



The effect of leachate input characteristics on the leachate collected after passage through a leachate collection system

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Abstract

A landfill leachate collection system (LCS) is intended to collect and remove leachate for treatment, thereby reducing the driving force (hydraulic head) for advective contaminant transport through the liner system. However the long-term performance of the granular drainage layer and pipes conducting the leachate to the sump(s) for collection is greatly affected by the leachate characteristics. A calibrated numerical model ‘BioClog’ is used to examine the differences between the chemical characteristics of the leachate between when it first enters and after it has passed through a granular drainage layer. The results show that the treatment of leachate within the filter layer and drainage layer can substantially reduce the leachate concentrations between its first entry into the system and its collection. This change in concentration is directly associated with the clogging of, and consequent leachate mounding within, the drainage layer. Thus the leachate collected at the sumps generally does not represent the leachate entering the LCSs and therefore should not be used directly as the source leachate concentrations for designing the LCSs when the clogging of systems needs to be addressed.

Keywords: leachate characteristics; clogging; leachate collection system; numerical modeling.

Nomenclature

A_k	coefficient of hydraulic conductivity (m/s)
B	thickness of drainage layer (m)
b_k	coefficient of hydraulic conductivity (-)
d_g	diameter of grain size (mm)
H_{FS}	thickness of filter-separator layer (m)
k	hydraulic conductivity (m/s)
L	drainage length (m)
n	porosity (-)
q	leachate infiltration rate (m/year)
β	slope of granular drainage layer to drainage pipes (-)

1. Introduction

The disposal of municipal solid wastes (MSWs) in landfills is considered an essential component of waste management in many countries. MSW leachate is predominantly generated from the percolation of water (e.g., precipitation) through the waste and from biodegradation of organic waste. The leachate contains contaminants including both suspended particles and dissolved elements and compounds which, if allowed to be released without treatment, may have a potential impact on the surrounding environment and human health [1]. Many regulations (e.g., United States, Europe, and Ontario Canada) require a barrier system (Fig. 1) at the base of the landfill to prevent contaminants from entering the groundwater and surface water. There are two components in a barrier system [2]: (a) a highly permeable leachate collection system (LCS), and (b) an underlying low permeability liner. The purpose of LCSs is to allow the leachate generated within the landfills to flow freely through the (usually granular) drainage layers to drainage pipes, and then to sumps where the leachate is collected and removed for treatment. The design of a suitable LCS is critical to ensuring good long-term performance of a landfill.

Both field and laboratory studies have shown that a clog mass is developed within the void spaces of drainage material permeated by MSW leachate due to the growth of biomass, precipitation of minerals, and deposition of suspended solids (e.g., [3–22]). The clogging of drainage media reduces the drainage capacity of LCSs and results in leachate mounding on the bottom liner which increases the driving force (i.e., hydraulic head) for contaminants to transport through the liner. Clogging of the drainage media is greatly affected by the leachate characteristics. However, the leachate collected at the drainage pipes or sumps may not represent the leachate before entering the LCSs. For example, Rowe [23] reported that the leachate concentrations measured in wells within the waste were much higher than those measured at the end of drainage pipes and sumps.

The objective of this paper is to examine the effect of source leachate characteristics and infiltration rate on the leachate collected after the passage through a LCS using a sophisticated, calibrated [e.g., 24–27], numerical model. The time-dependent leachate concentrations and average infiltration rate are considered. A LCS with a 30-cm thick gravel drainage layer and an overlying 30-cm thick sand filter layer is modeled.

