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Landfill Leachate Degradation in Tropical Maritime Climate; an Experimental Laboratory Scale Study

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Abstract. Landfills are a potential source of ground water contamination. The high COD, BOD, ammonia nitrogen (NH_3-N) and heavy metals contents of leachate are the main problem facing leachate treatment operators. Their problem is heavily influenced by climate factors largely due to the fact that in the long term the net water input into the landfill equals the leachate from it. Thus, climate features such as a narrow annual temperature range and even distribution of precipitation through the year make leachate degradation behavior in maritime tropical location unique. This study was conducted to establish the degradation pattern of different leachate characteristics in tropical maritime climate by using a leachate recirculation landfill simulation reactor (LSR) with 200L capacity. Anaerobic degradation of leachate from fresh waste in a LSR was investigated by monitoring pH, COD, BOD_5, total dissolved solids (TDS), conductivity, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N) and sulfate (SO_4). First order degradation factor for each parameter was determined; furthermore Pearson correlation of these parameters was done. Results indicate that: (1) highest degradation factor is related to NO_3 with value of 0.023 and lowest degradation factor is for TKN with value of 0.001, and (2) most of the parameters have statistically significant correlation with each other where maximum correlation is between TDS and conductivity and minimum correlation is between TKN and pH.

Keywords: Correlation, Degradation Factor, Landfill Simulation Reactor, Leachate.

1. Introduction

Recently, rapid population growth and urban development have made efficient management of domestic waste of paramount important. Landfilling has been the most economical and environmentally accepted method of solid waste disposal in the world [1,2]. The leachate normally is generated by rainfall and surface water flow into the landfill, through a period of time. This water become highly concentrated wastewater at the bottom of the landfill; leachate is a potential threat for the quality of groundwater. However, in a classical sanitary landfill where there is no attempt to prevent moisture from entering the wastes, leachate generate for thousands of years.

There are many factors affecting the characteristic of such leachates, that is, age, precipitation, seasonal weather variation, waste type and composition [3]. The landfill leachates contain complex compositions, such as high concentration of ammonia nitrogen and salt, suspended solids, nitrogen, phosphorus and heavy metals [4]. Landfill design consists of several parts aimed at the control of landfill leachate. A sanitary landfill consists of two main components, which are a final cover and a liner system. The final cover is used to minimize percolation due to precipitation into the landfill. On the other hand liner system is used to minimize the transport of contaminant to groundwater. Bottom liners systems usually include a clay liner, plastic liner, composite liner and a leachate collection system.

Although the geomembrane component of the composite liner is nearly impervious to liquid flow, defects in the geomembrane occur, even with carefully controlled manufacturing and installation. Many factors contribute to leakage, including the geometry, configuration, and cross-sections of the landfill. Leakage through a geomembrane hole is dependent on the hydraulic conductivity of the surrounding material.

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The primary mechanisms of leakage through landfill geomembrane liners are fluid permeation through the undamaged geomembrane cover, and fluid flow through geomembrane holes. A secondary cause of leakage may be material defects. Even with the best installation of geomembrane liners, one can expect 3 to 5 geomembrane defects per hectare [5]. These are caused by flows in geomembrane seams, punctures caused by sharp materials beneath the geomembrane liner and installation tools, tension forces induced by placing waste on the liner. Defects can range in size from pinholes having a diameter less than the thickness of the geomembrane to defective seams between geomembrane panels that are several meters long.

An important environmental factor to consider is climate [6]. Climates near the ocean are characterized by a narrow annual temperature range, warm summers and cool winters and no dry season, as precipitation is more evenly dispersed through the year. Due to these unique features of tropical maritime climate, leachate degradation behavior in this climate would be different from other places. Unfortunately there is a dearth of data or studies of the long term effect of such conditions on landfill leachate degradation. This study is an attempt to addressing the gap in knowledge mentioned in the introduction. The objectives are: (1) to characterizing leachate degradation in a tropical maritime environment using LSR, (2) to show that leachate degradation in LSR follows first-order kinetic and finally (3) to find a correlation among the parameters those describe the leachate.

