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Evaluation of the hydraulic conductivity for MSW using pilot plant test- A case study of Baghdad city/Iraq

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Abstract. The hydraulic properties of municipal solid waste (MSW) have been regarded as core factors affecting landfills' flows. To successfully design and applied, information on the conductivity of MSW is required. A laboratory examination of MSW's hydraulic conductivity in Baghdad City is presented in this study and assesses the influence of waste compaction on hydraulic conductivity parameter. A hydraulic conductivity test was carried out in a laboratory-scale cell using three mixtures of fresh shredded MSW samples **'SAM1', 'SAM2'** and **'SAM3'** collected from the households Baghdad City. The saturated vertical hydraulic conductivity was quantified according to different types of compactions using a falling head test. A clear trend of decreasing hydraulic conductivity with increasing compaction degree was highlighted after the monitoring process, reflecting the impact of varying waste densities and fine particles' movement in the column. This experiment shows that the average hydraulic conductivity values at 50, 70, and 90 degrees of compaction were 1.23×10^{-4} m/s, 0.96×10^{-4} m/s, and 2.55×10^{-5} m/s, respectively. The results distinctly showed that the MSW's hydraulic conductivity could be significantly affected by vertical compaction that is fundamentally attributed to accretion in density resulting in the low void ratio.
Keywords: MSW; hydraulic conductivity; compaction; landfill; degradation.

1. Introduction

The world and lifestyles are changing, but globally, the most popular waste disposal route is landfill [1]. The successful application and design of MSW landfills need acquaintance with the hydraulic conductivity of MSW [2]. The MSW's hydraulic conductivity need to be evaluated for the design of the landfill polluted systems. The hydraulic conductivity of MSW is considerably varied according to the waste composition, overburden pressure, and compaction [3]. Moreover, it varies with regard to time and space relying on the degree of the waste's degradation, which result in an alteration in size distribution and waste motifs' composition [4,5]. Generally, any porous media's hydraulic conductivity is mainly related to its voids [6]. As far as soils are concerned, correlations between the void ratio and hydraulic conductivity have been observed. Still, MSW's solid mass is time's a function, so the void ratio might not be the superior parameter ratio in MSW [7,8]. All the same, the dry unit weight can differ for MSW samples depending on the gravity of solids [9]. This fact needs to be considered when comparing hydraulic conductivity values of the various dry unit weights because the MSW specific gravity can largely differ [10]. According to the literature, hydraulic conductivity is a measure of porous media ability to carry on liquid. Although the test of hydraulic conductivity is theoretically simple, the water's movement within a media is so complicated [7]. Different aspects affect soils' hydraulic conductivity, like the size of particle, composition, void ratio, fabric, pore geometry, and features of the test fluid [7]. Yet, it is impossible to differentiate MSW samples according to these aspects because of the heterogeneity of MSW [11].

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A value of MSW's hydraulic conductivity needs to be estimated for the landfill containment system design. In accordance with environmental regulations, the density is primarily linked with the void ratio, pore geometry, and fabric [7][11]. Thus, the density is crucial to the hydraulic conductivity value for MSW in landfills and leach bed digesters. Also, as composition influences a soil's hydraulic conductivity, the MSW composition disparity is likely to affect its hydraulic conductivity [9]. The difference in the MSW composition is caused by the variation in the collection and recycling methods. After the recycling metal and glass process is done, it is found that 75% of the remaining MSW is food, plastic, paper, and garden wastes [12]. As far as the weight is concerned, despite plastic being considered a major part of MSW, it is worthy of paying attention because of its high volume compared to its weight and inability for biodegradation in nature. Information of the composition and density impact on hydraulic conductivity can help designers and operators for more efficient landfill systems and promote anaerobic digestion processes of MSW in a landfill [3]. Therefore, this study aims to determine the hydraulic conductivity of the shredded MSW of Baghdad city under a range of compaction degrees and with different waste compositions.