2. Model summary

The numerical model ‘BioClog’ [25, 27, 28] was developed, based on the findings from the field and laboratory studies cited in the previous section, to predict the leachate characteristics and clogging of LCSs. BioClog models the fate and transport of the key constituents of leachate that directly affect the clogging of drainage media. Three volatile fatty acids (i.e., acetate, butyrate, and propionate) are modelled because they contribute most of chemical oxygen demand (COD) in leachate and provide the primary nutrients for the growth of active biomass. Both the suspended biomass and suspended inorganic solids (together representing the total suspended solids, TSSs) in the leachate are modeled. The suspended biomass includes suspended active biomass (e.g., suspended acetate degraders, butyrate degraders, and propionate degraders) and suspended inert biomass (from the decay of suspended active biomass). The degradation of fatty acids generates carbonic acid which, together with dissolved calcium (Ca) in the leachate, gives rise to the precipitation of calcium carbonate with the deposition usually being controlled by the availability of calcium. Thus calcium (Ca) is modelled.

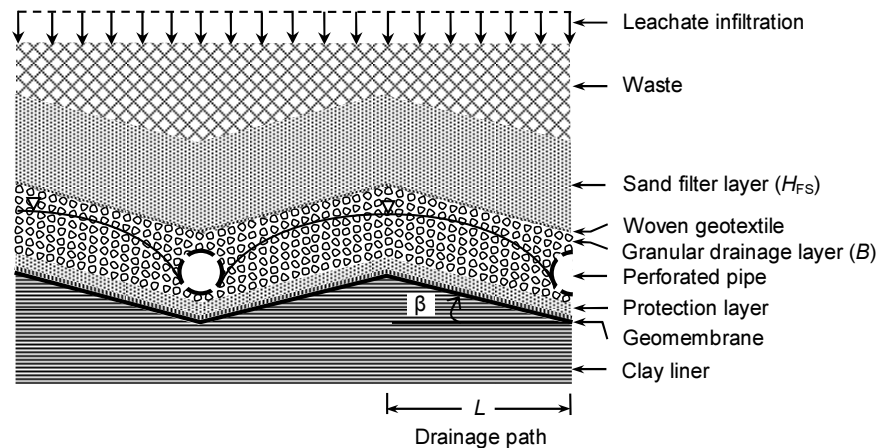


Fig. 1. Schematic showing a LCS with a gravel drainage layer and an overlying sand filter layer

BioClog simulates the clog mass (both the organic and inorganic mass) accumulating within the porous media and quantifies it in term of the thicknesses of five separate films. The organic mass is represented by the thicknesses of active biofilms (e.g., the acetate degraders film, butyrate degraders film, and propionate degraders film) and inert biofilm. The inorganic mass is represented by the thickness of the inorganic solids film. Each of active biofilms increases in thickness due to the growth of active biomass and deposition of suspended active biomass. The thickness of active biofilms decreases due to decay and through detachment from shearing. The thickness of the inert biofilm increases by the decay of active biofilms and the deposition of suspended inert biomass and decreases due to detachment by shear stress. The thickness of inorganic solids film increases due to the deposition of suspended inorganic solids and the precipitation of minerals.

Transient contaminant transport (for the nine different species discussed above) and fluid flow are modeled using the finite element method. The total thickness of the five films is calculated at each time step and the porosity of porous media is updated using equations from Yu and Rowe [29]. The reduction in porosity decreases the hydraulic conductivity of porous media which can be evaluated using empirical equation as (e.g., [20], [22]):

$$k = A_k e^{b_k n} \quad (1)$$

where k is the hydraulic conductivity; n is the porosity; A_k and b_k are the coefficients of hydraulic conductivity.

3. Problem definition and modeling parameters

The LCS shown schematically in Figure 1 is examined. The gravel drainage layer, of thickness $B = 0.3$ m, is overlain by a 0.3-m (H_{FS}) thick sand filter layer. A woven geotextile separator located between the gravel layer and sand layer to prevent the sand particles from moving into the gravel layer is not considered to contribute significantly to leachate treatment and is not modelled. The drainage path is $L = 40$ m and the slope from the drainage layer to drainage pipes is $\beta = 2\%$. The nominal diameters of gravel and sand considered are $d_g = 30$ and 2 mm, respectively. The gravel has initial porosity of $n_o = 0.41$ and initial hydraulic conductivity of $k_o = 0.12$ m/s. The initial porosity and hydraulic conductivity of sand are $n_o = 0.37$ and $k_o = 0.001$ m/s, respectively.

