Effect of Synthetic Leachate on Stabilized Pond Ash in Msw Landfill

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Abstract

Municipal Solid Waste dumping in landfill site generates hazardous liquid that may pollute surface water bodies. As leachate contains heavy metals that is hazardous to health as well as soil beneath the landfill, landfill is integrated with a barrier layer called liner. To mitigate the effect of leachate and make landfill system sustainable, bottom liners are expected to behave as nonporous layer prohibiting leachate penetration below the bottom layer. As most of the coal ash in India are actually available in the form of pond ash or lagoon ash, in the present investigation, it is attempted to study the feasibility of using pond ash, with some modification, as a landfill liner material. In this study, pond ash has been collected from Nalco Captive Power Plant, Angul, Odisha. Falling head permeability tests have been conducted on seven types of mixes serially named S1 to S7 indicating varying proportions of pond ash, lime and gypsum specimens. Each stabilized sample was permeated with water, acetic acid, and methanol solutions after regular intervals of curing time. Among all stabilized sample, Sample S7 mix having 85% pond ash,14 % lime and 1% gypsum mix showed minimum permeability substantially for both the acidic and alkaline permeant. Sample having minimum permeability in various liquids was chosen further to test the coefficient of permeability with a synthetic leachate solution. The leachate solution was prepared in the laboratory and the concentration used in it resumed the concentration parameters of minerals present in MSW leachate.S7 sample was permeated with the synthetic leachate solution for both cured and noncured conditions of sample and varying continuous flow periods. The permeability was found to be $3x10^{-7}$ cm/sec after 30 days of continuous flow in 180 days cured sample after synthetic leachate permeation. All the effluent liquid coming out of the permeability apparatus outlet was examined for pH, Total Dissolved Solid (TDS), and Electrical Conductivity (EC) and showed the controlled value of pH, TDS, and EC as per "Municipal Solid Waste Management and Handling Rules,2000,India" when checked for inland surface water quality. On account of the results received, it is expected that in a real scenario this landfill liner will show minimal permeability and permissible value of pH, TDS, and EC keeping the ground and ground water protected.

Keywords: Permeability, Stabilization, curing, Synthetic Leachate

Introduction

Engineered Landfill is one of the important aspects of the design of a waste disposal facility that involves barrier that separates waste from the groundwater system. The hydraulic conductivity of liners is major concern now a days because of the possibility of mixing of contaminant leachate water with the ground water beneath. The leachate generated out of MSW in Asian countries including India consist of harmful pollutants that is responsible for many diseases. Central Pollution Control Board (India) and Environmental Protection Agency (U.S) guidelines for construction of landfill liner require that the material of landfill liner should have permeability, equal to or less than $1x10^{-7}$cm/sec. Various studies have investigated fly ash in waste containment liner system to be suitable to act as barrier to contaminant migration [1] .On many counts, coal ashes are nothing different from natural fine-grained soils. However, some of their beneficial characteristics make them score over soils when it comes to selecting the appropriate materials for various geotechnical applications that assist the bulk utilization of coal ashes. Studies have shown that permeabilities of the order 10^{-7} cm/sec is obtainable after proper improvement of soil with lime or cement stabilization. cementitious material. The coarser particles in fly ash can be improved by stabilization of fly ash with lime, gypsum or cement as chemical admixture [2,3]. Comparing the components of leachates of Indian MSW, it has been observed that the COD, PH and TDS values lie between the ranges of 8000-18,000mg/l,7-10 mg/l and 1800-000 mg/l respectively. The concentration of hazardous ions in leachates can be minimized by providing Pond ash liner stabilized with lime and gypsum [5-7]. Although many researchers emphasized on use of stabilized coal ash as landfill liner material, very few have studied the permeability behavior of synthetic leachate .Negligible number of literature are available on effluent metal concentration of stabilized pond ash permeated with laboratory made synthetic leachate [12].This experimental work depicts the permeability behavior of stabilized pond ash mixes with both acidic and alkaline conditions of leachate along with effect of curing time on pH, TDS and EC.

Materials and methods

For execution of the current work, Pond ash from the lagoon was picked up from NALCO Captive Power Plant, Anugul, Odisha.The material characteristics of pond ash are shown in Table 4 and Table 5 respectively. For the proposed work, lime was collected from market and examined for purity by titration method as 75%. Gypsum was received from biomall.in. The manufacture producer ensured 96% purity of the same. Acetic acid as acid solution and methanol as a base solution has been used as permeant in falling head permeability test. Synthetic leachate was prepared taking into consideration the real MSW composition from literature which consisted of 16 chemical solutions measured and mixed per liter of distilled water proportion (Table 2). Pond ash mixed with various percentages of lime and gypsum are expressed in Table 1. All The pond ash sample used in this test was compacted adhering to the light compaction test method mentioned in code, IS 2720: Part VII. The compacted matrix represents the 0.1m high liquid wet liner underlying the landfill.

