Investigation of The Fate Of MSW Leachate In Different Soil Types Using Soil Column Method

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Abstract

The aim of this research is to investigate the fate of Municipal Solid Waste (MSW) leachate using the soil columns method. Leachate was extracted in the laboratory and fed to three different soil columns. One of the columns was packed by sandy soil. The second was packed by sandy clay loam soil, the depth of the soil in each was 60 cm. The third column was packed by layered soil, the depth of each layer was 30 cm. Samples of the percolated leachate were collected and investigated for several physical and chemical characteristics as a function of time, including COD and BOD. The results showed that, an obvious decreasing in the characteristics of the leachate occurred with the three columns as a function of time. The characteristics decreased with decreasing of Hydraulic Retention Time (HRT) up to a certain time then it started to increase. The adsorption capacity of the soil could play a great role in the changes that occurred in the characteristics of the leachate in the different soil types. The results demonstrated that the soil could play a role in delaying the arrival of the pollutants to groundwater.

Keywords: MSW leachate, soil columns, adsorption capacity, groundwater quality

1. Introduction

Landfilling is still a prevalent technique for Municipal Solid Waste (MSW) disposal. It is considered one of the easiest options in MSW disposal. The wide use of landfills poses the probability of groundwater contamination. Landfills have been identified as one of the major threats to groundwater resources (Despina et al., 1999). Leachate produced from landfills has become a real danger to the surroundings as it holds greatly concentrated organic and toxic pollutants. Many environmental problems exist because of landfills. Among which, is the impact of leachate on groundwater (Aik et al., 2010; Chiemchaisri & Srisukphun, 2003; Jahangir & Singhal, 2004).

The amount of leachate produced by the landfill increases by increasing the amount of precipitations falling on the landfill surface. When leachate penetrates through the soil layers, it contaminates the ambient environment. Constituents move within the soil matrix, mainly due to the concentrations gradients (Rattan & Shukla, 2004). The degree of contamination in the aquifers depends on the transport rate of contaminants and depository conditions at the site as the contaminants permeate through the soil media (Vasanthi et al., 2008). Therefore, understanding the leachate transportation within the soil depends on understanding the structures of the soil. The variations in soil porosity, hydraulic conductivity, particle size, surface area, and permeability will lead to variation in contact time with the leachate. Therefore, variations in the outlet leachate characteristics exist. Soil is expected to minimize the amount of contaminants percolate to the groundwater. It can attenuate the landfill leachate by adsorption, biodegradation, cation exchange, and to a lesser degree anion exchange reactions, precipitation, and filtration (Smith et al., 1999). It has been showed that the top soil has considerable effects on the elements that may pass through to the aquifer.

In waste disposal areas, the upper soil strata usually contains greater amount of organic matters than in lower strata (Al-Soufi, 1994). Many modelings have been done worldwide to evaluate the transport of various contaminants through the soil profile (Jeffery & Sajostrom, 2010; Gupta & Gurdeep, 2007).

The organic substances were initially adsorbed by soil and released when soil became saturated. Not all the constituents were removed from the MSW leachate when passed through the soil strata (Tuffaha, 2006).

2. Materials and Methods

A laboratory experiments were conducted using three soil columns for the investigations of the fate of the MSW leachate in different soil types. The experiments were repeated three times using different type of soil in each time. Three columns made of PVC plastic 100 cm long, were used for soil repacking, the inner diameters for each was 20 cm. To prevent clogging, a 10 cm of gravel layer with particle size between 10 mm and 4.46 mm, were mounted at the bottom of the columns. In the same time, a metal screen mesh at the bottom of each column was attached in order to prevent the soil plunging. A funnel was mounted at the end of each column for the collection of leachate, through attached valve on the funnel.

The experiment was held under the local conditions, two types of soil were used, representing the soils of west and east of Gaza city - Palestine. Sieve analysis and Hydrometer method were used to analyze the soils. It was found that, the first type of soil was sandy soil figure 1, representing the west soil of Gaza city, while the second type representing the east soil of Gaza city was sandy clay loam figure 2. The first column was packed to 60 cm depth of one of the two types of the soil, which was the sandy soil. And the second column packed with 60 cm depth of the sandy clay loam. However, the third column simulated a layered soil profile. The upper 30 cm was packed with sandy soil, and the second half with sandy clay loam.

The MSW leachate was applied to each column separately at flow rate 2 liters per hour. The applied MSW leachate was extracted in the laboratory under the local conditions. Table 1 shows the characterizations of the extracted leachate applied to each column.