Five different cases (i.e., combinations of leachate characteristics and infiltration rate) are modeled (Table 1). The time-dependent leachate source concentrations, before entering the LCS, of COD, Ca, and TSS are each considered as follows: the concentrations increase linearly from C_0 to C_1 over first t_1 years, remain stable at C_1 until year t_2 , then decrease linearly from C_1 to C_2 between t_2 and t_3 , and remain stable at C_2 after year t_3 .

The flow and transport through the sand filter layer is modelled as one-dimensional while the flow and transport in the gravel drainage layer is modeled in two dimensions. The effluent leachate from the sand filter layer is used as the input source leachate for the gravel drainage layer. For more details regarding the modeling and parameters see Yu [27].

Table 1. Source leachate characteristics and infiltration rates

Case No.	Times (years)			COD concentrations (mg COD/L)			Ca concentrations (mg/L)			TSS concentrations (mg/L)			Infiltration rate, q (m/year)
	t_1	t_2	t_3	$C_{0,COD}$	$C_{1,COD}$	$C_{2,COD}$	$C_{0,Ca}$	$C_{1,Ca}$	$C_{2,Ca}$	$C_{0,TSS}$	$C_{1,TSS}$	$C_{2,TSS}$	
Case 1	4	12	18	3600	31000	3600	125	2500	125	350	1000	350	0.3
Case 2	1	12	18	3600	31000	3600	125	2500	125	350	1000	350	0.3
Case 3	1	12	18	7200	62100	7200	200	4000	200	2000	6000	2000	0.3
Case 4	1	6	7	1250	32000	1250	360	2200	360	2000	3000	2000	0.3
Case 5	1	6	7	1250	32000	1250	360	2200	360	2000	3000	2000	0.05

4. Results

4.1. Effect of period of time for input peak strength

The leachate characteristics before entering the LCS (source) and effluent from both the sand filter layer and gravel drainage layer for Case 1 are shown in Figure 2. The COD concentration in the effluent from the sand filter layer increased gradually to about 8850 mg COD/L within the first 4 years and the treatment of COD within the sand filter layer at year 4 was about 72% (i.e., the source COD concentration at year 4 was 31000 mg COD/L). The COD concentration in effluent from the filter layer continued increasing and reached 31000 mg COD/L at 9 years because of severe clogging and consequent loss of treatment efficiency in the sand filter layer. There was no further treatment of COD within the filter layer after 9 years. In effluent from the gravel drainage layer the COD concentrations were almost the same to those in effluent from the filter layer for the first 7 years because there had been very little biomass accumulation within the gravel drainage layer during the period because of the significant treatment of the leachate as it passed through the sand layer. After 7 years, the biofilm started to establish within the drainage layer and the CODs in effluent from the drainage layer departed from those in effluent from the filter layer. The maximum COD concentration in effluent from the drainage layer was about 23530 mg COD/L at 8–9 years. The COD in effluent from the drainage layer decreased after 9 years and it reached stable concentration of about 2370 mg COD/L after 18 years (Fig. 2a) for these parameters.

The degradation of CODs decreases the pH value and generates carbonic acid which provides biological generated carbonate some of which precipitates with calcium as calcium carbonate (Fig. 2b). The calcium concentration in effluent from the sand filter layer was about 1340 mg/L at Year 4 (i.e., there was an about 46% reduction in calcium concentration within the filter layer from the calcium concentration of 2500 mg/L at Year 4). The calcium concentration in effluent from the filter layer gradually increased to 2500 mg/L at Year 9 and there was no treatment of calcium within the filter layer after 9 years for the same reason as discussed previously for COD. The effluent calcium concentrations from the sand filter layer and gravel drainage layer were almost same for the first 7 years because there was little biofilm growth or degradation of CODs within the drainage layer over this period (i.e., very little clogging of the gravel). The maximum effluent calcium concentration from the gravel drainage layer was about 2125 mg/L after 8–9 years. The calculated effluent calcium concentration from the drainage layer decreased gradually to 105 mg/L at Year 18 and remained stable thereafter.

