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Hydraulic Conductivity of Fresh Municipal Solid Waste at Various Compositions and Compactive Efforts

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Abstract. Bioreactor landfills are a recent invention in the field of waste management. However, the successful operation of these landfills mainly depends on additional moisture content and physical and engineering properties. Accordingly, the hydraulic properties of wastes and their impact on the flow of fluids within the waste mass will also be affected. Hydraulic con- ductivity is greatly influenced by the composition, particle size, unit weight, compaction, and biodegradation of MSW. Therefore, understanding municipal solid waste's hydraulic properties at various parameters need to be investigated. The objective of the present study is to determine the effect of different compositions and particle sizes of fresh MSW on hydraulic conductivity at various compactive efforts. The Bioreactor simulator was used for experimental investigation under anaerobic conditions in a laboratory. A constant head laboratory test was conducted on fresh MSW at different compositions, particle sizes, and energy levels. The coefficient of permeability k was found to be 1.16 $x10^{-2}$ to 9.85 $x10^{-3}$ cm/sec. The results show decreased hydraulic conductivity of MSW at a reduced particle size and increased energy levels. This study gives a wide range of k for predefined compositions of biodegradable & non-biodegradable components of fresh MSW at various compactive efforts.

Keywords: Municipal solid waste, Hydraulic conductivity, Composition, Particle size, Compactive efforts

1. Introduction

The municipal solid waste is a mixture of paper, food items, cardboard, plastic, tex- tile, leather, rubber, gardening material, wood, glass, ferrous & non-ferrous metals, brick & miscellaneous items. The nature of MSW is the heterogeneous mix in land- fills. United States represents 40% and 60% of non-biodegradable and biodegradable components in MSW, respectively [1]. Whereas developing countries like India con- tain 76.2 % of biodegradable material in Pune City[2]. Developing countries show more biodegradable waste as compared to developed countries. Similar results were found in the United States & India [3]. The per capita generation of MSW is high in the states of Gujrat, Delhi, and Tamilnadu (India), due to the rapid economic growth & urbanization. However, it is less for other states of India like Meghalaya, Assam, Manipur, and Tripura. The metro cities of India produce around 3% to 10% of paper, 1% to 9% of textile, and plastic from 1% to 10%, organic matter 30 to 48%, and soil-like particles 30 to 50%, respectively (Sharholy et al.2008). It depends on population density as well. Municipal Solid Waste (MSW) generation is increasing, resulting in environmental degradation and pollution. India generates 0.1 million tonnes of solid waste per day, expected to rise to 33 percent in the next 15 years [14].

MSW is categorized based on easy, medium, hardly biodegradable, and inert waste [4]. The non-biodegradable material contains metal, plastic bottles, glass, and inert waste, Whereas food, garden waste, paper, textile, cardboard, sanitary waste & nap- pies are considered a biodegradable materials. On the other hand, Dixon et al. 2008 reported that the composition of MSW varies from country to country, season to sea- son, locality, the standard of living, legislation, and the mentality of users. Hence- forth it becomes difficult to characterize MSW's engineering properties such as set- tlement, compressibility, shear strength, hydraulic conductivity, and unit weight with changing compositions at true landfill conditions [5],[6],[7].

During the biodegradation process of MSW, the composition, unit weight, and particle size alters due to increased percentage finer. Ultimately results in decreased hydraulic conductivity, increased unit weight, and lesser voids. However, these changes have not been explored due to the limitations of field measurements. Based on the heterogeneity mix present in MSW, the hydraulic conductivity of MSW was investigated at different percentages of paper and organic waste. Ramil et al.(2009) include paper content of 25% to 52% and organic waste of 48% to 75% [8]. The falling head permeability test was conducted for five different combinations of waste. The permeability 'k' and void ratio 'coefficient ranges between 1.57x10-4 cm/sec to 3.23 x 10-4 cm/sec, and the void ratio ranges from 4.47 to 4.83. The results show that 'k' is reduced for a higher percentage of organic content due compaction effect and more densification than paper.

