Hydraulic Conductivity of MSW in Landfills

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Abstract: This paper presents a laboratory investigation of hydraulic conductivity of municipal solid waste (MSW) in landfills and provides a comparative assessment of measured hydraulic conductivity values with those reported in the literature based on laboratory and field studies. A series of laboratory tests was conducted using shredded fresh and landfilled MSW from the Orchard Hills landfill (Illinois, United States) using two different small-scale and large-scale rigid-wall permeameters and a small-scale triaxial permeameter. Fresh waste was collected from the working phase, while the landfilled waste was exhumed from a borehole in a landfill cell subjected to leachate recirculation for approximately 1.5 years. The hydraulic conductivity tests conducted on fresh MSW using small-scale rigid-wall permeameter resulted in a range of hydraulic conductivity 2.8×10^{-3}–11.8×10^{-3} cm/s with dry unit weight varied in a narrow range between 3.9–5.1 kN/m^3. The landfilled MSW tested using the same permeameter produced results between 0.6×10^{-3}–3.0×10^{-3} cm/s for 4.5–5.5 kN/m^3 dry unit weights. The hydraulic conductivity obtained from large-scale rigid-wall permeameter tests decreased with the increase in normal stress for both fresh and landfilled waste. The hydraulic conductivity for fresh MSW ranged from 0.2 cm/s for 4.1 kN/m^3 dry unit weight (under zero vertical stress) and then decreased to 4.9×10^{-5} cm/s for 13.3 kN/m^3 dry unit weight (under the maximum applied normal stress of 276 kPa). The hydraulic conductivity of the landfilled MSW decreased from 0.2 cm/s to 7.8×10^{-5} cm/s when the dry unit weight increased from 3.2 to 9.6 kN/m^3. The results clearly demonstrated that the hydraulic conductivity of MSW can be significantly influenced by vertical stress and it is mainly attributed to the increase in density leading to low void ratio. In small-scale triaxial permeameter, when the confining pressure was increased from 69 to 276 kPa the hydraulic conductivity decreased from approximately 10^{-4} to 10^{-6} cm/s, which is much lower than those determined from rigid-wall permeameter tests. The published field MSW hydraulic conductivities are found to be higher than the laboratory results. Landfilled MSW possesses lower hydraulic conductivity than fresh MSW due to increased finer particles resulting from degradation. The decreasing hydraulic conductivity with increasing dry unit weight is expressed by an exponential decay function.

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CE Database subject headings: Solid waste; Hydraulic conductivity; Landfills; Waste management; Municipal wastes; Waste disposal; Density.

Introduction

The hydraulic conductivity of municipal solid waste (MSW) must be estimated for the design of the landfill containment systems (Sharma and Reddy 2004). In accordance with the U.S. environmental regulations, leachate head over the bottom liner must not exceed 0.3 m. Therefore, a leachate collection and removal system (LCRS) is designed to remove leachate accumulated over the bottom liner. LCRS consists of a granular drainage layer or equivalent geosynthetic layer and a network of drainage pipes, sumps, and pumps. Hydraulic analysis is performed for the proper design of the LCRS components and it requires the hydraulic conductivity of MSW as an input. In bioreactor landfills, where leachate and other liquids are recirculated to increase the moisture of the waste for enhanced degradation, the hydraulic conductivity of MSW is of paramount importance because it dictates the flow and distribution of leachate injected in the waste. The hydraulic conductivity of MSW varies significantly depending on the waste composition, compaction, and overburden pressure. In addition, the hydraulic conductivity of MSW varies spatially and with time depending on the extent of the degradation of waste, resulting in significant change in the composition and size distribution of the waste components.

In general, the hydraulic conductivity of any porous media is primarily a function of the interconnected void space. In the case of soils, correlations have been observed between hydraulic conductivity and the void ratio. However, solid mass of MSW is a function of time and hence void ratio may not be the best parameter to explain the void space in MSW. In many instances, dry

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Table 1. Variation of the MSW Hydraulic Conductivity with Dry Unit Weight Based on Laboratory Studies