2. Experimental

The present study was conducted using landfill simulation reactor (LSR). This LSR was constructed from a drum made of high density poly ethylene (HDPE) having a diameter of 500mm and a total height of 1000mm. Fig. 1 shows a schematic of LSR that was used in this study, it was filled with shredded waste having a density of approximately $1000 kg/m^3$ and a composition of food waste 72%, paper 14%, plastic 2%, glass 4%, metals 6% and textile 2%. The LSR equipped with a peristaltic pump allowing recirculation of leachate; the leachate recycling rate was 8L per day. Once a week 7L of leachate is withdrawn and replaced with tap water. This tap water corresponds to a precipitation input into the waste of around 1200mm. This means no impermeable surface sealing, only a permeable soil layer as cover. This value was obtained assuming that the net water input into the landfills equals the leachate amount generated. This assumption is justified by the fact that water storage becomes insignificant for the water balance of landfills when longer time periods are considered [7].

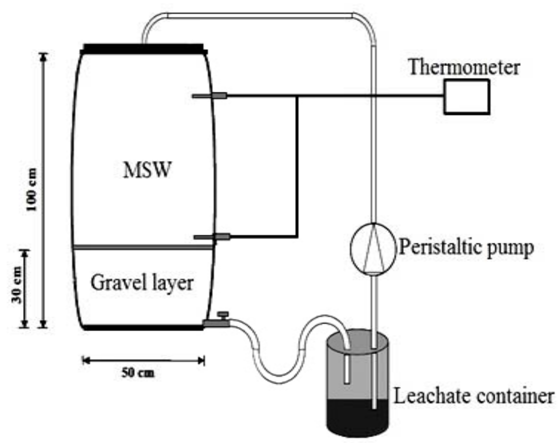

Fig. 1: Schematic LSR

The study was conducted to establish the degradation pattern of different parameters in landfill leachate. Parameters analyzed were pH, BOD_5, COD, total dissolved solids (TDS), Conductivity (Con.), TKN, ammonia nitrogen (NH_3-N), Nitrate-N nitrogen (NO_3-N) and Sulfate (SO_4). The techniques used for sampling analyses were in accordance with the Standard Method for the Examination of Water and Wastewater [8], except for TKN which was detected by Kjeldahl method. All analyses were undertaken at room temperature of 28±2°C except for conductivity and pH which were detected at 25°C and 23°C, respectively.

3. Results and Discussion

The characteristics of leachate from LSR at different stages are tabulated in Table 1. The whole duration of experiment took 130 days which on day 40 most of parameters reached their maximum. The sample leachate COD at initial and final day was 61,000mg/L and 4,830mg/L, respectively. This indicates a non-biodegradable fraction in this experiment was only 0.08.

Table1. Leachate characteristics for different stages

Parameters	Initial Day (15)	Intermediate Day (40)	Final Day (130)
pH	5.71	5.44	6.16
Temperature (°C)	28±2	28±2	28±2
COD (mg/L)	61000	149000	4830
BOD_5 (mg/L)	47100	44900	3280
BOD_5/ COD	0.77	0.3	0.68
TDS (mg/L)	15700	23700	1900
Con. (μS/cm)	26700	33400	2780
TKN (mg/L)	302	466	85
NH_3-N (mg/L)	299	45	69
NO_3-N (mg/L)	2.9	2.3	0.2
SO_4 (mg/L)	452	368	37

3.1. Leachate Characteristics Changes

Fig. 2 demonstrates the variation of COD and BOD_5 over time during degradation of waste in LSR. It shows that the BOD concentration was decreased from its initial value of 47,100mg/L to 44,900mg/L on day 40, followed by a degradation phase from day 15 to day 40. The BOD_5 concentration was decreased further to 19,100mg/L on day 75 or in other way 59% reduction. The maximum value for COD was achieved in day 40. This means that the exponential phase in BOD happened before COD did and BOD reached the maximum of its value before COD did. The reason for this phenomenon is the soluble microbial product (SMP) which is in contributed to the COD value in the effluent.