Table 1 Proportioning mixes

Pond ash (% by weight)	Lime (% by weight)	Gypsum (% by weight)	Sample ID
100	0	0	S1
90	10	0	S2
86	14	0	S3
89.5	10	0.5	S4
89.5	14	0.5	S5
89	10	1	S6
85	14	1	S7

Permeability of all the samples designated in Table 1 were conducted in a falling head permeability test following IS code permeating it with tap water, acidic acid solution, methanol solutions, and synthetic leachate solutions respectively. The chemical species of Na^{+}, K^{+}, Ca^{++}, Mg^{++}, Cl^{-} and SO_4^{2-} that usually constitutes major inorganic components of the most municipal solid waste leachates are considered for preparation of synthetic leachate along with the predominant divalent cations like Ca^{++} and Mg^{++}[12,14].

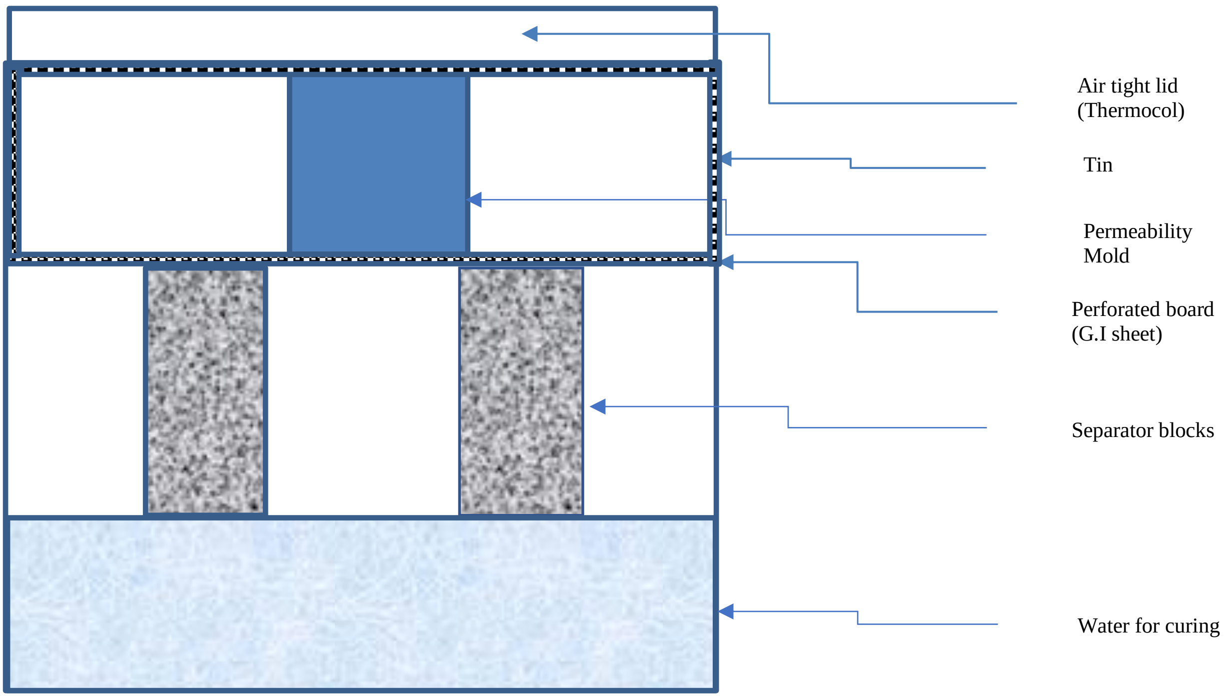


Figure 1. Sketch of curing apparatus for permeability test

All the stabilized specimens starting from S1 to S7 were cured in a local arrangement made with the help of tin, thermocol sheet, and galvanised iron sheet(G.I sheet) as shown in Figure 1.Galvanised iron sheets are excellent corrosion resistant

Table 2 Chemical composition of Synthetic leachate in the present test

Chemical Composition	Quantity(mg/l)
Nacl	1400
$NaNO_3$	50
$CaCl_2$	2880
$MgSO_4$	150
$NaHCO_3$	3000
$MgCl_2.6H_2O$	3000
$FeSO_4$	2000
$CuSO_4.5H_2O$	40
$MnSO_4.H_2O$	500
$ZnSO_4.7H_2O$	50
$NiSO_4.6H_2O$	500
$Al_2SO_{3.}16H_2O$	30
CH_3COOH	7,000
K_2HPO_4	30
$KHCO_3$	310
K_2CO_3	320

The sample for curing was kept inside the tin where humidity arrangement was made by keeping water up to 10 cm height inside throughout. The cured sample kept in the permeability mould itself was taken out of humidity tin and after the adequate time of completion of the curing period, it was permeated with tap water, acetic acid, and methanol solutions to study the permeability behavior.

