DETERMINATION OF BOD KINETICS COEFFICIENT (k_1) FOR THE LEACHATE LESS THAN 5 YEARS FROM PULAU BURONG LANDFILLS

By

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The dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfillment of requirements for the degree of

BACHELOR OF ENGINEERING (CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

May 2006

ACKNOWLEDGEMENTS

Firstly, thank God that this project had been completed successfully in time. Through this project I have learnt and gained a lot of precious knowledge and experience which cannot get from normal classroom lectures. Have I would like thank to my supervisor, PM Dr. Hamidi Abd. Aziz who are helped me out far more than he will ever realize, and I greatly appreciate him for this. Thanks goes out to Mr. Sabil (Post-graduate student) for guiding me through it with his expertise. I want to thank Puan Shamsiah Mohamed Ali (Enviromental Lab Technician) for all the help she gave me in the lab. Thanks to my mother (Hamidah Siran) and my sisters (Nor Faizah, Huzaifah) for supporting me. Lastly, thanks to all my friends (Thor Ah Kew, Badrol Hisham, Tan Kuan Kee) for putting up with me during my stressful times.

THANK YOU

ABSTRAK

Nilai Pekali kinetik BOD (k_1) dan nilai BOD muktamad(L_0)merupakan parameter utama dalam olahan air sisa termasuklah larut lesapan. Kedua- dua nilai ini amat diperlukan dan berguna untuk mereka bentuk sistem tangki pengudaraan enap cemar teraktif, tangki pengoksidan dan lain- lain. Pada masa sekarang, nilai tersebut belum lagi ada untuk larut lesapan. Terdapat beberapa kaedah untuk menentukan nilai pekali kinetik k_1 dan nilai BOD muktamad, L_0. Kaedah tersebut seperti "Least-square technique", "Slope method", "Moment method", "Logarithmic method" dan "Rhame`s method". Objektif kajian ini dijalankan adalah untuk mencari nilai k_1 dan L_0 untuk larut lesapan dari tapak pelupusan sampah Pulau Burong. Nilai ini amat diperlukan untuk membina sistem rawatan larut lesapan yang lebih kurang sama di Malaysia dan juga di luar negara. Keputusan dari pengiraan yang dibuat, nilai untuk k_1 dan L_0 adalah dalam lingkungan 0.02349-0.1205 per hari (Purata = 0.0718 per hari)dan 355.389-747 mg/L untuk kolam A dan nilai Lo adalah dalam lingkungan 355.389 -747 mg/L (Purata = 495 mg/L).Untuk kolam B, nilai k_1 dan L_0 adalah dalam lingkungan 0.0236 -0.110 per hari (Purata = 0.0743 perhari) dan L_0 329.27-707 mg/L (Purata = 545 mg/L). Daripada keputusan ini, didapati "Slope method" memberikan nilai k_1 yang terkecil sekali dan nilai Lo yang terbesar sekali bagi kedua- dua kolam. Manakala "Logarithmic method" menghasilkan nilai k_1 yang terbesar bagi kedua- dua kolam tersebut.

ABSTRACT

Rate of BOD degradation (k_1) and the ultimate BOD (L_0) are among the main parameters in biological treatment of wastewater, including leachate. These values are used for the design of aeration tank in activated sludge system, oxidation pond etc. Currently these values are not available for leachate. There are a few methods commonly used to determine k_1 and Lo. These includes Least-square technique, Slope method, Moment method, Logarithmic method and Rhame`s method. The objectives of this study is to determine the rate constant, k_1 and ultimate BOD, L_0 values for semi aerobic leachate at Pulau Burong landfills. These values are very important and useful in the future for design leachate treatment plant with similar characteristic in Malaysia and overseas. Results indicated that the k_1 values were in the range of 0.02349 day^{-1} to 0.1205 day^{-1} (Average = 0.0718 day^{-1}) and L_0 values 355.389 to 747 mg/L (Average = 495 mg/L) for Pond A. For pond B, the k_1 values were in the range of 0.0236 to 0.110 day^{-1} (Average = 0.0743 day^{-1}) and L_0 329.27 to 707 mg/L (Average = 545 mg/L) respectively. Results indicated that for both ponds, the Slope method produced the lowest k_1 value but the highest L_0 value. In comparison, the Logarithmic method produced the highest k_1 values for both ponds.

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CHAPTER 1 : INTRODUCTION

1.1 INTRODUCTION

The disposal of solid waste to landfill is a waste management strategy common to many countries worldwide. Despite an increasing emphasis on alternative options, solid waste disposal to landfill retains an important role in Malaysia. In many other areas of the world, the more 'sophisticated' strategies have little applicability and basic landfilling is more common. Leachate is the liquor that is collected at the base of landfills after rainwater has entered the emplaced waste materials and leached out contaminants. Depending on the nature and age of the wastes, the characteristics of the leachate will change. The leachates from landfilling domestic wastes, which are more likely to be of a biodegradable nature, are discussed in this research.

