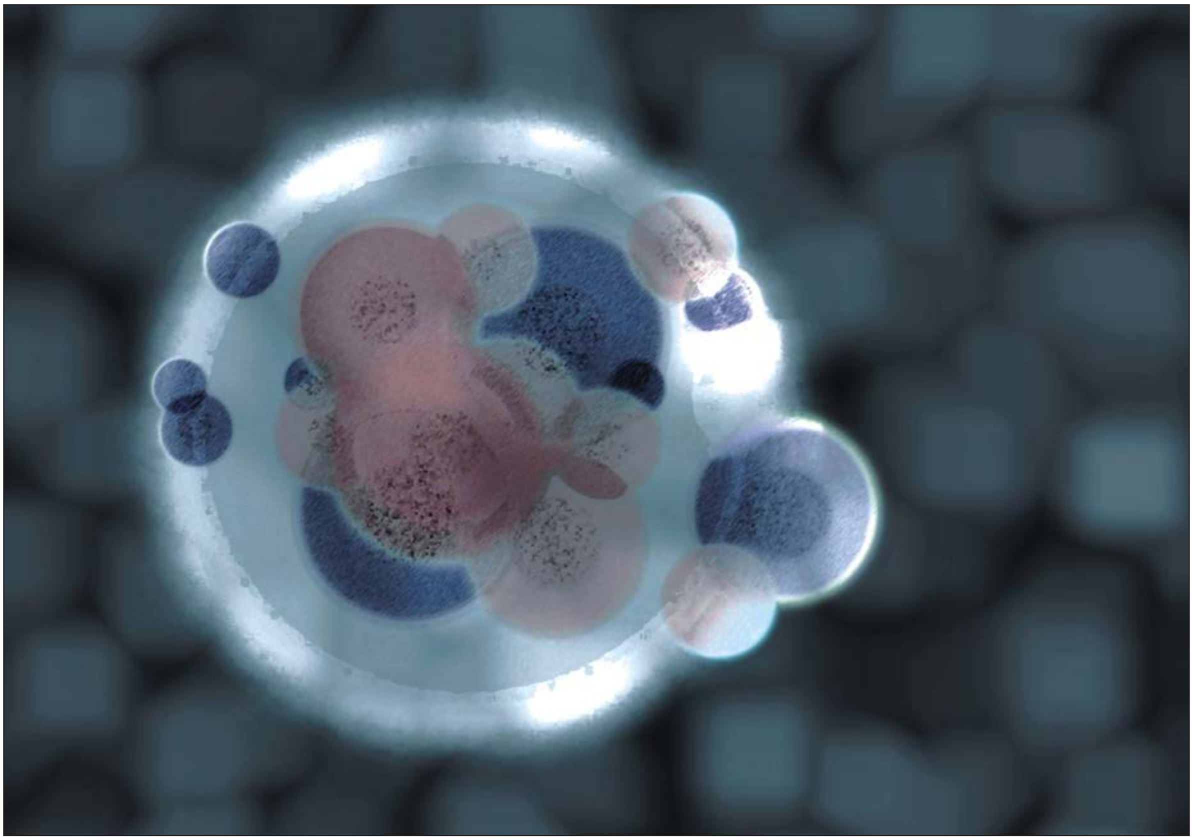

Journal of Biological Sciences

ISSN 1727-3048

Journal of Biological Sciences 6 (2): 324-330, 2006
ISSN 1727-3048

Preliminary Assessment of Proposed Soil Liner Compatibility with Leachate at New Landfill of Tehran