Results and discussion

Physical and chemical properties of pond ash

For particles passing more than 90% of the total weight of soil on a 475micron sieve, a particle size distribution curve is generally plotted after finding out the percentage finer (%) in the hydrometer apparatus.For pond ash, the particle diameter and percentage finer were plotted in the X and Y

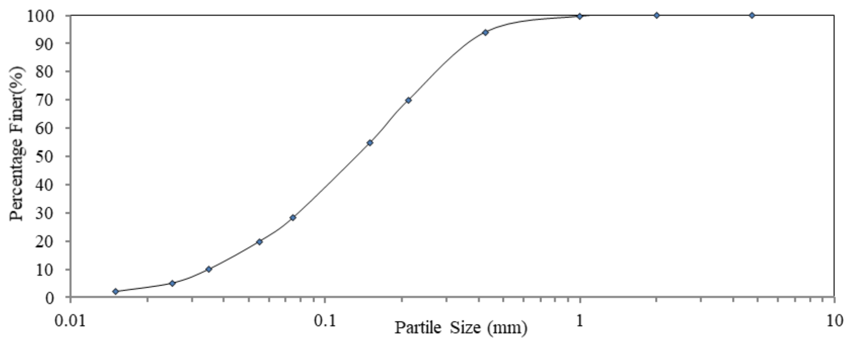


Figure 2. Particle Size distribution of pond ash

axis respectively following the procedures mentioned in IS: 2720-1985 (Part 4). The uniformity coefficient (Cu) was found to be 5.14 indicating uniform gradation of sample.

Scanning Electron Microscopy (SEM)

The microstructure analysis of the pond ash collected from NALCO, CPP thermal power stations, Odisha, India has been carried out using scanning electron microscope (SEM) techniques available at CSIR(IMMT), Bhubaneswar, India.