Leachates can be classed as acetogenic or methanogenic depending on the state of degradation of the waste materials in the landfill. Leachate from 'young' wastes is characterized by high chemical oxygen demand (COD) and biological oxygen demand (BOD) values, and by high ratios of BOD to COD. Methanogenic leachates are derived from older landfills where extensive degradation of organic materials in the wastes has occurred. End products of methanogenesis in the landfill are methane and carbon dioxide. Leachate is categorized by lower COD values, very much lower BOD values, and lower BOD to COD ratios. Biochemical oxygen demand (BOD) predominantly reflects the biodegradability of the organic matter in a sample.

Biological nitrification/denitrification is proposed for landfill leachate treatment plants in Malaysia Leachates from domestic landfills are rich in ammoniacal nitrogen but usually contain little phosphorus. The primary biochemical reactions occurring in the treatment of methanogenic leachates thus focus on nitrification. However, the frequent constraints on the discharge of nitrate-nitrogen in the treated leachate may require significant removal of nitrate after initial nitrification processes.

In Hong Kong, for instance, 200 mg/l (as nitrogen) is the maximum total of all nitrogen species allowed in the discharge of trade effluents to sewer. The maximum may be much lower for discharge to controlled waters. In such circumstances, it is either necessary to remove the ammoniacal nitrogen as a primary treatment or to denitrify after the nitrification step. The leachate treatment plant was perfoming inefficiently party due to a damaged aeration system and a change in leachate composition over time. Therefore, it was decided that repairs to the aeration system were necessary. While these repairs were taking place a review of the past operating data and the most recent analyses of the raw leachate was undertaken. This analysis revealed that the fundamental problems were that the concentration of nutrients were insufficient for efficient biodegradation.

Rate of BOD degradation (k_1) and the ultimate BOD (L_0) are among the integrated parameters in biological treatment of wastewater, including leachate. This value is used for the design of aeration tank in activated sludge system, oxidation pond etc. Currently this value is not available for leachate. There are a few methods commonly used to determine k_1 and L_0. These include Least-square technique, Slope method, Moment method, Logarithmic method and Rhame`s method.

1.2 OBJECTIVES OF STUDY

The objectives of this study is to obtain the rate constant, k_1 and ultimate BOD values, L_0 from samples of leachate collected with using different methods (Least-square technique, Slope method, Moment method, Logarithmic method and Rhame`s method) These values are very important and useful in the future for design leachate treatment plant with similar characteristic in Malaysia and overseas.

1.3 SCOPE OF THIS STUDY

Biochemical oxygen demand (BOD) is recognized as one of the most important parameters in assessing organic pollution in aquatic systems. The standard BOD testing procedure involves incubating a sample, diluted or otherwise, over 14 day period at 20^0C and determining amount of dissolved oxygen used by microorganisms for the Biochemical oxidation or carbonaceous organic matter. The result of BOD test is therefore very much dependent on the types of constituents present in the tested sample which may influence the bioactivity of microorganisms.

CHAPTER 2: LITERATURE REVIEW

2.1 BOD

Biochemical Oxygen Demand (BOD) is the amount of oxygen expressed in mg/L or parts permillion (ppm), that bacteria take from water when they oxidize organic matter. The carbohydrates (cellulose,starch,sugar), proteins, petroleum hydrocarbons and other materials that comprise organic matter get into water from natural sources and from pollution. They may be dissolved like sugar, or suspended as particulate matter, like solids in sewage. Organic matter can be oxidized (combined with oxygen) by biochemical action of bacteria. Because organic matter always contains carbon and hydrogen, oxidation produces carbon dioxide (the oxygen combining with the carbon) and water (the oxygen combining with the hydrogen). Biochemical oxygen demand (BOD) is recognized as one of the most important parameters in assessing organic pollution in aquatic systems.

The standard BOD testing procedure involves incubating a sample, diluted or otherwise, over a 5-day period at 20^0C and determining the amount of dissolved oxygen used by microorganisms for the biochemical oxidation of carbonaceous organic matter. The result of BOD test is therefore very much dependent on the types of constituents present in the tested sample which may influence the bioactivity of microorganisms. As shown in Figure 2.1 , the BOD of freshly polluted waste develops in two stages. During the first stage, the carbonaceous material is largely oxidized, while in second stage a significant amaout of nitrification takes place. During the first stage, the rate of organic breakdown at any time is assumed to be directly proportional to the amount of biological stabilization of a waste may take a long time, and for practical purposes a 5-

day incubation period, BOD_5, has been accepted as a standard reference, (Borzacconi, et al.,1999).

Particular care must be taken when neutralizing the wastes and when seeding the dilution water with sewage, polluted stream water, or special biological cultures that have become adapted to specific industrial wastes. In order to obtain the maximum BOD value, it is also important to use the proper dilution to ensure that any toxic effect is removed and that not all the dissolved oxygen is used. When increasing dilutions shows increasing BOD values, the dilutions should be increased until the BOD levels off at its maximum, (Cecen, et al,.2001). The BOD value is affected by environmental factors such as temperature, salinity, pH and may be repressed by the presence of chlorine, metals, and organic compounds which inhibit the bioactivity of microorganisms.