Furthermore, the effect of waste composition on physical, hydraulic, and biochemical properties with the degradation process was studied by [5]. The composition of MSW material taken for laboratory studies was based on finer portion passing from 20mm sieve-like soil material and retained on 20mm such as wood, paper, and plastic. It was found that the hydraulic conductivity decreased with the increased biodegradable material. In addition, it shows the presence of more fine particles with degradation, resulting in a lesser void ratio. The minimum initial coefficient of permeability was recorded as 0.1 cm/sec. Reddy et al. (2015) explained the importance of the composition of MSW for geotechnical testing purposes in laboratories and fields to simulate true landfill conditions [9]. Dixon et al. (2005) also reported that MSW's unit weight depends on its composition [3]. However, the composition of MSW includes weight of soil cover, waste placement, method of compaction, depth, moisture content, and age of waste. During an experimental investigation of the engineering properties of MSW, the composition of MSW is an essential parameter for safe landfill design. Hence it is accounted for analysis and design of landfills.

Though the importance of the composition of MSW is very much essential, very few studies were conducted on the hydraulic conductivity of MSW at varying compositions, particle sizes, and energy levels. Therefore, additional research is required in the current changing scenario of MSW. The present study investigates the hydraulic conductivity of fresh MSW at different compositions, particle sizes, and energy levels. The Particle size taken for the laboratory testing program was passing of 16mm,12.5mm,10mm, and 4.75mm, which is not greater than $1/10^{th}$ of the diameter of the simulator. As a result, organic content decreased from 65 to 56%, plastic content increased from 10 to 18%, and energy levels were defined based on the number of blows per layer, such as E_1, E_2, E_3, and E_4 from the literature. The simulator of 200x400 mm was used for laboratory testing, and a constant head test was performed.

2. Experimental Investigation

2.1 Sample collection and characterization

Fig.1.shows the study area of the dumping ground of Sangamner (MH), India, from where fresh MSW sample was collected. Around 25.8 MT tonnes of solid waste is generated daily in Sanganer city. Most of the waste generated by the city includes wet waste like paper, vegetable waste, market waste, clothes, dry waste, and plastic. The household's living standard and income level positively relate to waste generation. Around 250 kg of waste was collected, filled into plastic bags, and brought to the research laboratory of Sandip University, Nasik. Sample characteriza- tion of fresh MSW shows 56.8% of easily biodegradable material,7.6 % medium bio- degradable,15 % hardly biodegradable, 16.8 % of inert waste, and 3.8 % of residual fines [4].

Fig.1. Study Area of Dumping ground of Sangamner

2.2 Simulator Details

The dimensions of the simulator are 200mm in diameter and 400mm in height. Three simulators were fabricated and made up of mild steel material.Fig.2. depicts the pho- tograph of the experimental setup and components of the simulator. Each simulator consists of a pressure gauge, inlet valve, gas collection port, and drainage valve. The pressure gauge is provided at the top of the simulator to measure the amount of gas generated within the simulator. An Inlet valve is used to enter the water from the overhead tank

Finally, the drainage valve serves the purpose of collecting the water from the bottom of the simulator. The simulator maintained the anaerobic condition by providing an ‘O’ ring to the top plate. The overhead tank of 1m height is placed at the higher level of these three simulators to maintain the constant head of water. All the connections are connected through a flexible tube from the overhead tank to the simulators.