The percolated leachate was collected from the valve at the end of the column. Sample from the percolated leachate was taken every single hour for analyzing. However, the first outlet leachate sample of the sandy soil column was received faster only after 52 minutes from the inlet time. While the first sample from the sandy clay loam soil took longer time, it was received after 3 hours and 20 minutes. In the third column (layered soil), first sample had been received after 2 hours and 10 minutes. Six samples from each column were analyzed for all the following physical and chemical parameters: pH, E.C., TDS, NO_3^-, NH_3, $Cl^{-,}$ Alkalinity, Hardness, Ca^{++}, Mg^{++}, K^+, Na^{++}, COD, and BOD.

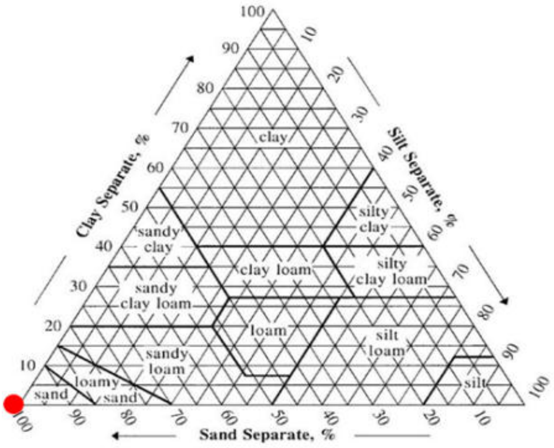

Figure 1. Soil texture triangle sand.

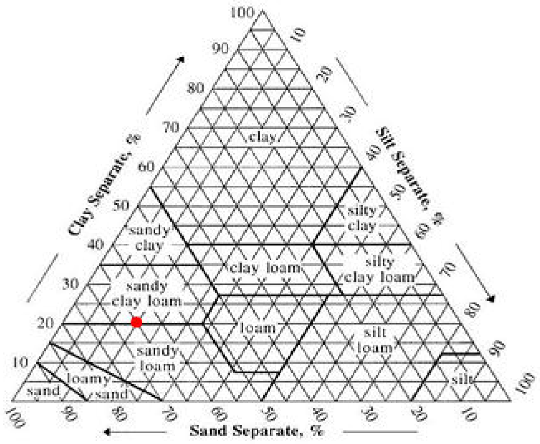

Figure 2. Soil texture triangle sandy clay loam.

Table 1. The characterizations of the extracted leachate applied to the columns.

Parameter	Unit	Sandy soil column	Sandy clay loam column	Layered soil column
pH	-	5.6	5.4	6.41
E.C	s/cm	22.8	27.0	13.0
TDS	g/l	14.14	16.740	8.0
NO_3^-	g/l	1.1	1.17	0.85
NH_3	g/l	0.55	0.55	0.31
Cl^-	g/l	1.77	2.86	2.13
Alkalinity	g/l as $CaCO_3$	9.72	7.78	3.89
Hardness	g/l as $CaCO_3$	5.21	1.46	6.18
Ca^{++}	g/l	1.17	2.67	2.45
Mg^{++}	g/l	0.55	1.92	0.015
K^+	g/l	1.29	1.76	1.54
Na^+	g/l	0.75	1.200	0.60
COD	g/l	42.9	49.0	75.0
BOD	g/l	22.5	17.5	8.0
BOD/COD	-	0.52	0.36	0.11

3. Results and Discussions

3.1 The fate of leachate in sandy soil

The characteristics of the leachate changed significantly, as it moved downward. The changes in the characteristics of the leachate percolated through the sandy soil are summarized in table 2.

The pH values of the outlet leachate from the sandy soil column increased from an inlet value of 5.4 to the range of outlet value from 6.3 to 6.9, figure 3. The increased values of pH were an indicator of high biological activities, leaded to dissociation of the fatty acids in the leachate.

E.C. and TDS decreased constantly by the time till the fifth hour. At the end of the experiment time, their values became more or less the same as the inlet value, figures 4 & 5. The E.C. and TDS were 23.18 s/cm and 14.37 g/l, respectively. The adsorption capacity of the soil increases with increasing of the Hydraulic Retention Time (HRT) (Liu, 1999). Matching to what approached by Gupta and Singh (2007), the TDS of the leachate decreased with the increasing of the (HRT). It was found that the TDS at the inlet was 14.14 g/l, and decreased to reach 12.68 g/l at the fifth hour table 2, as the retention time of the leachate increased. Decreasing continued until, the time that adsorption capacity of the soil might reached its maximum capacity. The adsorption regarded as the most purification process during infiltration and percolation (Malolo, 2011). Then after that, the TDS obviously increased to reach 14.37 g/l at the sixth hour, whereas the adsorption seemed to be diminished. The TDS behavior reflected the behavior of most of inorganic materials, with some variations in the sorption capacities, and in the exchange capacities. It was found that the concentrations of Mg++ decreased till the end of the fourth hour, while the Cl- decreased till the third hour, while the K+ concentration decreased only on the first two hours before it increased again. Unexpectedly, the NO3- concentration decreased drastically after the first hour, then increased constantly, figure 6. In the same time, the NH3 decreased continuously, this can be attributed probably, to the presence of an aerobic condition. Due to that the nitrification occurred and NH3 reduced to NO3-. The reeducates of NO3- in the first hour may be attributed to assimilation of NO3- , which can occur under aerobic and anaerobic conditions according to Cha et al., (2005).