2. Materials and methods

2.1. Experimental setup

A custom-made cell called an "alpha cell" has been used to experiment [11]. The diameter of the solid's alpha cell is 15-cm, the length is 40-cm, and has a Polymethyl Methacrylate (PMMA) watertight cylindrical tube with upper and lower ends closed with PVC plates. The falling head tests on waste samples were conducted placing a container to saturate, drain, and run the samples (figure 1). All tests were performed using de-aired water to ensure no air is added to the waste. Waste is placed in the cell in three lifts and compacted after each lift to ensure uniform density throughout the cell. A diffusion disk is placed at the bottom of the cell to distribute the water being introduced to the waste equally. The experiment was made by preparing the household waste. The water container was fixed at 20 cm from a Hungarian tube and fed tube with water using a suction pipe. This pipe was joined at the bottom of the tube and connected with the container. The water flow process from the container to the bottom of the tube and then passing to the tube was monitored regularly. A Piezometer tube device is inserted to measure the changes in water levels during the water flow process. Regarding the device for hydraulic conductivity test, a piece of fabric is cut and put into fitting with the base of the measuring pipe equipment, followed by a smooth layer of gravel (1-cm depth) and finally, a (1 cm) layer of sand is placed above the gravel layer. Then the MSW sample was put in the Permeameter to measure its hydraulic conductivity.

An appropriate tamping device (hammer) has been used to compact the samples and find their density. During loading and compacting of test materials, a small amount of waste material has been taken to measure its wetweight. After completing the loading and compaction stage, the waste sample in the Permeameter had been saturated with water. Firstly, the pipe was covered with a cap, and then water will be passed from the container to the waste sample by a controlled valve inserted at the bottom of the container. While the sample had been filled with water, the piezometer installed with the pipe measured water level changes. After that, the drained water from the sample with the time required to drain the water had been recorded. Water will pass from the container to the pipe through the drain. After completing the experiment, the wet sample was taken to the oven to measure its dry weight.

2.2. MSW Samples characterization and preparation

Three samples of MSW mixtures, ' SAM1', 'SAM2' and 'SAM3', obtained freshly from the first researcher's private property, were used. The collected fresh waste sample's graduation was determined by using a set of three sieves with opening diameters of 50, 20, and 10 mm. The fresh MSW samples were just about 50, 30, and 20% of MSW's weight basis keeps 50, 20, and 10 mm sieves, respectively. In this study, MSW samples obtained from the households were shredded by hand to be suitable for small-scale laboratory testing. The waste contained plastic, metal, food, bags and other materials, as shown in Table 1.

The waste samples were cut into small pieces, and their wet weight was measured. After that, the waste samples entered the oven for 24 hours, and their dry weight was measured. The collected waste is household waste, which includes approximately 99.4994% of the total solid residue containing 0.025% glass, 99.655% food, 0.0112% paper, 0.0076% building materials, 0.0050% garden waste and 26.526 % wood. The composition and characteristics of the samples are shown in table 1. It has been noticed that the waste sample contained about 47% organic matter, and the residue can be associated with soil or sub-soil materials.

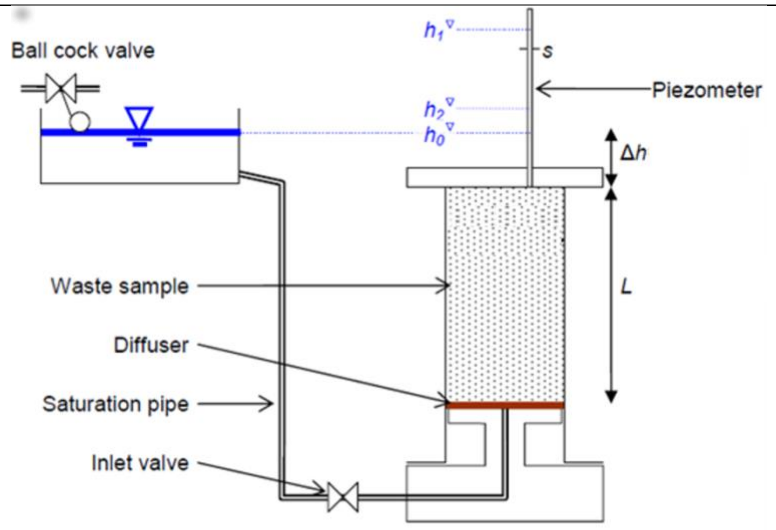

Figure 1. Demonstrative sketch of the alpha cell of the experiment setup [11].

Table 1. Composition of the MSW samples.