For the first 5 years the filter layer captured essentially all the TSS and the effluent TSS concentrations from both sand filter layer and gravel drainage layer were negligible. The effluent from the sand layer had a maximum TSS concentration of about 825 mg/L at Year 8 and the TSS subsequently decreased to a residual value of about 245 mg/L after 18 years. The effluent from the gravel layer had a maximum TSS concentration of about 425 mg/L at year 11 and the stable TSS concentration of about 60 mg/L was reached after Year 18.

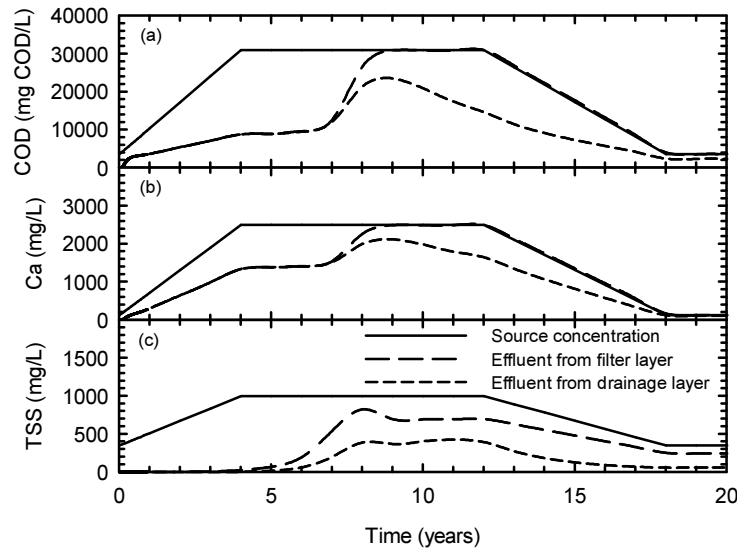


Fig. 2. Leachate characteristics in source and effluent from filter layer and drainage layer for Case 1: (a) COD, (b) Ca and (c) TSS

Figure 3 shows the leachate concentrations in the source and effluent from both the sand filter layer and gravel drainage layer for Case 2. The only difference between Case 1 and Case 2 is that the period of time that the peak leachate strength is maintained is from years 4 to 12 for Case 1 and from years 1 and 12 for Case 2 (i.e., the peak strength is reached earlier and is sustained longer for Case 2 than for Case 1). For Case 2 (Fig. 3a) the COD concentration in effluent from the sand layer was about 9080 mg COD/L at Year 4 (for Case 1 it was about 8850 mg COD/L) and the COD reached 31000 mg COD/L at Year 7 (for Case 1 it was between Year 8 and 9). The maximum effluent COD from the gravel drainage layer was about 24220 mg COD/L at year 7 (it was about 23530 mg COD/L at Year 8–9 for Case 1). The results show that the earlier arrival and longer maintenance of the peak influent COD resulted in the higher effluent COD from both the sand layer and gravel layer, and decreases the time for effluent CODs from the sand layer to reach the source COD concentration and from the drainage layer to reach the maximum COD value due to more total mass loading from Case 2 resulting in faster loss of leachate treatment efficiency of the sand layer.

