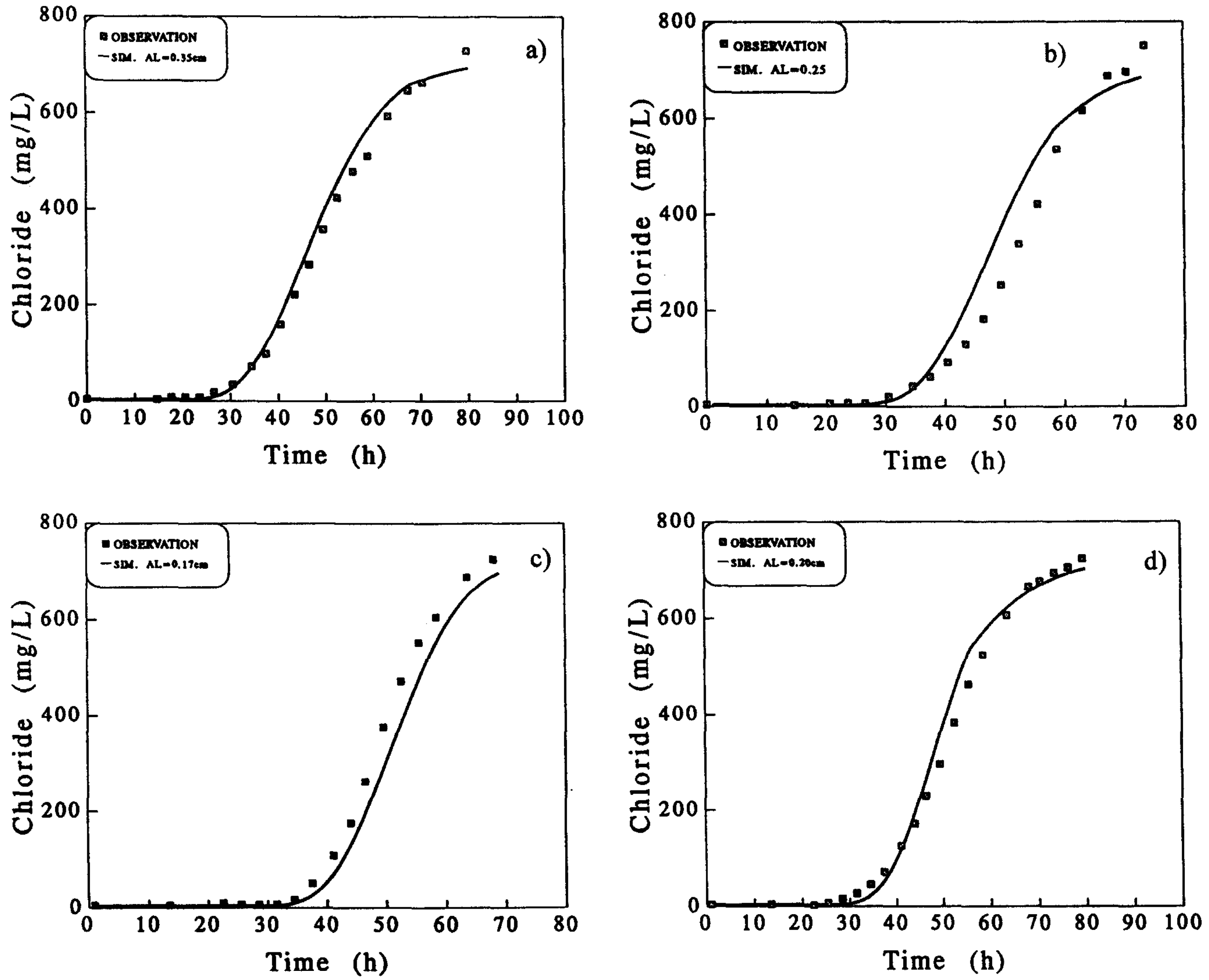

Fig. 7. Chloride breakthrough simulation curve.
a) A1 soil column; b) A2 soil column; c) B1 soil column; d) B2 soil column.