Materials	Samples		
	SAM1 (%)	SAM2 (%)	SAM3 (%)
Plastic	0.916	1.486	0.943
Wood	2.777	6.686	3.715
Glass	4.822	9.746	12.616
Cartoon	20.351	16.931	11.151
Clothes	0.688	2.229	1.572
Paper	58.976	30.072	31.285
Food	62.965	47.391	62.201
Waste of garden	3.515	5.144	8.491
Waste iron	8.204	9.200	11.214
Building	10.185	11.085	13.585
Nylon	5.314	4.322	4.389

2.3. Hydraulic conductivity calculation

In each sample, the falling head test has been applied to find the saturated downward hydraulic conductivity. Firstly, the sample is saturated as demonstrated in the previous section then the falling head test is run. Water is poured into the vertical tube, waiting for the water to be stabilized at the level $h1$. After that, the valve at the cells' bottom is opened, and the water surface had increased gradually until the tube shows the half-way point of water. The period, represented by (t), for the water to be stable and the length, represented by (*h*2), for the water to drop. Finally, the saturated vertical hydraulic conductivity *Ksat* for the waste sample can be calculated using the falling head permeameter formula [11]:

$$K_{sat} \frac{s}{S1} * \frac{L}{\Delta t} * \ln\left\{\frac{h1}{h2}\right\} \quad (1)$$

Where s and S1represent the cross-sectional areas of the standpipe (piezometer) and the waste sample respectively (m^2), L is the sample length (m), and t is the period for the water falling between h1 and h2 (s). This process was run three times with a different number of compaction for each sample to ensure consistency.

2.4. Optimum water content

The MSW compaction curve from the Standard Proctor Compaction Test was used to find the relationship between the maximum dry density and MSW moisture content. This information helps calculate the optimum water content when the maximum dry density of MSW can be found from compaction [13]. The moisture content is defined as a quantity of water in the MSW mass and represents either the naturally present or manually added water. Moreover, it defined by the percentage that can be recognized as water content. In the MSW, the test can be done by taking a small quantity of MSW sample to find the moisture content value. Firstly, measure the MSW sample's weight, then dry the sample by oven at a specific temperature. The next step is to measure the weight of the oven-dried MSW sample. The moisture content is calculated using the expression below [14]:

$$\omega = \left(\frac{Wd}{Ww}\right) * 100 \quad (2)$$

Where ω is the water content (percent), *Wd* is the dry weight (g/cm3), and *Ww* is the wet weight (g/cm3).

3. Results and discussion

3.1. Effect of dry waste density on hydraulic conductivity

The vertical hydraulic conductivity data of all MSW samples are demonstrated in Figure 2. As shown in that figure, hydraulic conductivity reduces when dry density increases. This tendency was recognized in all MSW samples SAM1, SAM2 and SAM3. The function of dry unit weight can be explained by the hydraulic conductivity of MSW [11] and is an expression of waste compounds, compacted material, weigh down pressure, and other combinations. Generally, the volume of voids reduces as the waste density rises, hindering the flow of fluid within the medium [11]. The mean value of the saturated vertical hydraulic conductivity of SAM1, SAM2 and SAM3 waste were 1.998×10^{-4} m/s, 1.978×10^{-5} m/s and 5.316×10^{-6} m/s, respectively.