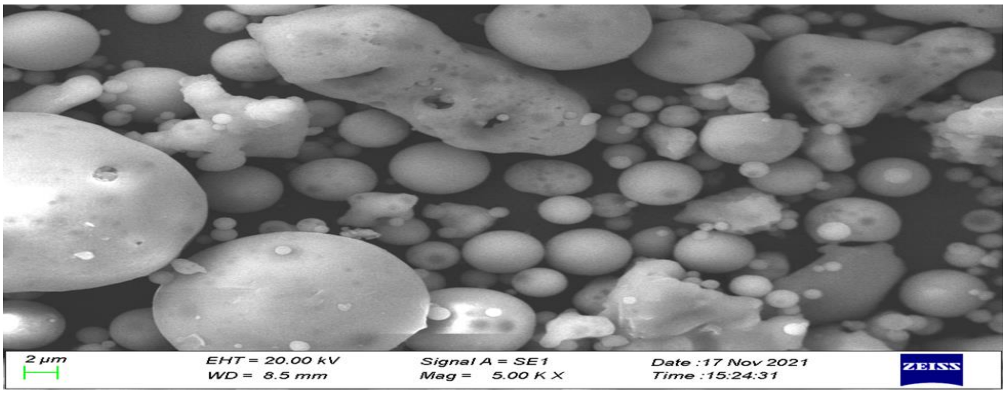


Figure 3 SEM of Pond ash at 5 K X magnification

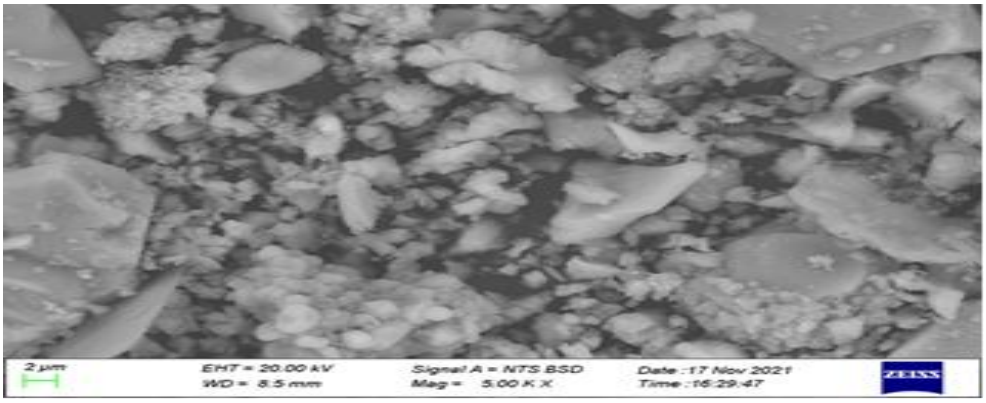


Figure 4 SEM of Lime at 5 K X magnification

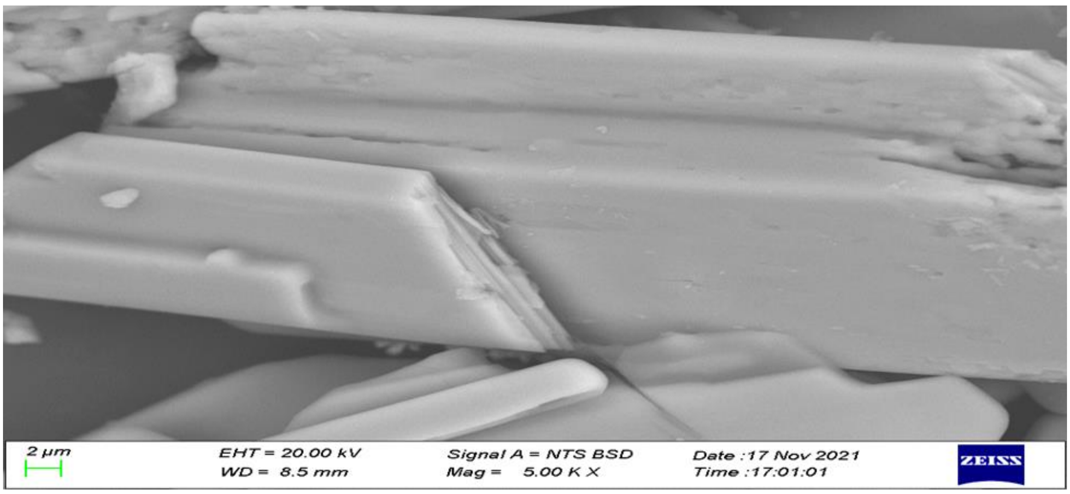


Figure 5 SEM of Gypsum at 5 K X

The microstructural studies through Scanning Electron Microscope (SEM) shows that the coal ash contains glassy solid spheres, hollow spheres, subrounded porous grains, irregular agglomerates and irregular porous grains of unburned carbon. If iron compounds are present, they can be spotted as opaque spheres or angular grains of magnetite and hematite. Figure 3,4, and 5 shows SEM of pond ash, lime and gypsum respectively. The chemical composition of pond ash shows predominant Aluminium and Silicious compounds present in the material.

Energy-Dispersive X-Ray Spectroscopy (EDS) test

The mineral groups present in coal such as hydrated silicates, carbonates, silicates, sulfates, and phosphates normally play a predominant role in deciding the chemical composition of ash. The Energy-Dispersive X-Ray Spectroscopy (EDS)studies indicate that the coal ashes predominantly contain quartz and feldspar minerals. Quartz, mullite, magnetite, and calcium compounds constitute about 10-15% of the weight of pond ash. EDS plots have been shown in figures 6,7 and 8. The EDS pattern of pond ash shows that there is a predominant SiO_2 and Al_2O_3 composition present in pond ash. According to the chemical requirements stated in ASTM C618-19(2019), the pond ash used in this study can be classified as Class F pozzolan containing the total sum of (SiO_2+ Al_2O_3+Fe_2O_3) composition expressed as a total percentage of the weight of total composition within 70% and CaO percentage as the weight of total composition lies below 18%.

