Journal of Hazardous Materials 58 (1998) 249–259

Landfill leachate characteristics and modeling of municipal solid wastes combined with incinerated residuals

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Abstract

Sanitary landfilling of municipal solid wastes (MSW) combined with incinerated residuals is a disposal method specific to Taiwan. The purpose of this study was to explore the influences that adsorption, desorption, and biological reactions in landfilling may have on the quality of leachate. Not only did different combinations and the stratification of waste have to be considered, but anaerobic and semiaerobic landfilling have also been simulated. COD concentrations of leachate were processed by using a numerical method to get a simulation model for the estimation of variations in the organic pollutants in the leachate. The intensities of leachate from both semiaerobic and anaerobic landfilling, were also explored with this model. Comparing the simulation with the experimental data, we found that the degradation of the leachate quality was approximately similar for both type of data. © 1998 Elsevier Science B.V.

Keywords: MSW; Incinerated residuals; Leachate model; Landfill; Semiaerobic landfill; Co-disposal

1. Introduction

The incineration of municipal solid wastes is a waste treatment policy in Taiwan. Many large scale incinerators have been designed to solve the problem of waste treatment. During the setting-up period for the incinerators, large quantities of MSW must still be disposed of. Therefore, landfill combining MSW with incinerated residuals is a special waste disposal method that will reduce the need to find a separate landfill site. This study investigates the characteristics of landfill using different kinds of waste

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PII S0304-3894(97)00136-2

combinations. The principal purpose of this study was to explore the influences that adsorption, desorption, and biological reactions in the landfilling process may have on its leachate quality and to establish a model of the leachate quality. The model that explains the results of landfill of MSW combined with incinerated residuals will be useful for waste disposal in the future. This study consists of the following parts:

(a) An experimental study of semiaerobic landfill combining MSW with incinerated residuals.
(b) An experimental study of anaerobic landfill combining MSW with incinerated residuals.
(c) A determination of the parameters of adsorption and desorption.
(d) To establish a model of the leachate quality.

2. Background review

Modeling of the leachate quality of landfill has been widely reported. A survey of the results from the papers listed below has caused the development of models to explain the phenomena of leachate from landfill. The relevant research from these papers is as follows.

2.1. Straub and Lynch [1]

$$R = (S/S_0)^m \, b(C_{\max} - C), \tag{1}$$

$$\partial C/\partial t + q/\theta(\partial C/\partial Z) + 1/\theta(\partial J/\partial Z) = R + rC/\theta, \tag{2}$$

where $R =$ the contaminant generation rate; $S =$ the mass of leachable contaminant; $C =$ the concentration of the contaminant; $q =$ the vertical flux of moisture; $\theta =$ the volumetric moisture content; $J =$ the combined diffusion flux.

2.2. Lou [2]

Based on the Hydrologic equation, the mass balance of precipitation on the landfill site was developed for a leachate model.

2.3. Demetracopoulos et al. [3]

$$\partial(C\theta)/\partial t + \partial(Cq)/\partial Z = \partial[\theta E(\theta)\partial C/\partial Z]/\partial Z + \theta R \tag{3}$$

$$R_1 = KS/S_0(C_{\mathrm{st}} - C) \tag{4}$$

$$R_2 = \mu_{\mathrm{m}} XC/[Y(K_{\mathrm{m}} + C)] \tag{5}$$

$$R = R_1 + R_2 \tag{6}$$

where $E(\theta)$ = longitudinal dispersion coefficient; K = a rate coefficient; μ_m = microorganism maximum specific growth; X = microorganism concentration; Y = the microorganism yield coefficient; K_m = the substrate concentration at $1/2$ the maximum specific growth rate.

2.4. Chow [4]

Large scale lysimeters were set up to simulate a landfill site. After more than 800 days, a mathematical model was developed by processing the leachate quality.

2.5. Wu and Wang [5]

$$\partial C/\partial t + u\partial C/\partial Z = \partial(D\partial C/\partial Z)/\partial Z + Y/\theta(K_a \rho_a + K_b \rho_b) - K_d C \quad (7)$$

$$\mathrm{d}\rho_a/\mathrm{d}t = -K_a \rho_a \quad (8)$$

$$\mathrm{d}\rho_b/\mathrm{d}t = -K_b \rho_b \quad (9)$$

where k_a = the degradation coefficient for easily degraded organics; k_b = the degradation coefficient for difficult degraded organics; ρ_a = the density of easily degraded organics; ρ_b = the density of difficult degraded organics; Y = the COD yield coefficient of organics, (use 1.33); k_d = the degradation coefficient of dissolved COD; V = the average velocity of leachate flow through the pore space; D = the dispersion coefficient.