The ultimate BOD, BOD_u, is the sum of carbonaceous BOD already satisfied and the carbonaceous BOD remaining (Eq. 1). The ultimate BOD demand may be attained after about 20 days of incubation at 20^0C. After 5 days of incubation at this temperature, about 60-90% of the ultimate (first-stage) demand of typical domestic waste satisfied.

$$\mathbf{L_a = L_s + L_t} \qquad \textbf{(1)}$$

Where

La = ultimate BOD, BOD u (mg/L)

Ls = BOD definitive (mg/L)

Lt = BOD balance (mg/L)

Equations 2 - 4 describe the rate at which the carbonaceous BOD definitive. The rate constant k, is dependent upon the waste characteristic and temperature. In equation 3 and 4, typical values of k may very from 0.10 to 0.30 for domestic waste- waters, from 0.15 to 0.25 for untreated domestic waste waters and high- rate treatment effluent, from 0.04 to 0.07 for high- level biological treatment plant effluent, and from 0.04 to 0.06 for streams with minor pollution, (Borzacconi, et al., 1999).

$$\mathbf{-dL/dt = k_1L_t} \quad \textbf{(2)}$$

$$\mathbf{Lt/L_a = e^{-kt} = 10^{-kt}} \quad \textbf{(3)}$$

$$\mathbf{L_s = L_a - Lt = L_a\,(1\text{-}10^{-kt})} \quad \textbf{(4)}$$

Where

t = time (days)

L_a = BOD_u or initial BOD (mg/L)

k_1 = reaction constant, $\log_e$ (breakdown/day)

k = reaction constant, $\log_{10}$ (breakdown/day)

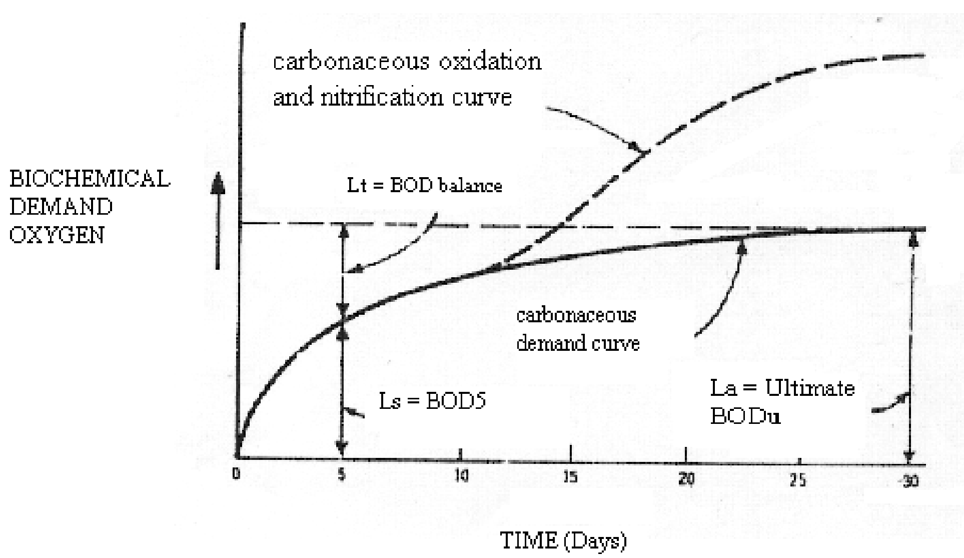

Figure 2.1 Development of Biochemical oxygen demand
Source: (Borzacconi,et al.,1999)

2.2 Kinetics of BOD

The BOD of a leachate is estimated by measuring the oxygen consumed during the degradation of organic matter by the amount of dissolved microbial flora present in the leachate. The most common procedure is the dilution method, which basically consists of diluting the leachate (depending on the degree of contamination) with a nutrient solution saturated with air. Then the solutions are stored in the dark in closed bottles and the dissolved oxygen is measured periodically. Usually, 5 day are used for the test, and the results are reported as BOD_5.

Periodical measurements of the dissolved oxygen (not only at the start and end of the 5 day) are required to ensure that the procedure is being carried out correctly and to detect possible errors such as an excessive dilution, presence of toxic compounds or the lack of a microbial population sufficiently adapted. Although other modelling approaches have been presented (Adrian and Sanders, 1992; Mayou, 1990), the BOD curve can be described by a first-order kinetics equation (Metcalff & Eddy, 1977):

$$\frac{dL}{dt} = -kL \qquad (5)$$

Eq. (1) is easily integrated to yield :

$$y = L_0 \, (1 - \exp(-kt)) \qquad (6)$$

or;

$$y = L_0 \, (1 - 10^{-k_{10} t}) \qquad (7)$$

where:

y = amount of oxygen consumed (or BOD) at time t

t = time elapsed since the start of the assay

L_0 = total amount of oxygen consumed in the reaction

(or ultimate BOD)

k, k_{10} = reaction constants

For the determination of k_1 and L_0 three methods are commonly used: the linear regression method, the Thomas method, and the non-linear regression method. In the linear (Metcalff and Eddy, 1997) and the non-linear (Marquardt, 1999) regression methods the coefficients are estimated by minimising the square of the sum of the errors between the experimental values and the ones predicted by each method. The method of Thomas (Adrian, 1998) is based on functions similarity. In this method, $(t/y)^{1/3}$ is plotted as ordinate vs. t as abscissa, and fitting the points to a straight line with intercept a and slope b. This results in a straight line. The parameters are then estimated using the slope (b) and the intercept (a) of this line:

