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Laboratory Investigation of Hydraulic Conductivity of Fresh and Degraded Municipal Solid Waste

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Abstract. This paper presents a laboratory investigation of the hydraulic conductivity of municipal solid waste (MSW). A series of laboratory tests were conducted on fresh and aged samples in a large-scale rigid wall permeameter. The unit weight of samples varied in the range of 7.24 to 9.81kN/m^3. The hydraulic conductivity varied in a narrow range of 9.70 x 10^{-2} to 1.45 x 10^{-3}. The study showed a decrease in hydraulic conductivity as the unit weight and age of the sample increased. However, there was no unique relation observed between hydraulic conductivity and unit weight. The age of the sample was observed to be a controlling factor in hydraulic conductivity because of degradation. The results demonstrated that hydraulic conductivity is a function of void spaces present in the sample and independent of degradation and unit weight. An exponential decay function expresses the decreasing hydraulic conductivity with the decrease in void ratio.

Keywords: Hydraulic Conductivity, Municipal Solid Waste, Degradation

1 Introduction

Hydraulic conductivity (k) of Municipal Solid Waste (MSW) is an important parameter considered in the design of landfills, particularly in the design of leachate collection and removal systems [1]. Understanding of k gives insight into the leachate pressure distribution and its effect on effective stresses and shear strength of MSW [2]. However, understanding the movement of liquid through porous MSW is a hard task. In the field, this movement depends on the heterogeneous nature and placement of MSW. Other significant factors contributing to a variation of k of MSW are composition, compaction, overburden pressure, and percent of degradation [3]. The degradation effect over k is a highly complex phenomenon and has not yet been sufficiently studied [4]. Furthermore, a change in particle size because of degradation may increase or decrease the value of k [5].

The laboratory has no standard method available for measuring k of MSW. However, researchers used constant head and variable head permeability test methods widely used to measure k for soils [5],[6],[7],[3]. Most researchers worked on the correlation between dry unit weight (γ_d), and k. Fig. 1 shows the k from different studies as a function of γ_d. There is a wide range of k in eight orders of magnitude. It can be observed that there is no specific correlation between k and γ, but the trend suggests a decrease in k as γ increases. However, some studies reported variation in k with the same γ because of degradation. Breitmeyer et al. (2019); Miguel et al. (2018); Reddy et al. (2011); Beaven et al. 2008 also got the value of k at different stages of decomposition [5],[4],[8],[9]. The study of Reddy et al. (2011) showed an exponential correlation between k and the degree of degradation [8]. Miguel et al. 2018 [4] showed a decrease in k as degradation increases. Similar observations were reported by Breitmeyer et al. (2019) [5]. It is well understood that k of any material depends on the voids present in the material. Many correlations have been derived between the k and void ratio (e) in soil mechanics. Published literature shows a limited number of studies on k of MSW as a decomposition function, $\gamma_{d,}$ and e at variable comapactive effort.

This paper focuses on the effect of degradation on k at different values of γ_d. Fresh and aged MSW samples were tested in the laboratory. γ_d was varied by varying the compactive efforts. The correlation between γ_d and k was studied at different compactive energy levels. Variation of k as a function of e was also investigated.