Source	Unit weight (kN/m^3)	Hydraulic conductivity (cm/s)
Korfiatis et al. (1984) Column test, refuse of six months old collected from a landfill in New Jersey	8.6	5.0×10^{-3}–3.0×10^{-3}
Blieker et al. (1993) Fixed ring consolidometer, decomposed MSW samples from Keele Valley landfill in Toronto	5.9–11.8	1.6×10^{-4}–1.0×10^{-6}
Brandl (1994) Pretreated MSW collected from an abandoned and newly constructed landfill	9.0–17.0	2.0×10^{-3}–3.0×10^{-6}
Beaven and Powrie (1995) Large scale compression cell, crude as well as processed MSW from the tipping face of a landfill	5.0–13.0	1.0×10^{-2}–1.0×10^{-5}
Gabr and Valero (1995) Constant and falling head tests, 15–20 year old samples recovered from auger cuttings	7.4–8.2	1.0×10^{-3}–1.0×10^{-5}
Powrie and Beaven (1999)		
Constant head test in Pitsea compression cell, unshredded	3.8	1.5×10^{-4}–3.4×10^{-5}
MSW from tipping face of a landfill	7.1	2.7×10^{-6}–3.7×10^{-8}
Jang et al. (2002) Constant head test using a modified tempe cell	7.8–11.8	1.1×10^{-3}–2.9×10^{-4}
Penmethsa (2007) Constant head test, laboratory generated MSW samples in four different phases of degradation	6.4–9.3	1.0×10^{-2}–8.0×10^{-4}

unit weight has been preferred over void ratio for MSW (Hettiarachchi 2005). However, dry unit weight is not only a function of void space but also varies with the specific gravity of the solids. Attention must be paid to this fact before comparing hydraulic conductivity values reported at different dry unit weights as the specific gravity of MSW may vary widely.

Published literature shows a limited number of laboratory studies on the hydraulic conductivity of MSW as a function of dry unit weight. Results from some of these studies are summarized in Table 1. In many of these studies, water was used as a permeant. Few studies on field evaluations of hydraulic conductivity of MSW are reported in the literature and they are summarized in

Table 2. Variation of the MSW Hydraulic Conductivity with Dry Unit Weight Based on Field Studies

Source	Unit weight (kN/m^3)	Hydraulic conductivity (cm/s)
Landva and Clark (1986)		
In situ test pits, Calgary	12.5–14.5	2.6×10^{-2}–1.6×10^{-2}
In situ test pits, Edmonton	10.0–12.9	1.3×10^{-2}–1.1×10^{-2}
In situ test pits, Mississauga	10.7–13.6	5.0×10^{-3}–1.0×10^{-3}
In situ test pits, Waterloo	10.5–13.1	1.3×10^{-2}–1.1×10^{-2}
Ettala (1987)		
Modified double cylinder infiltrometer and pumping tests	Heavy compaction	2.5×10^{-6}–5.9×10^{-7}
	Slight compaction	2.5×10^{-5}–2.0×10^{-5}
Oweis et al. (1990)		
In situ pump test		1.0×10^{-3}
In situ falling head test		1.6×10^{-4}
Test pit infiltration	—	1.3×10^{-3}
Shank (1993)		
Slug test, 20 years old MSW	—	9.8×10^{-4}–6.7×10^{-5}
Jain et al. (2006)		
Borehole permeameter test	3–6-m depth	6.1×10^{-5}–5.4×10^{-6}
	6–12-m depth	2.3×10^{-5}–5.6×10^{-6}
	12–18-m depth	1.9×10^{-5}–7.4×10^{-6}

Table 2. Landva and Clark (1986) reported results obtained from the field hydraulic conductivity tests conducted in Calgary, Edmonton, Mississauga, and Waterloo in Canada. The dry unit weights varied from 10 to 14.5 kN/m^3 and the field hydraulic conductivity varied on the orders of $10^{-2}-10^{-3}$ cm/s, which is noticeably higher compared to the laboratory hydraulic conductivity values presented in Table 1. Other studies have reported lower hydraulic conductivity values similar to those presented in Table 2 (Ettala 1987; Oweis et al. 1990; Shank 1993; Jain et al. 2006). However, dry unit weight information is not reported to allow for comparison assessment.

LCRS design approaches are often simplified by assuming the hydraulic conductivity of MSW to be constant throughout the landfill (e.g., water balance analysis). However, the limited data available suggest otherwise and indicate that the hydraulic conductivity should, in the least, be a function of the dry unit weight of MSW. The dry unit weight is a function of waste composition, compaction, overburden pressure, and other contributors (Hettiarachchi 2005). This variation in hydraulic conductivity becomes more important when bioreactor landfills are designed and implemented. During leachate recirculation, the leachate must be distributed uniformly in bioreactor landfills to avoid the possibility of a variable moisture profile leading to variable degradation and settlement of waste within the landfill. The objective of this paper is to present the results of a laboratory study and an assessment of published laboratory and field testing results to investigate the variation of hydraulic conductivity with the dry unit weight of MSW. Both fresh and landfilled MSW samples recovered from a bioreactor landfill were tested and analyzed during this study.