$$k_{10} = 2.61 \frac{b}{a} \tag{8}$$

$$L_0 = \frac{1}{2.3 \; k_{10} \; a^3} \tag{9}$$

2.3 Biodegradation

Biodegradation is an important mechanism in the organic matter removal in natural systems. Biochemical oxygen demand (BOD) is a widely used parameter for the determination of biodegradable organic compounds in aquatic systems, effluents and wastewater (Matos and Sousa, 1996; Hu *et al.,* 1999; Orupõld *et al.,* 1999). During aerobic degradation microorganisms oxidize organic matter in the presence of oxygen; as a result, dissolved oxygen (DO) is consumed by this oxidation. In 1925 Streeter and Phelps formulated a model that evaluated the BOD budget in aquatic systems. Current water quality models are derived from the Streeter-Phelps model and include the effects of sedimentation, advection, dispersion, mixed-order model of BOD decay and aeration from the atmosphere (Rauch *et al.,* 1998; Tyagi *et al.,* 1999; Borsuk and Stow, 2000). The biological oxygen depletion was directly related with oxidation of the organic substrate by microbial communities under aerobic conditions (Henze *et al.,* 1997;Gotvajn and Zagorc-Koncan, 1999).

The development of easy-to-use methods for practical applications is important for the mathematical modeling of ecological processes, which have prompted researchers to perform experiments based on long-term BOD to assess the aerobic mineralization of organic substrates (Weijers, 1999; Brum *et al.,* 1999). The consumption of oxygen was related to the oxidation of an organic resource via first-order kinetics models (Characklis, 1990; Antonio *et al.,* 1999). The oxygen uptake curve reflects the aerobic mineralization kinetics of organic substrates. According to Davis and Cornwell (1991) the depletion of DO and the effect of aeration can be described as:

$$\frac{dOC}{dt} = k_d L - k_a OC \qquad (10)$$

where:

OC= the change in oxygen concentration per unit time [mg L-1],

L = total oxygen consumption [mg L-1] ≡ ultimate OC,

k_d = deoxygenation coefficient constant [day-1],

k_a = aeration coefficient [day-1] derived from the method of DO determination by stirring the sample when using a probe to take DO measurements and,

t = time [day].

The experimental method used to assess the oxygen uptake from aerobic degradation assumes that aeration effects, due to handling and stirring procedures, occur during the experiment. Usually, the BOD test is free from this interference, because the samples are measured only once (e.g. at 5th day of incubation). The aeration process is intrinsic to the method of measuring dissolved oxygen concentrations in long-term aerobic mineralization experiments; with this respect, this study aims at determining k_a and discussing the effect of DO The progresses of aeration over time for Treatment 1 and 2 are illustrated in Figure 2.2. For all the bottles (1 to 6), a DO concentration increase was observed. Figure 2.2 includes the fittings of the cumulative oxygen enrichment, applying $k_d = 0$ in the Equation of effect of aeration.

The fitting provides the aeration coefficient (k_a) with a determination coefficient (r^2) that ranged from 0.93 to 0.98. Table 2.1 also shows dispersion in k_a values for both treatments. The initial DO concentration did not interfere with the determination of k_a, which is a random process. The differences in k_a for Treatments 1 and 2 can be attributed to the periodical handling of the samples, which could contaminate the media (distilled water).

However, the caution in asepsis of the oxygen electrode was warranted. On the other hand, this kind of interference is inherent in long-term BOD experiments; they usually last an average of 45 days, and the samples are submitted to a large number of measurements as performed by Farjalla *et al.,* 1999. The differences in the incubation temperature and DO saturation percentages for each bottle interfered on the final DO concentration. The DO saturation percentages varied from 92.8 to 121%.

Table 2.1 : Parameterization derived from the kinetics fitting of the aeration process from oxygen uptake experiments

Source: (Farjalla *et al.,* 1999)

BOD bottle	$[DO]_i$ ($mg\ L^{-1}$)	SD	$[DO]_f$ ($mg\ L^{-1}$)	SD	DO_f (%)	T (°C)	k_r	Error(*)	r^2
Treatment 1									
1	0.56	0.17	7.64	0.46	92.8	20.2	0.042	0.006	0.98
2	2.04	0.13	8.34	0.39	100	19.7	0.041	0.005	0.98
3	1.58	0.15	8.80	0.14	105	19.5	0.107	0.008	0.98
mean	1.40	0.13	7.82	0.17	-	-	0.066	0.005	0.98
Treatment 2									
4	7.68	0.05	10.15	1.37	121	19.2	0.015	0.009	0.93
5	7.71	0.05	8.90	0.06	105	18.7	0.068	0.011	0.96
6	7.64	0.09	9.23	0.07	109	18.3	0.095	0.016	0.94
mean	7.67	0.04	8.39	0.05	-	-	0.065	0.008	0.97
Treaments mean	-	-	-	-	-	-	0.0655	-	-

