Pergamon

Environment International, Vol. 22, No. 2, pp. 225–237, 1996

0160-4120/96 $15.00+.00

PII S0160-4120(96)00008-6

ASSESSMENT OF LEACHATES FROM SANITARY LANDFILLS: IMPACT OF AGE, RAINFALL, AND TREATMENT

Paris Honglay Chen
Dept. of Soil and Water Conservation, National Chung-Hsing, University, Taichung, Taiwan, ROC

EI 9502-122 M (Received 12 February 1995; accepted 12 December 1995)

The purpose of this study is to search for effects of landfill age and rainfall on landfill leachate in Taiwan, as well as to carry out a site-treatment study of a typical leachate treatment plant (Tatun). According to the results of analysis, the critical time, so-called leachate-mature-time, is much shorter than the record, 10 to 20 y, in the literature. In addition, it is clearly shown that the leachate flow increases linearly with increasing rainfall, i.e., the leaching coefficient C value decreases. The total organic carbon and the conductivity exhibit different dilution slopes on continuous and continual raining days; the higher slope is observed at continual days. Finally, the typical treatment of leachate in Taiwan includes two parts, biological treatment and a chemical-aided precipitation system. The biological treatment processes are dominating in the removal efficiency of biochemical oxygen demand, chemical oxygen demand, ammonia nitrogen (NH_4^+-N), and total Kjeldahl nitrogen. However, the best removal of suspended solids, volatile suspended solids, and total phosphorus is obtained with the chemical precipitation system.

INTRODUCTION

In Taiwan, properties of municipal wastes differ from that of other countries, relatively high capacities of water are observed, and the average rainfall of Taiwan is approaching 2500 mm annually. In spite of run-in and run-off, the falling in-flow loads in the disposal site area are significant (Gau and Chou 1988). Hence, the treatment of leachate has become a crucial task.

The investigation indicates that anaerobic processes dominate in most landfills due to a limited oxygen penetration into the compacted refuse. The degradation of organics takes place in nature, which ordinarily needs a period of 10~20 y or longer time to reach a steady state (Hsieh and Huang 1991). Changes of the leachate composition over time have also been reported. Therein, a decrease in biochemical oxygen demand (BOD) or chemical oxygen demand (COD) concentrations is often affected with landfill manners (landfill speed, return leachate process, etc.). In general, the leachate concentration, BOD, of initial landfill is higher than at any other time, and then gradually reduces with increasing landfill age. The reason for the lower leachate concentration during the raining season is because the leachate is diluted with rainwater. However, increasing concentrations in an initial period of rainfall are expected, due to the fresh wash-out effect (Kao et al. 1986; Huang 1987). Chian and DeWalle (1977) reported that higher COD/TOC (total organic carbon) and BOD/COD ratios were found in young unstable leachates, and about 2/3 of the total organic carbon consisted of short-chain fatty acids, which reflects that the high rates of anaerobic methane degradation were adequate. Generally, in sanitary landfills up to 2~5 y old, not only the substrates and microbiological contents decreased progressively with age, but also the composition of leachate changed significantly. At the middle or end of the landfill, the main leachate organic compounds were refractory long-chain carbohydrates, and/or humic substances. Consequently, a decrease in BOD/ COD ratios was observed. Gau et al. (1991) indicated that when wastes are disposed of in the landfill, microbiological degradation of the organic waste initiates, resulting in a leachate with a high concentration of easily degradable components (volatile acids). With age, the refractory high molecular weight compounds were found instead of the degradable organic matter. For example, the BOD/COD ratios of initial leachate were 0.6 to 0.8 in the Futekeng sanitary landfill site in Taipei, Taiwan. Nevertheless, the values of BOD/COD were lowered to 0.2~0.4 after 5 y of operation. In the middle of the landfill, the effluent COD concentration still maintained a high value inspite of the biological treatment processes. Application of traditional flocculation to leachate treatment did not to achieve the discharge standard for the residual refractory organic compounds. Kennedy et al. (1988) indicated that an excellent anaerobic treatment system could receive high organic loadings of leachate with low landfill age, and remove approximately 90% of COD. The characteristics of residual organic matters were close to the leachate of middle landfill age or higher, and the general biological or chemical treatment processes would not give a effective and economical performance.

As stated above, the leachate produced by landfills contains a high concentration of organic compounds. The leachate also includes significant inorganic matters including heavy metals. Furthermore, the leachate is dark brown and has a strong odor. Therefore, treatment of the landfill leachate is essential (Mennerich and Alber 1986). In Taiwan, basic information on the treatment processes of leachate is usually obtained from other countries, due to a lack of native available data for characteristics of leachate, leachate flow, and treatment performance of leachate etc. It is thus difficult to control contaminations. So, establishing information of Taiwan landfill leachate is extremely urgent.

The main objectives of this research were: 1) to study characteristics of leachate with different landfill age in Taiwan; 2) to investigate the efecte of rainfall on the leachate; 3) to evaluate the performance of the typical treatment plant, i.e., Tatun leachate treatment plant; and 4) to determine the necessity of tertiary treatment by jar-test. In this work, the results obtained can serve as references to improve the design and operations of leachate treatment plants.

METHODS

Landfill age effects study

The relationship between the characteristics of leachate and landfill age were investigated with nine sanitary landfill sites including the Tatun plant in the central region of Taiwan. All water quality analyses in this study were repeated three or more times, and were performed according to the Standard Methods (APHA et al. 1985) for the following characteristics:

Dissolved oxygen (DO)—Method 421B;
Biochemical oxygen demand—Method 507 with Method 421B for dissolved oxygen;
Chemical oxygen demand—Method 508B with 20x150 mm test tubes;
Ammonia nitrogen—Method 417D following Method 417A;
Total Kjeldahl nitrogen (TKN)—Method 420A with Method 417D for final ammonia;
Nitrate nitrogen—Method 418A;
Nitrite nitrogen—Method 419;
Suspended solids (SS)—Method 209C with Whatman GF/C filter paper;
Volatile and fixed suspended solids (VSS)—Method 209D;
Total phosphorus—Method 424D following sulfuric acid-nitric acid digestion of Method 424C;
Iron, copper and chromium—Method 303A.

Rainfall effects study

A study of leachate flow and characteristics of leachate depending on rainfall was also completed. The measure of rainfall was taken by a rain gauge (TOA, Model B-3400) established on the top of the management building in the Tatun leachate treatment plant. The leachate flow was determined by water level (Leshalu, Model 49) calculation. Total organic carbon (Dohrmann, Model DC-180) and conductivity (TOA, Model CM-11P) were used as criteria of characteristics of the leachate.