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Abstract: A new sanitary landfill was proposed to be constructed to receive the municipal solid waste generated in the city of Tehran with a capacity of about 7000 tons per day. Fresh leachate was characterized to have high organic content BOD5 of about 30,000 mg L^{-1} and TOC of about 25900 mg L^{-1}. The clayey soil proposed to be used as bottom liner material for the landfill is characterized as being saline. An attempt was made to preliminarily assess the compatibility of the local soil with leachate in terms of possible changes in unsaturated hydraulic conductivity of liner material. Soil samples were compacted and placed in a column to be tested for compatibility in accordance with EPA Method 9100 of SW846 test method series. The results of the experiment indicated that even in presence of fresh leachate being employed to the columns at a head of 15 cm for 10 days, a very limited infiltration to the compacted soil occurred. As a preliminary assessment, it could be concluded that the local clayey soil can potentially be used as bottom liner material in terms of very limited changes in its hydraulic conductivity when subject to leachate mounding. Further research is required with additional samples.

Key words: Leachate, liner, compatibility, clay, hydraulic conductivity

INTRODUCTION

The Municipal Solid Waste (MSW) generated in greater Tehran is currently being disposed of at Kahrizak landfill located at south of the city of Tehran. The MSW is disposed of at this site at a rate of about 7000 tons per day. This site is to be closed due to operational and environmental problems. Operationally the site has reached almost full capacity and currently the incoming MSW is dumped on previously disposed waste. The incoming MSW to this site is characterized through its high organic content which is directly associated with the high portion of food waste (i.e., about 68%). This high organic content results in relatively high rates of primary leachate generation due to the high moisture content of the food waste which is about 70% by weight (Safari and Baronian, 2002). Since the landfill lacks any leachate and gas control and treatment systems, the infiltration of leachate into subsurface soil and groundwater is likely to occur through bottom of waste filled areas as well as the unlined leachate storage and treatment ponds.

A new site was proposed for construction of a new sanitary landfill for Tehran. This site is located some 50 km south of Tehran at Hooshang Abad area. One of the main problems to be addressed is the potential adverse impact(s) associated with leachate emission to the surrounding environment. Reduction of such environmental impacts is accomplished through application of application of bottom liners. One of the alternative materials for the bottom lining systems at the proposed site was considered to be the clayey soils abundantly available at the proposed landfill site.

The clayey soil of the proposed landfill site seems to be significantly saline and to contain relatively high concentrations of gypsum and lime. Therefore it is presumed that its desired permeability could be deteriorated when subject to a low pH leachate (i.e., fresh leachate) through dissolution of mineral salts, carbonates and sulphates.

Characteristics of a soil bottom liner are subject to change due to interaction with leachate (Rowe *et al.*, 1995). Among the main features is the hydraulic conductivity of the liner which represents the sole containment component of the landfill.

A large number of relevant studies can be found concentrating on the changes of hydraulic conductivity of bottom liners subject to leachate infiltration (Rowe *et al.*, 1995; Quigly *et al.*, 1992; Rowe and Badr, 1996; Cancelli *et al.*, 1992; James *et al.*, 1997; Gleason *et al.*, 1997; Ruhl and Danied, 1997; Quant, 1995; Baykal *et al.*, 1995).

The sole mechanism of contaminant transport in porous media is considered to be the velocity of the flow which is characterized by the hydraulic properties of a given soil. Therefore in addition to the chemical interaction of leachate constituents with mineral content of the soil, the issue of pore space clogging has also to be taken into account. Clogging occurs in both forms of physical (i.e., accumulation of fine particles in pore spaces) and biological (i.e., biofilm growth in around the particles and consequent decrease in effective porosity) forms (Rowe *et al*., 1995; Cooke *et al*., 2001; Koerner and Koerner, 1995; Rowe *et al*., 2000). Most of relevant studies are conducted to assess the potential clogging in leachate drainage layer of the landfills. While to the extent reviewed, potential clogging mainly through biofilm growth around liner soil particles seems to be rarely (if any) studied. Generally biological clogging is believed by the author to be capable of influencing the hydraulic behaviour of the top layer of a given soil bottom liner in the case of Kahrizak landfill leachate which is mainly characterized as being of very high organic content. Biological clogging of the surface of the compacted soil samples which is not studied in this research, is recommended to be investigated as part of the controlling mechanisms of leachate movement in bottom liners.