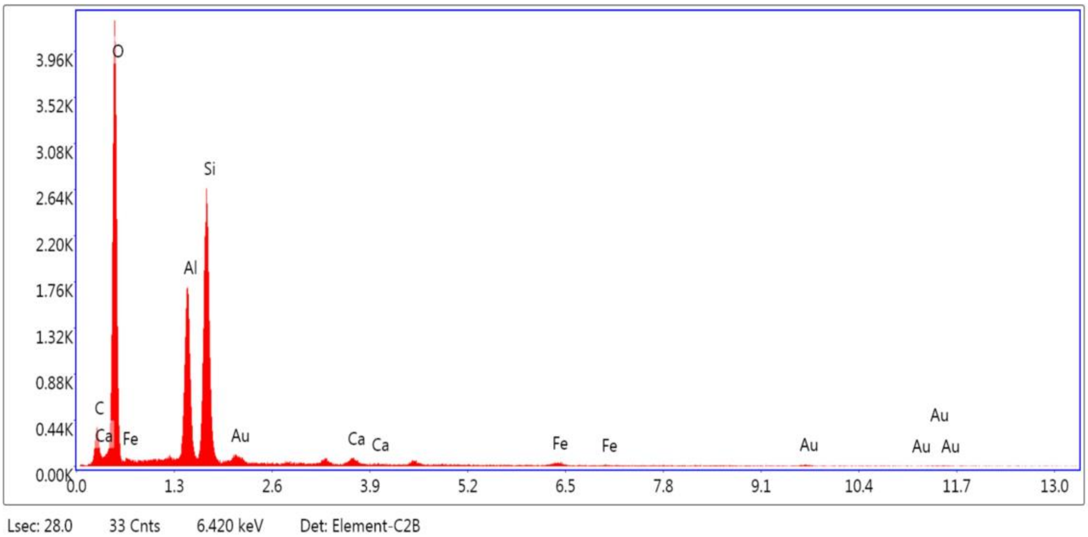


Figure 6 Energy-Dispersive X-Ray Spectroscopy pattern of pond ash

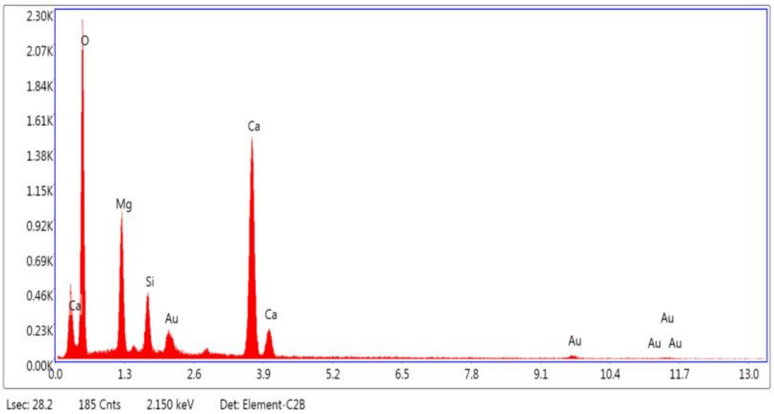


Figure 7 Energy-Dispersive X-Ray Spectroscopy pattern of lime

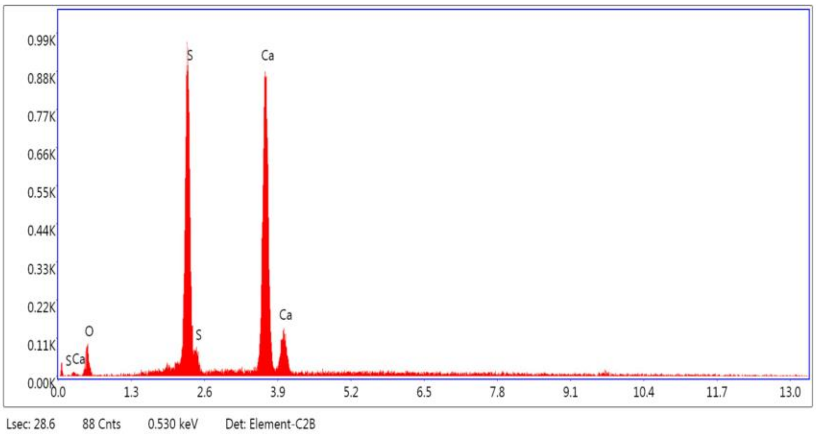


Figure 8 Energy-Dispersive X-Ray Spectroscopy pattern of gypsum

The EDS pattern of lime shows that there is predominant CaO composition (24.06%) present in lime which will help in further pozzolanic reaction in stabilized pond ash. The EDS pattern of gypsum shows that there is predominant CaO composition (53.79%) present in lime which will help in further fixation of pozzolanic reaction in cured stabilized pond ash

Table 3 Chemical composition of Pond ash

Constituents	Percentage
SiO_2	56.8
Al_2O_3	25.0
Fe_2O_3	8.82
MgO	0.79
P_2O_5	0.18
SO_3	0.29
K_2O	0.80
CaO	1.15
Na_2	0.16
TiO_2	1.65
Carbon	4.10
Volatile matter	0.19

Moisture content -dry density relationship

Standard proctor tests for various samples starting from S1 to S7 were performed in a proctor mould using a standard proctor rammer. The compaction curve for various pond ash samples in Figure 6 does not show any identical change in nature of the curve. It may be due to the reason that pozzolanic reaction could not take place in a short duration of mixing of admixture.

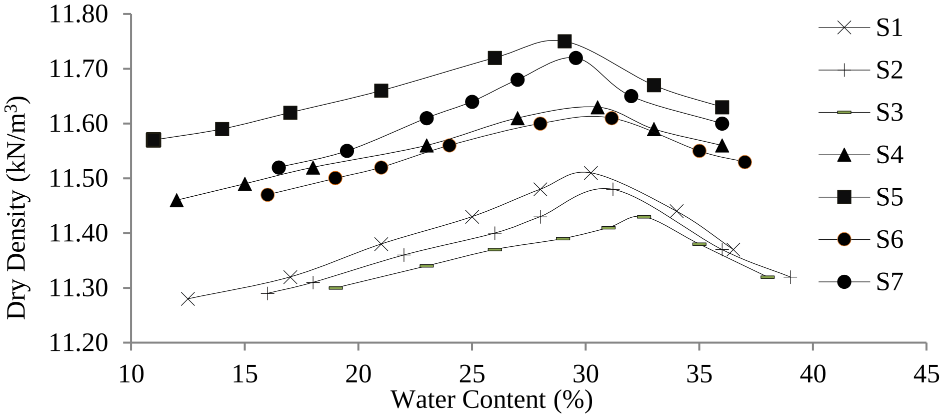


Figure 9. Dry density variation of pond ash mixes

It is evident from Figure 9. that the dry density first shifted to the right side of the wet of optimum after addition of only lime to it. At 14% lime content representing S3 sample mix, Dry density of 11.42 kN/m^3 was observed at Optimum Moisture Content of 32.5% .It was further noticed that a gradual shift of compaction curve took place after gypsum was added to pond ash-lime mixes. Highest value of Dry density of 11.76 kN/m^3 was observed at 10% lime and 1% gypsum mix representing sample S6 which may be attributed to the fact that the stabilized sample has already filled the voids . Hence with further mix of lime that is for S7 sample, dry density did not give that much variation .