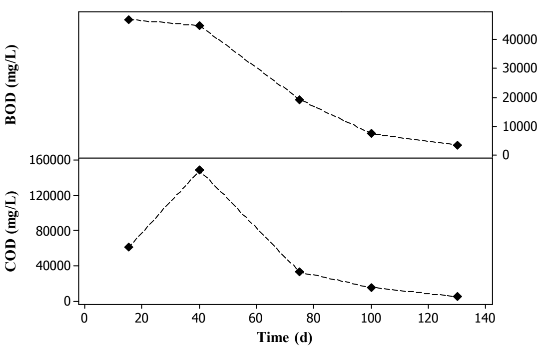

Fig. 2: Profile of COD and BOD_5

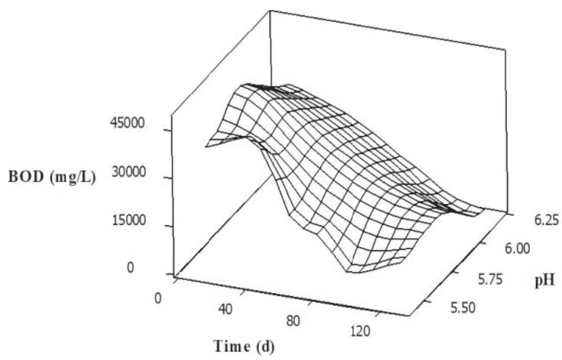

Fig. 3: Profile of BOD_5 vs. time & pH

SMP are soluble cellular components that are released during biomass decay. Various articles have proven that formation of SMP in anaerobic system indeed contributed to a certain percentage of COD in the effluent [9,10]. BOD_5/COD ratio decreased drastically from 0.77 on day 15 to 0.3 on day 40. SMP by increasing the COD is responsible for this phenomenon. BOD_5/COD ratio started increasing after that and reached 0.68 at the end of experiment, implying that the leachate still contained high fraction of organic compounds. It also means that the degree of solid waste stabilization did not reach to stable level yet [11].

Fig. 3 presents the variation of BOD over time and with pH. Decreasing in BOD concentration was followed by increasing pH. Therefore it will lead to increasing alkalinity of the leachate. Low values of BOD_5 shows that the majority of readily biodegradable content of landfill leachate which mainly consists of volatile fatty acids had been already removed [10]. Fig. 4 presents the changes in TDS and conductivity values with time. TDS increased from 15,700mg/L to 23,700 mg/L and decreased rapidly from maximum amount of 23,700mg/L to 11,000mg/L on day 75 (70% reduction) and then decreased slowly throughout the experiment to 1,900mg/L on day 130. TDS profile during the experiment shows that leachate was being degraded sharply and then tends to decrease slightly until end of the treatment. Although there is no exact relationship between conductivity as μS/cm and TDS as mg/L, the trends of changes for both parameters indicate that conductivity is linked directly to the TDS.

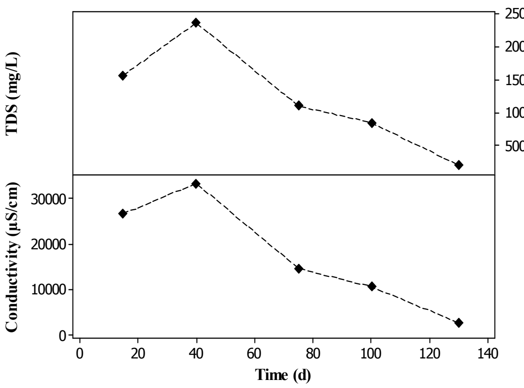

Fig. 4: Profile of TDS and conductivity

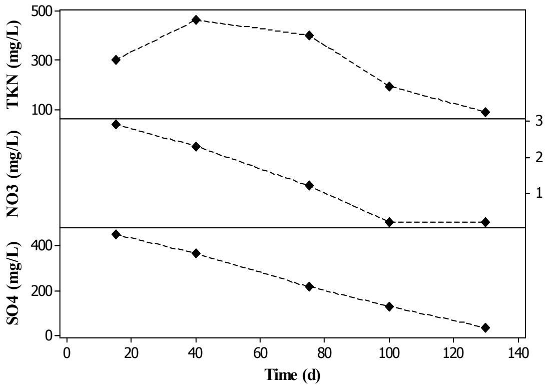

Fig. 5: Profile of TKN, NO3 & SO4

Total Kjeldahl Nitrogen or TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4). Initial value of TKN was 302mg/L. It increased to maximum value of 466mg/L on day 40 (Fig. 5). This is because ammonia is produced as a by-product of anaerobic digestion, principally from the mineralization of organic nitrogen during the deamination of proteins and amino acids. Fig. 5 also shows the degradation in NO_3 and SO_4 having almost the same pattern. More than 90% of degradation acquired on day 100 for both of them.

3.2. Degradation of Leachate Parameters

The whole duration of degradation took 130 days, where degradation for day 75 and 100 have been determined and for each parameter displayed in Table 2. Results show the minimum degradation factor belongs to nitrogen; this indicates nitrogen to be the parameter with the longest release of relevant concentrations into the leachate phase due to bacterial synthesis and conversion of organic nitrogen compounds to inorganic nitrogen by nitrification [12, 13].