Table 1. Leachate characteristics in the central region of Taiwan.

Items / Sites	BOD mg/L	COD mg/L	NH_4^+-N mg/L	TKN mg/L	SS mg/L	VSS mg/L	pH	P mg/L	Fe mg/L	Zn mg/L	Cr mg/L	Age y
Touwu, Miaoli Co.	967	1214	133	162	102	96	6.7	6.7	28.6	1.0	0.3	0.67
Tatun, Taichung Co.	414	1944	866	1054	120	109	8.0	10.6	6.6	5.6	5.0	0.92
Tienchung, Changhua Co.	743	3641	1452	1605	66	58	7.8	27.5	11.8	ND	1.3	1.00
Peitou, Changhua Co.	247	1311	379	452	54	42	7.7	8.9	0.8	ND	ND	1.00
Puyen, Changhua Co.	43	825	13	75	10	8	8.0	21.7	9.8	ND	0.3	1.25
Tienwei, Changhua Co.	70	1456	47	544	20	16	8.5	23.5	21.8	0.6	0.5	1.58
Hsichou, Changhua Co.	386	2282	962	1029	110	78	8.4	7.9	8.4	ND	0.3	1.92
Fangyuan, Changhua Co.	18	204	29	102	5	4	8.2	5.2	1.0	ND	0.2	2.08
Taichung City	620	3447	2505	2648	194	160	8.2	15.4	7.7	3.4	1.1	4.50

Typical treatment performance study

In the performannce studies of the Tatun leachate treatment plant, the selected sampling points included influent, aeration basin, clarifier, intermittent tank, quick mix, slow mix, chemical sedimentation, and effluent. The pH, temperature, conductivity, dissolved oxygen, SS, VSS, BOD, COD, NH_4^+-N, TKN, P, Fe, Cu, and Cr were assayed.

Tertiary unit necessity evaluation study

In the jar-test experiments, samples originated from the intermittent tank of the Tatun leachate treatment plant, i.e., the effluent from the biological treatment. The coagulants, $FeCl_3$, and poly-aluminum chloride (PAC) were tested over the pH range of 2-9 and 4-9, respectively, and at various concentrations. The 1-L samples were placed into the proper beakers which contained different coagulant dosages. Then they were put into a jar tester with a 'rapid mix' of 5 min at a velocity of 90 rpm, followed by a 'slow mix' of 30 min at a velocity of 25 rpm, and finally, sat for 30 min. COD, SS, pH, sludge volume were determined respectively by taking samples at the supernate and settlement. A plot of COD removal percentage vs. coagulant dosages showed the initial optimum coagulant dosages. Secondly, the studies of pH effect were also performed at constant coagulant dosages. Eventually, replicated experiments of coagulant dosages were carried out under the pH optimum.

RESULTS AND DISCUSSION

Leachate characteristics in the central region of Taiwan

The leachate characteristics of nine sanitary landfills in the central region of Taiwan are shown in Table 1.

Influence of landfill age on characteristics of leachate

The relationship between characteristics of leachate and landfill age was investigated at nine sanitary landfill sites. The variations of BOD/COD, BOD/TKN, C/N, VSS/FSS (fixed suspended solids), and pH with landfill age are discussed as follows.

Variation of BOD/COD: BOD/COD ratios represent the proportions of easily biodegradable organics which contain primarily a major form of carbon. The lower ratios are observed for the higher oxidation conditions.

Therefore, the carbon sources with the need for microbiological metabolism are low in the following biological process. A plot (Fig.1) of the ratios vs. landfill age shows that the ratios first decrease sharply within approximately one year and then progressively level off with increasing landfill age. The phenomenon indicates that the reactions of biodegradable organics are rapid during approximately one year and half and then steady state is soon reached. This means, that the proportions of biodegradable organics decrease already greatly after about one year and half. After this period, the microbiological reactions of BOD degradation are limited. Another reason for decreasing the ratios is probably due to rainwater washing. The above results imply that the major processes of leachate treatment are biological processes before about one year and half of landfill age. After one year and half, because BOD/ COD ratios are smaller (≈0.13), the features of lower biodegradable organics show that the treatment of leachate usually requires an extra chemical-aided precipitation system or pretreatment procedures.

Variation of BOD/TKNP: BOD/TKN represents the nutrient ratio of organic matter to nitrogen (similar to C/N) in landfill leachate. According to the result presented in Fig. 2, it appears that the BOD/TKN ratios become almost independent of landfill age above approximately one year or one year and half. Before that time, an decrease in the BOD/TKN ratios is rapidly concomitant with increasing landfill age, which is due to the highly microbioactivity for easily degradable components (fatty acids etc.). After that time, under the steady-state conditions, a BOD/TKN ratio of less than 0.3 can be achieved, and the C/N ratio is approximately equal to 0.1. It represents that the microbial degradation rate for organic nutrients is limited while the ratios of carbon to nitrogen decrease.

Variation of VSS/FSS: VSS/FSS represents the ratio of organic to inorganic suspended solids. This ratio decreases with increasing landfill age. The observed decrease is due to the degradation of organic matters and the washing effect of leaching rainwater. Figure 3 indicates that the variation of VSS/FSS ratio is similar to other ratios as mentioned above. The VSS/FSS ratio first decreases sharply within approximately one year and then progressively levels off to reach steady state

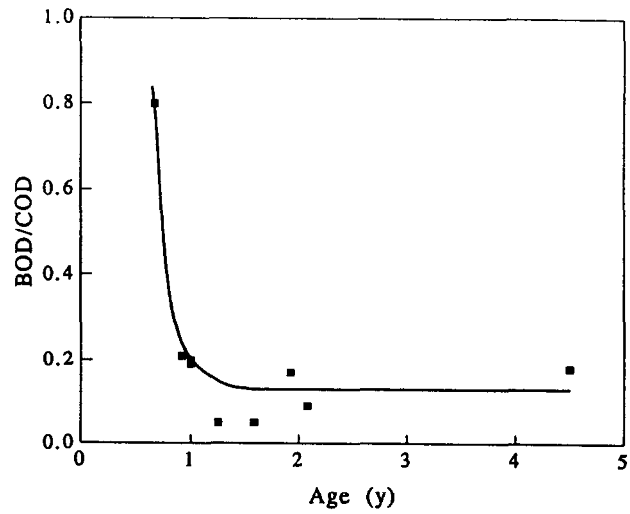

Fig. 1. Relationship between BOD/COD ratios and landfill age.