Permeability Test Result

Determination of permeability is required in this study to investigate effectiveness of stabilized pond ash to be used as landfill barrier material. In order to satisfy the criteria of material to be used as landfill liner in composite liner system, the permeability of soil must be less than 10^{-9}m/s so as to prevent leachate penetration through the unsaturated zone and into the ground water. As Pond ash did not have self-binding properties, with curing time there is stagnant value of permeability was observed in case of only Pond Ash. The initial coefficient of permeability value of compacted pond ash was of the order of 10^{-4} cm/s. After gradual increase in lime percentage and curing period after 180 days, hydraulic conductivity of lime and gypsum stabilized pond ash reduced to power of 10^{-9} cm/sec. In the presence of gypsum, the lime stabilized pond ash resulted in denser material satisfying the requirement of coefficient of permeability of Municipal Solid Waste landfill liner material. The test for evaluating the coefficient of permeability was conducted in a falling head permeameter by following the procedure of IS: 2720-1987 (Part 17).In order to know the hydraulic conductivity of stabilized pond ash specimens, the samples were prepared in permeability moulds compacted to their respective OMC and MDD with different proportions of lime and gypsum. The samples are saturated initially then the time interval was recorded for the fall of water level from the initial head to the final head in the stand pipe. The variation of coefficient of permeability of samples S1 to S7 with curing period are shown in Figures 10,11, and 12 respectively for various permeants.

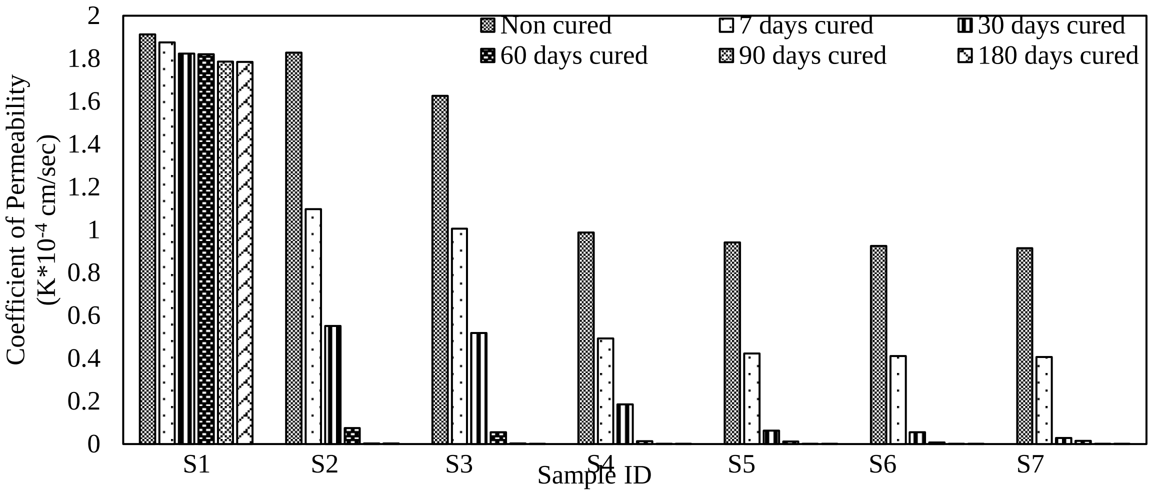


Figure 10 Coefficient of Permeability of various samples with water

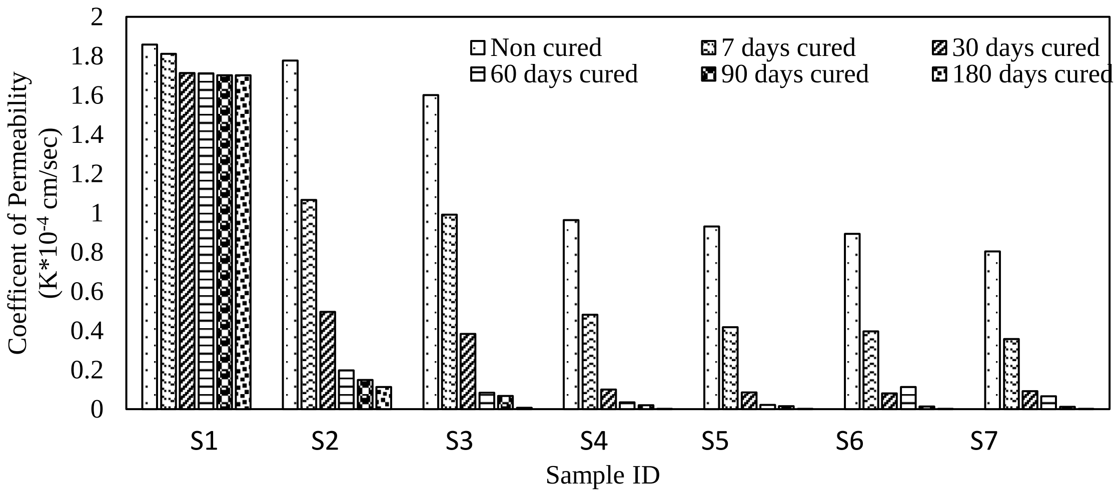


Figure 11 Coefficient of Permeability of various samples with Acetic acid solutions

It is observed that for all mixes of pond ash and lime or pond ash, lime and gypsum, there is a reduction in hydraulic conductivity with an increase in curing period. The initial permeability of compacted pond ash was of the order of 10^{-4} cm/s. In the presence of gypsum, the enhanced pozzolanic activity of lime-stabilized pond ashes result in denser, high-strength material. Permeability of pond ash was observed to be reduced by less than two orders of magnitude at 14% lime addition. It was noticed that with the acetic acid solution as permeant, the permeability showed low value than when permeated with methanol solution for every curing conditions.