As a first step, leachate characterization is necessary in order to ensure the efficiency of the proposed treatment processes. Leachate samples were therefore taken from the existing waste disposal site. Previous studies have shown that Kahrizak fresh leachate has extremely high organic content compared to the leachate generated in many European countries (Safari and Baronian, 2000). The objective of the study was to preliminarily assess the changes in hydraulic conductivity of the compacted soil samples when subject to leachate. The soil samples taken from the proposed borrow pit at the site were therefore compacted at geotechnical laboratory in accordance with standard procedures. For a preliminary assessment of potential changes in hydraulic conductivity of the compacted soil samples a free head column experiment was carried out. Accordingly the rate of infiltration was monitored throughout the experiment.

Site characteristics: The proposed landfill site is located at some 50 km south of Tehran spread along two sides of the old Tehran to Ghom road. Topographically the site has a mild slope of about 2% on an average basis. Existence of a hilly chain around the area seems to be acting as a barrier against probable flooding of the nearby seasonal Shoor River (Ghazban and Kiamirad, 2005). The area is determined to have a semiarid to arid climate. The annual average amount of precipitation and evaporation are determined to be 165-2560 mm, respectively. The closest residential area to the site is the city of Hassan Abad at some 10 km north of the proposed site.

According to the geological map of the area published by the Organization of Geology and Mineral Explorations of Iran (Fig. 1), the geological formations of the area belong to the Tertiary and Quaternary and comprise Red Upper formation and Alluvial Terraces. Generally the site is covered with clay and silt although 1 to 2 m stripes of gravel are also observed. Regarding the availability of rich clayey soil as well as scarcity of water resources (especially lack of local groundwater system) the site was considered to be ideal for disposal of municipal solid waste.

Leachate characteristics: Three leachate samples were taken in about three weeks interval from fresh leachate at the foot of the waste dumps receiving waste at the time of sampling. The leachate samples were taken in the morning at about 9:00 am to ensure the freshness of the samples. The volume of each sample was about 12 L which was transferred to laboratory in standard storage conditions and immediately subject to analysis. The sampling date and locations are presented in Table 1.

All samples had light brownish colour and sourly odour which based on experience is a good indicator of leachate freshness. Each sample was divided in triplicate in the laboratory to be analysed. Filtered samples for TOC were subject to pH adjustment through addition of Phosphoric acid to lower the pH below 2, for later concentration measurement using the TOC measurement device.

Samples for BOD5 were subject to analysis quite shortly after sample delivery to the laboratory. The most suitable range of BOD5 provided by the standard practice was taken into account based on which the samples were diluted using aerated dilution water. Seed from biological wastewater treatment units were also added.

All other parameters (except for pH) were measured using spectrophotometer. The results of the analysis for general constituents are shown in Table 2. As shown in Table 2, fresh (i.e., primary) leachate has a low pH (4.76 to 5.48) and high concentration of BOD5 and COD ranging from 22000 to 38000 mg L^{-1} and 60600 to 68800 mg L^{-1} respectively. This along with the relatively high concentration of TOC ranging from 23400 to 28400 mg L^{-1} confirms the high organic content of the fresh leachate at Kahrizak site. Almost the same values are expected at the proposed landfill at Hooshang Abad if the incoming waste stream is not changed significantly.