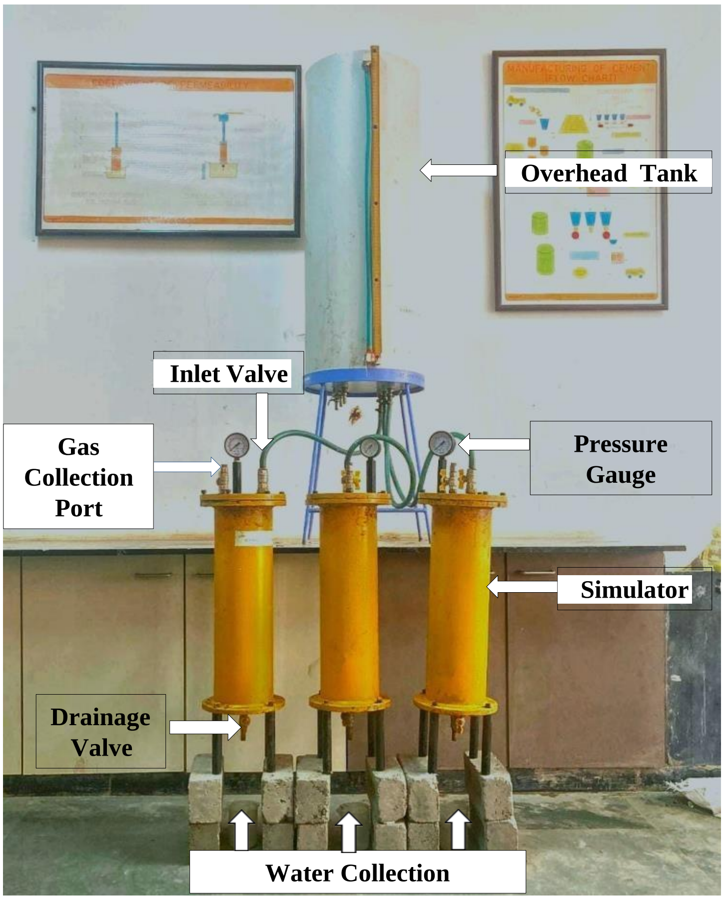

Fig.2 Photograph of Experimental Setup

2.3 MSW sample compositions, preparation, and filling

MSW samples were segregated according to the particle size passing from 16mm,12mm,10mm, and 4.75 mm sieve sizes containing paper, plastic, organic, textile, and other soil-like materials. During the characterization of MSW, the organic content and plastic were found somewhat less for experimental investigation, thas why additional organic waste and plastic material was added to a sample to achieve the targeted percentages. Therefore, five different compositions of MSW were pre- pared with increasing non-biodegradable and decreasing biodegradable matter.

Table 1 shows the compositions of MSW known as CM_1 to CM_5. The composition mix (CM_1) was taken for a particle size of 16mm by adding 20.63% paper, Plastic 10%, organic 65%, textile 2.5%, and 1.25% of other soil-like materials. All compo- nents of MSW were mixed properly, and added additional water to achieve desired moisture content. The mix was kept for 24 hrs in a container to form a homogeneous mix and taken for testing on the second day. The remaining compositions of MSW were prepared as per Table 1 by the same method, called CM_2, CM_3, CM_4, and CM_5.

Fig.3 shows the graphical representation of MSW composition with easy, medium, hard, inert, and other soil-like particles.

Table1. Five different compositions of MSW in percentage

Composition type	Paper	Plastic	Organic	Textile	Other
CM_1	20.63	10.00	65.63	2.50	1.25
CM_2	18.75	11.88	63.75	3.75	1.88
CM_3	16.88	13.75	61.25	5.63	2.50
CM_4	13.75	16.25	59.38	7.50	3.13
CM_5	12.50	18.75	56.25	8.75	3.75