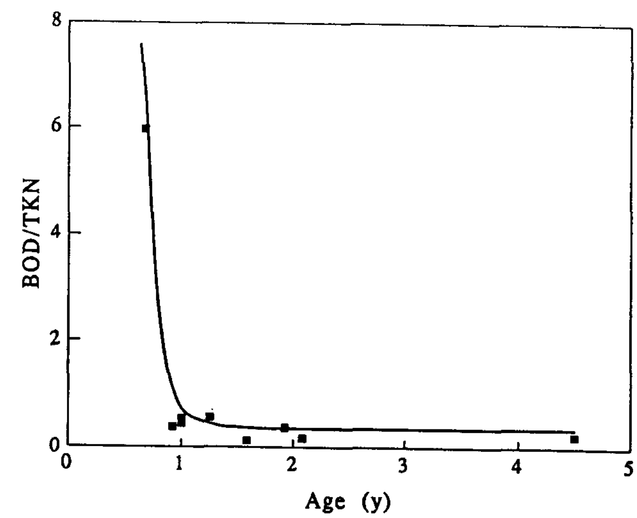

Fig. 2. Relationship between BOD/TKN ratios and landfill age.

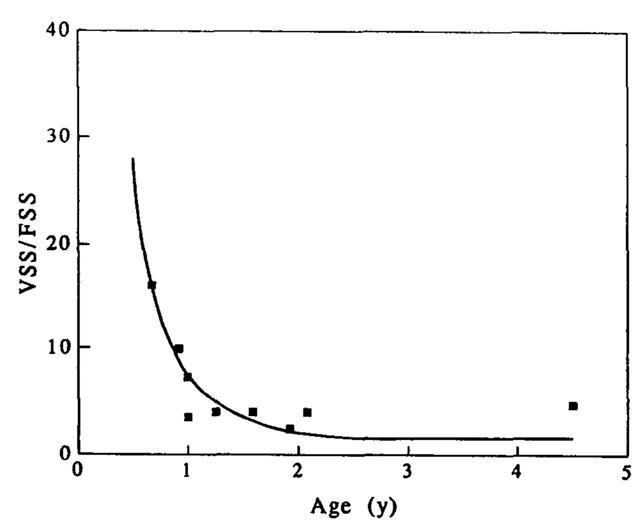

Fig. 3. Relationship between VSS/FSS ratios and landfill age.

above one year to one year and half. VSS/FSS ratio is around 1.6 at steady state.

Variation of pH: Figure 4 shows also an increasing pH value with landfill age up to asteady state. The phenomenon is due to biological decomposition of organic nitrogen to ammonia nitrogen, i.e., the ammonia nitrogen content generally increases with time, thus, an increasing pH is observed.

Apparently, the characteristics of leachate are highly influenced by the landfill age, and the relationship between them bases on about one year to one year and half as a critical mark. The steady state is achieved above one year to one year and half for the various characteristics of leachate. Consequently, it is necessary to revise the design and operational parameters based on the landfill age slightly in order to develop more efficient and reliable treatment processes to treat leachate into innocuous materials.

Influence of rainfall on leachate flow

Variations of rainfall and leachate flow with time are shown in Fig. 5. During this study, the leachate base flow varied from 7.5 to 19.5 m^3/d, and the mean was about 15 m^3/d. As would be expected, the leachate flow increased with increasing rainfall on raining days. Linear regression analysis for leachate flow against rainfall yielded values of $R^2=0.932$. The relationship between the leachate flow and rainfall could be described by:

$$Q = 21.25 + 2.40i \qquad (1)$$

where

Q = leachate flow of mean days (m^3/d)

I = rainfall of mean days (mm/d)

Many methods are used to predict leachate flow; among them, the rational formula is the best simple and available method. The equation is described by the expression:

$$Q = (1/1000) \cdot C \cdot i \cdot A \qquad (2)$$

where

C = leaching coefficient

A = area of landfill (m^2)

In this study, the result data are fixed to the rational equation to predict the leaching coefficient C value. As can be seen from Fig. 6, the C value decreases with an increase of rainfall in this investigation, but not linear.

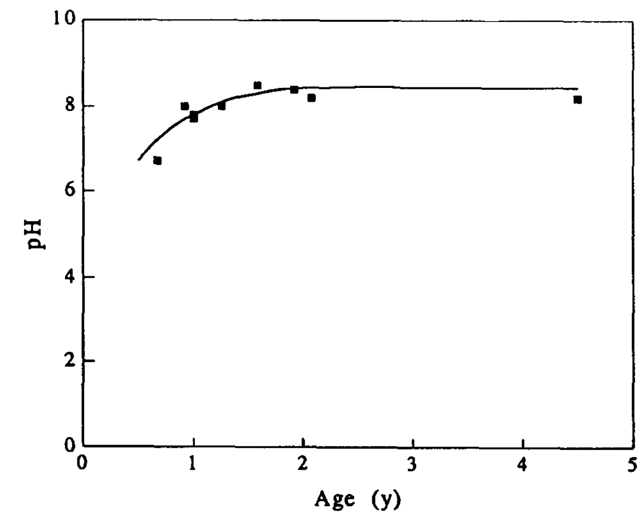

Fig. 4. Relationship between pH and landfill age.

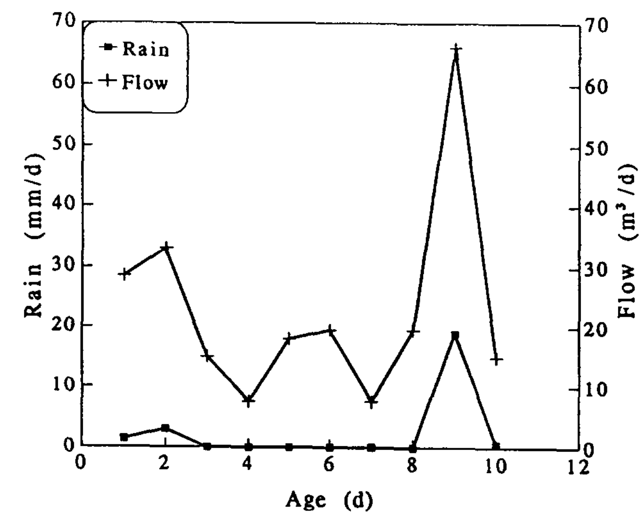

Fig. 5. Trend of the rainfall and leachate flow.