Table 1: Leachate sampling date and locations at Kahrizak landfill

Sample ID	Date	Location
1	10/11/04	Bottom of the mnning trench
2	22/11/04	Bottom of the mnning trench
3	5/12/04	Bottom of a new trench opened for operation 10 days before sampling

Table 2: Concentration of general quality constituents of fresh leachate at Kahrizak landfill site

Sample ID	Temp. (°C)	pH	BOD5 (mg L^{-1})	COD (mg L^{-1})	TSS (mg L^{-1})	Cl- (mg L^{-1})	SO_4^{--} (mg L^{-1})	PO_4^{--} (mg L^{-1})	NH_4 (mg L^{-1}) N-NH_3	NO_3^- (mg L^{-1}) N-NO_3	TOC (mg L^{-1})
1-1	17.5	4.76	34600	67800	1226	4250	1900	86	245	210	26400
1-2	17.5	4.78	32800	68200	1004	4400	1800	81	243	220	28400
1-3	17.5	4.79	34200	67900	1567	4400	1700	84	242	210	27800
2-1	19	4.80	38000	60600	6328	3750	1700	73	271	240	24100
2-2	19	4.81	32000	61300	11252	3800	1600	79	268	250	23400
2-3	19	4.81	30000	61800	10312	3850	1700	83	266	240	23800
3-1	16.5	5.48	24000	68800	5548	6350	1700	89	207	300	27100
3-2	16.5	5.48	24000	66200	6772	6300	1800	90	201	280	25500
3-3	16.5	5.48	22000	68600	6268	6250	1800	80	201	260	27100
Average	17.67	5.02	130177	65688	5586	4816	1744	82	238	245	25955

Leachate quantity: Leachate generation is usually divided into two phases. At early stages of waste disposal primary leachate is mainly generated as a result of compaction of waste and consequent flushing out the moisture content in excess of field capacity (Safari and Baronian, 2002 ; Bagchi, 1994). The high moisture content of waste to be disposed of in the proposed landfill provides a relatively high potential for higher rates of primary leachate generation. Secondary leachate is generally determined to be generated after partial and/or full closure of a waste disposal cell. The main factor affecting generation of secondary leachate is considered to be precipitation (Blakey, 1992).

The scarcity of precipitation and high rate of evaporation in the area results in the minimum and almost negligible contribution to generation of secondary leachate at the proposed site. A site specific approach was therefore taken into account for estimation of leachate generation rate.

Accordingly, leachate generation rate was determined using a simplified water balance scheme (Safari and Baronian, 2002). The proposed water balance method takes into account both hydrological properties of the landfill area (i.e., mainly precipitation and evaporation) as well as waste characteristics (i.e., mainly moisture content and field capacity). Description of the procedure for estimation of leachate generation rate is beyond the scope of this study, therefore the results are only presented here. The results of the model showed that for a single cell filled with waste vertically the primary leachate is generated at an estimated rate of about 758 m^3/day on an average basis for about 10 days. This rate of leachate generation results in a leachate mounding of about 15 cm taking into account the proposed leachate drainage scheme.

MATERIALS AND METHODS

Soil samples: This study was carried out at the Faculty of Environmental Studies of the University of Tehran in winter 2005. Clay soil samples were taken and analysed by geotechnical laboratory. Two samples (namely S1 and S2) were taken from a depth of 5m to represent the realistic conditions in accordance with the practical requirements. The soil samples were classified as CL-ML and CL in S1 and S2, respectively (Fig. 1 and 2). Almost 95% of the soil in the area is of CL-ML type which is considered suitable as liner material.

The samples have shown to have relatively high sulphate and gypsum content (Table 3). This is presumed to be the limiting factor in terms of potential increase in hydraulic conductivity of the compacted soil when subject to leachate infiltration.

Experimental setup: For a preliminary assessment of leachate clay compatibility, a simple experimental setup