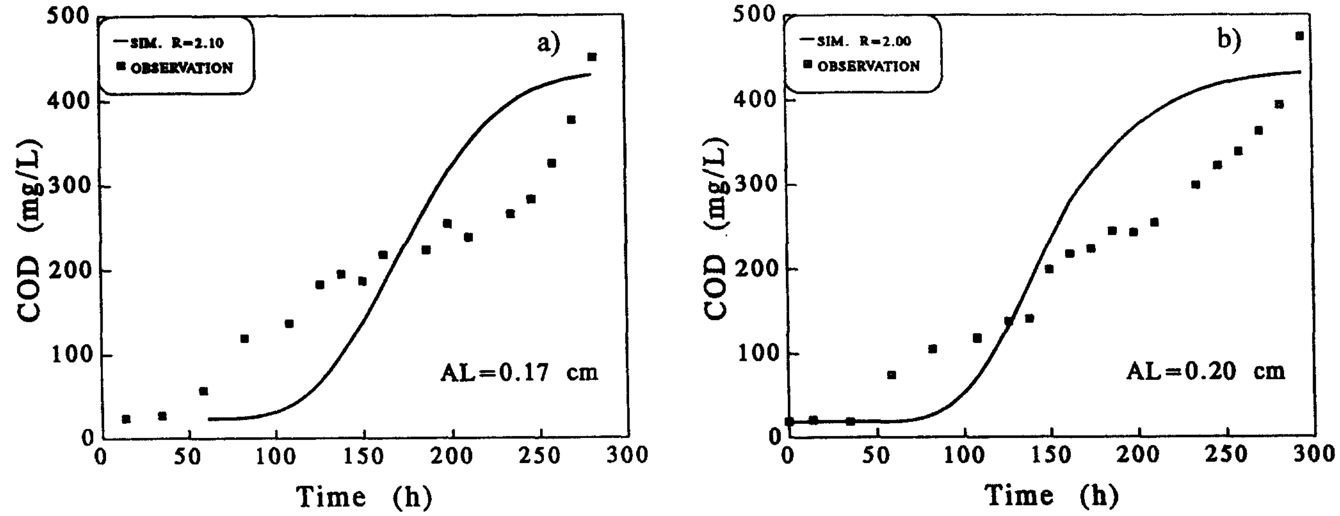

Fig. 8. COD breakthrough simulation curve.
a) B1 soil column; b) B2 soil column.

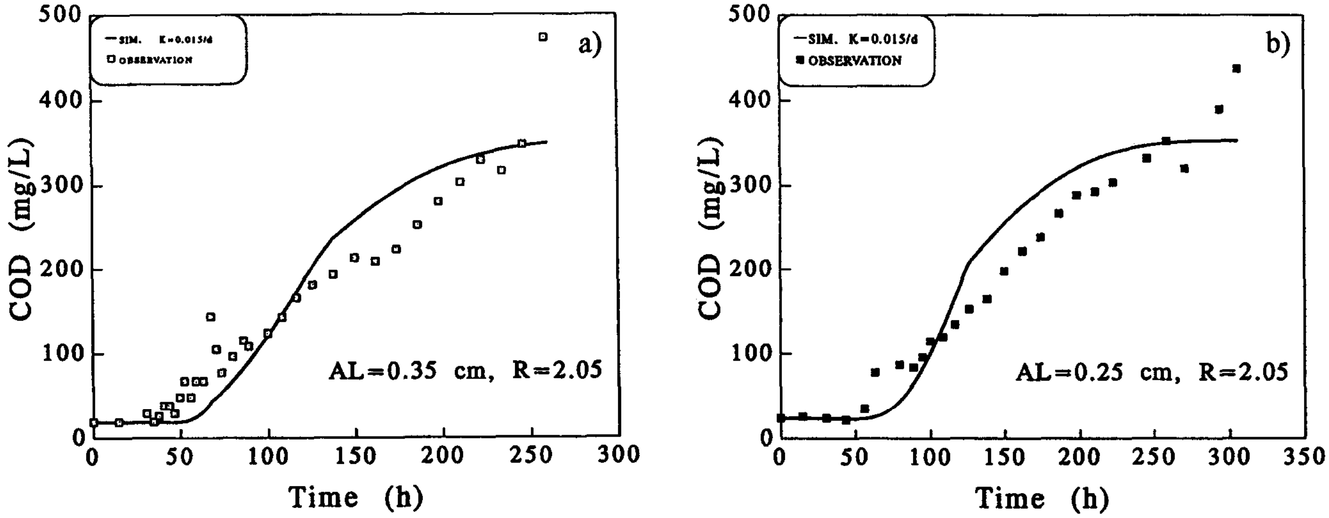

Fig. 9. COD breakthrough simulation curve.
a) A1 soil column; b) A2 soil column.