Table 2. Degradation of leachate parameters in percentage for different days

	Day 75	Day 100	Day 130
COD	46	75	92
BOD_5	59	84	93
TDS	30	46	88
Con.	45	60	90
TKN	-33	36	72
NH_3	-31	53	77
NO_3	59	93	93
$S0_4$	48	92	92

Table 3. Leachate degradation factor in days 60, 85, 115 and mean of them ($\bar{k}$)

	k_{60}	k_{85}	k_{115}	$\bar{k}$
COD	0.01	0.02	0.02	0.017
BOD_5	0.02	0.02	0.02	0.02
TDS	0.01	0.01	0.02	0.013
Con.	0.01	0.01	0.02	0.013
TKN	-	0.01	0.01	0.01
NH3	-	0.01	0.01	0.01
NO3	0.01	0.03	0.03	0.023
SO4	0.01	0.01	0.02	0.013

3.3. Degradation Factor

Comprehensive scientific investigations on landfills and in LSRs were carried out to predict the long-term emission behaviour. For this reason extrapolation calculations on the basis of the emissions into the leachate phase were done. The course of emissions in time can be described with equation 1 [14]:

$$C_t = C_0 * e^{-kt} \quad (1)$$

Where C_t is concentration at time t, C_0 is concentration at the beginning of the LSR test, t is test period and k is first order degradation factor. Table 3 shows degradation factor for days 60, 85 and 115; mean value ($\bar{\boldsymbol{k}}$) of degradation factor for each parameters was obtained also. Maximum factor belongs to nitrate with value of 0.023 and minimum belong to TKN and ammonia with value of 0.01. Probably this phenomenon is due to conversion major fraction of organic nitrogen compounds to NH_3-N not to NO_3.

3.4. Correlation analysis

As suggested in the literatures [15, 16], correlation of leachate data can be useful in site remediation. Hence, it is attempted in this work to determine the degree of association among the variables measured. Hence, the Pearson product moment correlation or Pearson's correlation for short is used. A Pearson correlation is a number between -1 and +1 that measures the degree of association between two variables. Positive value for the correlation implies positive association where negative value for the correlation implies negative or inverse association. The Pearson correlation ($\boldsymbol{r}$) is:

$$\boldsymbol{r} = \frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{(n-1)S_X S_Y} \quad (2)$$

In which $\bar{\boldsymbol{X}}$ and $\bar{\boldsymbol{Y}}$ are the respective means and $\boldsymbol{S_X}$ and $\boldsymbol{S_Y}$ the respective standard deviations of the $\boldsymbol{X}$ and $\boldsymbol{Y}$. Correlation analysis was performed using Stat. Basic. Cor. procedure in statistical package of Minitab software [17]. Tables 4 shows the Pearson correlation coefficient factor between different parameters of leachate. The investigated correlation coefficient between the parameters (Table 3) show that there was a very high correlation between the parameters, indicating close association of these parameters with each other and this is in agreement with other studies [18, 19].

Table 4. Correlation coefficient of parameters

	pH	**COD**	**BOD**	**TDS**	**Con.**	**TKN**	**NH_3**	**NO_3**
COD	-0.47							
BOD_5	-0.36	0.82						
TDS	-0.64	0.95	0.9					
Con.	-0.55	0.91	0.96	0.99				
TKN	-0.75	0.72	0.73	0.88	0.82			
NH_3	-0.27	0.27	0.15	-0.02	0.03	0.31		
NO_3	-0.28	0.99	0.73	0.82	0.91	0.68	0.27	
SO_4	-0.43	0.72	0.98	0.86	0.93	0.72	0.3	0.98

TDS had a strong correlation with almost all of the parameters except to NH_3. Therefore the single parameter of TDS can give a reasonable good indication of a number of parameters [20]. Maximum correlation is between TDS and conductivity and minimum correlation value is for TKN and pH.

4. Conclusions

This study was conducted to establish the degradation pattern of different leachate characteristics in tropical maritime climate by using a landfill simulation reactor. Conversion of organic nitrogen compounds to inorganic nitrogen by nitrification led to minimum degradation factor would achieve for TKN and ammonia with value of 0.01. Maximum degradation factor belongs to nitrate with value of 0.023. Correlation between concentrations of different parameters in leachate can be used when remediating the site. Most of the parameters were found to statistically significant correlation with each other indicating close association of these parameters with each other. Maximum correlation was found between TDS and conductivity with value of 0.99 and minimum correlation was between TKN and pH with value of -0.75.

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