Sample Characterization and Preparation

Waste samples were collected from Orchard Hills Landfill in Davis Junction, Illinois, which is owned and operated by Veolia Environmental Services. The incoming waste consisted of approximately 70% MSW, 17% construction and demolition waste (CDW), 11% soils, and 2% other types of waste. The waste components included 11.7% wood, 13.1% cardboard, 5.8% textiles, 4.8% sanitary waste, 4.4% metals, 11% plastics, 0.1% medical waste, 4.4% glass, 8.2% paper, 6.9% cooking/garden waste, 9.3% inert waste, and 20.1% fines (<20 mm). The individual components of the fines were difficult to characterize visually but it consisted of about 47% organic materials and the remaining may be attributed to soil or soil-like materials (Grellier et al. 2007). Even though there was 17% CDW in the sample, the presence of a higher percentage of other materials still qualifies the samples to be identified as MSW.

At the Orchard Hills Landfill, leachate recirculation was accomplished by spraying the leachate on the working face during filling operations and subsequently using a network of multilevel horizontal leachate recirculation lines (LRLs) installed within the waste. The LRLs consisted of 15-cm diameter perforated high-density polyethylene (HDPE) pipes in gravel-filled trenches spaced at 15–20 m between centers. Leachate was recirculated intermittently for 1.5 years depending on the availability of leachate at the site.

Collection of MSW Samples

Fresh waste samples were collected at the working phase of the landfill. Landfilled waste was collected while installing the gas extraction well No. 16 (GEW16). A borehole was drilled using a bucket auger 0.9 m in diameter and 1.5 m in length. Samples were recovered at 3-m intervals to a maximum depth of 29 m below the ground surface. Samples recovered at 19.8 m were used in the laboratory evaluation of hydraulic conductivity in this study. The landfilled MSW recovered at 19.8 m at GEW16 is believed to be between 15 and 19 months old. Two LRLs were found at the close proximity of the sampling location at GEW16: LRL29 located 7.5 m south of GEW16 at a depth of 12 m and LRL26 located 12 m north of GEW16 at a depth of 22 m. Approximately 530 and 620 m^3 of leachate were recirculated at LRL26 and LRL29, respectively, for approximately 1.5 years. Consequently, MSW samples collected at GEW16 are assumed to represent landfilled MSW subjected to low amounts of leachate recirculation for a short duration.

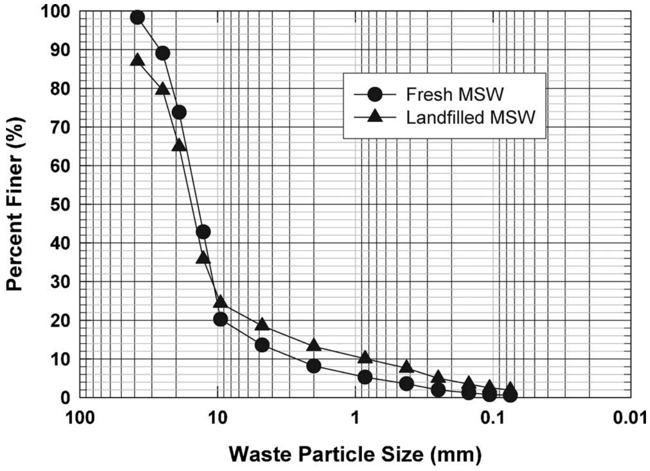

Fig. 1. Particle-size distribution of fresh and landfilled waste

Preparation of MSW Test Samples

A set of three large sieves with opening diameters of 100, 50, and 20 mm were used to determine the gradation of the landfilled and fresh waste samples collected from the landfill. The fresh MSW samples had approximately 53, 16, and 11% (by wet weight basis) of the MSW retained on 100, 50, and 20-mm sieves, respectively, and 20% (by wet weight) finer than 20 mm. The landfilled MSW had approximately 40, 12, and 13% (by wet weight) retained on 100, 50, and 20-mm sieves, respectively, and the percent passing 20-mm sieve was 35%. These results show that greater amounts of finer materials were present in the landfilled waste, which may be due to degradation of waste as well as the presence of daily cover soil.

For this study, MSW samples collected from the field were shredded with a slow-speed, high-torque shredder (Shred Pax Corp., AZ-7H, Wood Dale, Ill.) to suit small-scale laboratory testing. The particle-size distribution of MSW after shredding is shown in Fig. 1. These results show that shredding resulted in a similar size distribution for both fresh and landfilled MSW samples.