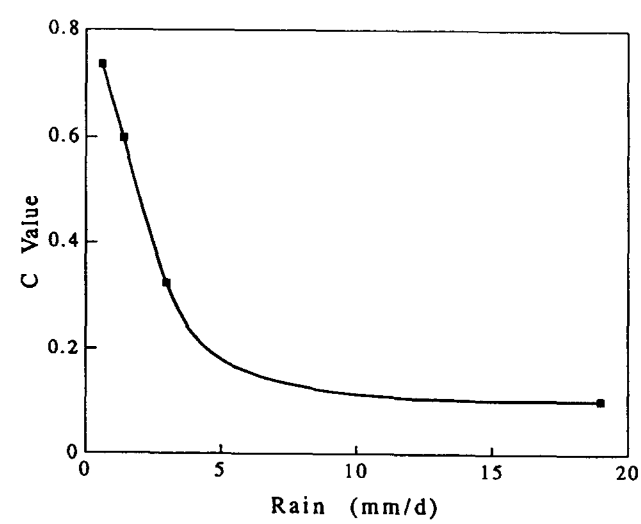

Fig. 6. Relationship between leaching coefficient C value and rainfall.

Influence of rainfall on characteristics of leachate

In this study, total organic carbon (TOC) and conductivity were used to investigate the relationship between characteristics of leachate and rainfall. For convenience and validity, TOC was measured instead of COD. Linear regression analysis for COD against TOC could be described as follows:

$$[COD] = -1.79 + 2.21[TOC] \quad (3)$$

The correlation was significantly good (R^2=0.990). Equation 3 shows that the COD concentrations were about 2.2 times the TOC concentrations in our studies.

Variation of TOC: The variation of TOC with rainfall indicated that the data were divided into two parts: the continuous and continual raining days. Here, continuous means continuing without interruption and continual, steadily recurring. Under the continuous days, TOC concentrations decreased with an increase of rainfall due to dilution by rainwater. The correlation was significantly good between them as shown in Fig. 7. Linear regression equation was described in the following:

$$\text{Continuous: } [TOC] = 1448.13 - 10.99i \quad (4)$$

The correlated coefficient R^2 was equal to 0.984. Also, Fig. 7 shows the relationship between TOC and rainfall in the continual days. These data could be approximated by the following equation:

$$\text{Continual: } [TOC] = 1133.19 - 19.70i \quad (5)$$

The correlated coefficient R^2 was 0.954. The results in Fig. 7 exhibit that a different dilution slope existed between the continuous and continual days, i.e., the higher slope was observed at continual days. The reason was the wash-out of organic materials by the leaching rainwater in the continuous days. During this period, higher TOC concentrations of leachate were observed, which resulted in the lower dilution slope. As for the continual days, the organic matter could be removed by microbial degradation of landfill stratums because less significant washing-out occurred. Thus, lower concentrations of organic particles and a larger dilution slope were obtained. Similarly, Chang et al. (1990) had indicated that the concentrations of organic materials of leachate were lower in the dry season than the wet season.

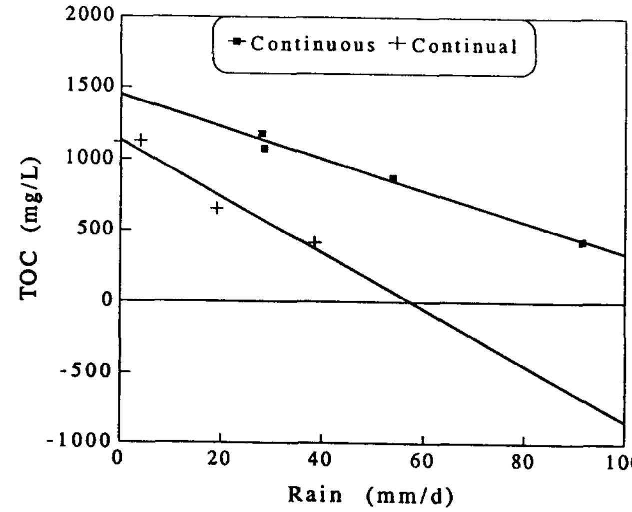

Fig. 7. Relationship between TOC and rainfall for continuous and continual raining day.

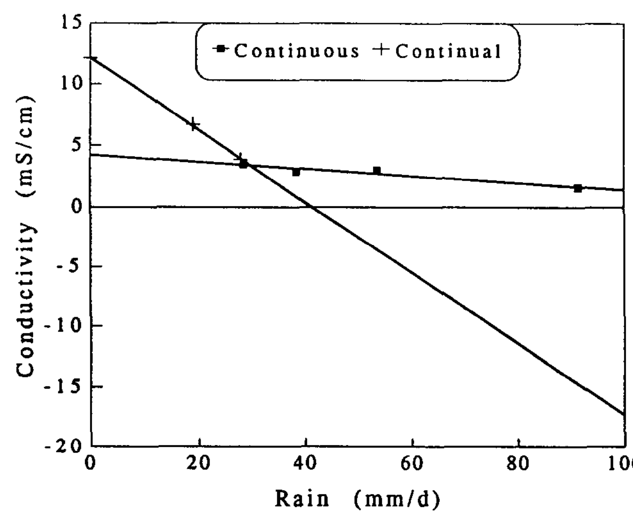

Fig. 8. Relationship between conductivity and rainfall for continuous and continual raining day.

Variation of conductivity: A larger conductivity was obtained while the total dissolved solids (TDS) were higher in water. Hence, the measure of conductivity could represent the TDS contents.

Similarly, the variation of conductivity with rainfall also indicated that the data could be divided into two parts (the continuous and continual raining days) to further the comparisons. The conductivity decreased with an increase of rainfall in the continuous days (Fig. 8). Linear regression analysis for conductivity against rainfall yielded values of R^2=0.932. The expression was described in the following:

Table 2. Leachate components at the Tatun landfill.

Items	Ranges	Means
pH	7.9 – 9.8	8.3
Temp. (°C)	23.2 – 27.0	25.5
Conductivity (mS/cm)	12.3 – 18.3	16.1
DO (mg/L)	0.2 – 2.1	0.6
SS (mg/L)	144 – 314	239
VSS (mg/L)	108 – 213	180
BOD (mg/L)	162 – 438	296
COD (mg/L)	1940 – 5704	3340
NH_4^+-N (mg/L)	1540 – 2312	1892
TKN (mg/L)	1713 – 2386	2119
P (mg/L)	11.8 – 19.4	15.1
Fe (mg/L)	3.84 – 5.02	4.48
Cu (mg/L)	ND	ND
Cr (mg/L)	0.96 – 1.38	1.22

Table 3. Characteristics of the Tatun leachate.