The BOD and COD concentrations were decreased almost constantly with the time, when leachate percolated through the sandy soil, figures 8 & 9. It was decreased from 22.5 g/l at the inlet down to 12 g/l after the fourth hour for the BOD and from 42.89 g/l at the inlet down to 37.7 g/l after the fourth hour for the COD. Then after, BOD and COD concentrations have increased to values of 14 g/l and 38.53 g/l, respectively. The behavior of the BOD and COD concentrations demonstrated the effect of the adsorption mechanism in the initial hours. Then after the fourth hour, the adsorption of the sandy soil reached its maximum capacity, coinciding with the increasing of the retention time. Whereas the adsorption diminished, the biodegradation that occurred released the organic substances, and the COD increased. This agreed with what achieved by Chiemchaisri & Srisukphun (2003). In addition, the effluent of the leachate and the high concentrations of the organic substances in the leachate may cause a plugging on the ion exchange in the soil, causing an inefficient removal of the organic substances after the fifth hour.

Table 2. Variations in leachate characteristics as a function of time (sandy soil).

Parameter	Unit	Inlet	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
pH	-	5.6	6.5	6.45	6.32	6.61	6.88	6.9
E.C	s/cm	22.8	21.6	21.4	21.13	21.1	20.5	23.18
TDS	g/l	14.14	13.39	13.3	13.1	13.08	12.68	14.37
NO_3^-	g/l	1.06	0.62	0.73	0.73	0.76	0.78	0.86
NH_3	g/l	0.55	0.48	0.43	0.41	0.39	0.37	0.32
Cl^-	g/l	1.77	1.68	1.68	1.68	2.13	2.48	3.19
Alkalinity	g/l as $CaCO_3$	9.72	8.99	8.75	8.26	7.78	8.26	8.51
Hardness	g/l as $CaCO_3$	5.21	6.25	6.25	6.25	6.25	8.13	8.75
Ca^{++}	g/l	1.17	1.63	1.67	1.67	1.67	1.84	2.01
Mg^{++}	g/l	0.55	0.53	0.5	0.5	0.5	0.85	0.91
K^+	g/l	1.3	1.26	1.26	1.28	1.28	1.35	1.45
Na^+	g/l	0.75	0.76	0.9	0.9	0.9	1.0	1.2
COD	g/l	42.89	41.94	38.0	37.56	37.7	38.03	38.53
BOD	g/l	22.5	19.0	17.0	15.0	12.0	12.0	14.0
BOD/COD	-	0.53	0.45	0.45	0.40	0.32	0.32	0.36

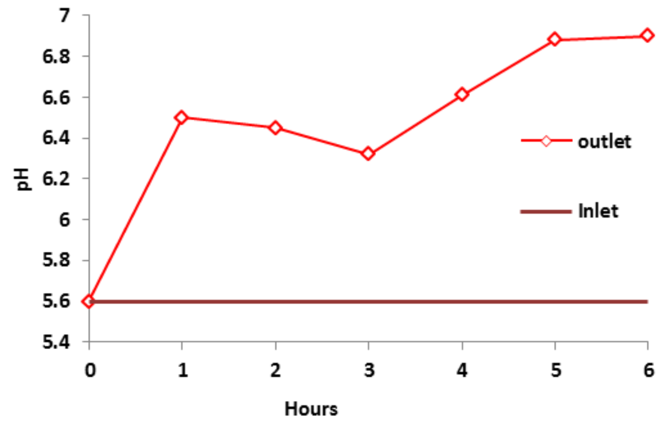

Figure 3. The variations in pH of leachate in sandy soil as a function of time.

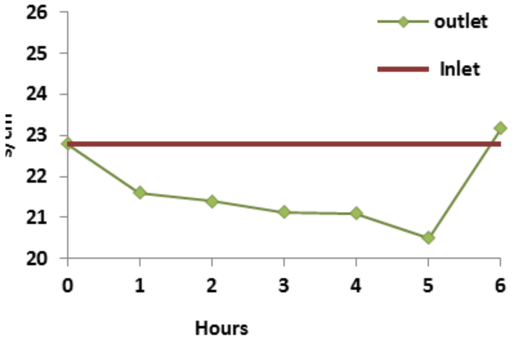

Figure 4. The variations in E.C. of leachate in sandy soil as a function of time.