Both fresh and landfilled MSW samples had an average in situ moisture content of 45% (by dry weight). The average organic content was approximately 78% for fresh MSW and 61% for landfilled MSW. Degradation during the 15–19 month period after disposing at the landfill is believed to be the main reason for the lower organic content of landfilled MSW.

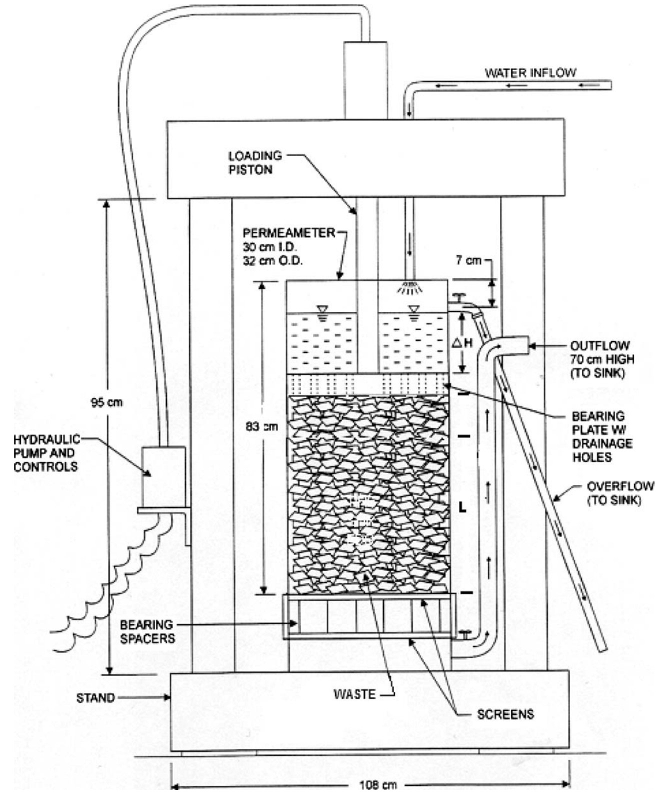

Fig. 2. Schematic diagram of the large-scale rigid-wall permeameter

Hydraulic Conductivity Testing

The hydraulic conductivity of MSW samples was determined using three different permeameters: small-scale rigid-wall, large-scale rigid-wall, and small-scale triaxial. For all tests, deionized water at constant temperature was allowed to flow through the samples.

Small-Scale Rigid-Wall Permeameter

A small-scale rigid-wall permeameter was used to conduct constant head hydraulic conductivity tests in accordance with ASTM D 2434 (ASTM 2006). The sample diameter was 6.3 cm, height varied between 10 and 12 cm, and weight varied between 0.15 and 0.24 kg. Four fresh and four landfilled MSW samples were tested.

Large-Scale Rigid-Wall Permeameter

Fig. 2 shows the schematic diagram of the specially designed large-scale rigid-wall permeameter used in this study. It has an inner diameter of 30 cm and a height of 95 cm, which can potentially be filled to 60 cm with the waste samples. Shredded fresh MSW (about 7.2–8.2 kg) was compacted in layers of 7–8-cm thickness, applying 15 standard Proctor hammer blows per layer. This resulted in compacted samples 30 cm in diameter and 30 cm in height. The large-scale rigid-wall permeameter used in this experiment is capable of applying a variable normal stress on the MSW sample. To simulate the overburden effective stress, the MSW samples were tested for the hydraulic conductivity under different normal stress values. Each sample was first tested under zero normal stress. Then, the normal stress was increased gradually to a specified level (35, 69, 138, and 276 kPa). The variation in the sample compression was also recorded. This procedure was repeated to test landfilled MSW samples.

Small-Scale Triaxial Permeameter

Small-scale triaxial hydraulic conductivity testing was performed using a triaxial laboratory setup in general accordance with the ASTM D5084 (ASTM 2006). Each sample was 5 cm in diameter but length and weight varied between 7.5–11 cm and 0.10–0.18 kg. Waste samples were first saturated under a nominal confining pressure by flushing deionized water from the base upwards under a low hydraulic gradient. After saturation, hydraulic conductivity tests were performed at different effective confining pressures (69, 138, and 276 kPa) on four fresh and four landfilled MSW samples. While increasing the confining pressure, the samples were allowed to consolidate and the change in volume was recorded for strain and unit weight calculations.