Items	Ranges	Means
BOD/COD	0.060 – 0.154	0.095
BOD/P	11.3 – 32.5	19.8
BOD/TKN	0.076 – 0.184	0.137
NH_4^+-N/TKN	0.870 – 0.969	0.912

Continuous: Conductivity = 4.23 - 0.03i (6)

According to the result presented in Fig. 8, the conductivity was also decreased via the dilution of rainwater in the continual days. Linear regression analysis could be described by the following equation:

Continual: Conductivity = 12.19 - 0.29i (7)

The correlation was significantly good (R^2=0.999). A analogous trend was observed between Fig. 8 and Fig. 7. A different dilution slope existed between the continuous and continual days and the higher slope was observed at continual days.

Performance of the treatment plant

Leachate characteristics: The characteristics of leachate in the Tatun plant are listed in Table 2. The distribution of pH is around 8.3 on average, which locates the pH range (7~9) of aerobic biological unit processes. Table 2 shows that the difference of water quality is quite large between treated and designed-to-treat leachate. The concentrations of BOD, COD, and SS appear below original design values (BOD 500 mg/L, COD 10000 mg/L, and SS 500 mg/L), only the TKN concentration is higher than the initial design (≈500 mg/L).

Table 3 illustrates the typical characteristics of the Tatun plant leachate that has reached the mature stage. The BOD/COD ratios reflect that a large quantity of refractory organics are included in leachate. Clearly, the aeration tank in Tatun might face severe limitations to remove organic matters. Hence, the data suggest that the chemical-aided precipitation system is required to be incorporated into the biological treatment processes. The BOD/TKN ratio, ranging from 0.07-0.184, represent the nutrient ratio of organic matter to nitrogen in landfill leachate. The microbial activities are slower, while the BOD/TKN ratios are lower. In addition, a BOD/P ratio is in the range of 11.3-32.5. This data shows that the phosphorus source is sufficient in aerobic biological processes.

Variation of leachate:

1) pH: The pH value of influent leachate was observed to vary between 7.9 and 9.8, then reduced to 5.5-6.8 at the end of the aeration tank. Besides, the influent leachate TKN ranged from 1713 to 2386 mg N/L and dropped to 349-1013 mg N/L at the end of the aeration tank. It was apparent that the prosperous nitrification of the aeration tank affected pH value significantly due to H^+ ions released by the ammonification.

2) BOD/COD: Figure 9 shows no significant decrease in BOD/COD after the aeration unit. This result is due to a simultaneous decrease of BOD and COD. As can be seen from Table 4, the average removal rate of BOD and COD is 78.4% and 65.0%, respectively, with biological treatment only. With chemical treatment only, the average removal rate of effluent is for BOD 51.2% and for COD 52.7%. The above analyses indicate that removal of organic matter is obtained by both biological and chemical treatment. When the chemical-aided precipitation system is incorporated into the biological treatment processes, the total removal efficiency of BOD and COD is 88.8% and 85.0%, respectively.

3) Nitrification: Figure 10 presents the nitrification performance on the unit processes of the treatment sequence in Tatun. The reductions in NH_4^+-N and TKN values show a parallel trend, since NH_4^+-N is primary content of TKN. As shown in Fig. 10, TKN ranges from 1713 to 2386 mg N/L in the influent but drops to 349-1013 mg N/L at the end of the aeration tank. This result exhibits that the major influent TKN is removed by nitrification in the aeration tank. Nevertheless, the effluent TKN in the biological sedimentation tank still reaches 249-399 mg N/L. This represents that it is important to add other treatment processes. Table 4 shows that the average removal of NH_4^+-N and TKN is

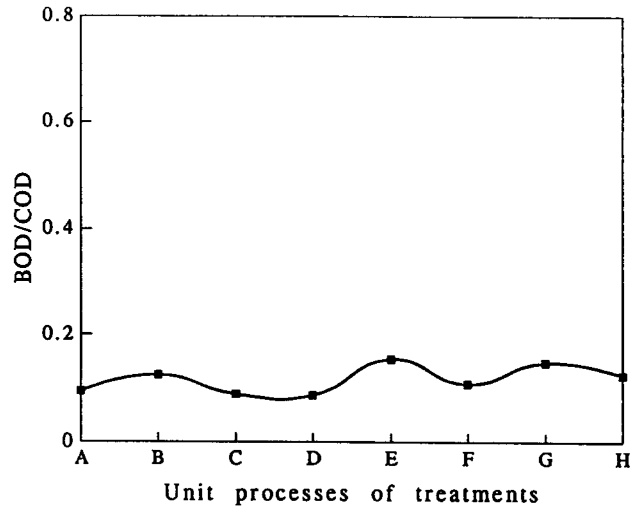

Fig. 9. BOD/COD variation of the unit processes of the treatment sequence in Tatun. A: influent; B: aeration; C: clarifier; D: intermittent tank; E: quick mix; F slow mix; G: chemical sedimentation; H: effluent.

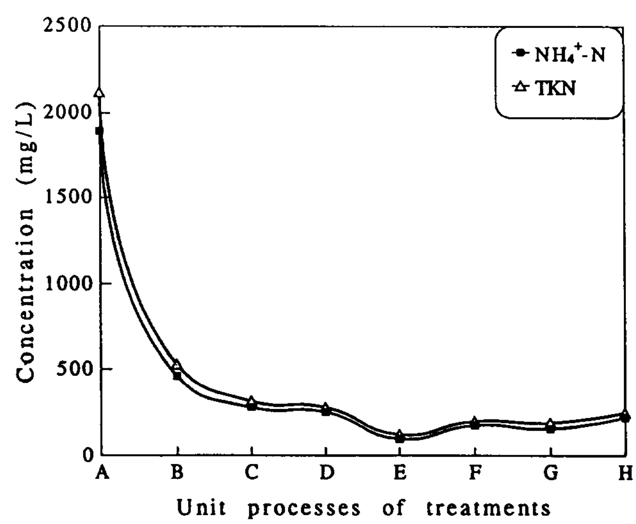

Fig. 10. NH_4^+-N and TKN variations in the unit processes of treatment sequence in Tatun. A: influent; B: aeration; C: clarifier; D: intermittent tank; E: quick mix; F: slow mix; G: chemical sedimentation; H: effluent.

82.5 and 73.3%, respectively, with biological treatment only. Approximately 45.2% NH_4^+-N and 41.1% TKN reduction are achieved by chemical treatment only. Overall performance of the plant is for the removal of NH_4^+-N 88.0% and for TKN 83.3%.