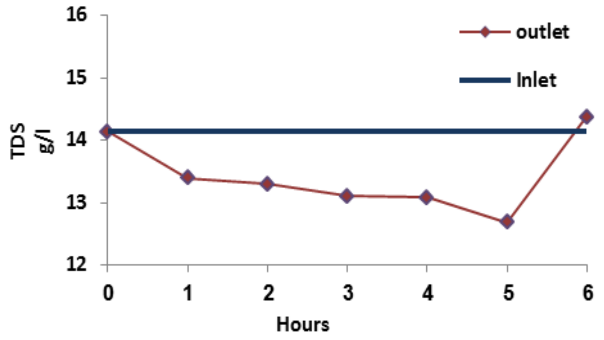

Figure 5. The variations in TDS of leachate in sandy soil as a function of time.

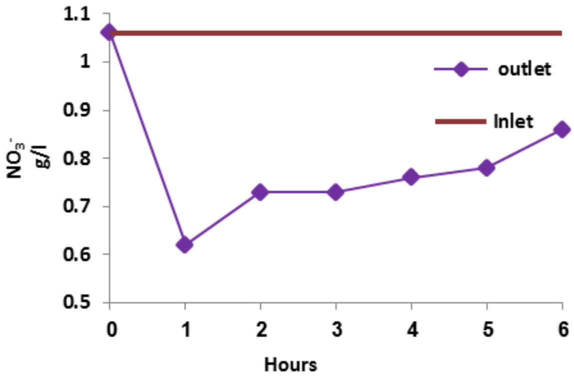

Figure 6. The variations in NO_3^- of leachate in sandy soil as a function of time.

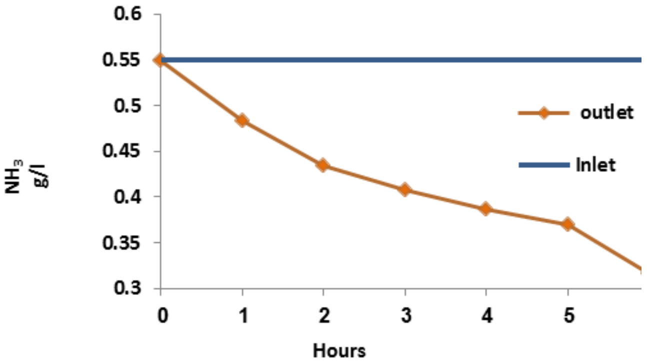

Figure 7. The variations in NH_3 of leachate in sandy soil as a function of time.

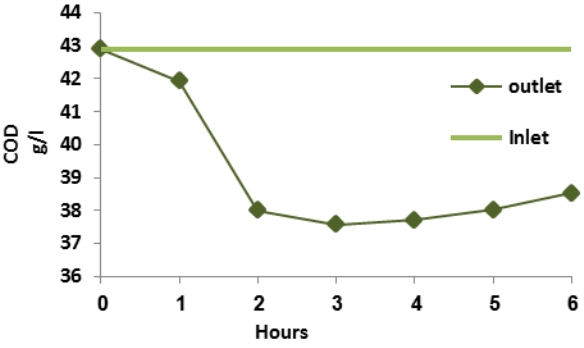

Figure 8. The variations in COD of leachate in sandy soil as a function of time.

3.2 The fate of leachate in sandy clay loam soil

The results obtained are shown in table 3. The characteristics of the leachate have significantly changed when applied to the sandy clay loam soil column. The pH has increased from 5.41 on the inlet leachate to 6.57 at the out let leachate after the sixth hour as apparent in, table 3. The pH firstly increased in the first hour and decreased in the second hour. While pH increased slightly in the third hour, it decreased again in the fifth hour before it increased slightly at the last hour (see figure 10). The fluctuating of the pH values indicated that there was no balance between the acid producing process (e.g. lipid degradation) and the acid consuming process (e.g. methane formation) . This is consistent with what was stated by Khoury et al., (2000).

E.C. and TDS concentration decreased in the first hour. Then their concentration unexpectedly increased from 26.58 and 16.48 g/l at the first hour to 28.13 and 17.44 g/l, respectively at the last hour (see figures 11 and 12) , matching what was stated by Tuffaha (2006). This could be attributed to the flushing out of the soluble ions from the soil to the leachate. Moreover, the permeating of sever contaminated leachate through the soil matrix can significantly affect the adsorption and ion removal mechanism (Francisca & Glatstien, 2010). Though, the concentration of TDS at the outlet increased more than its concentration at the inlet.