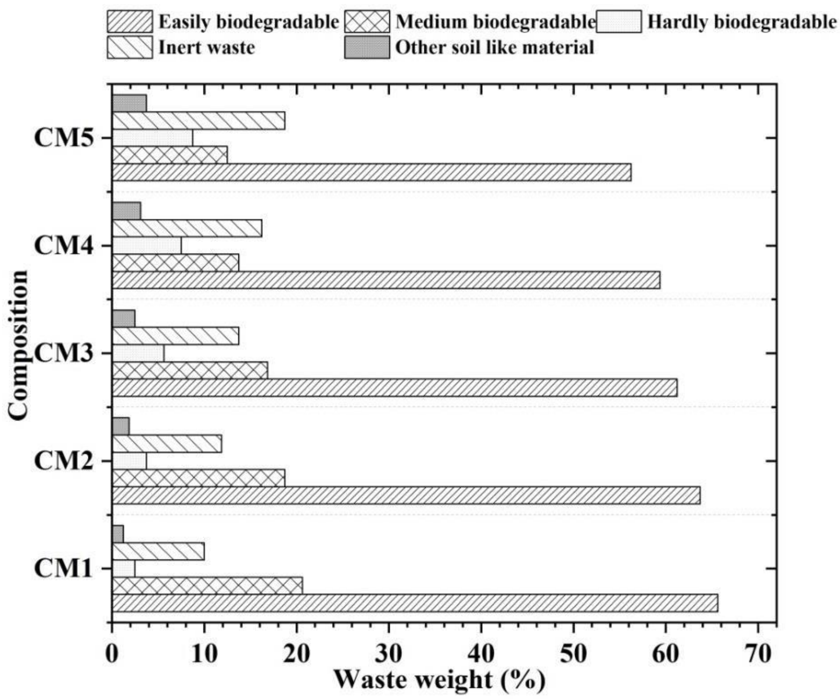

Fig.3 MSW composition mix

3. Hydraulic conductivity Measurement

Based on the compositions and compactive, the constant head permeability test was conducted on the Fresh MSW sample. First, the simulator was checked for any leakages, and the bottom valve was made closed. Next, the filter paper and gravel layer were placed at the bottom of the simulator to avoid clogging. Over which the first layer of composition mix (CM_1) was placed and compacted with 25 blows, i.e., Ener- gy level one 576 kJ/m^3(E_1) as per the standard proctor test. The same procedure was followed for the second and third layers. Once the sample was compacted, the gravel layer was placed on top, and the assembly was closed. The sample density achieved during the testing varies from 3.2 kN/m^3 to 6.8 kN/m^3 at energy levels E_1 to E_4, respectively. Finally, the inlet valve was made open and allowed the sample for saturation.

The continuous water flow was checked to know the sample's saturation level. Before the discharge measurement, the gas, which was generated in the simulator, was removed safely. The discharge was measured for 60 secs, the procedure was repeated three times for accuracy purposes, and the average was noted down [10]. The same procedure was repeated for the rest of the targeted energy levels of 1152 kJ/m^3 (E_2), 1100 kJ/m^3 (E_3), and 2200 kJ/m^3 (E_4). Finally, the remaining composition mix CM_2, CM_3, CM_4, and CM_5 were tested for the different particle sizes and energy levels using the same procedure. Around eighty constant head laboratory tests were conducted during the testing program.

4. Results and discussion

The establishment of the waste composition is essential for this study, especially to identify the trend or effect of composition on permeability. Therefore, to sustain the properties of fresh MSW, each sample composition was weighed on the same day to ensure that there was no additional leachate generation leading to extra weight and several other changes to the sample properties. In sangamner city, most of the recyclable material was gathered or sorted out during the waste collection before the waste plastic bag was thrown into the compactor. These recyclable materials were sold before wastes were sent to the transfer station. As a result, a very low per- centage of glasses, plastic, and metal were found in the collected samples. How- ever, these materials can still be found in the samples but small pieces. Thus, thewaste composition, the only waste group from paper, plastic, organic, and textile, was recovered., As expected throughout during collection of MSW, the organic waste was the highest composition of all, as shown in Fig. 3

4.1 Waste permeability and composition

The constant head test was conducted to determine MSW's hydraulic conductivity. The permeability 'k' coefficient based on the above, plastic and organic waste per- centages were rearranged into five different compositions. As a result, the organic waste ratio from 65 to 56% and plastic content increased from 10 to 18%, respective- ly. Chen and Chynoweth (1995) observed the gas generation inside the permeameter due to MSW's biodegradation; it was drained through piezometers [11]. The gas for- mation was done due to the space available, i.e.porosity in the MSW sample. The space formed by the gas is replaced by MSW particles, leading to a decreased volume of voids and, consequent, the permeability of MSW. The present study also shows thegas generation in the simulator during the targeted saturation level, which was noted on the pressure gauge and drained out properly.