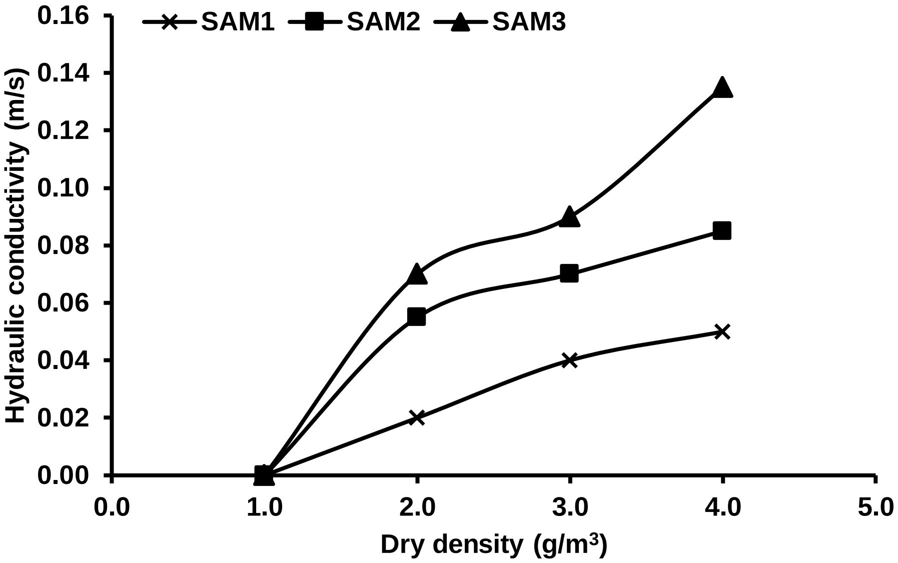

Figure 2. Variation of hydraulic conductivity with a density of the three MSW samples "SAM1", "SAM2", and "SAM3", respectively.

The 'SAM3' waste sample illustrates that conductivity has a lower dependence on dry density. This result highlights the impact of this sample's maximum particle size, which is higher than that of SAM1 and SAM2 waste, thus permitting bigger voids to exist even when compacted at higher pressure. The samples' compaction indicates an obvious reduction trend resulting from a different dry densities range [15].

3.2. Effect of Size Distribution on Hydraulic Conductivity

Figure 3 shows the particle size distribution for samples SAM1, SAM2 and SAM3. All MSW samples between 91-96% are a composite of particles with sizes less than 4.80 mm. It can be noticed that the particles of the shredded MSW samples had sizes ranging between 0.75 mm and 20 mm.

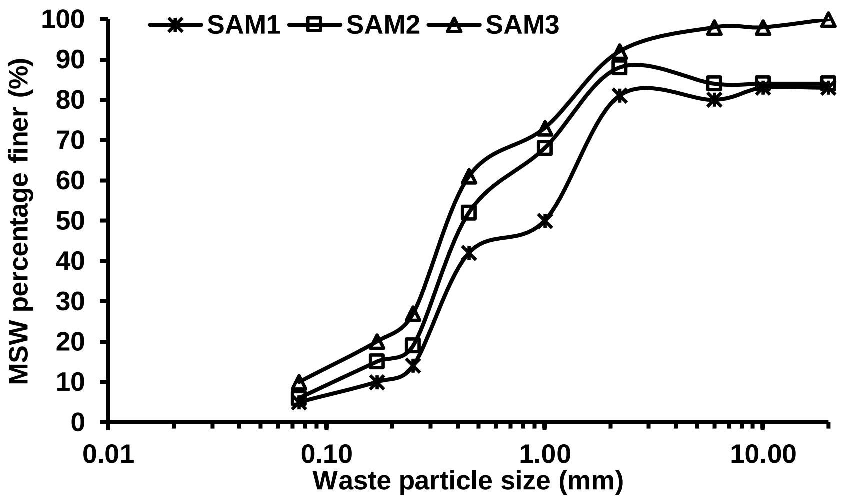

Figure 3. Particle size distribution of the three MSW samples "SAM1", "SAM2", and "SAM3", respectively.

Approximately 75% (by dry weight) of MSW had particles with sizes less than 10 mm for samples SAM1 and SAM2, while approximately 90% of MSW contained particles less than 10 mm for sample SAM3. This study's results are consistent with Gavelyte et al., 2016 [3], who also reported the gradation of shredded MSW.

3.3. Optimum water content

Figure 4 shows the laboratory test results of the moisture content with dry unit weight interactions. It can be noticed that the compaction curves' shape for waste in the laboratory was coordinated with the shape of normal compaction curves for soils. When the water content increase, unit weights will be gradually increased until they reach the highest value, after that increased moisture content will result in a decrease in the unit weights [14]. This process is the same as in soils. Adding solids would result in qualifying to smooth the movement between the particles from water addition resulting in the arrangement of more densely packed materials. Moreover, water addition can be linked to softening the wastes solids, causing compressibility increase and rebound (significant for wastes) decrease reflecting the impact of compaction forces. The efficiency of adding moisture will weaken at optimum wet conditions, highlighting the impact of decreasing densities due to the solids' replacement with water [16].