NO3- concentration (figure 13) decreased from 1.18 g/l at the inlet leachate to 0.47 g/l after the third hour (table 3). Then it increased after the fourth hour and reached 0.6 g/l at the end of the sixth hour of the experiment. A comparison between the NH$_3$ behavior and the NO$_3^-$ behavior can indicate the presence of aerobic condition, which caused a nitrification process. Nitrification process led to the reduction of the NO$_3^-$ in the last three hours of the experiment figure 13. In addition to that, nitrification led to almost constant decreasing in the NH$_3$ concentration as presented in figure 14.

The BOD, figure 15, and COD, figure 16, found to be decreased with the time, when leachate passed through the sandy clay loam soil. The BOD and COD concentration dropped almost to the half in the first hour, where BOD decreased from 17.5 g/l to 8.4 g/l and COD decreased from 49 g/l to 24.6 g/l, table 3. Decreasing continued constantly in the third and in the fourth hours. Then after a short while , the concentration started to increase slightly till the end of the experiment. This can be attributed to the adsorption, and the filtration of particulate BOD and COD on the soil surface, as the soil had its maximum adsorption capacity at first hours. Then the adsorption capacity minimized at the last hours and the organic released due to the biodegradation that occurred.

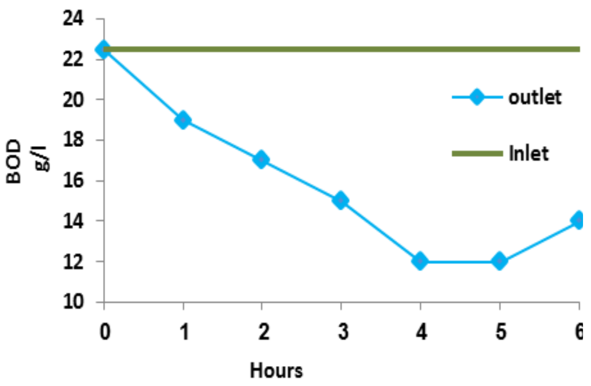

Figure 9. The variations in BOD of leachate in sandy soil as a function of time.

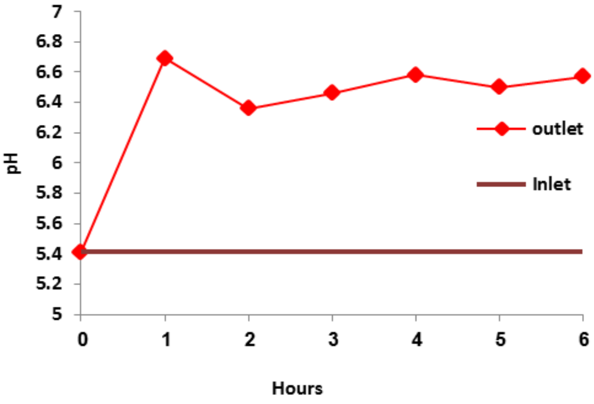

Figure 10. The variations in pH of leachate in sandy clay loam soil as a function of time.

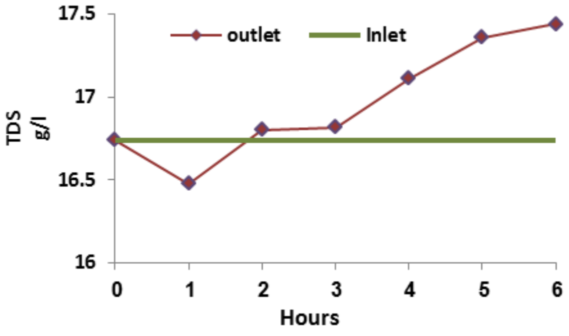

Figure 11. The variations in TDS in sandy clay loam as a function of time.

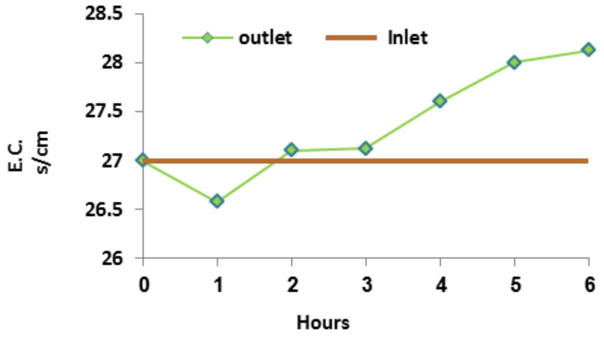

Figure 12. The variations in E.C. in sandy clay loam as a function of time.

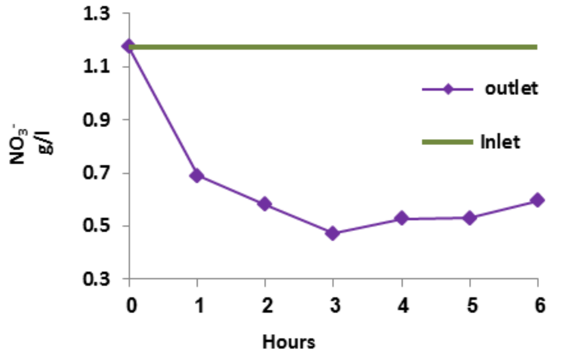

Figure 13. The variations in NO_3^- in sandy clay loam soil as a function of time.