Results and Discussion

The four hydraulic conductivity tests carried out on fresh MSW using a small-scale rigid-wall permeameter resulted in a range of hydraulic conductivity of $2.8 \times 10^{-3} - 11.8 \times 10^{-3}$ cm/s. The dry unit weight of these samples varied in a narrow range between $3.9 - 5.1$ kN/m^3. The landfilled MSW tested using the same permeameter produced results between 0.6×10^{-3} and 3.0×10^{-3} cm/s for $4.5 - 5.5$ kN/m^3 dry unit weights. No trend was observed between the hydraulic conductivity and either dry unit weight or age of MSW under the tested conditions in this study.

The hydraulic conductivity obtained from large-scale rigid-wall permeameter tests are summarized in Figs. 3(a and b). The compression (strain) increased and hydraulic conductivity decreased with increase in normal stress for both fresh and landfilled waste. The hydraulic conductivity for fresh MSW ranged from 0.2 cm/s for 4.1 kN/m^3 dry unit weight (under zero vertical stress) and then decreased to 4.9×10^{-5} cm/s for 13.3 kN/m^3 dry unit weight (under the maximum applied normal stress of 276 kPa). The hydraulic conductivity of the landfilled MSW decreased from 0.2 to 7.8×10^{-5} cm/s when the dry unit increased from 3.2 to 9.6 kN/m^3. The results clearly demonstrated that the hydraulic conductivity of MSW can be significantly influenced by the vertical stress. This is mainly attributed to the increase in density leading to the low void ratio.

Results obtained from the small-scale triaxial permeameter tests are summarized in Fig. 4. When confining pressure was increased from 69 to 276 kPa, the hydraulic conductivity decreased from approximately 10^{-4} to 10^{-6} cm/s. These results show no definite correlation between the dry unit weight and hydraulic conductivity determined from small-scale flex-wall triaxial permeameter tests.

Laboratory versus Field Hydraulic Conductivity of MSW

The hydraulic conductivities obtained using the rigid-wall permeameter tests and the triaxial permeameter tests are compared in Fig. 5. It appears that the results from the large-scale rigid-wall permeameter tests demonstrate a correlation between the hydraulic conductivity and dry unit weight of MSW. Interestingly, the average hydraulic conductivity obtained from the small-scale rigid-wall permeameter tests also fits into this trend traced by the

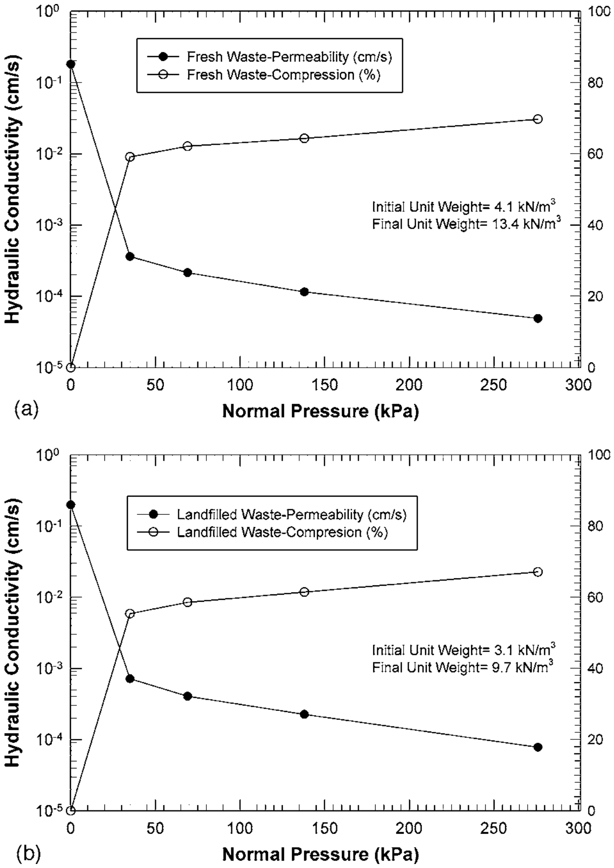

Fig. 3. (a) Variation of hydraulic conductivity and compression of fresh MSW in the large-scale rigid-wall permeameter with normal pressure; (b) variation of hydraulic conductivity and compression of landfilled MSW in the large-scale rigid-wall permeameter with normal pressure

results from the large-scale rigid-wall permeameter tests. This observation is made for both fresh MSW as well as landfilled MSW. Although data are scattered, there is a noticeable decrease in the hydraulic conductivity of the landfilled MSW compared to fresh MSW. The hydraulic conductivities from triaxial permeameter tests are scattered in a narrow range of dry unit weights and are consistently lower than the values determined by the rigid-wall permeameter tests.