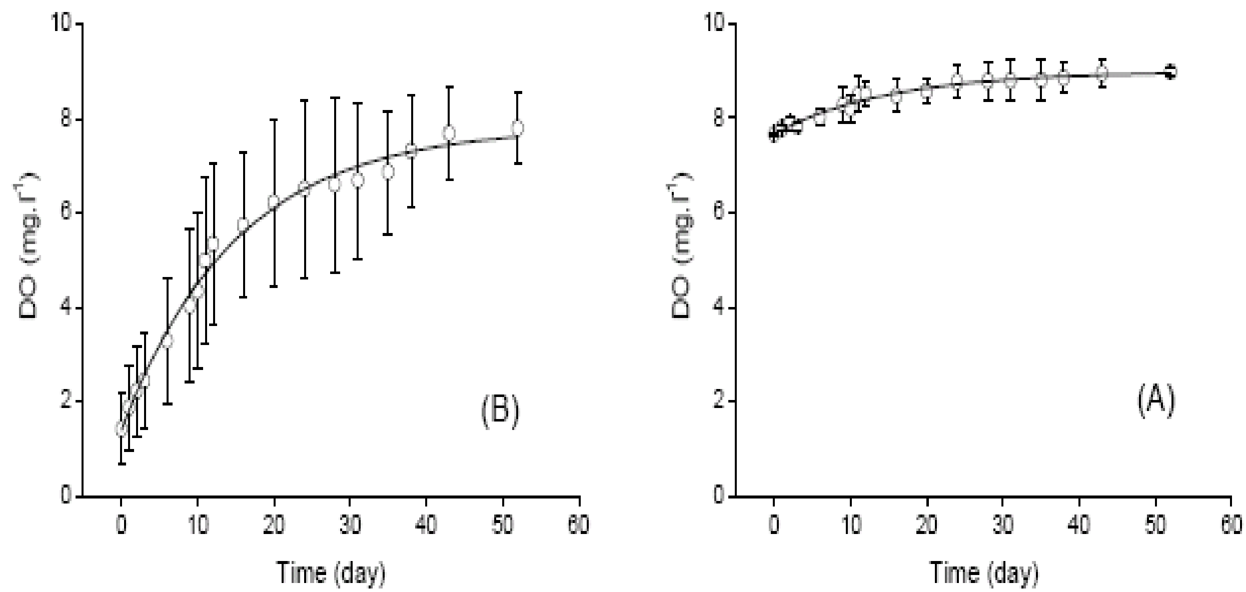

Figure 2.2 : The cumulative oxygen aeration process in Treatment 1 (A) and Treatment 2 (B). The fittings using the kinetics model are shown as solid lines. The error bars indicate the standard deviation of the mean DO from bottles (D).

Source : (Farjalla *et al.,* 1999)

These results indicated that the aeration process due to the long-term BOD experiment tended to increase the DO concentrations of the media even to saturation, independently of its initial DO concentrarion. This process as slow as DO increase only a little during the course of the experiments. This interference can be treated as a residual error. Indeed, in some cases, the variation in DO ([DO]final – [DO]initial) during the 52-day aeration process corresponded to only one day of variation, due to the deoxygenation in experiments with a high load of organic matter, as observed in oxygen uptake experiments with *Scirpus cubensis* (k_d = 0.00421 day-1) and *Cabomba piauhyensis* (k_d=0.00158 day-1), in which 200 mg dry weight of these aquatic macrophytes tissues were used (Cunha & Bianchini Jr., 1998). Similar experiments with leaves, barks, branches and litter showed a mean k_d volume of 0.0031 day-1 (Antonio *et al.*, 1999).

The fittings aeration process with Treatments 1 and 2 led to very close mean values for k_a (0.655 day1; t Test: t = 0.2815). This value is similar to the aeration coefficient found for the oxygen uptake of low concentrations of tannic acid (k_a = 0.6551 day-1);since oxygenation prevailed in *the mineralization is polyphenol* (Cunha-Santino & Bianchini Jr., 2003). Oxygen uptakeexperiments made by Bitar *et al.* (2002), with low *concentrations of organic matter* (20mg L-1), resented a mean k_d = 0.0463 day-1 (n =10).

The application of k_a obtained in this study to the experiments of oxygen uptake of aquatic macrophytes showed that the effect of aeration process in incubation with high concentrations of organic matter was attenuated or neutralized; this was probably due to the fact that the deoxygenation coefficient was more elevated, and the aeration effect was disguised. The latter are equally important under high concentrations of organic matter (Lemos and Bianchini Jr., 1998; Brum *et al.*, 1999). On the other hand, for incubations with low concentrations of organic matter (Cunha-Santino and Bianchini Jr.,2003) the effect of handling the samples can affect the budget between deoxygenation and aeration processes, resulting in an interference in the determination of k_d, with the ultimate values for BOD being underestimated.

2.4 Nitrification

In some waste treatment requirements, emphasis is placed on the removal of nitrogen from the leachate in order to minimize the release of plant nutrients to receiving water. The nitrogenous material must first be converted aerobically to nitrates. The level of dissolved oxygen should be near zero when reduction takes places. As the pH value of pond rises during high light intensity, significant quantities of ammonia may be liberated from the pond surface; where significant anaerobic lysis is operating, breakdown protein residues are directly converted to ammonia, nitrogen gas may be released, and the conversion of ammonia into protein in newly synthesized algal cells may provide a useful path for further denitrification.