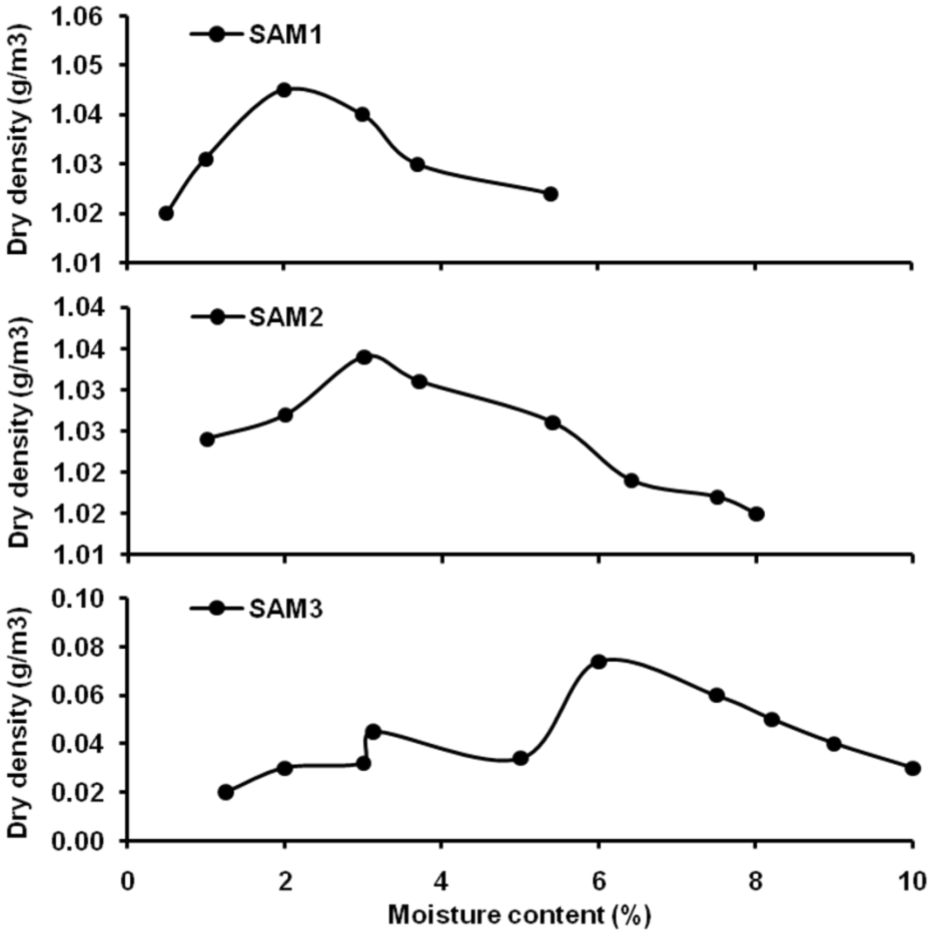

Figure 4. Relationship between moisture content and dry density of the three MSW samples "SAM1", "SAM2", and "SAM3", respectively.

The main aim of compaction of MSW is to keep the particles of MSW densely packed collectively, leading to promote the dry density of MSW. The maximum dry density of MSW is appropriate for many construction works. However, the compaction process with a maximum dry density of MSW will potentially exacting water content named optimum moisture content. Therefore the compaction process relies on the interconnection between the water content of MSW and the dry density of the waste materials [17].

3.4. MSW compaction test analysis

The hydraulic conductivity test under laboratory conditions was conducted on three fresh MSW samples using a falling head test resulted in a range of hydraulic conductivity values. The compaction increased with an increase in regular stress on fresh waste, resulting in a decrease in hydraulic conductivity. An overall compaction test and test variables and test results for three model samples, SAM1, SAM2, and SAM3, are presented in Table 2. These laboratory test results effectively investigate features of compacted wastes with control variables in relation to the trends values.

Generally, the higher the compaction attempts, the higher the dry unit weight. Time-efficient compaction can be gained from high moisture contents and high compaction efforts. High moisture contents can result in higher waste workability, and this is due to soften waste consistency and uniform arrangement of particles, which permitted efficiently fast journey by the compactor resulting in a shorter compaction period. Adding moisture to the wastes throughout compaction period performs the production of leachate, water, or other liquids to the waste, which in turn reduced the compaction time, enhanced the unit weight, and the workability of the wastes included the environmental and economic impact in landfill applications [18].

Table 2. Overview of the statistical comparisons between the characteristics of the three samples "SAM1", "SAM2", and "SAM3".