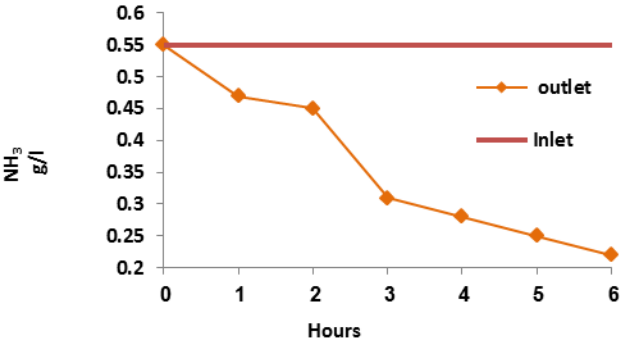

Figure 14. The variations in NH_3 in sandy clay loam soil as a function of time.

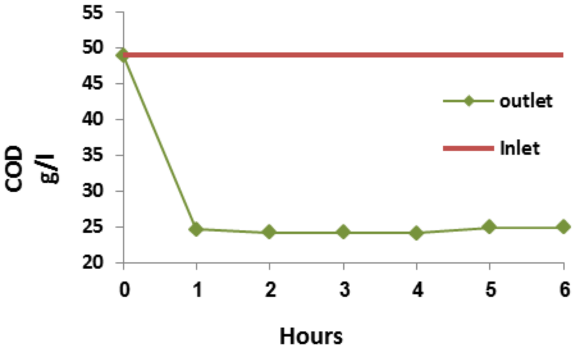

Figure 15. The variations in COD of leachate in sandy clay loam as a function of time.

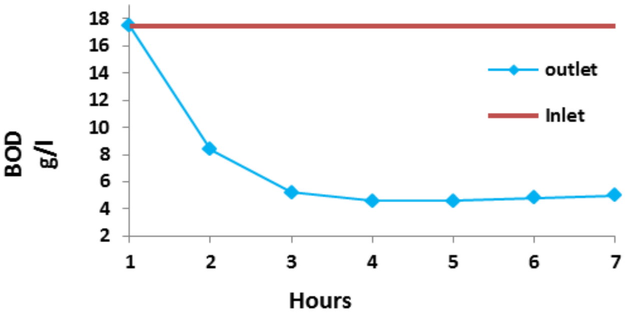

Figure 16. The variations in BOD of leachate in sandy clay loam as a function of time.

Table 3. Variations of leachate characteristics as a function of time (sandy clay loam).

Parameter	Unit	Inlet	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
pH	-	5.41	6.69	6.36	6.46	6.58	6.5	6.57
E.C	s/cm	27.0	26.58	27.1	27.13	27.6	28.0	28.13
TDS	g/l	16.74	16.48	16.8	16.82	17.11	17.36	17.44
NO_3^-	g/l	1.18	0.69	0.58	0.47	0.53	0.53	0.6
NH_3	g/l	0.55	0.48	0.45	0.31	0.28	0.25	0.22
Cl^-	g/l	2.87	3.19	2.84	2.84	2.48	2.48	2.48
Alkalinity	g/l as $CaCO_3$	7.78	10.45	9.11	8.51	7.9	8.14	10.33
Hardness	g/l as $CaCO_3$	14.58	15.52	14.06	14.27	13.33	12.71	9.9
Ca^{++}	g/l	2.68	4.35	4.42	3.6	3.01	2.72	2.51
Mg^{++}	g/l	1.92	1.13	0.85	1.28	1.41	1.44	0.88
K^+	g/l	1.76	0.35	0.38	0.34	0.4	0.44	0.48
Na^+	g/l	1.2	1.13	1.08	1.08	1.13	1.15	1.15
COD	g/l	49.0	24.6	24.2	24.15	24.1	24.9	24.9
BOD	g/l	17.5	8.4	5.2	4.6	4.6	4.8	5.0
BOD/COD	-	0.357	0.341	0.206	0.183	0.183	0.193	0.202

3.3 The fate of leachate in layered soil

In the third column, leachate was applied to a two-layer soil column, consisting of sandy clay loam soil and sandy soil. The characteristics of the leachate were significantly changed as it was percolated through the layered soil as presented in table 4. pH out of this column increased during the first two hours and then decreased slightly till the end of the experiment, figure 17. In a general view, the pH was around the neutral. The biological activities were active at the initial hours, where the leachate was contacted first time to the soil. This led probably to dissociations of the fatty acids in the leachate. After that a balance could happen between the acid producing process and the acid consuming process. Anaerobic conditions were presented, causing a reduction process and removing of hydrogen ions from the leachate, and the pH stabilized to about neutral. This is compatible with what was stated by Smith et al., (1999).