2.6. Terashima and Naito [6]

$$\partial(C\theta)/\partial t + \partial(q\theta)/\partial t + \partial C/\partial Z = \partial[\theta E(\theta)\partial C/\partial Z]/\partial Z + S \quad (10)$$

$$\mathrm{d}q/\mathrm{d}t = -K_1 q(C_0 - C) + K_2 C(q_0 - q) \quad (11)$$

where q = the amount adsorbed per unit weight of adsorbent; k_1, k_2 = the empirical constants; C = the equilibrium concentration of adsorbate in solution after adsorption; k_c, k_q = the transport coefficients of adsorption and desorption; C_0 = the maximum concentration of organics in solution; q_0 = the maximum concentration of organics in solid.

Table 1
Conditions of semiaerobic landfill

Number	Density (g cm^{-3})	Materials of lysimeter
1	0.67	MSW
2	0.71	52% MSW + 48% incinerated residual (combined)
3	0.71	48% incinerated residual + 52% MSW (stratified)
4	0.71	52% MSW + 48% incinerated residual (stratified)
5	0.81	79% incinerated residual + 21% MSW (stratified)
6	0.81	21% MSW + 79% incinerated residual (stratified)
7	1.26	incinerated residual

Table 2
Conditions of anaerobic landfill

Number	Density ($g\ cm^{-3}$)	Materials of lysimeter
8	0.8	MSW
9	0.6	93% MSW + 7% incinerated residual
10	0.6	23% MSW + 77% incinerated residual(stratified)
11	0.6	23% MSW + 77% incinerated residual(combined)

2.7. Su [7]

$$S_e = S_0 e^{-kt} \tag{12}$$

$$t = CD/Q^n \tag{13}$$

where S_e = the COD of the effluent; S_0 = the COD of the fresh feed; C, n = constants; D = the depth; t = the detention time; Q = the flow rate.

3. Experimental

In our study, MSW and incinerated residuals were buried together in lysimeters in some different combinations and stratifications, as shown in Tables 1 and 2. All the lysimeters were designed to the same scale. Before the test materials were placed in the lysimeters, the materials had to be shredded to a particle size of less than 1 cm. After pretreatment of the materials, fixed quantity samples were fed into the lysimeters. All the lysimeters were placed in an isothermal batch in order to control the test temperature.

Then, a fixed quantity of water, which was determined by the average daily precipitation, was added daily into the lysimeters. The leachate from lysimeters was collected everyday and the COD was measured for each sample.

Furthermore, lysimeters of the same scale were put in the isothermal batch for the adsorption test. The test temperature was controlled at 4°C in order to inhibit the activities of microorganism. Leachate taken from a large landfill site was added into the lysimeters for the sake of developing the adsorption and desorption parameters. By processing the effluent concentration of the leachate, the adsorption and desorption parameters could be determined.

4. Model

Although some of the models described in the background review have been well established, they hardly explain the exact phenomena of the leachate quality. The model developed by Wu and Wang [5] focused on biological reactions. The transport of pollutants was simulated as occurring at a constant rate. The model developed by Terashima and Naito [6] resulted in an opposite view on this issue. It focused on adsorption and desorption in landfilling. These two models partially explain the segment phenomena of the leachate quality. If the main characteristics of these two researches are considered together, it is possible to establish a more useful model.

This is the reason why modeling of leachate quality in this study was established with the consideration of the effects of adsorption, desorption and biological reactions in landfilling may have on its leachate quality.

Based on the Langmuir adsorption equation,

$$q = k_1 k_2 C/(1 + k_1 C) \tag{14}$$

where q = the amount adsorbed per unit weight of the adsorbent; k_1, k_2 = the empirical constants; C = the equilibrium concentration of adsorbate in solution after adsorption. It can be derived that

$$\mathrm{d}q/\mathrm{d}t = (k_1 k_2 - k_1 q)\mathrm{d}C/\mathrm{d}t - k_1 C \mathrm{d}q/\mathrm{d}t \tag{15}$$

Combined with the transport phenomena of organic matter determined by membrane theory [6],

$$\mathrm{d}C/\mathrm{d}t = k_c(C_0 - C) \tag{16}$$

$$\mathrm{d}q/\mathrm{d}t = k_q(q - q_0) \tag{17}$$

where k_c, k_q = the transport coefficients of adsorption and desorption; C_0 = the maximum concentration of organics in solution; q_0 = the maximum concentration of organics in solid.