For calcium (Fig. 3b), the effluent concentrations from both the filter layer and drainage layer was about 1390 mg/L at Year 4 (c.f., 1340 mg/L for Case 1) and the maximum effluent concentration from the gravel layer was about 2160 mg/L at Year 7 (c.f., about 2125 at Year 8–9 for Case 1). For TSS (Fig. 3c), the maximum effluent TSS concentration was about 730 mg/L at Year 6 (c.f., about 825 mg/L at Year 8 for Case 1) from the sand layer and about 420 mg/L at Year 10 (c.f., about 425 mg/L at Year 11 for Case 1). The slight decrease in effluent TSS from both filter layer and drainage layer for Case 2 compared to Case 1 was due to faster clogging of sand filter for Case 2 resulting in more deposition of TSSs within the sand layer during the early time period. The modeling shows that the stable effluent concentrations for COD, calcium, TSS from the sand filter layer (and from the gravel drainage layer) are almost same for Cases 1 and 2.

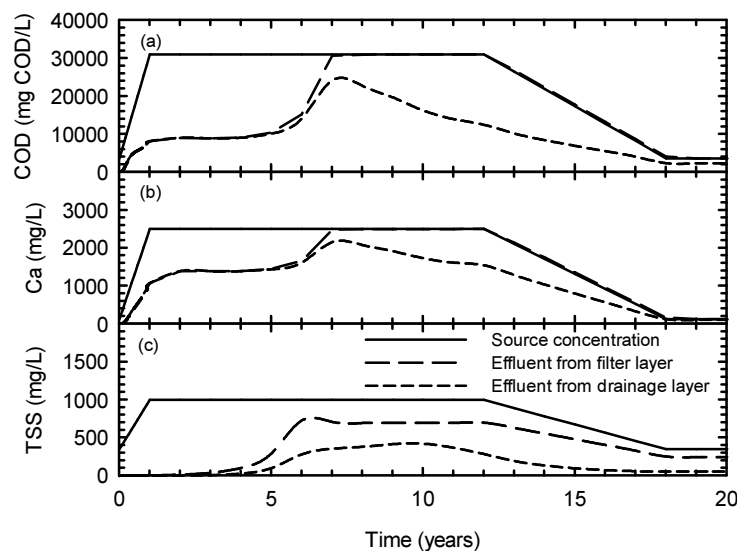


Fig. 3. Leachate characteristics in source and effluent from filter layer and drainage layer for Case 2: (a) COD, (b) Ca and (c) TSS

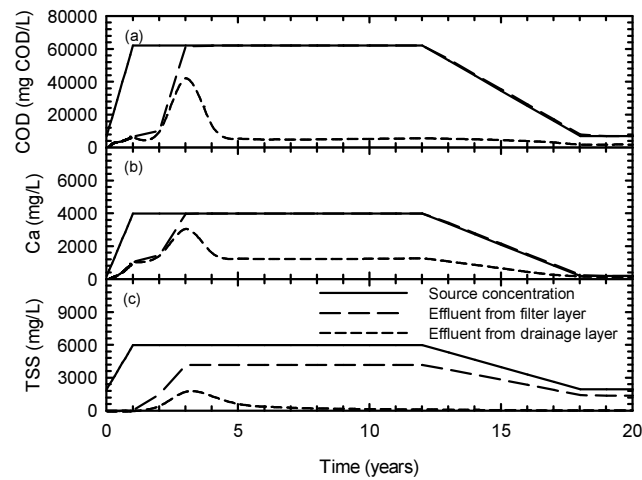


Fig. 4. Leachate characteristics in source and effluent from filter layer and drainage layer for Case 3: (a) COD, (b) Ca and (c) TSS