Materials	Samples		
	SAM1	SAM2	SAM3
Optimum moisture content (%)	2	3	6
Dry density (g/m^3)	0.075	1.035	1.051
Maximum dry density (g/m^3)	0.081	1.0444	1.0523
Number of compaction	50	70	90
Degree Of Compaction tamping	91.48	95.12	99.102
Hydraulic conductivity (m/sec)	1.23*10$^{\wedge-4}$	0.96*10$^{\wedge-4}$	2.55*10$^{\wedge-5}$

When the vertical stress was zero, the hydraulic conductivity value for fresh MSW was 0.2 cm/s and then decreased to 1.23*10$^{\wedge-4}$ m/s when the number of compactions was 50. The MSW sample's hydraulic conductivity decreased to 2.55*10$^{\wedge-5}$ m/s under the number of compaction was 90. The results visibly demonstrate that vertical compression can notably influence the hydraulic conductivity of MSW. These results are mainly accredited to the low void ratio which is a result of increasing density of MSW [7]. It can be noticed that the hydraulic conductivity values in each model have been reduced because of the number of compaction degrees.

Model SAM1 has a hydraulic conductivity value of (1.23×10^{-4} m/s), while model B is (0.96×10^{-4} m/s) and model C is (2.55×10^{-5} m/s). The compaction time required for model A is (16min), model B (32 min) and C (46 min). Compaction time play an important economic role in the landfill management. Reducing the time taken to compact the waste can decrease the demand for supplies, including compactor numbers, operators, the cost of maintenance, greenhouse gas emissions, etc. [5]. The moisture to the wastes have an advantage, including the increase in workability and unit weight and to shorten the period of compaction of the waste [12]. The mutual special impacts have noteworthy economic modulation for landfill applications [19].

An evaluative comparison of considered hydraulic conductivity results in this study with those explained in the literature on field landfill studies showed a high variation in their values. The hydraulic conductivity test carried out by [16,20,21] revealed that decomposed MSW sample landfill had much lower hydraulic conductivity values ranges (1.05×10^{-4} m/s - 3.0×10^{-6} m/s) than the fresh

MSW tested in this study (1.23×10^{-4} m/s - 2.55×10^{-5} m/s). The reported field MSW hydraulic conductivities show lower values than that of laboratory results. Moreover the MSW of landfills has less hydraulic conductivity than fresh MSW, highlight the increase in the minute particles resultant from degraded MSW particles. The hydraulic conductivity reduction with dry unit weight increasing is explained by the function of an exponential decay [7].

4. Conclusions and recommendations

This study was carried out to find hydraulic conductivity and compaction features of three MSW samples in laboratory conditions. Effects of settings of operation (moisture content, compaction degree, and compaction period) on hydraulic conductivity were examined.

The main points that can be concluded from this study are:

- The hydraulic conductivity values of MSW were (1.23×10^{-4}, 0.96×10^{-4}, and 2.55×10^{-5}) m/sec for samples SAM1, SAM2 and SAM3.
- Hydraulic conductivity values in each model have been reduced because of the number of compaction degrees. The compaction time required for model SAM1 is (16 min), model SAM2 (32 min) and SAM3 (46 min).
- The packing density had a clear impact on the MSW's hydraulic conductivity.
- The interconnection between the void ratio and space considers a significant impact on the hydraulic conductivity of MSW. Dry unit weights can be deemed a more suitable parameter to measure in replacement of the void ratio when a specific gravity can be considered a constant. The results from this research clearly illustrated that the hydraulic conductivity of MSW is considerably affected by the downward pressure and generates a trend where a decrease in hydraulic conductivity results in an increase in dry unit weight.
- Fresh MSW used in this study resulted in higher hydraulic conductivity values than the hydraulic conductivity in landfilled MSW as reported by literature. The reduction in MSW hydraulic conductivity in landfill can be linked to the increasing smaller particles resulting from ecological degradation;
- This work's perspective is to model the saturated flows resulting from this finding suitable for various solid waste types.

This research will help enumerate the difference in hydraulic conductivity of MSW attributable to the setups of various laboratory test and the distinctive variety of hydraulic conductivity values of freshly waste materials. Further research is necessary to thoroughly assess the impact of other factors like particle size and sample size and the leachate's quality on the hydraulic conductivity of MSW. Also, the characterization of MSW due to its heterogeneity and degradability should be studied well to find the temporal and spatial variation of hydraulic conductivity.

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