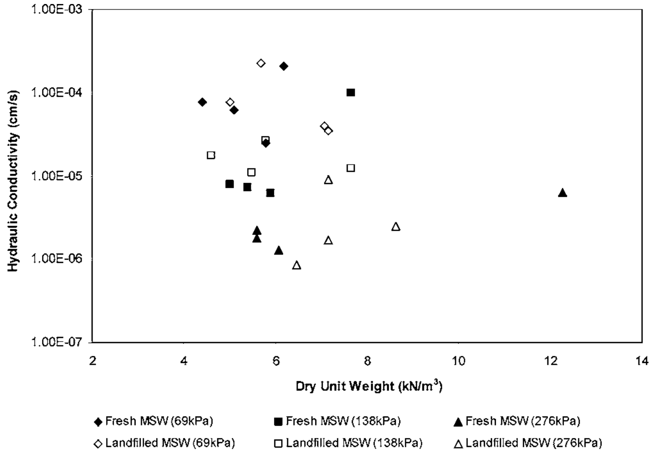

Fig. 4. Variation of hydraulic conductivity with dry unit weight of landfilled MSW under different confining pressures in the small-scale flexi-wall (triaxial) permeameter (confining pressure given in parenthesis)

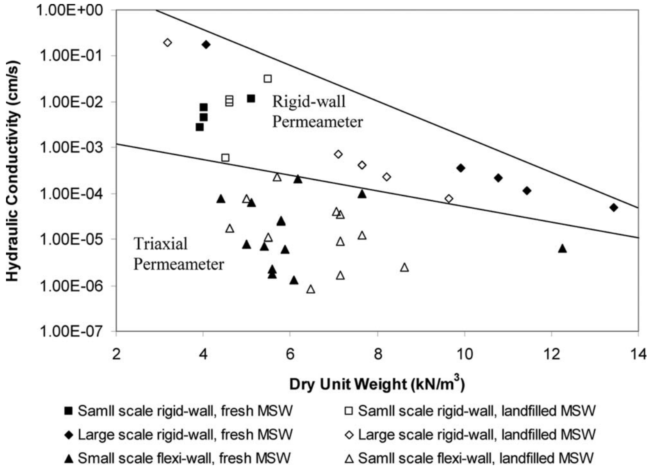

Fig. 5. Variation of hydraulic conductivity of MSW with dry unit weight in rigid-wall and flexi-wall (triaxial) permeameters

Laboratory determined hydraulic conductivities and dry unit weights of MSW obtained from published literature (summarized in Table 1) are compared with the results from the current study in Fig. 6. The upper-bound trend traced by the results from the current research is in agreement with the data from the published literature. The upper bound of this decreasing hydraulic conductivity with increasing dry unit weight trend can be quantified by the following exponential decay function:

$$k(\text{cm/s}) = 4.64 \exp\left(-7.53\frac{\gamma_d}{\gamma_w}\right)$$

where γ_w=unit weight of water.

Based on the results shown in Figs. 4 and 5, the validity of triaxial permeameter testing to accurately determine hydraulic conductivity of MSW is questionable. A landfill is constructed by depositing layers (or lifts) of MSW and the unit weight of a given

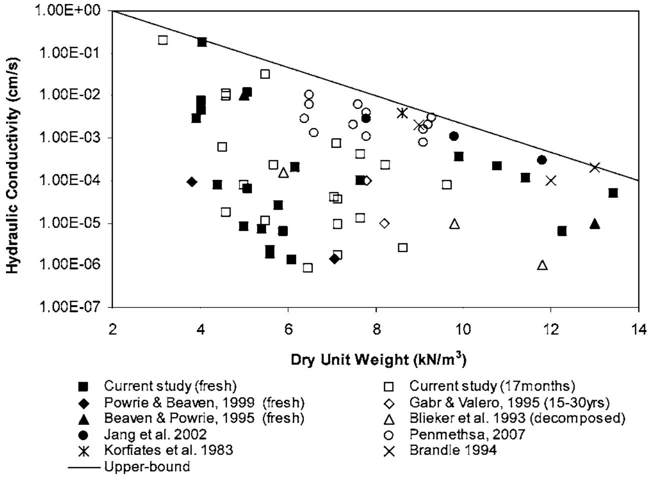

Fig. 6. Hydraulic conductivity–dry unit weight envelope for MSW based on laboratory studies (age of the MSW is indicated in parenthesis)