The biodegradable matter falls into two groups. One group can be degraded easily by microorganisms, and the other can not. The mass balance equation for the lysimeters is given as

$$\partial C/\partial t + V(\partial C/\partial Z) = \partial(D\partial C/\partial Z)/\partial Z - (\mathrm{d}\rho_a/\mathrm{d}t + \mathrm{d}\rho_b/\mathrm{d}t)y/\theta - k_d C \tag{18}$$

where

$$\mathrm{d}\rho_a/\mathrm{d}t = -k_a\,\rho_a \tag{19}$$

$$\mathrm{d}\rho_b/\mathrm{d}t = -k_b\,\rho_b \tag{20}$$

where k_a = the degradation coefficient for easily degraded organics; k_b = the degradation coefficient for difficult degraded organics; ρ_a = the density of easily degraded organics; ρ_b = the density of difficult degraded organics; y = the COD yield coefficient of organics, (use 1.33); k_d = the degradation coefficient of dissolved COD; V = the average velocity of leachate flow through the pore space; D = the dispersion coefficient; θ = the moisture content.

The equation of leachate may therefore be integrated from Eqs. (15)–(20) to obtain

$$\partial C/\partial t = -V\partial C/\partial Z + D\partial^2 C/\partial Z^2 + (k_a\,\rho_a + k_b\,\rho_b)y/\theta - k_d C - \rho/\theta((k_1 k2 - k_1 q)k_c(C_0 - C) - k_1 k_q C(q - q_0) \tag{21}$$

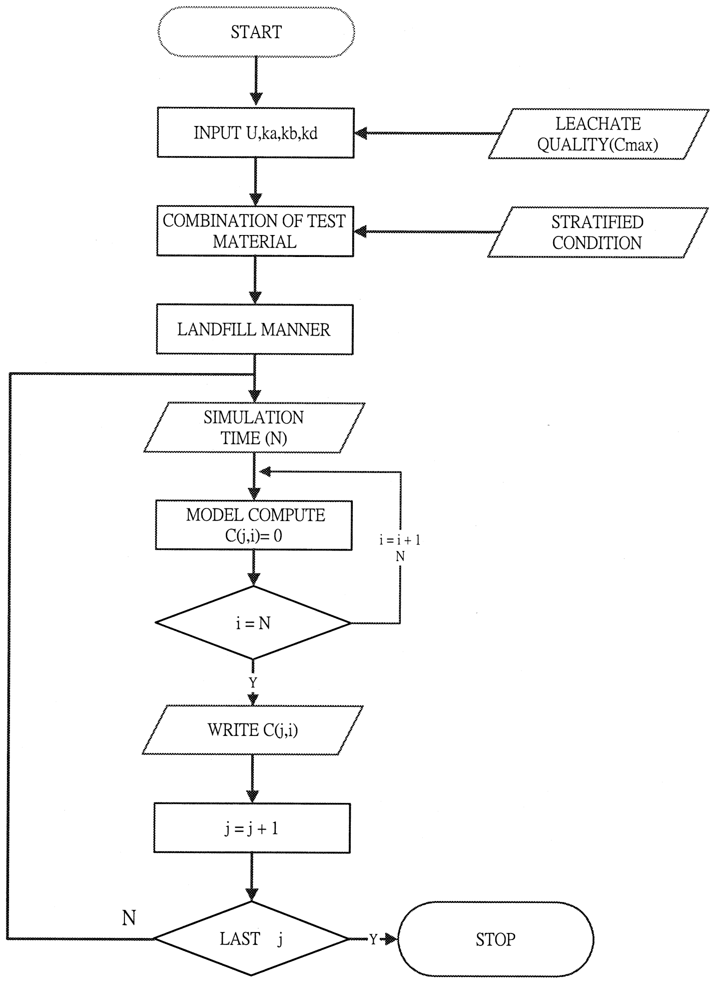

Fig. 1. Flow chart of model with explicit difference method.