The E.C. and TDS decreased at the first hour, from 13 and 8.06 g/l to 11.52 and 7.14 g/l respectively, table 4. Then the concentration increased slightly for two hours before it decreased again for the rest of the outlet samples as shown in figures 18 and 19. This is attributed to the adsorption capacity and the ion exchange mechanism. The E.C. levels and TDS concentration seemed to be on its maximum value in the first outlet sample, and then there was almost stabilization in their concentration. TDS increased after the first hour, due to the dissolutions of the available salts. This was supported by the observations by Yildiz et al., (2004). The existing of two layers of different soil may contribute in the fluctuating that occurred in the concentration on the inorganic, due to the present of two different sorption capacity and different Cation Exchange Capacity CEC. This can be supported by the behavior of the other inorganic matter. NO_{3-} decreased in the first two hours, then it increased almost constantly, figure 20. This could attributed to an aerobic condition occurred, which led to the depletion of the NH_3, figure 21. As it is shown, NH_3 decreased almost all the time.

The COD was decreasing all the time before it started to increase in the last two hours, figure 22. While the BOD, figure 23, decreased in the first two hours, then stabilized for three hours, before it increased in the last two hours. The decreasing in the COD and BOD can explain the presence of the readily degradable soluble organics. In addition to the adsorption capacity, which could reached its maximum capacity before the last two hours, when the concentrations of COD and BOD increased, due to the releasing of the organic substance as a result of the biodegradation that occurred. Layered soil helped in delaying the leachate movement, thus increasing the retention time of the leachate ; hence increasing the removal efficiency to a certain time till the adsorption capacity diminished. The diminishing of the adsorption capacity probably occurred due to the increasing of the accumulated ions on the specific surface area. The filtrations of particular BOD and COD can play an important role in the decreasing of their concentration.

Table 4. Variations of leachate characteristics as a function of time (layered Soil).

Parameter	Unit	Inlet	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
pH	-	6.41	6.91	7.12	6.98	6.99	6.89	6.74
E.C	s/cm	13.0	11.52	12.0	12.4	12.2	12.0	11.85
TDS	g/l	8.06	7.14	7.44	7.69	7.56	7.44	7.35
NO_3^-	g/l	0.85	0.33	0.11	0.17	0.21	0.32	0.36
NH_3	g/l	0.31	0.05	0.02	0.01	0.012	0.009	0.009
Cl^-	g/l	2.13	2.13	2.13	1.77	1.77	1.77	1.77
Alkalinity	g/l as $CaCO_3$	3.89	3.16	3.04	3.28	3.28	3.4	3.52
Hardness	g/l as $CaCO_3$	6.67	12.13	12.33	12.05	13.36	12.33	12.46
Ca^{++}	g/l	13.8	2.09	2.01	17.56	2.09	2.17	2.09
Mg^{++}	g/l	0.78	1.68	1.78	1.86	1.98	1.67	1.76
K^+	g/l	1.54	0.02	0.019	0.020	0.018	0.017	0.022
Na^+	g/l	0.6	0.58	0.48	0.46	0.48	0.46	0.44
COD	g/l	75.0	63.0	58.0	54.0	50.0	60.0	63.0
BOD	g/l	9.0	8.0	7.0	7.0	7.0	8.0	8.5
BOD/COD	-	0.12	0.13	0.12	0.13	0.14	0.13	0.13

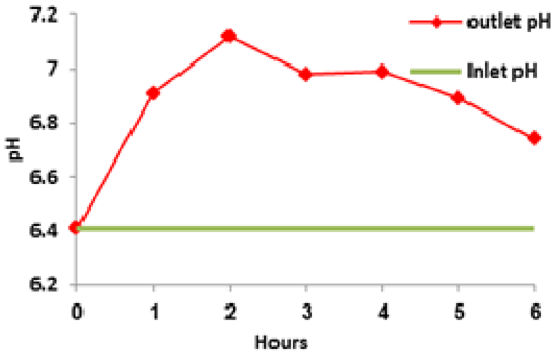

Figure 17. The variations in pH of leachate in layered soil as a function of time.

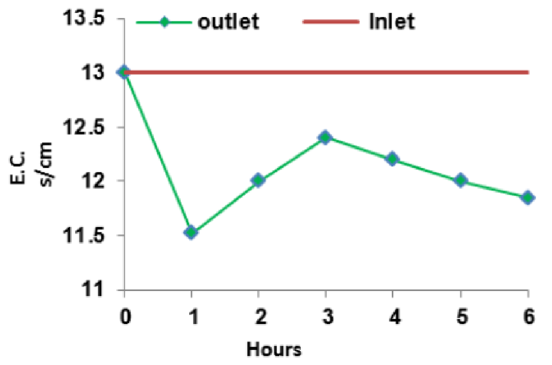

Figure 18. The variations in E.C. in layered soil as a function of time.