The permeability coefficient ranged from 1.16x10-^{2} to 9.85 x10^{-3}, whereas the void ratio was between 1.33 to 1.99. The result showed a value similar to the permeability obtained by other researchers, between 10^{-2} cm/sec and 10 $^{-4}$ cm/sec, as published by Oweis I. S. (1998) [12]. Table 2 shows the permeability coefficient, density, and void ratio at energy levels E_1, E_2, E_3, and E_4 for mentioned particle sizes. It was observed that hydraulic conductivity and void ratio decreased at increased energy levels. In addition, it shows increased compressibility of MSW during compaction. Resulting in the conversion of more fine particles from E_1 to E_4.

The changes in density condition in the MSW will rely only on the rearrangement of waste composition during the mechanical compaction process in the simulator. The same predictions were made by [6],[13]. From visual observation, it was found that the paper content soaked the water in the simulator due to less water flow at the outlet during discharge measurement. Fig. 4 to fig.7 shows the coefficient of permeability Vs. void ratio @ 16 mm,12.5mm,10mm, and 4.75mm for different composition mix- es.The results show as the percentage of non-biodegradable matter like plastic materi- al increased in the MSW samples, the hydraulic conductivity also increased. The sur- face of plastic material is smooth and can cause an easy flow of water through the sample. The obtained results were somewhat contradictory to published results.

4.2 Waste permeability and particle size-

The comparison of the average hydraulic conductivity of MSW and its wastecompo- sition shows that permeability is highest for the 16mm particle size at E_1, and it is lowest for the 4.75 mm particle size at E_4. It shows the increased densification of particles with lesser particle sizes. Comparing permeability and density are inversely proportional to each other; the higher the permeability lower will be the density, the lower the permeability higher will be the density at the same sample composition and energy levels, except at some energy levels. Variances in some sieve sample composi- tion and energy levels affect MSW's compressibility, as shown in Table 2. This was due to the rearrangement of the particles within the sample. All compositions shown were compressible components of MSW. These compressible compositions of differ- ent sieve sample particles at different energy levels have significance.

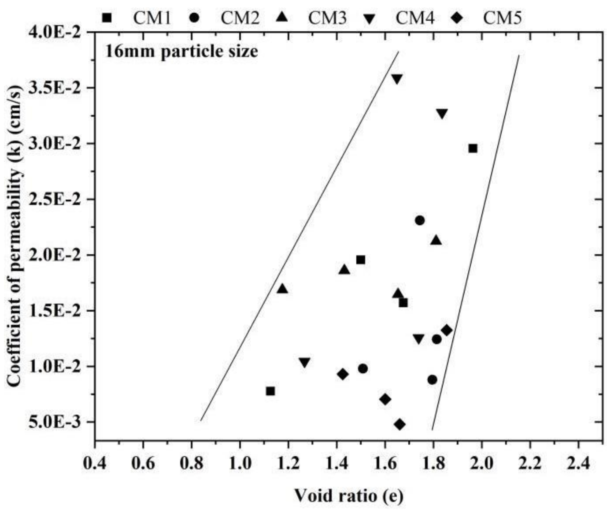

Fig. 4 Coefficient of permeability Vs. Void ratio @ 16 mm Parti- cle size for different composition mix