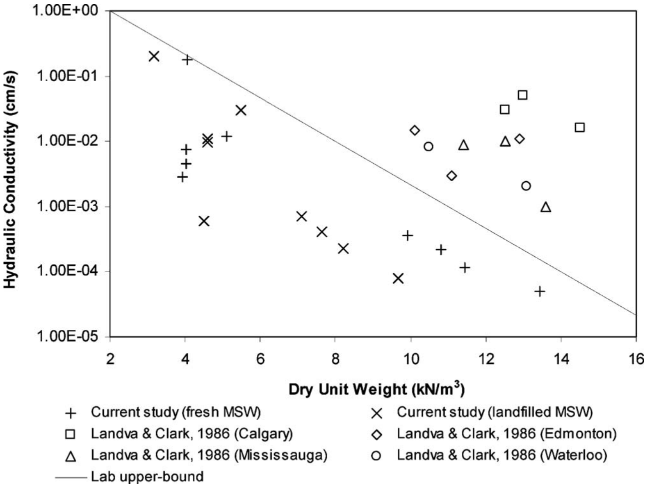

Fig. 7. Comparison of laboratory results by rigid-wall permeameter (from current study) with field evaluated hydraulic conductivity values reported by Landva and Clark (1986)

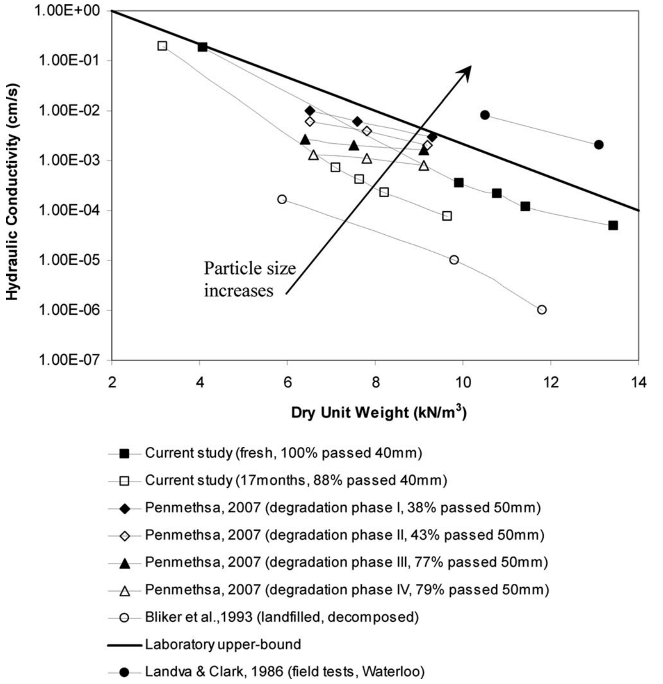

Fig. 8. Variation of hydraulic conductivity—dry unit weight relationship of MSW with particle size

MSW layer is increased by the addition of new MSW layers at the top. Therefore the deformation occurs in the direction of loading (vertical) and there will be no deformation in the direction extending at a right angle from the deformation (horizontal). This two dimensional stress strain behavior qualifies a landfill to be analyzed by plane-strain conditions and the rigid-wall permeameter is a good representation of plane-stain conditions. While a small-scale rigid-wall permeameter simulates conditions near the surface of a landfill (with low or zero overburden pressure), the large-scale rigid-wall permeameter used in this study allowed for the simulation of plane-strain deformation of MSW at different depths by varying normal pressure. The axisymmetrical deformation caused by the confining pressure in a triaxial permeameter creates a three dimensionally stressed MSW sample. As the loading is three dimensional, it also permits MSW particles to move in a three dimensional space, which may not be the case in a layered structure. Therefore, the use of a rigid-wall permeameter (with or without normal pressure) may be a better approach than a triaxial permeameter (or testing with confining pressure) to measure the hydraulic conductivity of MSW. This argument is supported by the MSW field hydraulic conductivity-dry unit weight data published by Landva and Clark (1986). Fig. 7 compares the hydraulic conductivity obtained by the rigid-wall permeameter from the current study for fresh as well as landfilled MSW with the field data published by Landva and Clark (1986). The field values are located above the upper bound identified for laboratory results. Since rigid-wall permeameter estimates the hydraulic conductivity values close to the laboratory upper bound, a rigid-wall permeameter may be used to simulate field conditions. However, more field hydraulic conductivity data are needed to ascertain the differences between the field and laboratory determined hydraulic conductivity values.