The equation of leachate may be solved by adopting the Explicit Difference Method to get the simulation results. The flow chart of this model is shown in Fig. 1.

5. Results

The maximum value of COD concentration depends on the amount of organics whether they can be degraded easily or not, but the initial stage of leachate concentration was affected by the parameter k_a. Therefore, it is important to find out which factors influence this parameter. The influence of landfill characteristics on k_a, such as the bulk density of the landfill, the amount of easily degraded organics, the amount of precipita-

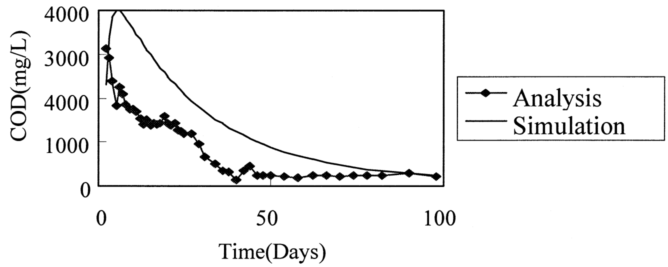

Fig. 2. Comparison of simulation data and analysis results from lysimeter no. 1 (MSW).

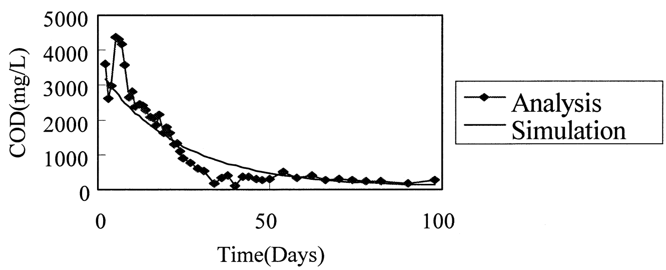

Fig. 3. Comparison of simulation data and analysis results from lysimeter no. 2, i.e., 52% MSW and 48% incinerated residual in combination.

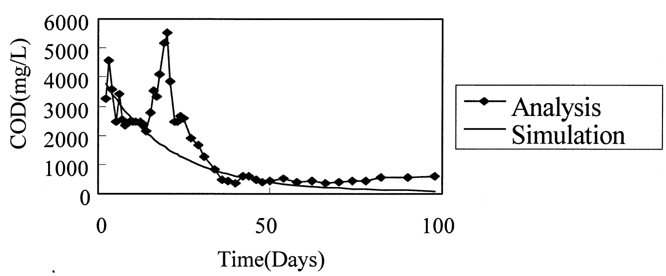

Fig. 4. Comparison of simulation data and analysis results from lysimeter no. 3, i.e. 48% incinerated residual on upper layer and 52% MSW on lower layer in stratification.

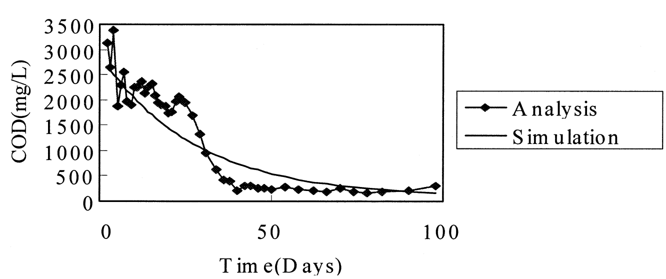

Fig. 5. Comparison of simulation data and analysis results from lysimeter no. 4, i.e. 52% MSW on upper layer and 48% incinerated residual on lower layer in stratification.

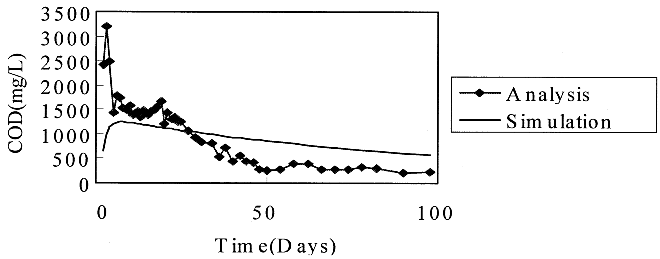

Fig. 6. Comparison of simulation data and analysis results from lysimeter no. 5, i.e. 79% incinerated residual on upper layer and 21% MSW on lower layer in stratification.