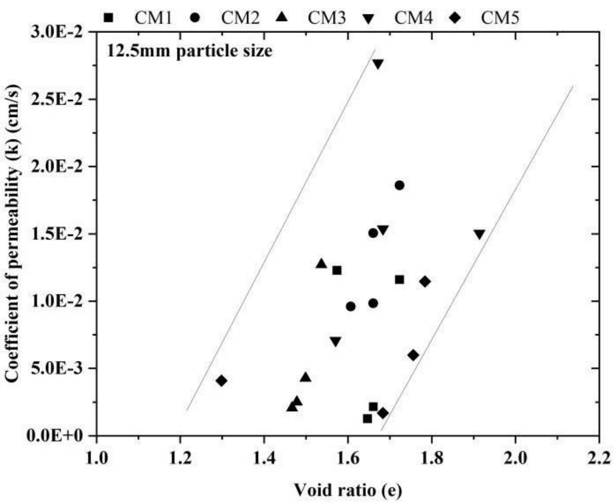

Fig. 5 Coefficient of permeability Vs. Void ratio @ 12.5 mm Particle size for different composition mix

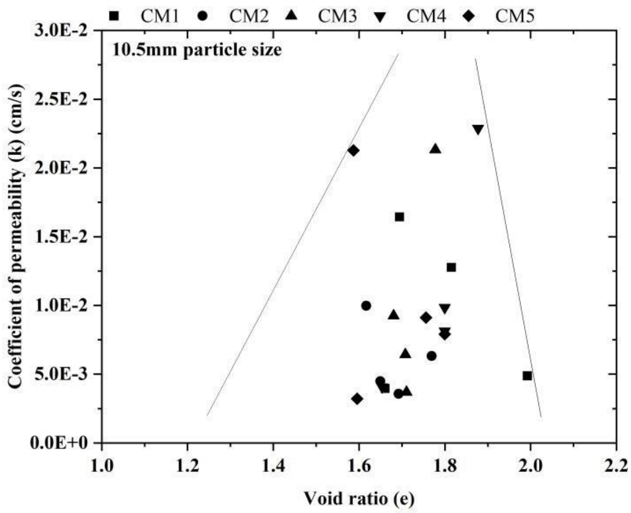

Fig. 6 Coefficient of permeability Vs. Void ratio @ 10 mm Particle size for different composition mix

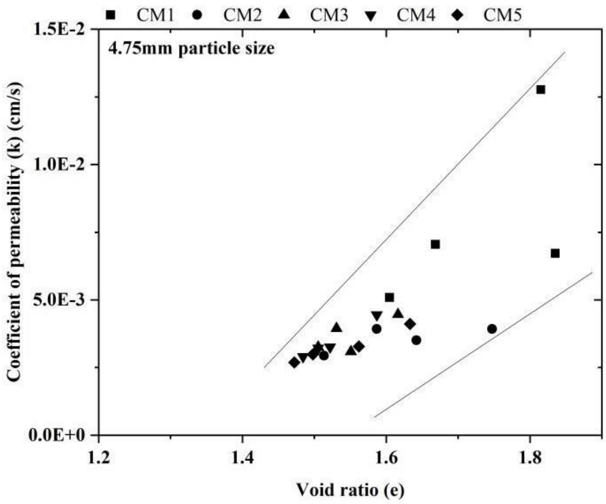

Fig.7 Coefficient of permeability Vs. void ratio @ 4.75 mm Particle size for different composition mix

Table 2. Hydraulic conductivity and density at Energy levels E_1, E_2, E_3 and E_4