4.2. Effect of input leachate concentrations

The effect of a higher source leachate strength from Case 3 (compared to Case 2) on the effluent leachate characteristics from both the sand filter and gravel drainage layer is examined in this subsection. Figure 4 shows the leachate characteristics in source and effluent for Case 3. For COD (Fig. 4a), the effluent concentration from the sand layer reached the source concentration within 3 years (compared to 7 years for Case 2) due to the higher leachate strength in Case 3 which resulted in a faster clogging rate and quicker loss of treatment efficiency of the sand filter layer. The maximum effluent COD concentration from the gravel drainage layer was about 42370 mg COD/L at Year 3 (the treatment was about 32% compared to about 22% for the maximum effluent COD value at Year 7 for Case 2). However the COD decreased quickly to about 5650 mg COD/L at Year 5 and was stable at about 1950 mg COD/L after Year 18 because of biomass accumulation within the gravel drainage layer. For calcium (Fig. 4b), the effluent from the drainage layer reached the maximum value of about 3065 mg/L at Year 3 (about 23% treatment compared to about 14% for the maximum effluent calcium from Case 2) and decreased to about 1255 mg/L at Year 5. The effluent calcium from the drainage layer was stable at about 160 mg/L after Year 18. For TSS (Fig. 4c), the effluent concentration from the sand layer reached a maximum value of about 4200 mg/L at Year 3 and remained stable at 1400 mg/L after Year 18. TSS in the effluent from the drainage layer reached a maximum value of about 1765 mg/L (about 71% treatment compared to about 58% for at maximum TSS for Case 2) and was stable at about 60 mg/L after 18 years.

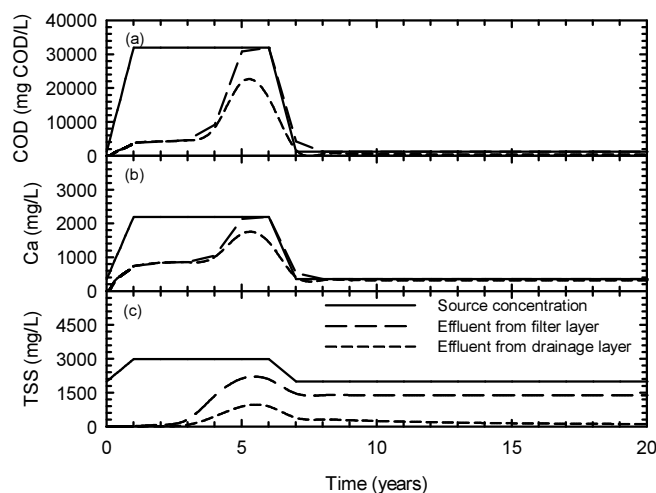


Fig. 5. Leachate characteristics in source and effluent from filter layer and drainage layer for Case 4: (a) COD, (b) Ca and (c) TSS

The modeling shows that, other conditions being equal, the increase in source leachate concentrations accelerated the clogging rate of the filter layer and decreased the time for the maximum leachate concentrations to occur in effluent from both the filter layer and drainage layer. The results also indicate that, for cases examined, increasing the source leachate concentrations resulted in higher treatment efficiency of leachate within the LCS (even though the effluent leachate concentrations from Case 3 are higher than those from Case 2) because of more clogging within the drainage layer associated with the higher source leachate concentrations.

4.3. Effect of infiltration rate

The leachate concentrations for Case 4 and Case 5 were the same but the infiltration rate for Case 4 was 0.3 m/year and for Case 5 it was 0.05 m/year (Table 1). Figure 5 shows the source and effluent leachate characteristics from the filter layer and drainage layer for Case 4. Both the effluent COD and calcium concentrations from the filter layer reached the source concentrations at Year 6. The maximum effluent COD and calcium concentrations from the drainage layer were about 21920 mg COD/L and 1700 mg/L, respectively, between Year 5 and 6 and were about at 380 mg COD/L and 320 mg/L, respectively, at Year 20. For TSS (Fig. 5c), the maximum effluent TSS concentrations from the sand layer and gravel layer were about 2135 and 895 mg/L, respectively at Year 5–6. The effluent TSS was stable at 1400 mg/L from the sand layer after Year 8 and was about 115 mg/L from the gravel layer at Year 20.