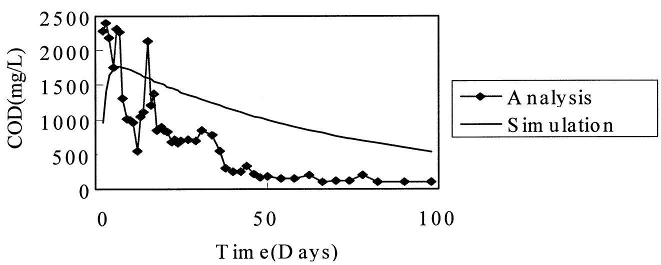

Fig. 7. Comparison of simulation data and analysis results from lysimeter no. 6, i.e. 21% MSW on upper layer and 79% incinerated residual on lower layer in stratification.

tion, the stratification and different combinations have all been considered in this study. A series of experiments had been done to obtain the results. Finally, we found that the amount of organics and the bulk density of landfill would influence the value of the parameter, k_a. The performance of stable situation on leachate quality might be faster when the density of the landfill was decreased, while the value of k_a might increase. It was also shows that decreasing the amount of easily degraded organics may increase the value of k_a.

The characteristics of leachate collected from the lysimeters helps to explain the landfilling performance. The COD concentration of leachate may raise rapidly when the landfill samples consist of MSW. When bioreactions occur, the organic matter tends to

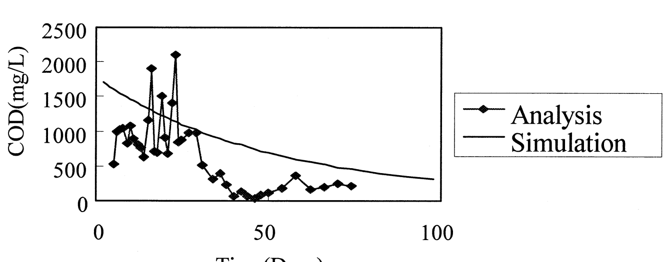

Fig. 8. Comparison of simulation data and analysis results from lysimeter no. 7 (incinerated residual).

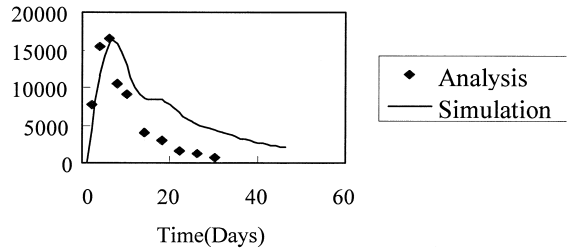

Fig. 9. Comparison of simulation data and analysis results from lysimeter no. 8 (MSW).

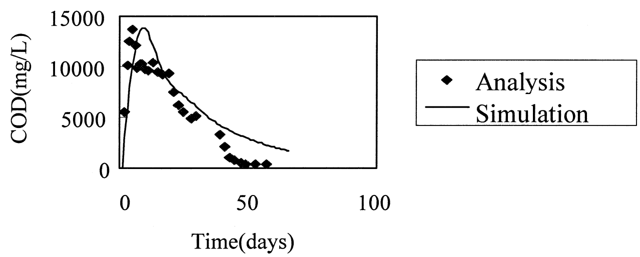

Fig. 10. Comparison of simulation data and analysis results from lysimeter no. 9, i.e., 93% MSW and 7% incinerated residual in combination.

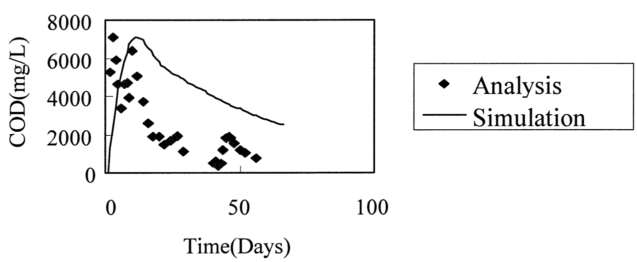

Fig. 11. Comparison of simulation data and analysis results from lysimeter no. 10, i.e., 23% MSW and 77% incinerated residual in combination.