Dependency of Hydraulic Conductivity on Size Distribution of MSW

If hydraulic conductivity of MSW is only a function of void space, theoretically, fresh as well as landfilled MSW should possess the same hydraulic conductivity when tested at the same dry unit weight. However, Fig. 5 suggests otherwise. As clearly shown, hydraulic conductivity obtained by the large-scale rigid-wall permeameter for landfilled MSW is slightly lower than fresh MSW for a comparable dry unit weight. The difference in hydraulic conductivity of fresh and landfilled MSW may be attributed to the difference in their particle-size distributions. As shown in Fig. 1, shredding reduced the maximum particle size of samples tested in the current research to approximately 40 mm for both fresh and landfilled MSW. Fig. 1 also indicates that the landfilled MSW had more fine particles than the fresh MSW. For example, the effective size (i.e., diameter for 10% passing) of the fresh MSW distribution is 3 mm while it is 0.8 mm for the landfilled MSW. This provides an indication of higher hydraulic conductivities for MSW with fewer small particles.

Tests conducted by Penmethsa (2007) also confirm the dependency of hydraulic conductivity on size distribution of MSW. Results from the current research (large-scale rigid-wall permeameter test results) are compared with data published by Penmethsa (2007) in Fig. 8. Penmethsa (2007) observed a decrease in particle size of MSW with an increase in degradation and as a result hydraulic conductivity versus dry unit weight curve for Phase I (the lowest level of degradation) is located above the curve for Phase II. Following the same trend, the curve for Phase IV (the highest level of degradation) produces the lowest hydraulic conductivities among all four phases. To further support this explanation, data published by Blieker et al. (1993) and Landva and Clark (1986) are also plotted in Fig. 8. Blieker et al. (1993) conducted tests on heavily decomposed samples recovered from the Keele Valley landfill in Toronto, Canada. Even though details are not available, it can be assumed that particles were very small in size due to heavy decomposition. Also their decision to use a fixed ring consolidometer (with 63-mm diameter and 19-mm sample height) infers the lack of large particles in their samples. Data by Blieker et al. (1993) for decomposed MSW traces the lowest trend in Fig. 8. Conversely, the field data from Calgary (Landva and Clark 1986) provide the highest hydraulic conductivities. It is not surprising to see high hydraulic conductivities from in situ tests because these tests were conducted on unprocessed real MSW samples and they should represent the largest particle sizes among all samples. Even though a quantitative analysis is not feasible, Fig. 8 clearly demonstrates the trend of increasing hydraulic conductivity with increasing particle size. Therefore, the conclusion is that the differences in hydraulic conductivity in fresh and landfilled MSW may not be merely due to difference in the age of the waste but could also be due to the difference in particle size resulting from degradation.

Conclusions

The following conclusions can be drawn from the results of this study:

1. The hydraulic conductivity of MSW is primarily a function of interconnected void space and hence void ratio. Assuming a constant specific gravity, dry unit weights can be considered as a more conveniently measurable parameter to replace the void ratio. The results from the rigid-wall permeameters clearly demonstrated that the hydraulic conductivity of MSW is significantly influenced by the vertical pressure and produces a trend of decreasing hydraulic conductivity with increasing dry unit weight. The hydraulic conductivity from the triaxial permeameter (tested under confining pressure) did not exhibit a significant variation with the dry unit weight;
2. The upper-bound trend traced by the results from this study is in agreement with the data in the published literature. Upper bound of this decreasing hydraulic conductivity with increasing dry unit weight trend can be estimated by an exponential decay function. The limited literature on field MSW hydraulic conductivities indicated that they are located above the upper bound identified for laboratory results. Since the rigid-wall permeameter estimates the hydraulic conductivity values close to the laboratory upper bound, the rigid-wall permeameter may be a conservative but realistic approach to simulate the field conditions;
3. Landfilled MSW possesses lower hydraulic conductivity than fresh MSW. The decrease in hydraulic conductivity in landfilled MSW is attributed to the increase in the finer particles resulting from degradation; and
4. Overall, this study helped to quantify the variation in hydraulic conductivity of MSW due to different laboratory test setups and the typical range of hydraulic conductivity values for fresh and landfilled waste. Additional research is warranted to systematically evaluate the influence of factors such as particle size and sample size as well as quality of the leachate on the hydraulic conductivity of MSW. A field testing technique with justifiable data analysis method is necessary to accurately determine hydraulic conductivity of MSW. In addition, the spatial and temporal variation of hydraulic conductivity due to the heterogeneous and degradable nature of MSW should be properly characterized.

Acknowledgments

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