4) SS and VSS: SS ranged from 144-314 mg/L in the influent but decreased to 120-203 mg/L after the biological clarifier. This data revealed that the low removal efficiency of sludge was observed under

Table 4. Treatment performance in Tatun (%).

Items	Biological treatment[a] (%)	Chemical treatment[b] (%)	Overall performance (%)
BOD	53.0 – 98.4[c] (78.4)[d]	7.9 – 74.6 (51.2)	74.8 – 97.2 (88.8)
COD	39.2 – 87.2 (65.0)	6.0 – 86.2 (52.7)	45.5 – 93.0 (85.0)
NH_4^+-N	60.0 – 100 (82.5)	0 – 100 (45.2)	52.4 – 100 (88.0)
TKN	62.3 – 89.3 (73.3)	0 – 75.5 (41.1)	71.4 – 94.8 (83.3)
SS	4.2 – 68.0 (38.6)	23.1 – 80.0 (59.0)	32.2 – 95.0 (72.6)
VSS	17.2 – 66.7 (43.0)	23.1 – 79.3 (56.3)	32.2 – 94.0 (71.3)
P	21.5 – 52.0 (34.3)	90.2 – 96.4 (93.0)	80.0 – 98.0 (91.5)
Fe	22.9 – 75.3 (47.0)	2.0 – 78.4 (46.9)	50.0 – 95.0 (76.9)
Cr	20.0 – 87.5 (49.0)	12.5 – 76.9 (48.8)	76.8 – 93.8 (84.4)

[a] the first stage biological treatment): influent → aeration tank → biological sedimentation tank → intermittent tank.
[b] the second stage (chemical treatment): intermittant tank → qick-mixing tank →slow-mixing tank → chemical sedimentation tank.
[c] ranges
[d] means.

biological unit processes. However, all SS and VSS decreased to a large extent due to chemical treatment (Fig. 11). The average removal of SS and VSS, based on data from Table 4, was 38.6% and 43.0%, respectively, with biological treatment. Conversely, approximately 59.0% SS and 56.3% VSS reduction were achieved by chemical treatment. Overall performance of the plant was SS 72.6% and VSS 71.3%, respectively.

5) Total phosphorus: Figure 12 illustrates total phosphorus variation with the unit processes of treatment sequence in Tatun. The data from Fig.12 indicate that the phosphorus loadings are sufficient to provide for biological treatment system. The concentrations of P are effectively reduced to less than 1.5 mg/L by chemical treatment, which corresponds to the existing and the 1998 effluent quality standards (10.0 mg/L and 4.0 mg/L, respectively). About 34.3% P is removed with biological treatment only, based on data from Table 4. But, the chemical treatment can significantly reduce the concentrations of P by about 93.0%. The mean overall removal efficiency is approximately 91.5%.

6) Heavy metal: Figure 13 summarizes, iron and chromium variation on the unit processes of treatment sequence in Tatun. The data from Fig. 13 shows that a part of Fe and Cr removed after aeration tank was retained in the sludge. But, the whole settled sludge from the clarifier was found to be recycled to the aeration tank. Therefore, Fe and Cr were actually accumulated in aeration tank, and might result in toxicity to inhibit the microbial growth at higher concentrations. Table 4 exhibits that no significant differences were observed for Fe and Cr removal efficiencies (about 47% to 49%) with biological and chemical treatment, respectively. The overall average removal efficiencies of heavy metals were about 76.9% for Fe and 84.4% for Cr, respectively.

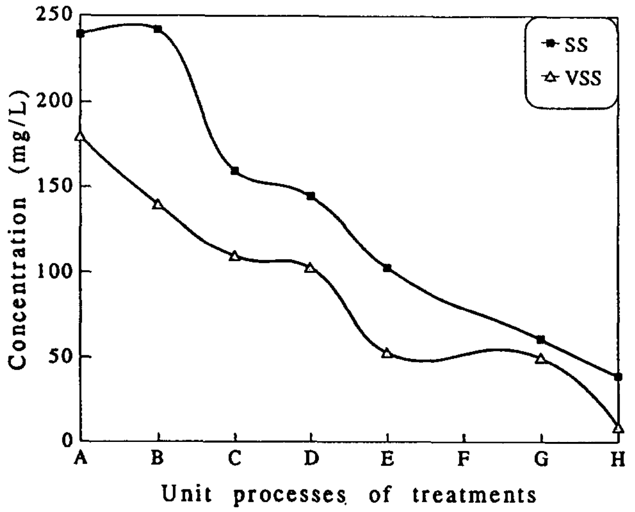

Fig. 11. SS and VSS variations with the unit processes of treatment sequence in Tatun. A: influent; B: aeration; C: clarifier; D: intermittent tank; E: quick mix; F: slow mix; G: chemical sedimentation; H: effluent.

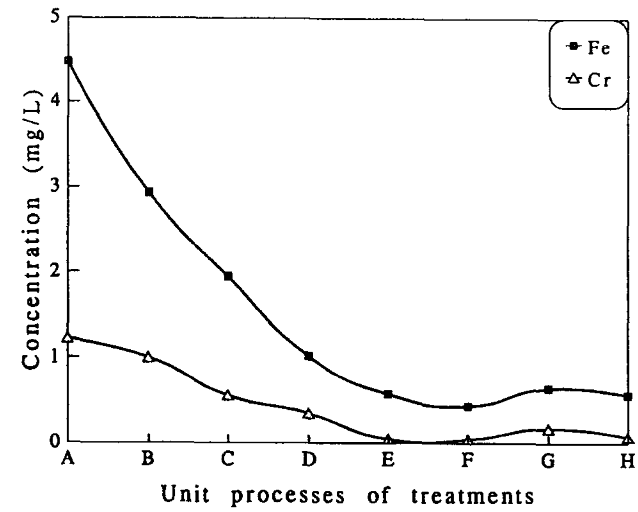

Fig. 13. Fe and Cr variations with the unit processes of treatment sequence in Tatun. A: influent; B: aeration; C: clarifier; D: intermittent tank; E: quick mix; F: slow mix; G: chemical sedimentation; H: effluent.