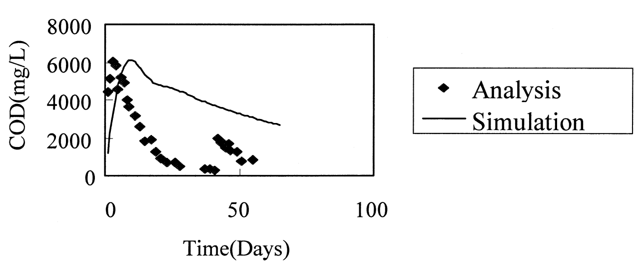

Fig. 12. Comparison of simulation data and analysis results from lysimeter no. 11, i.e., 23% MSW and 77% incinerated residual on lower layer in stratification.

Table 3
Parameters of semiaerobic landfill

Number	V (cm day^{-1})	K_a (g g^{-1} day^{-1})	K_b (g g^{-1} day^{-1})	K_d (1 day^{-1})	θ
1	0.54	0.037	0.001	0.5	0.30
2	0.52	0.042	0.001	1.0	0.38
3	0.53	0.05	0.001	1.0	0.38
4	0.52	0.035	0.001	1.0	0.38
5	0.44	0.01	0.001	0.5	0.37
6	0.42	0.015	0.001	0.5	0.37
7	0.32	0.02	0.001	1.0	0.34

degrade, therefore COD concentration of leachate continuously decays and then becomes stable situation.

Figs. 2–8 show the leachate qualities of semiaerobic landfill. These data also indicate that if incinerated residuals are put together with MSW, the leachate quality will greatly improve. In lysimeter 2 and lysimeter 3, MSW and incinerated residuals of the same weight were buried. Another experimental example is also considered in lysimeter 4 and lysimeter 5. In Fig. 4, it becomes evident that the concentration of COD was lower and the stable situation on leachate quality was reached faster than the results shown in Fig. 5. Comparing the results in Fig. 6 with those in Fig. 7, we see that they also share this same phenomenon. From these experimental data, some important conclusions may be reached. The stratification of MSW and incinerated residuals can help to produce a better leachate quality than a combination of these two materials does. The stratification of incinerated residuals can be more efficient on leachate quality in lower layers of the lysimeter than in upper layers. The quantity of incinerated residuals also influences the leachate quality. When the quantity of incinerated residuals increases, the leachate quality decays, and maintain a stable situation faster than in the other cases.

Not only semiaerobic landfill bares the phenomena above, but also does anaerobic landfill. Figs. 9–12 show experimental results for anaerobic landfill combining MSW with incinerated residuals. Comparing those two types of landfilling, the decaying tendency of leachate COD from anaerobic landfill was weaker than for semiaerobic landfill. Based on the Langmuir isothermal adsorption equation, adsorption and desorption of anaerobic landfill is similar to semiaerobic landfill. Therefore, it could be concluded that the difference may be caused by bioreactions. Models ignoring biological reactions in landfilling are limited as to their leachate quality prediction capacity.

Table 4
Parameters of anaerobic landfill

Number	V (cm day^{-1})	K_a (g g^{-1} day^{-1})	K_b (g g^{-1} day^{-1})	K_d(1 day^{-1})	θ
8	6.50	0.052	0.001	0.068	0.43
9	4.44	0.039	0.001	0.068	0.36
10	3.60	0.020	0.001	0.068	0.37
11	4.35	0.015	0.001	0.068	0.37

The results of leachate quality analysis were processed with a numerical method in order to obtain some of the parameters of the model above. The adsorption and desorption coefficients could be determined by adsorption test remaining in the circumstances of 4°C. The results show that the coefficient of adsorption is 0.00743 and the coefficient of desorption is 0.000787 for the MSW, and 0.000314 and 0.000932, respectively for the incinerated residuals. COD of the daily precipitation was assumed to be 0. The values of V, ρ, θ, D, C_0 and q_0, were calculated or estimated and are shown in Tables 3 and 4. They were assumed to be constants throughout a single experiment so that the leachate quality could be simulated. Figs. 2–12 also show the comparisons between the simulation data and the analysis results.

6. Conclusion

According to the results of leachate quality, landfill combining MSW with incinerated residuals is an efficient method of waste disposal. The quality of the leachate would be better than for traditional disposal method. The results of simulation still differ somewhat from analysis, but, the tendency of decaying of the leachate quality was approximately similar. Therefore, this model is useful for simulating the leachate quality of landfill combining MSW with incinerated residuals for both anaerobic landfill and semiaerobic landfill.

Acknowledgements

This study was supported by the National Science Council, Taiwan, R.O.C. in NSC 81-0421-E-032-03-Z.

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