2.5 Effect of Temperature and Oxygen on Nitrification.

Three sets of nitrification studies were conducted under different oxygen (average concentrations of 17, 5, and 100%) conditions and at 35 ^{o}C. Each study was conducted with old waste and at both 1000 and 500 mg N/L. As shown in Figure 2.3, significant ammonia removal occurred in all studies at 35^{o}C and 500 mg N/L.

Both biotic and abiotic controls were operated. The abiotic control was conducted to determine whether the ammonia removals observed were due to biotic processes, not something abiotic, such as sorption. As shown in Figure 2, there is a slightly increasing trend of ammonia mass in the abiotic control, suggesting that at the higher temperatures, there is a larger release of ammonia from the waste. The biotic control was operated with no ammonia present in the system to determine whether ammonia was produced during the tests. While operating the biotic control, there was no evidence of ammonia production.

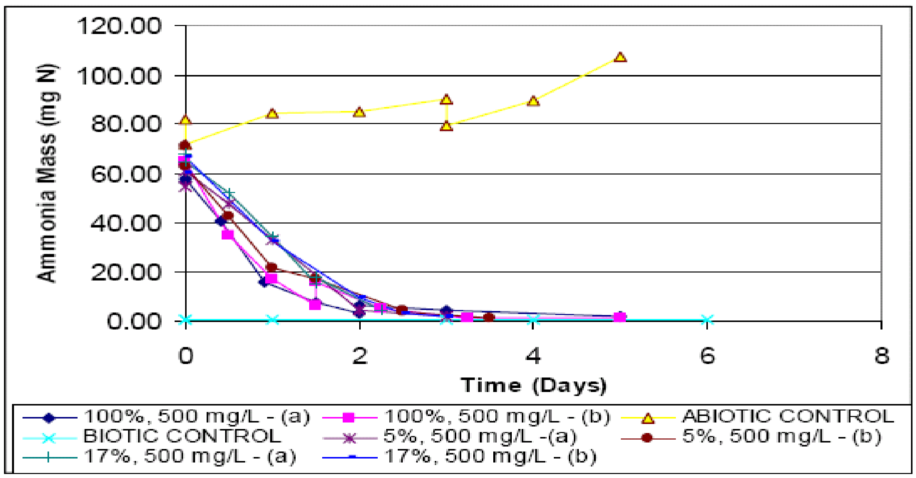

Figure 2.3 : Ammonia masses overtime in studies conducted at 35^0C and 500 mg N/.(Debra et al., 2006)

In almost all studies, ammonia disappearance was followed with an increase in nitrite and nitrate masses, also indicating nitrification had occurred (as shown in Figures 2.4 and 2.5). Nitrate and nitrite production have been observed in previous microcosm studies. Denitrification of some of the nitrate and or nitrite occurred, as some nitrogen gas production was observed (see Figure 2.5). As shown in Figure 4, there was less nitrogen gas produced in the studies conducted at 17% oxygen than those at 100% oxygen (Debra et al., 2006).

The occurrence of denitrification in the studies with higher oxygen levels was anticipated because the presence of micro-anoxic areas within the compost were expected, as this phenomenon has been observed in previous microcosm studies with a 100% oxygen in the gas-phase; however, at lower oxygen levels, anoxic pockets are expected to be more prevalent.

Nitrous oxide concentrations in the gas-phase were also observed, as shown in Figure 2.6. Nitrous oxide production in aerated systems is most probably due to denitrification. Denitrification is slightly inhibited in the presence of oxygen; thus, when oxygen is present, denitrification does not convert nitrate/nitrite completely to nitrogen gas, but rather stops at nitrous oxide. The most nitrous oxide was observed in one of the 5% oxygen tests; however, the percentage of initial nitrogen that was converted to nitrous oxide was similar in most of the studies.

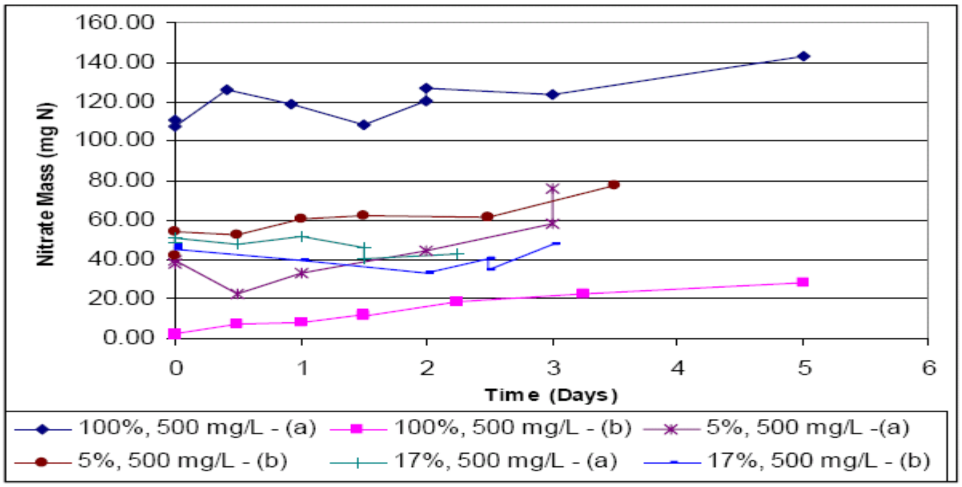

Figure 2.4 : Nitrite masses overtime in studies conducted at 35^{0}C and 500 mg N/L. (Debra et al., 2006)