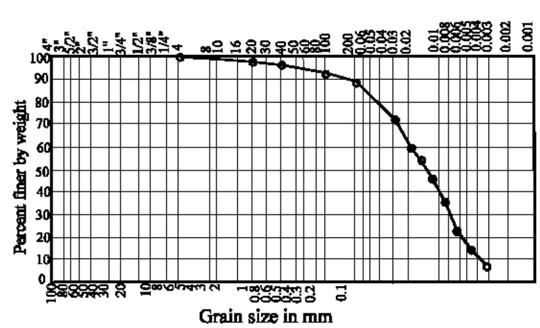

Fig. 1: Grain size distribution of soil sample S1

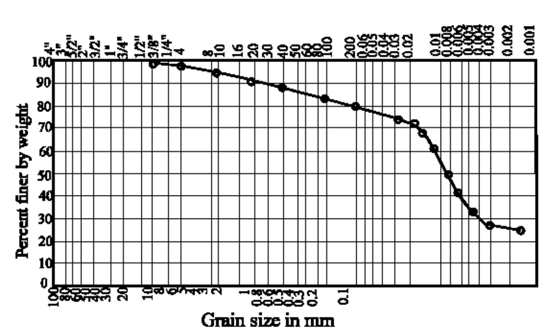

Fig. 2: Grain size distribution of soil sample S2

Table 3: Chemical characteristics of the soil samples of Houshang Abad site

Soil Sample ID	Sulphate content, Total SO_3 (%)	Chloride content, Cl^- (%)	pH at 25°C	Organic content (%)	$CaSO_4$, $2H_2O$ (%)	Electric Conductivity micro-mhos (cm^{-1})
S1	4.01	0.71	8.15	0.27	4.05	5400
S2	0.58	0.72	8.50	0.20	2.23	3400