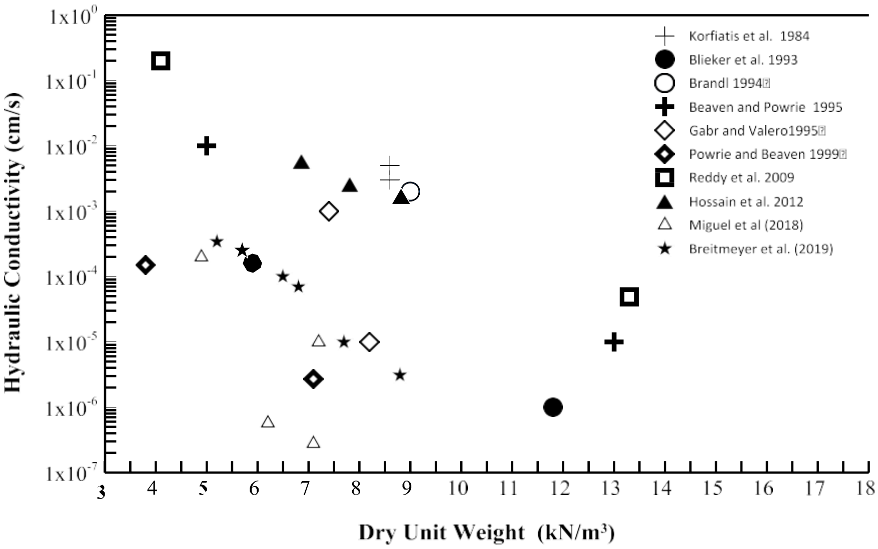

Fig. 1. Hydraulic conductivity versus Dry unit weight correlation reported in the literature

1.1 Sample Collection and Characterization

MSW samples were collected from the working phase of the solid waste management site in Vilholi Nasik (Maharashtra, India). The details of the landfill site and sample collection procedure are explained in [10]. The composition of MSW was done according to [11]. Incoming fresh MSW (S_1) included food 57.8%, paper and cardboard 1.92%, plastic 1.68%, textile 0.32%, leather 0.3%, rubber 0.09%, garden trimming 30.48%, wood 0.34%, glass0.53%, ferrous and non-ferrous metal 0.36%, and soil 4.33%. Windrows sample (S_2) of an age of 2 months was collected from the windrows section while five-year-old MSW (S_3), ten-year-old MSW (S_4), and fifteen-year-old MSW (S_5) were excavated from the landfill during the reconstruction phase. The MSW components were easily biodegradable, moderately biodegradable, hardly biodegradable, and inert waste [12]. The composition of all samples is tabulated in table 1.

Table 1. Composition of MSW in Nasik, MH, India

Sr No	Category	Component	Waste Composition (% by wet Mass)				
			S_1	S_2	S_3	S_4	S_5
1	Easily Biodegradable	Food	54.0	54.1	0.0	0.0	0.0
2		Garden Trimmings	24.5	25.2	8.2	0.0	0.0
3	Medium Biodegradable	Paper	3.4	1.0	0.2	0.0	0.0
4		Cardboard	1.8	4.9	0.0	0.0	0.0
5	Hardly Biodegradable	Wood	3.1	1.3	12.7	5.2	10.8
6		Textile	0.8	0.8	8.5	3.7	1.2
7		Leather	0.8	0.5	2.9	3.0	0.0
8		Rubber	0.6	0.9	2.9	0.0	0.0
9	Inert Waste	Plastic	3.3	5.4	26.4	3.7	0.0
10		Glass	0.8	1.7	9.3	0.6	0.0
11		Ferrous Metal	0.3	0.7	0.0	2.0	0.0
12		Nonferrous Metal	0.3	1.5	0.3	3.1	3.0
13		Ash, fine earth and others	6.2	1.9	28.7	78.7	84.9

It can be seen that the fresh MSW and windrows sample consists of approximately 11% non-biodegradable components. As the age of MSW increased from 5 to 15 years, the non-biodegradable component increased up to 88% showing completion of the biodegradation process. The moisture content of the S_1, S_2, S_3, S_4, and S_5 samples was 81%, 68%, 22%, 13%, and 3%, respectively. Specific gravity (Gs) of all MSW samples was determined using a water pycnometer. The average G_s values were 1.15, 1.12, 1.16, 1.29, and 2.08 for the S_1, S_2, S_3, S_4, and S_5 samples.