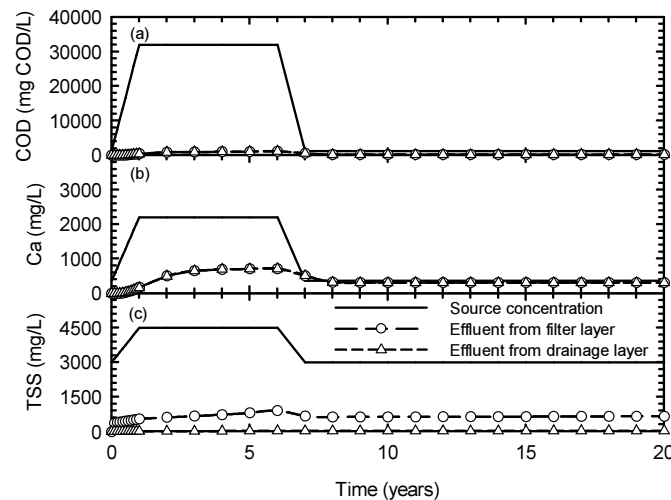


Fig. 6. Leachate characteristics in source and effluent from filter layer and drainage layer for Case 5: (a) COD, (b) Ca and (c) TSS

Figure 6 shows the effluent leachate from the sand and gravel layer for Case 5 using the same LCS and leachate concentrations as Case 4 but a six-fold lower infiltration rate. The maximum effluent CODs from the sand layer and gravel layer were about 1170 and 1155 mg COD/L, respectively, at Year 6. At Year 20 the effluent CODs were about 220 mg COD/L from both the sand layer and gravel layer. The treatment of CODs was mostly within the sand filter layer due to higher retention time of COD resulting in more treatment of COD within the filter layer. There was little treatment of CODs within the drainage layer because of very low input COD and little biomass accumulation within the drainage layer during this period. Thus the effluent calcium concentrations from both the sand layer and drainage layer were almost same due to little degradation of CODs within the drainage layer during this period. The effluent calcium concentration reached the maximum value of about 715 mg/L at Year 6 and was about 310 mg/L at Year 20. The effluent TSS concentration from the sand layer reached the maximum value of about 605 mg/L at Year 6 and was about 445 mg/L at year 20. In effluent from the gravel layer, the TSS concentrations were below 25 mg/L within the first 20 years.

The results show that, for cases examined, the decrease in infiltration rate extended the retention time of leachate within the sand filter layer resulting in most the leachate treatment within the filter layer. There was little clog mass accumulation within the gravel layer due to the very low input leachate concentrations to the drainage layer. The fact that the effluent leachate concentrations from Case 5 were lower than those from Case 4 at the same point in time indicates that more treatment of leachate occurred within the LCS when the infiltration rate was lower and other conditions equal.

5. Conclusions

A numerical model (BioClog-2D) was used to examine the change in leachate characteristics after leachate passage through a LCS with a gravel drainage layer and an overlying sand filter layer. The treatment of leachate within the LCS was substantial and the reduction in leachate strength between the source and effluent resulted in clogging of the filter layer and drainage layer. Based on the cases examined, the following conclusions were reached:

- The earlier the peak leachate concentration (e.g., the faster the waste placement), the higher maximum effluent COD and calcium concentrations from the gravel layer, and shorter the time for the effluent COD and calcium to reach the maximum values when other conditions are equal.
- The higher the source leachate concentration the faster the clogging of the sand filter layer and sooner the maximum leachate concentration is observed in the effluent. The treatment efficiency of leachate within the LCS is increased for an increase in the source leachate concentrations.
- Reducing the infiltration rate increases the leachate treatment efficiency within the LCS based on the same LCS design and source leachate concentrations.

- The leachate concentrations collected at end of pipes (i.e., the effluent leachate from the drainage layer in this paper) are much lower than those before entering the LCSs (i.e., the source leachate in this paper) due to the treatment of leachate within the LCSs. Thus the use of effluent leachate after passage through the LCS as the source leachate for designing the landfill LCS can under-estimate the potential clogging of the LCS and therefore result in an unsafe design.

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