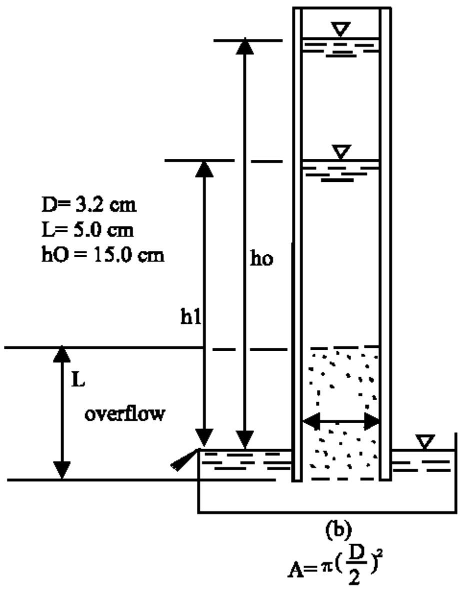

Fig. 3: The schematic experimental setup

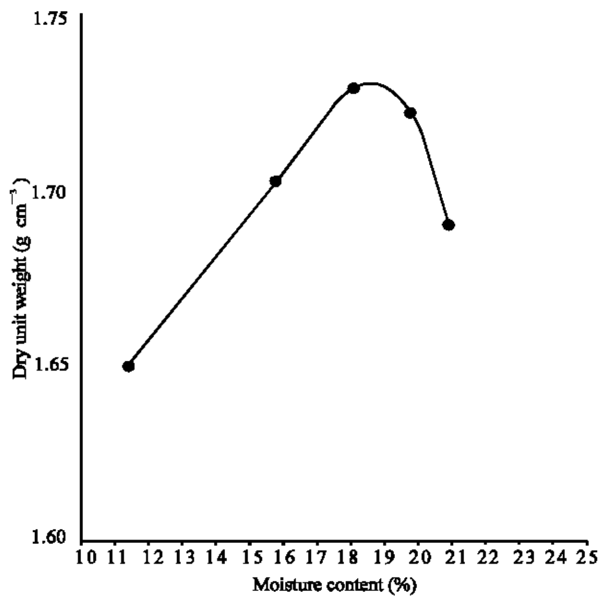

Fig. 4: Compaction curve of soil sample S1

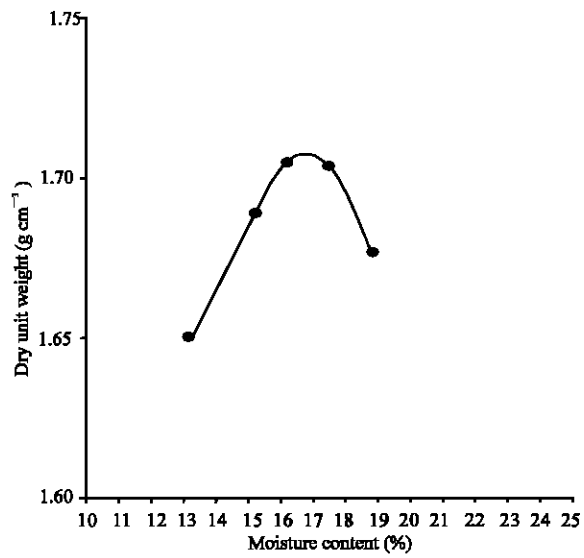

Fig. 5: Compaction curve of soil sample S2

was selected in accordance with EPA Method 9100 of SW846 test method series (USEPA, 1986).

The apparatus developed for the two tests comprised of two polypropylene columns of an effective height of 25 cm and inner diameter of 3.2 cm. A nesting for the columns was also prepared as the chamber of leachate drainage (through a built in perforated part) which had an outlet to discharge the potentially infiltrated leachate out to a storage container (Fig. 3).

The clay samples were compacted at the geotechnical laboratory in accordance with standard proctor method. The optimum moisture content was determined to be 18.6 and 16.8% for S1 and S2, respectively. Compaction curves are shown in Fig. 4 and 5 for soil samples S1 and S2, respectively. The compacted clay samples were right away transferred directly to the columns so as to minimize the effect of sample disturbance. The height of compacted clay sample placed within the columns was 5 cm.

A leachate mounding of 15 cm was considered to simulate the real condition over the leachate drainage layer in the landfill. Therefore a leachate constant head of 15 cm was applied to the columns. Initial leachate head of 15 cm was maintained for 10 days manually through discharging the leachate from the column and addition of fresh leachate sample stored in standard storage conditions as required. Addition of fresh leachate on a daily basis was accomplished mainly to simulate a worst case situation since the fresh leachate demonstrated to be slightly acidic.

Table 4: Observed infiltration of leachate in the compacted clayey soil samples

Obs. No	Date	Time (day)	Infiltration (mm) Column 1	Column 2	Comments
1	27/12/04	1	0	0	Fresh leachate added up to 15 cm
2	28/12/04	2	0	0	Fresh leachate added up to 15 cm
3	29/12/04	3	0	0	Fresh leachate added up to 15 cm
4	2/1/2005	7	6	7	Fresh leachate added up to 15 cm
5	5/1/2005	10	3	4	Fresh leachate added up to 15 cm
6	11/1/2005	16	9	12	Skim and settled sludge appeared
7	15/1/05	20	14	16	
8	25/1/05	30	29	31	
9	30/1/05	35	32	34	
10	1/2/2005	37	34	36	

RESULTS

The results of the head decrease (i.e., infiltration) in the two columns are presented in Table 4. As shown in Table 4, limited infiltration is initiated within a couple of days after start of the experiment (as measured on day 7). No significant difference is observed between the two columns in terms of the extent of infiltration.

As shown in Table 4, after day 10 when no fresh leachate was added to the columns, a smooth accumulative infiltration is observed. Also after 37 days apparently no leachate discharge from the columns was observed.

It is worth noting that after 15 days from the start of the experiment (i.e., 5 days after maintaining the last batch of fresh leachate addition) floating skim on the top of the leachate surface and settled sludge on the surface of the soil sample were observed. This seems to be significantly contributing to the limitation of potential infiltration due to biological clogging of the soil pore spaces as well as the bio-film growth on the surface of the sample (Rowe *et al*., 1997). This may also be confirmed by the observed increase in pH of the leachate from 4.75 at the start of the experiment to 6.29 at the end.