Particle size distribution was conducted. All MSW samples were air-dried for several days to reach a constant water content of 5 -7% and then sieved through a set of sieves from a sieve of 80 mm to a sieve of 0.075 mm. Fraction retained on each sieve was weighed, and the percentage passing was calculated. Fig. 2 shows the particle size distribution of fresh and aged MSW samples. The fresh waste contained approximately 30% of particles finer than 10mm. However, as the age of the sample increased from two months (windrows sample) to 15 years percentage of finer increased by up to 60%. This increased amount in the finer particle is attributed to the degradation process, which disintegrates the particles causing a size reduction. Fig. 2 shows the general trend of decreased particle sizes in fresh MSW to highly degraded 15-year-old MSW samples. Reddy et al. (2015) made similar observations with a decrease in MSW particle size when the degree of decomposition increased from 43 to 73% [11].

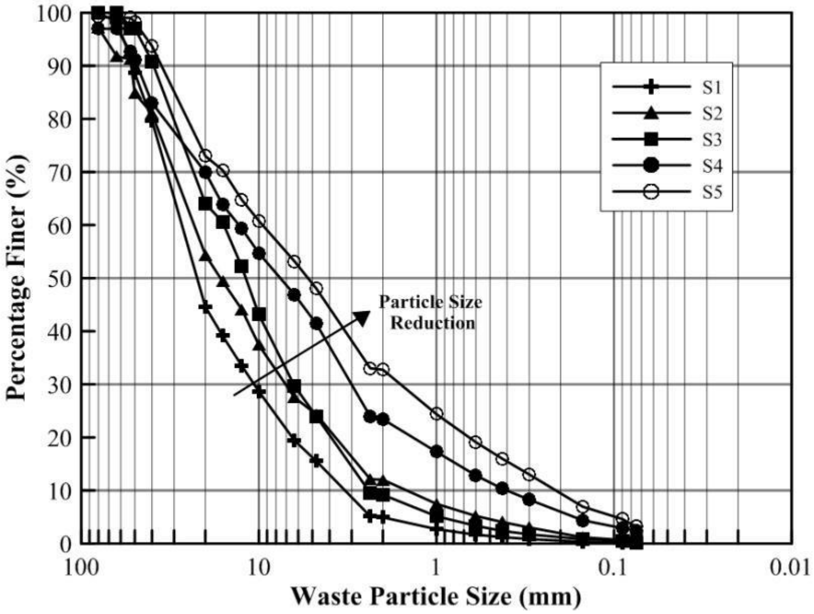

Fig. 2. Particle size distribution of fresh and degraded MSW samples

2. Hydraulic Conductivity Measurement

A schematic of a large-scale rigid wall permeameter designed in this study to measure k of MSW in the laboratory is shown in Fig. 3 (a) & and experimental set up photograph Fig.3 (b). The permeameter consisted of an acrylic cylindrical mold with an inner diameter of 43cm and a height of 60cm. Mould was placed between two aluminum endplates clamped together by stainless steel rods and sealed with O rings. A drainage valve was installed on a bottom plate connected to the measuring tank through flexible tubing. A geotextile and 3 cm gravel layer was placed between the MSW sample and the bottom plate to avoid possible clogging into the bottom drainage valve. The top plate had provision for a water inlet. A perforated plate was placed above a 3cm layer of gravel above the MSW sample for uniform water distribution. The perforated plate was screwed to a central piston. The piston went through an opening on the top plate without contacting the plate, allowing the perforated plate and sample to settle without any friction. The top endplate and piston opening was sealed with a Neoprene membrane sleeve. A dial gauge was fixed at the top of the top plate and connected to the piston to monitor vertical movement.

2.1 Testing Procedure

A constant head hydraulic conductivity test was used to determine k for all five MSW samples. Unthreaded samples were prepared using compaction at various energy levels at optimum value. Each sample was initially mixed homogeneously with water considering the amount of moisture present to achieve targeted moisture content. An additional 5 to 10 ml per kg of a water sample was added to account for any evaporation loss. To achieve equilibrium, the water content sample was stored in closed containers for 16-24 hrs, and water content was measured before the test. The sample was compacted in layers of 7- 8 cm thickness to achieve the required density. The additional pressure of 1 to 2 kPa was applied through the central piston to maintain the density throughout the test. The movement of the piston was monitored from the dial gauge. The sample was saturated by allowing water to percolate upwards by regulating the drainage valve at X. until water emerged from an air vent first and then from a valve at X.