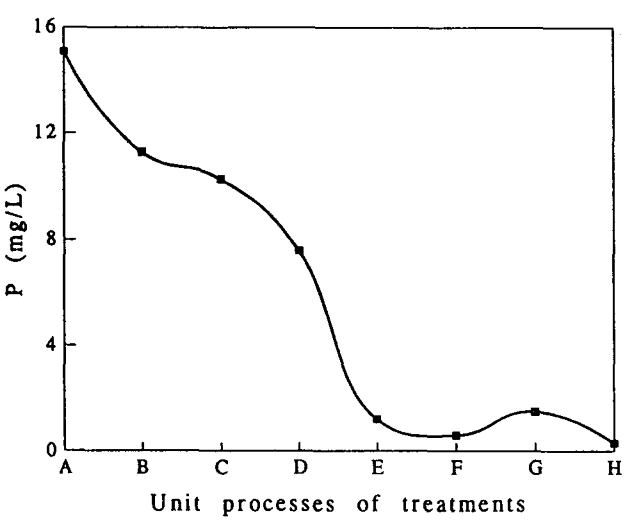

Fig. 12. Total phosphorus variation with the unit processes of treatment sequence in Tatun. A: influent; B: aeration; C: clarifier; D: intermittent tank; E: quick mix; F: slow mix; chemical sedimentation; H: effluent.

Characteristics of effluent: Table 5 summarizes the characteristics of effluent in the Tatun plant. This data indicates that the concentrations of SS correspond to the requirements of current discharge standards (80 mg/L), but it is so difficult to meet the needs of effluent standards (50 mg/L) in 1998. The COD effluent varied from 262 to 397 mg/L can reach 500 mg/L of current discharge standards, however, more effort is needed to meet the requirements of 200 mg/L in 1998. The NH_4^+-N concentrations (78-264 mg N/L) in effluent have already exceeded the limits (20 mg N/L) of discharge standards currently. Therefore, it is necessary to search for a valid treatment method of biotechnology. In addition, the results exhibit that the concentrations of total phosphorus and heavy metals (Fe, Cu, and Cr) in the effluent are all below the current and 1998's discharge standards.

Tertiary unit necessity evaluation

Coagulation with $FeCl_3$:

1) Effect of coagulant dosage (I): The jar-test was performed by adding 100, 200, 400, 500, 600, 800, and 1000 mg $FeCl_3$/L without pH adjusted. With the addition of 500 mg $FeCl_3$/L, the best COD removal efficiency was observed (Fig. 14). Therefore, a dose of 500 mg $FeCl_3$/L was initially selected.

2) Effect of pH: In order to understand the effect of pH, the coagulant dosages of $FeCl_3$ were controlled at 500 mg/L, and different pH (2, 4, 5, 6, 7, 9) were adjusted to proceed the jar-test at the same conditions. Figure 15 shows that the maximum COD removal percentage was achieved at about pH 7. Therefore, pH 7 was chosen to carry out the following study.

3) Effect of coagulant dosage (II):

Throughout this run, pH was kept at 7, while the coagulant dosages of $FeCl_3$ were 450, 500, 550, 600, 650 and 700 mg/L. The highest removal efficiency for total nitrogen was obtained by chemical coagulation

Table 5. Effluent quality at Tatun.

Items	Ranges	Means
pH	5.5 – 8.3	6.7
Temp. (°C)	18.4 – 25.0	22.2
Conductivity (mS/cm)	9.5 – 11.0	10.1
DO (mg/L)	2.3 – 4.7	3.3
SS (mg/L)	19 – 120	61
VSS (mg/L)	17 – 120	50
BOD (mg/L)	23 – 110	44
COD (mg/L)	262 – 397	304
NH_4^+-N (mg/L)	78 – 264	157
TKN (mg/L)	89 – 275	191
P (mg/L)	0.3 – 3.8	1.5
Fe (mg/L)	0.22 – 1.12	0.65
Cu (mg/L)	ND	ND
Cr (mg/L)	0.06 – 0.26	0.18

ND: detect limit ≤ 0.01 mg/L.

Table 6. Comparisons of $FeCl_3$ and PAC flocculations.

Items \ Coagulants	$FeCl_3$	PAC
Optimum dose (mg/L)	650	800
Optimum pH	7	8
COD conc.[a] (mg/L)	194	109
COD removal (%)	84.6	91.0
SS removal (%)	92.0	76.0
Total nitrogen removal (%)	58.7	58.6
Sludge volume (ml)	180	260
Color	Very light orange	Light orange

[a] represents the COD concentrations after chemical flocculations.

with adding either $FeCl_3$ or PAC (Table 6). It revealed that chemical coagulation was less effective for the nitrogen removal. After chemical flocculation treatment, the NO_3^--N concentrations still reached about 1500 mg/L as N (Table 7). The NH_4^+-N concentrations were 38.0 and 77.8 mg/L as N, respectively, for $FeCl_3$ and PAC additions. This results would not meet the requirements of current discharge standards (20 mg N/L). It appeared that an extra biological treatment was essential to remove the total nitrogen in the Tatun plant. The trend suggested that a nitrification unit is required to minimize NH_4^+-N problems, and a much lower level of nitrate would be conceivable by effective denitrification units.

Table 7. Comparisons of nitrogen removal between $FeCl_3$ and PAC.

Items / Coagulants	NH_4^+-N (mg/L)	Organic nitrogen (mg/L)	NO_3^--N (mg/L)	NO_2^--N (mg/L)	Total nitrogen (mg/L)	Total nitrogen removal (%)
Influent	215.0	66.6	3615.6	0.92	3898.1	-
$FeCl_3$	38.0	32.0	1540.0	1.08	1611.1	58.7
PAC	77.8	11.2	1524.0	0.48	1613.5	58.6

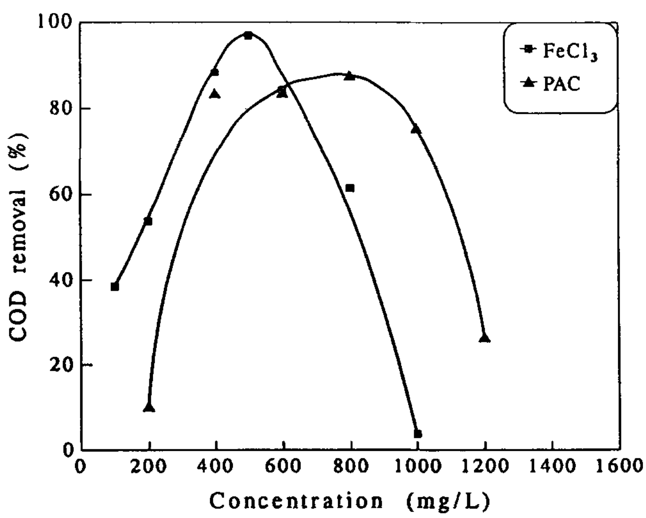

Fig. 14. Relationship between COD removal efficiency and coagulant dosages (Test 1).