Unsaturated hydraulic conductivity of the compacted soils in the column was also calculated in accordance with the test method employed for the experiment (Eq. 1). The changes in unsaturated hydraulic conductivity of the columns are presented in Table 5.

$$2.3(L/t)Ln(h0/h1) \quad (1)$$

Where, the parameters are described in Fig. 3.

The unsaturated hydraulic conductivity of the samples in both columns seems not to be touched significantly through the course of the experiment. Both the columns show relatively similar behaviour in terms of infiltration. The general trend seems to be exponential with a smooth slope approaching the end of the experiment.

Table 5: Changes in unsaturated hydraulic conductivity of compacted soil samples (m sec^{-1})

Duration (days)	Column 1	Column 2
4	1.36E-08	1.59E-08
3	8.96E-09	1.20E-08
6	1.37E-08	1.85E-08
4	1.20E-08	9.79E-09
10	1.56E-08	1.58E-08
5	6.68E-09	6.80E-09
2	1.14E-08	1.16E-08

The results of this preliminary assessment indicates that not only the hydraulic conductivity of the compacted soil samples were not increased but also a decreasing trend is observed when the soil is subject to longer exposure to leachate. As stated earlier the significant increase in pH of the leachate stored at the top of the compacted soil samples in both columns can be associated with initiation and continuation of biological reactions. In other words the possibility of microbial growth attached to the surface of the soil could be considered as a limiting factor for infiltration of leachate.

DISCUSSION

Preliminary assessment of the unsaturated hydraulic conductivity of soil samples compacted at laboratory provided no evidence of increase in hydraulic conductivity. On the contrary, the hydraulic conductivity was shown to decrease, though slightly, through the course of experiment. Changes in leachate quality also were observed during the experiment which is in fact the case at landfill sites. The increased pH of the leachate can be considered a good indicator of initiation of biological growth within the leachate storage area of columns as well as the upper surface of the compacted soil samples. The most aggressive leachate in terms of posing increasing effect on hydraulic conductivity of a given liner is the fresh or primary leachate which is shown to be associated with low pH values. The less influencing leachate in this regard is the older leachate with higher pH and being subject to organic content degradation.

Preliminarily it can be concluded that there could be a potential for use of the site soil in constructing bottom liner for the new landfill of Tehran in terms of compatibility with leachate. Additional samples and tests are essentially required for better evaluation and understanding of the hydraulic behaviour of the compacted soil when exposed to leachate.

Leachate clay compatibility is mainly studied employing hydraulic conductivity measurement procedures. In other words the soil sample is generally saturated followed by observation of changes in hydraulic conductivity. This seems not to resemble the real conditions. The critical point is that the bottom liner of a landfill may not be saturated throughout its life span. Another issue is to consider the amount of leachate introduced to the liner as well as the duration of this exposure.

Taking a vertical profile of a cell in a landfill trench, it can be shown that the primary leachate is flushed out as a result of early and in the meantime intense compaction of waste. The duration of this process is determined to be a few days in circumstances where contribution of precipitation is very limited (like the case studied in this research). Therefore it can be concluded that representing the real conditions at a landfill site, it is necessary to take into account the landfilling scheme. Number of daily cells in a trench as well as general configuration of filling operation are therefore of crucial importance on estimation of leachate quantity and consequently on duration of liner exposure to leachate. Such an approach can also be of an influence on determination of the life span of a given liner in terms of possible shorter service duration than required overestimated values.

Therefore the important issues to be considered when leachate liner compatibility tests are run are proposed as (1) duration and amount of leachate remaining on the surface of liner and (2) alteration in leachate quality throughout the exposure duration. Although the duration of such tests using compacted clayey soil samples is relatively long, it can be proposed not to perform the tests with saturated samples but to conduct infiltration test with unsaturated compacted soil samples.

ACKNOWLEDGMENT

This research was fully funded by the Faculty of Environmental Studies of the University of Tehran through research project entitled Municipal Solid Waste Landfill Leachate Compatibility with Clayey Soil to be used as Liner for the new landfill of Tehran.

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