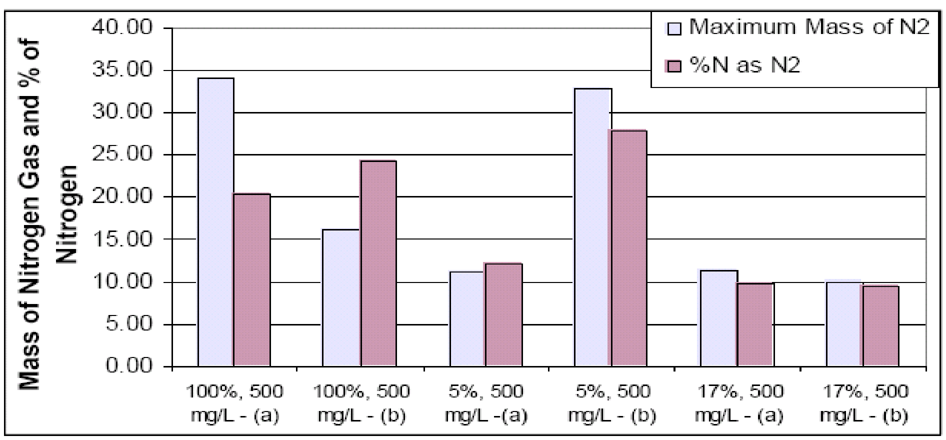

Figure 2.5 : Maximum mass of nitrogen gas producted during each study and the % of initial nitrogen that was converted to nitrogen gas. (Debra et al., 2006)

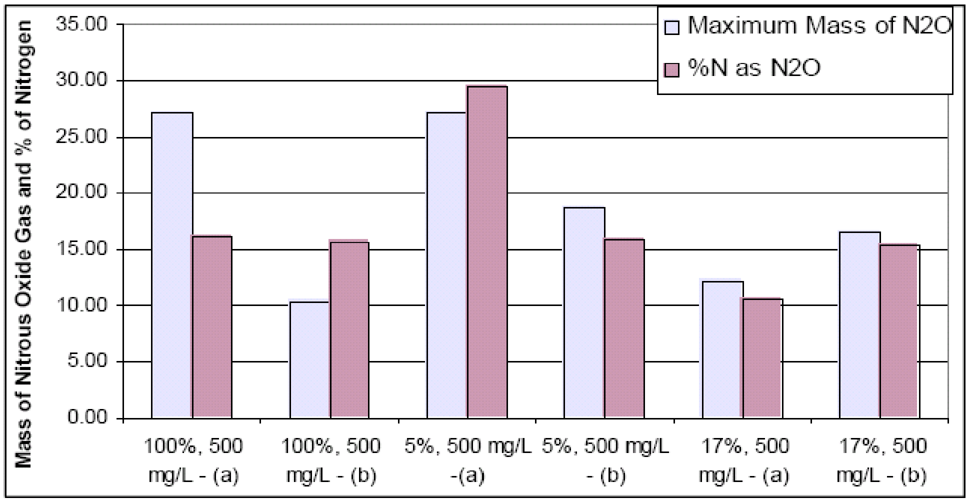

Figure 2.6 : Maximum mass of nitrous oxide gas produced during each study and the % of initial nitrogen that was converted to nitrous oxide. (Debra et al., 2006)

2.6 Organic Indicators of Waste Decomposition

Several parameters have been suggested to determine the degree of waste decomposition: pH, oxidation reduction potential, COD, BOD, BOD/COD, alkalinity, heavy metals, ionic strength, and the sulfate to chlorine ratio (Pohland and Harper, 1985; Chian and DeWalle, 1977; Reinhart and Grosh, 1998).

The most commonly used indicators are BOD, COD, and the ratio of the two. Though no standard values exist for these indicators, Table 2.2 summarizes some suggested ranges that correlate with the phase of decomposition. Several authors assign a BOD/COD value of less than 0.1 to stabile leachate (Reinhart and Grosh, 1998; Pacey, 1999; Pohland and Harper, 1985; Ehrig, 1988). Pacey (1999) has suggested that BOD should be less than 100 mg/L and COD should be less than 1000 mg/L. Table 2.3 summarizes various leachate composition data from several studies.

Variability may be expected in the values of COD and thus the BOD to COD ratio due to inorganic constituents that may contribute to COD. For instance, Kylefors et al. (1999) found that Fe(II), Mn(II), and sulfide contributed up to one third of the COD in the leachates they tested. In addition, poor sampling methods that expose anaerobic leachate to oxygen in the air may cause Fe(II) to oxidize to Fe(III) and precipitate out of the leachate. Thus, some of the COD will be lost.

Table 2.2 : The Use of Organic Indicators to Define Waste Decomposition

Source : (Debra et al., 2006)

COD and BOD are expressed in mg/L.