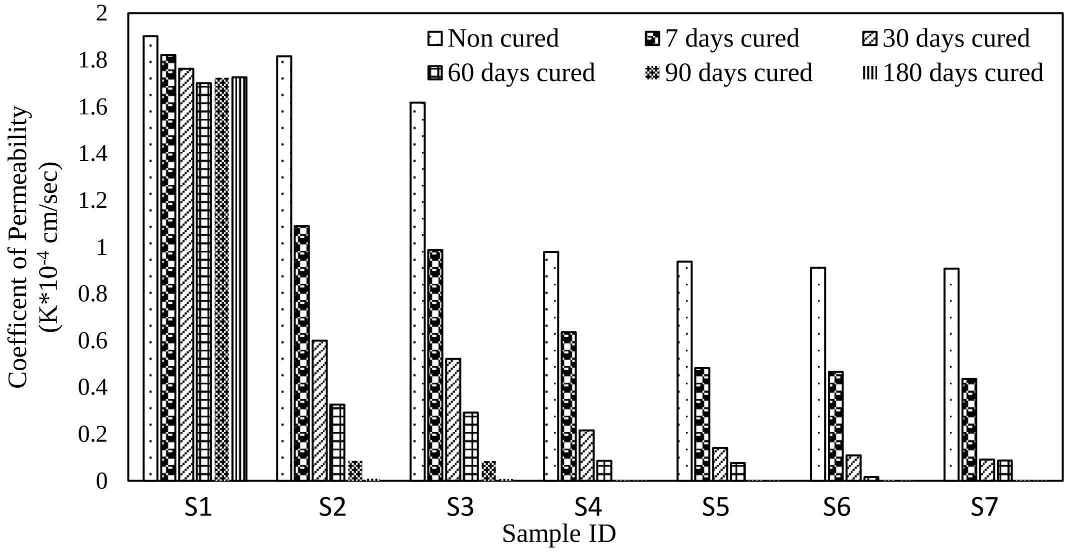


Figure 12 Coefficient of Permeability of various samples with Methanol solutions

Results of lime stabilized specimens showed decreases in the permeability to methanol than in any other solution. It might be suspected that the methanol reacted with the ash or stabilizer and resulted in the decrease in permeability. However, similar work with soils indicated that dilute organic liquids do not readily affect the permeability of the soil. The final permeability of the specimens indicates that permeation with acetic acid solution lowered the permeability when compared with values for permeation with water or the methanol solution.

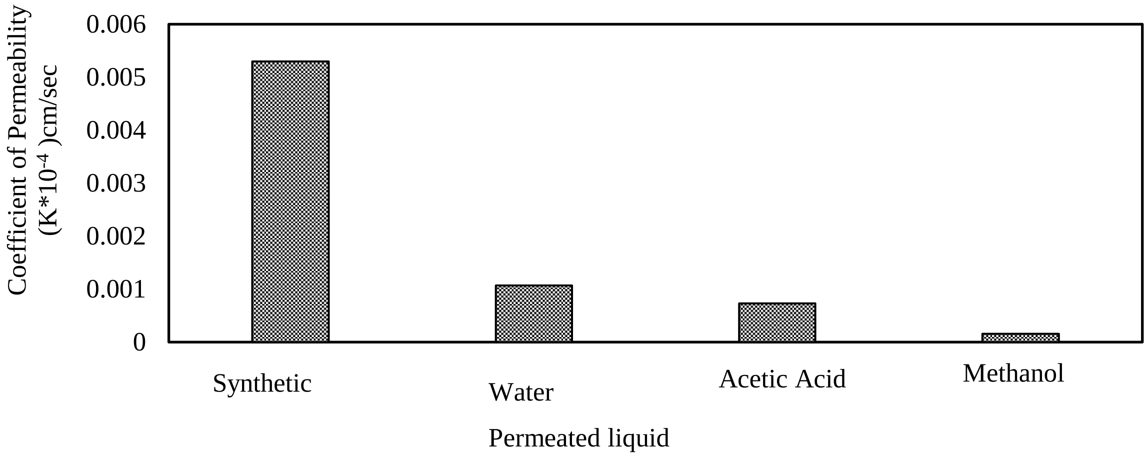
Figure 13 Cured sample permeated with synthetic leachate in falling head permeability apparatus

The acid might be responsible for increasing the degree to which a stabilized specimen cures while also increasing the rates of the curing process. Synthetic leachate resonating landfill leachate composition from MSW landfill sites of various landfills in India are prepared in laboratory and its effect on the hydraulic conductivity of stabilized Pond Ash was investigated in falling head permeability apparatus. Synthetic leachate is prepared taking into consideration the real MSW leachate composition. Many researchers have used synthetic leachate to evaluate the effect of chemical permeants on hydraulic conductivity of landfill soils [11]. The synthetic leachate is intentionally made rich in calcium to challenge the proposed liner of S7 mix. Figure 10 shows the porcelain container attached to the outlet of permeability mould to collect the effluent solution at different interval of flow time. The proposed liner of S7 mix sample that was pre hydrated in water up to full saturation. water was allowed to pass through outlet. After 24 hours of hydration, the mix was permeated with the synthetic leachate.