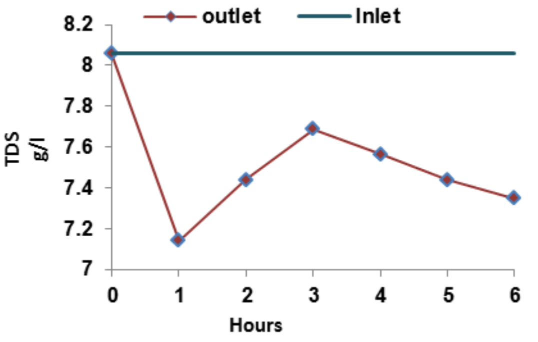

Figure 19. The variations in TDS in layered soil as a function of time.

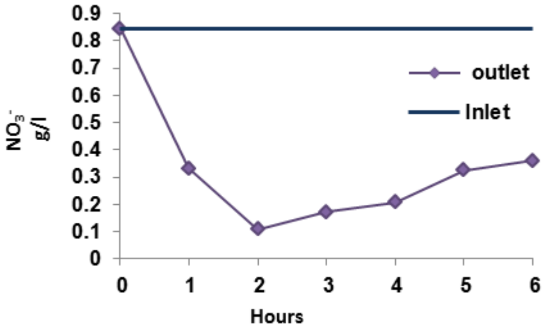

Figure 20. The variations in NO_3^- in layered soil as a function time.

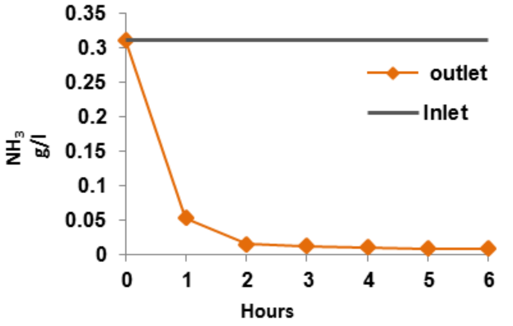

Figure 21. The variations in NH_3 in layered soil as a function time.

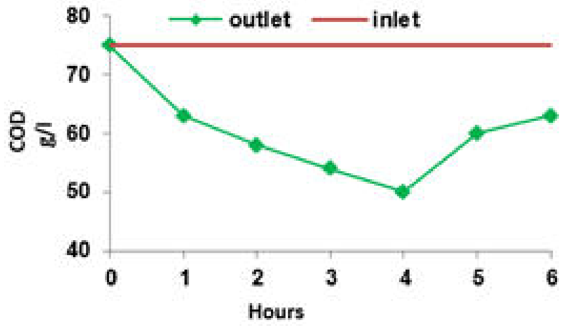

Figure 22. The variations in COD in layered soil as a function of time.

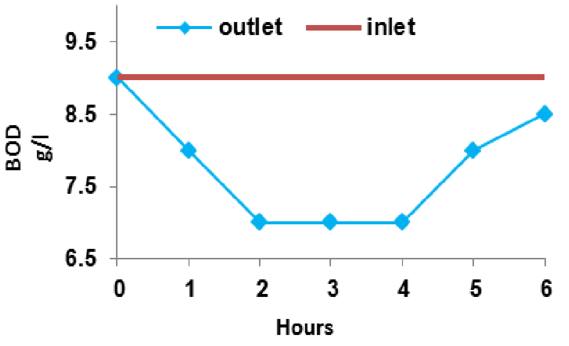

Figure 23. The variations in BOD in layered soil as a function of time.

4. Conclusions

Columns investigation experiments were performed in order to investigate the fate of the leachate in different soil types. Three columns were used for the simulation of the percolation of an extracted leachate in three types of soil. The characteristics of the leachate changed significantly, as it moved downward in the soil columns. Several mechanisms affecting the attenuation of the contaminants of the leachate in the soil among this mechanism are adsorption, cation exchange, and filtration which increased with the increasing of the hydraulic retention time HRT. As the HRT increased the contaminants concentration decreased, till a certain time. Then the contaminants concentration increased again. It was found that, the adsorption capacity of the soil played an important role in decreasing the concentrations of the contaminants. Layered soil helped in delaying the leachate movement. The concentration of the inorganic matter can't be controlled by obvious roles in this short period of the experiment. The study showed that the soil can play a role in only delaying the transfer of the pollutants , rather than removing the contaminants.

Therefore, and basing on the study results, the contaminants of the MSW leachate will reach the groundwater, with time passing in the active landfill.

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