Particle size 16mm												
	E_1-576 KJ/m^3			E_2-1152 KJ/m^3			E_3-1100 KJ/m^3			E_4-2200 KJ/m^3		
Sr. No.	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e
	cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3	
1	2.96E-02	2.57	1.96	1.96E-02	3.91	1.50	1.57E-02	2.85	1.68	7.78E-03	5.48	1.13
2	2.31E-02	3.57	1.74	8.79E-03	2.64	1.80	1.24E-02	3.26	1.81	9.79E-03	3.86	1.51
3	2.12E-02	3.26	1.81	1.69E-02	4.61	1.18	1.65E-02	4.16	1.65	1.86E-02	4.54	1.43
4	3.28E-02	3.33	1.84	1.26E-02	4..07	1.74	3.59E-02	3.67	1.65	1.04E-02	4.83	1.27
5	1.33E-02	4.03	1.86	7.06E-03	7.79	1.60	9.31E-03	5.63	1.43	4.81E-03	6.26	1.66
Particle size 12.5 mm												
	E_1-576 KJ/m^3			E_2-1152 KJ/m^3			E_3-1100 KJ/m^3			E_4-2200 KJ/m^3		
Sr. No.	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e
	cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3	
1	1.16E-02	4.49	1.72	1.23E-03	4.94	1.57	1.27E-02	5.36	1.65	2.16E-03	6.26	1.66
2	1.86E-02	4.49	1.72	9.59E-03	6.01	1.61	1.50E-02	6.26	1.66	9.84E-03	6.26	1.66
3	1.27E-02	5.47	1.54	2.52E-03	6.64	1.48	4.27E-03	6.16	1.50	2.07E-03	6.95	1.47
4	1.50E-02	3.33	1.91	1.54E-02	5.84	1.68	2.77E-02	4.02	1.67	7.08E-03	6.07	1.57
5	1.15E-02	4.59	1.78	5.99E-03	4.87	1.76	4.10E-03	7.13	1.30	1.69E-03	5.84	1.68

Particle size 10 mm												
	E_1-576 KJ/m^3			E_2-1152 KJ/m^3			E_3-1100 KJ/m^3			E_4-2200 KJ/m^3		
Sr. No.	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e
	cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3	
1	1.28E-02	3.24	1.82	1.64E-02	3.86	1.69	4.88E-03	3.34	1.99	3.96E-03	6.26	1.66
2	9.97E-03	4.48	1.62	4.49E-03	4.88	1.65	6.32E-03	4.73	1.77	3.57E-03	5.70	1.69
3	2.13E-02	4.06	1.78	9.24E-03	4.92	1.68	6.43E-03	4.64	1.71	3.69E-03	5.42	1.71
4	2.29E-02	3.89	1.88	9.85E-03	4.45	1.80	8.14E-03	4.45	1.80	4.07E-03	6.40	1.65
5	2.13E-02	4.79	1.59	9.12E-03	4.87	1.76	7.91E-03	4.45	1.80	3.21E-03	6.23	1.60
Particle size 4.75 mm												
	E_1-576 KJ/m^3			E_2-1152 KJ/m^3			E_3-1100 KJ/m^3			E_4-2200 KJ/m^3		
Sr. No.	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e	k	Density	Void ratio e
	cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3		cm/sec	kN/m^3	
1	1.28E-02	3.24	1.82	7.05E-03	5.07	1.67	6.72E-03	4.17	1.84	5.09E-03	5.47	1.60
2	3.92E-03	3.55	1.75	3.92E-03	4.79	1.59	3.51E-03	4.25	1.64	2.94E-03	5.87	1.51
3	4.47E-03	4.48	1.62	3.09E-03	5.25	1.55	3.94E-03	5.56	1.53	3.26E-03	6.03	1.51
4	4.44E-03	4.79	1.59	3.26E-03	5.72	1.52	3.21E-03	6.03	1.51	2.90E-03	6.49	1.48
5	4.11E-03	4.33	1.63	3.28E-03	5.10	1.56	2.98E-03	6.18	1.50	2.69E-03	6.80	1.47

5. Conclusions

The laboratory investigation of measurement of hydraulic conductivity using constant head tests was conducted on fresh MSW under various compositions and compactive efforts. The permeability coefficient (k), void ratio (e), and dry unit weight (γ) were measured at different particle sizes.

- The k of MSW in this study was more sensitive to particle size and composition. This is attributed to a change in the structure of MSW. As the particle size reduced, the percentage finer increased, and k decreased.
- An experimental investigation conducted in this study shows that percentage of non-biodegradable material affects the k. The presence of non-biodegradable material such as plastic increases the k because smooth surfaces within the sample structure enhance the water flow. On the other hand, the higher percentage of biodegradable material reduced the value of k because of ease of compressibility, reducing the presence of voids within the sample.
- Overall, this study helped to quantify the variation in k of different composition and particle sizes of MSW.

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