Immediately after saturation, the central piston was pushed down to ensure the perforated plate was in touch with a gravel bed. A new sample height was then recorded. Next, a constant head permeability test was performed three times for each sample by measuring discharge for up to 3 minutes.

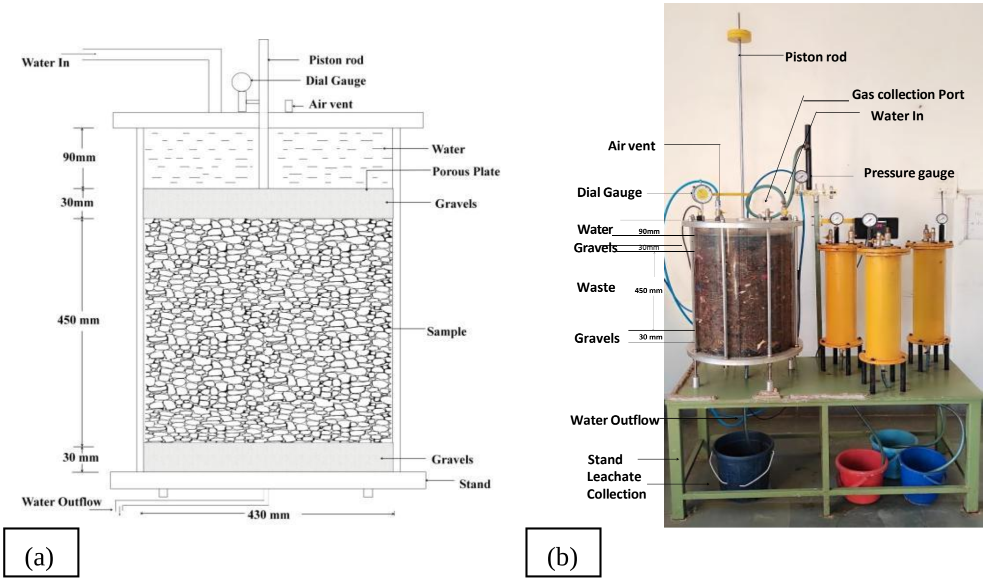

Fig. 3. (a) Schematic diagram (b) Photo of hydraulic conductivity measurement set up

3 Results and Discussion:

Twenty constant head hydraulic conductivity tests were performed on fresh and aged MSW samples, resulting in a range of k of 9.70 x 10^{-2} to 1.45 x 10^{-3}. Table 2 summarises the densities achieved and corresponding values of k and e. The γ_d of the tested samples varied in the range of 7.24 to 9.81kN/$m^{3,}$ while the e varied from 1.63 to 0.94. Fig. 4 shows the variation of k to γ_d for different samples tested. The k of each sample was decreased by as much as 68% with increasing γ_d. A separate trend of k with γ_d for each sample was observed in this study, which is shown in Fig. 4. The slopes in Fig. 4 were obtained by least-square linear regression representing the order of magnitude decrease in k with an increase in γ_d. For aged samples (S_3, $S_{4,}$ and S_5), the slope is flat compared to fresh samples (S_1 and S_2), indicating little variation of k with an increase in $\gamma_{d.}$ This indicates that pore structure within the MSW mass varies significantly as MSW degrades.