Phase:	Acid	Methanogenic	Stabilized	Reference
Organic Indicator:				
BOD COD BOD/COD	>10,000 --- > 0.7	20% of COD < 2000 ---	--- --- ---	Robinson, 1995
BOD COD BOD/COD	--- 3×10^{-4} - 3×10^{-7} ---	--- < 2000 ---	--- --- < 0.1	Reinhart and Grosh, 1998
BOD COD BOD/COD	--- --- ---	--- --- ---	--- --- 0.02 - 0.013	Pohland and Harper, 1985
BOD COD BOD/COD	--- --- > 0.4	--- 3000 - 4000 < 0.1	--- --- ---	Ehrig, 1988
BOD COD BOD/COD	--- --- ---	--- --- ---	< 100 < 1000 < 0.1	Pacey, 1999

1. These values are suggested ranges to define leachate decomposition.

Table 2.3 : Organic and Ammonia Concentrations (mg/L) in Landfill Leachate from Older, Methanogenic Landfills

Source : (Debra et al., 2006)

BOD	COD	BOD:COD	Ammonia as N	Reference
5.7 - 1100 (50, na)	76 - 6997 (50, na)	--- (na, na)	12.4 - 1571 (50, na)	Range of concentrations from 21-30 year old, German landfills (Krumpelbeck and Ehrig, 1999)
290 (50, na)	1225 (50, na)	0.24 (50, na)	445 (50, na)	Average concentrations from 21-30 year old, German landfills (Krumpelbeck and Ehrig, 1999)
44 (35, 120)	320 (85, 550)	0.11 (35, -)	110 (104, 190)	Average concentrations from old, Danish landfills (Kjeldsen and Christophersen, accepted for publication)
39 (1, na)	398 (1, na)	0.10 (1, na)	233 (1, na)	A sample composition at Sandsfarm Landfill (Robinson, 1995)
11 (1, na)	190 (1, na)	0.06 (1, na)	282 (1, na)	A sample composition at Bishop Middleham Landfill (Robinson, 1995)
38 (1, na)	517 (1, na)	0.07 (1, na)	399 (1, na)	A sample composition at Odsal Wood Landfill (Robinson, 1995)
1.0 (1, na)	53 (1, na)	0.02 (1, na)	42.6 (1, na)	A sample composition at East Park Drive Landfill (Robinson, 1995)
2.5 (1, na)	64 (1, na)	0.04 (1, na)	29.8 (1, na)	A sample composition at Marton Mere Landfill (Robinson, 1995)
20 - 550 (na, na)	500 - 4500 (na, na)	--- (na, na)	30 -3000 (na, na)	Range of concentrations reported in the literature for methanogenic leachate (Ehrig, 1988)
180 (na, na)	3000 (na, na)	0.06 (na, na)	750 (na, na)	Average concentrations reported in the literature for methanogenic leachate (Ehrig, 1988)
33 (3, 5.57)	75 (3, 7.23)	0.44 (3, 0.05)	0.5 (3, 0)	Average values from the last three days of a laboratory experiment with leachate recycle (Pohland, 1975).
34 (3, 9.54)	224 (3, 23.3)	0.15 (3, 0.026)	1.07 (3, 0.40)	Average values from the last three days of a laboratory experiment with leachate recycle and pH adjustment (Pohland, 1975).
36 (3, 4.04)	194 (3, 17.6)	0.19 (3, 0.035)	3.5 (3, 0.91)	Average values from the last three days of a laboratory experiment with leachate recycle, pH adjustment, and nutrient addition (Pohland, 1975).

1. The values represent actual composition results, averages or ranges of concentrations (or ratios) from leachate composition data. The landfills sampled are older, methanogenic landfills. The laboratory experiment data (Pohland, 1975) comes from stabilized waste.
2. Number of samples and standard deviation are given in parentheses (n, std.dev.)

2.7 Leachate Production and Characteristics

Leachate is the liquor that is collected at the base of landfills after rainwater has entered the emplaced waste materials and leached out contaminants. Depending on the nature and age of the wastes, the characteristics of the leachate will change. The leachates from land filling domestic wastes, which are more likely to be of a biodegradable nature. Rainfall is the main contributor to generation of leachate. The precipitation percolates through the waste and gains dissolved and suspended components from the biodegrading waste through several physical and chemical reactions. Other contributors to leachate generation include groundwater inflow, surface water runoff, and biological decomposition (Reinhart, 1998). Liquid fractions in the waste will also add to the leachate as well as moisture in the cover material. Moisture can be removed from the landfill by water consumed in the formation of landfill gas, water vapor removed in the landfill gas, and leachate leaking through the liner (Tchobanoglous, 1993). Since the short term leachate quantity depends heavily on precipitation, it is sometimes hard to predict.

Long term leachate quantity is not as difficult to predict. Leachate quality is also difficult to predict because each landfill is unique and the wastes vary widely (Bagchi, 1990). The major factors that affect leachate quantity and quality are; the type of disposed waste, hydrogeolic and climactic conditions, the age of the landfill, the phase of waste decomposition occurring, and the chemical and physical properties of the precipitation (Bagchi, 1990). Leachate quantity and quality is site specific. In arid regions, leachate quantity can be zero, while in areas of wet climate, 100 % of