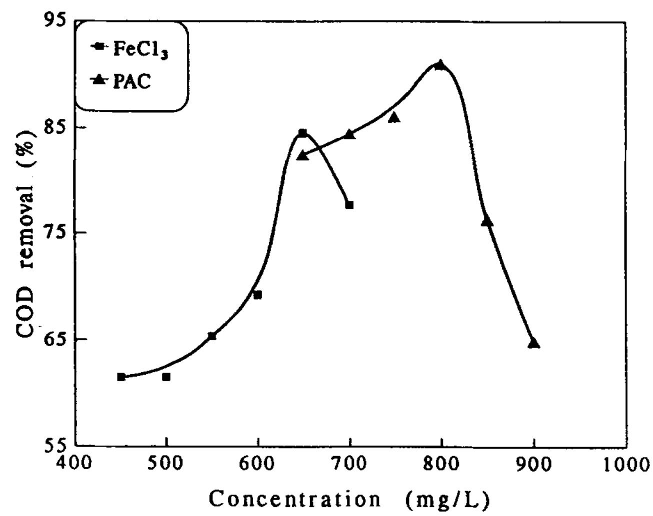

Fig. 16. Relationship between COD removal efficiency and coagulant dosages (Test 2).

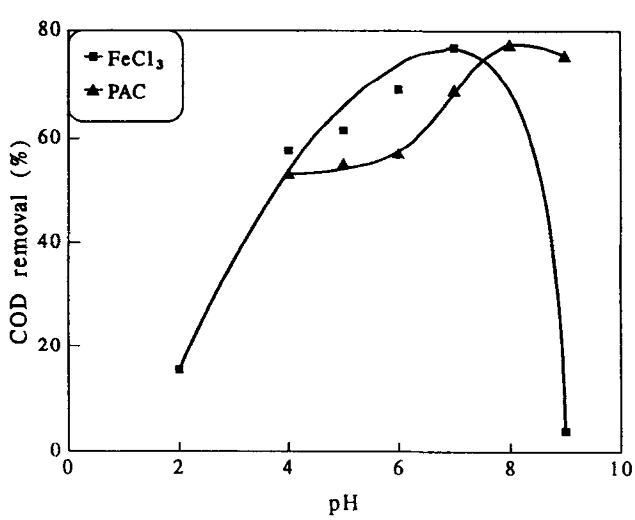

Fig. 15. COD removal efficiency at various pH.

CONCLUSIONS

The steady state is achieved above one year to one year and half for various characteristics of leachate. Consequently, it is necessary to revise the design and operational parameters based on the landfill age slightly in order to develop more efficient and reliable treatment processes to treat leachate into innocuous materials.

The data showed that the leachate flow increased with an increase in rainfall, but the leachate coefficient C value decreased with increased rainfall. As for the relationship between the characteristics of leachate and rainfall, the higher slope was observed at continual raining days. And the higher COD concentrations were observed in the continuous raining days.

According to the results of analysis, the biological treatment processes were dominating for the removal efficiencies of BOD, COD, NH_4^+-N, and TKN. However, the best removals of SS, VSS, and P were obtained with the chemical-aided precipitation system. As for the heavy metals, no significant differences were observed for the removal efficiencies of Fe and Cr with biological and chemical treatment.

The results of coagulation show the optimum coagulant dosages of $FeCl_3$ and PAC, in addition to the optimum pH values. The COD concentrations are all corresponding to 1998's effluent standards by chemical coagulation with addition of either $FeCl_3$ or PAC. The concentrations of ammonia and nitrate in the treated effluent will not meet the current discharge standards. A tertiary nitrification-denitrification unit is necessary.

Acknowledgment—This research was supported by Grant NSC82-0115-E-005-093 from the National Science Council, Republic of China.

REFERENCES

APHA; AWWA; WPCF. Standard Methods for the examination of water and wastewater. 16th Edition. American Public Health Association, Washington, D.C.; 1985.

Chang, J.E.; Kao, C.F.; Hsu, C.H. Research on the removal of organics in landfill leachate. In: Proc. 15th Conf. on Wastewater Treatment Technology in Republic of China, Taiwan, ROC; 1990: 125-138. Available from: The Chinese Institute of Environmental Engineering, Taiwan, ROC.

Chian, E.S.K.; DeWalle, F.B. Evaluation of leachate treatment, Vol.I: characterization of leachate. U.S. Environmental Protection Agency, Cincinnati, Ohio, USA.; 1977 (EPA 600/2-77-186a).

Gau, S.H.; Chang, P.C.; Chang, F.S. A study on the procedure of leachate treatment by Fenton method. In: Proc. 16th Conf. on Wastewater Treatment Technology in Republic of China, Taiwan, ROC; 1991: 527-537. Available from: The Chinese Institute of Environmental Engineering, Taiwan, ROC.

Gau, S.H.; Chou, C.T. The mathematical modeling study for leachate volume of semi-aerobic sanitary landfill. In: Proc. 3rd Conf. on Solid Waste Management Technology in Republic of China, Taiwan, ROC; 1988: 195-211. Available from: The Chinese Institute of Environmental Engineering, Taiwan, ROC.

Hsieh, C.S.; Huang, C.Y. Solid waste management. 3rd Edition. Taipei, Taiwan, ROC: Shu Hsing Publisher; 1991.

Huang, C.H. A countermeasure on leachate treatment of sanitary landfill. In: Proc. 2nd Conf. on Solid Waste Management Technology in Republic of China, Taiwan, ROC; 1987: 207-219. Available from: The Chinese Institute of Environmental Engineering, Taiwan, ROC.

Kao, C.F.; Chang, T.E.; Kao, W.T. Treatment of landfill leachate using improved anaeration filter bed. In: Proc. 16th Conf. on Wastewater Treatment Technology in Republic of China, Taiwan, ROC; 1986: 477-490. Available from: The Chinese Institute of Environmental Engineering, Taiwan, ROC.

Kennedy, K.J.; Hamoda, M.F.; Guiot, S.G. Anaerobic treatment of leachate using fixed films and sludge bed system. J. Water Pollut. Control Fed. 60: 1675-1683; 1988.

Mennerich, A.; Alber, H. Anaerobic pretreatment of high concentrated landfill leachate. In: Proc. Aquatech '86 Water Treatment Conference, Amsterdam, Netherlands; 1986: 359-371. Available from: National Chung-Hsing University, Taichung, Taiwan, ROC.