Table 2.Hydraulic Conductivity Measured in large scale permeameter

Energy Level	E1			E2			E3			E4		
Waste	k (cm/s)	γ_d (kN/M^3)	e	k (cm/s)	γ_d (kN/M^3)	e	k (cm/s)	γ_d (kN/M^3)	e	k (cm/s)	γ_d (kN/M^3)	e
S_1	9.70E-02	7.24	1.63	7.01E-02	7.84	1.43	5.28E-02	8.45	1.25	3.97E-02	8.52	1.23
S_2	6.54E-02	7.69	1.47	4.70E-02	7.84	1.43	4.03E-02	8.17	1.33	2.06E-02	8.45	1.25
S_3	6.74E-03	8.30	1.29	6.04E-03	8.47	1.25	5.28E-03	9.12	1.09	3.94E-03	9.32	1.04
S_4	2.74E-03	7.91	1.41	2.24E-03	8.01	1.37	1.42E-03	8.60	1.21	1.24E-03	9.27	1.05
S_5	2.38E-03	8.20	1.32	1.82E-03	9.12	1.09	1.61E-03	9.92	0.92	1.45E-03	9.81	0.94

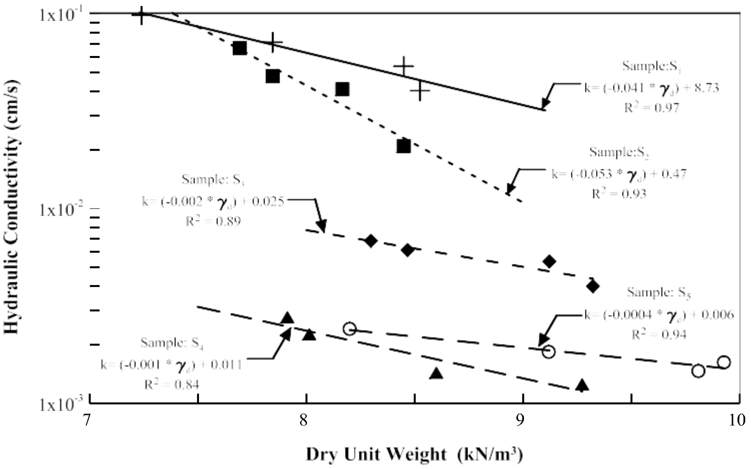

Fig. 4. Relationship between hydraulic conductivity and dry unit weight.

The sample's age was observed to be a significant factor controlling k because of degradation. The k decreased by 4% to 9% as the sample's age increased from fresh (S_1) to 15 years (S_4). Similar observations were made by [8],[13]. The results clearly showed that k is influenced by degradation. This is mainly attributed to changes in the structure of MSW, reduction in particle size, and increased density, leading to decreased void ratio. Fig. 5 shows the variation of k to percentage finer (D_{10}). It can be seen that k decreases as the percentage finer increases. This is caused because of free space available between larger particles and more water-absorbing capacity of biodegradable material. As biodegradation proceeds, larger particles break into smaller particles, filling empty spaces within the MSW structure and increasing the water flow path. Fig. 5 also shows the effect of compactive energy on k. For the same percentage, finer (D10) k reduces by 1 when compactive energy increases from E_1 to E_4.