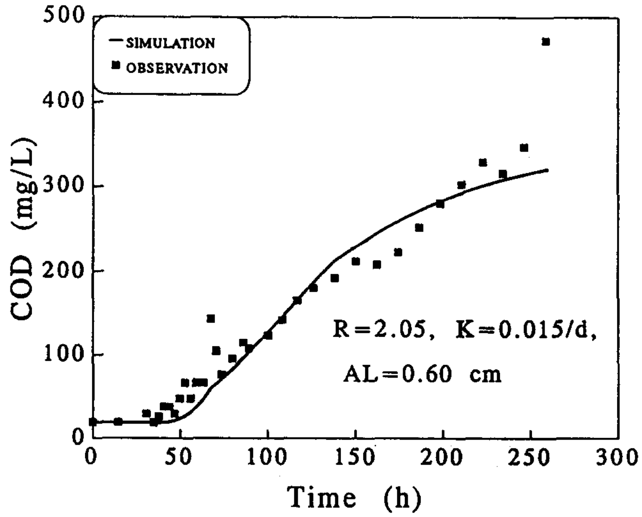

Fig. 10. Numerical fit curve without parameter identification in A1 column.

B2, respectively (Figs. 7a-7d). The retardation coefficient (R) is 2.05 ± 0.05; 2.1 for column B1 (Fig. 8a), and 2.0 for column B2 (Fig. 8b). The biological decay coefficient (K) is 0.015/d both in columns A1 and A2 (Figs. 9a and 9b). The dispersion coefficient (AL) could be taken as 0.60 cm to get a better simulated curve in Fig. 10; however, the result would not represent the real situation at the site.

Among all the parameters chosen, the sensitivity studies in Fig. 11 show the Darcy velocity (V') as the most sensitive parameter, followed by the retardation coefficient (R'), effective porosity (P'), dispersion coefficient (AL'), and biological decay (K'). The sensitivity of retardation is close to that of the Darcy velocity.

CONCLUSIONS

The BOD/COD value of leachate through groundwater is lower than that of actuate leachate in landfill. Chloride and $HgCl_2$ were excellent tracer and inhibitor, respectively, in this study. COD is quickly adsorbed by the red soil of Taichung sanitary landfill. There is little difference between the linear, Langmuir, and Freundlich adsorption models. The COD decay coefficient is 0.0145/d at 25°C and in anaerobic conditions. The dispersion coefficient is between 0.17 and 0.35 cm; the retardation coefficient is 2.025. The most sensitive parameter is Darcy velocity, followed by the retardation coefficient, effective porosity, dispersion and decay coefficient.

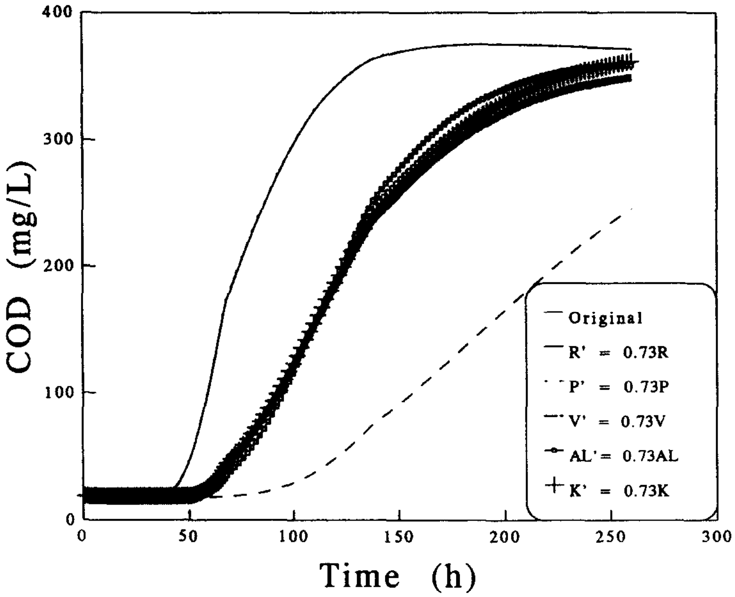

Fig. 11. Parameters' sensitivity comparison.

Among them, the sensitivity of retardation and Darcy velocity are close.

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