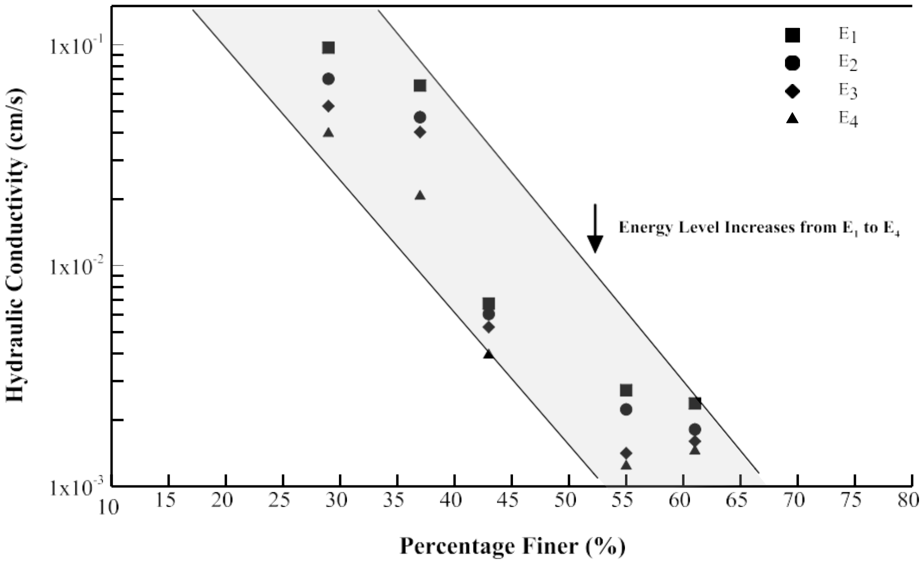

Fig. 5. Variation of hydraulic conductivity with percentage finer

The k measured in this study is shown as a function of e in Fig. 6. k decreases as the value of e decreases regardless of decomposition and compactive efforts used to vary the density. Empirical correlations have been developed between k and e in soil mechanics [14]. For example, Breitmeyer et al. 2019 [5] showed the similarity between fluid flow in MSW and normally consolidated clay. The following equation has been suggested to co-relate the k with e [15].

$$k = \lambda\left(\frac{e^{\beta}}{1+e}\right) \tag{1}$$

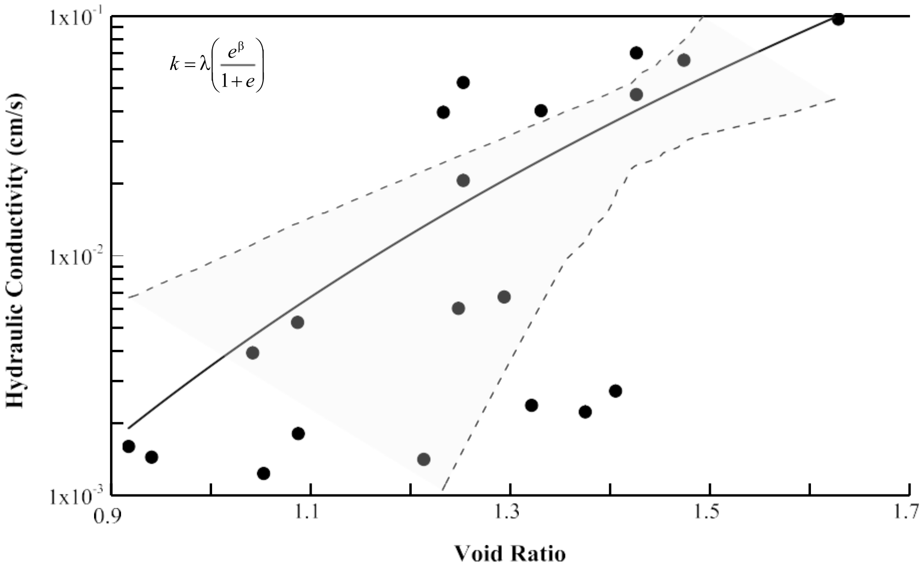

Fig. 6. Hydraulic Conductivity versus void ratio

Where λ and β are empirically derived parameters. Equation 1 best fits the laboratory data generated in this study using linear least-squares regression, as shown in Fig. 4. The best fit parameters were $\lambda = 6.95 \times 10^{-3}$ cm/s and $\beta = 7.45$ with correlation coefficient of 0.79. The shaded area in Fig 4 includes 95% of the data measured in this study.

4. **Conclusion**:

The effects of dry unit weight, compactive effort, and degradation on the hydraulic conductivity of MSW have been studied using large-scale laboratory tests. Fresh and degraded aged samples were collected from the landfill site. The main findings of this study are:

1. The k of MSW is a function of γ_d. The value of k decreased as γ_d increased at constant decomposition because of a change in the pore structure. Thus, the correlation between k and γ_d is not unique and varies as a state of degradation changes.
2. The k of MSW in this study is more sensitive to degradation. This is attributed to a change in the structure of MSW and a reduction in particle size. As the percentage finer increased due to degradation, k decreased.
3. A correlation exists between k and e of MSW in this study. The k can be predicted with a good correlation coefficient from the empirical equation, irrespective of degradation.

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