The permeability was checked on 1,3,7,15, and 30 days of the flow period of synthetic leachate permeation. Table 8 shows the permeability value of S7 mix permeated with synthetic leachate. The addition of lime at 10% and 14% with very low percentages of gypsum mixes were tested for permeability value with and without

Figure 14 Variation of Coefficient of permeability of 180 days cured S7 sample

permeated with various liquid curing conditions. In the presence of gypsum, the enhanced pozzolanic activity of lime stabilized pond ashes results in high-strength material. The addition of 1% gypsum with 14% lime reduces the hydraulic conductivity of pond ash to great extent. The decrease in hydraulic conductivity of pond ash at 10% and 14% lime is about 13% and 15% respectively which further reduces to 46 % and 63% after curing period of 28 days at room temperature of 27°C.Gypsum reduced the permeability when added with 14% lime to



almost 99%.The pond ash mixed with 14% lime and 1% gypsum finally acted like a nonpermeable media after curing for 28 days reducing the hydraulic conductivity to nearly 99.9%.This change is not only because of precipitation of untreated lime but also due to their relative differences in particle size distribution characteristics.

Characterization of effluent leachate parameters

pH Test

The laboratory prepared synthetic leachate was used as permeation liquid in falling head permeability apparatus after 30,60 ,and 180 days cured S7 sample. The effluent liquid coming out from outlet of permeameter was tested for pH value in pH meter after continuous flow period of 1 ,7,15 ,and 30 days. The effluent leachate coming out of S7 sample after curing period of Test for different effluent concentrations were conducted in pH meter according to Is:2720(part 26)-1987.

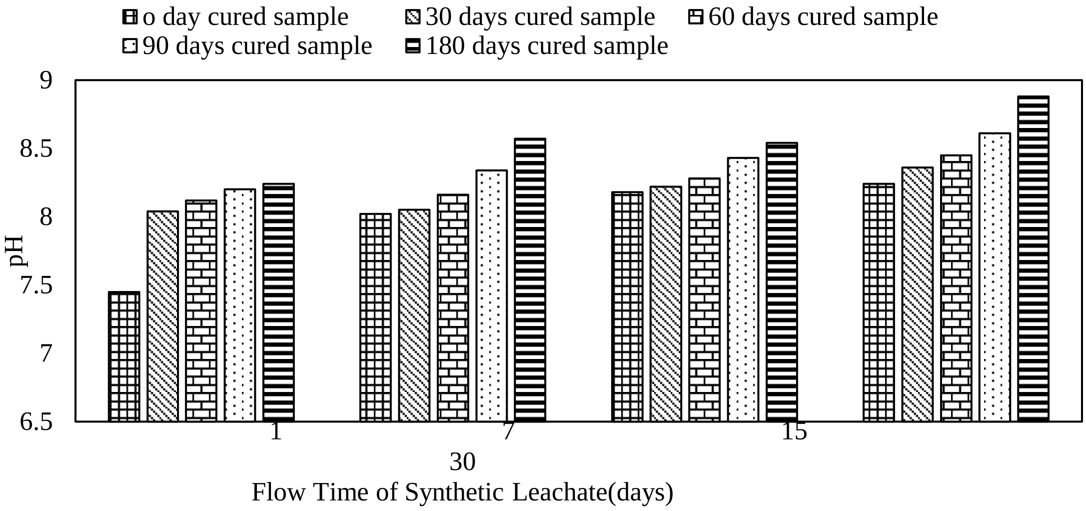


Figure 15. pH versus flow period for effluent leachate collected in S7 mix sample

The variation in pH value is shown in Figure 15. indicates that the continuous flow period of synthetic leachate affects the pH of effluent leachate sample collected from outlet of permeability apparatus [11,13-16].

Electrical Conductivity Test

The conductivity of any solution depends on the quantity of total dissolved solids present and for dilute solution it is approximately proportional to the dissolved solid contents The laboratory prepared synthetic leachate was used as permeation liquid in falling head permeability apparatus after 30,60 and 180 days cured S7 sample. The effluent liquid coming out from outlet of permeameter was tested for Electrical Conductivity (μs/cm) in Conductivity Meter apparatus after continuous flow period of 1 ,7,15 and 30 days. The conductivity test for different effluent concentrations were conducted according to Is:14767-2000. The conductivity of any solution depends on the quantity of total dissolved solids present and for dilute solution it is approximately proportional to the dissolved solid contents.

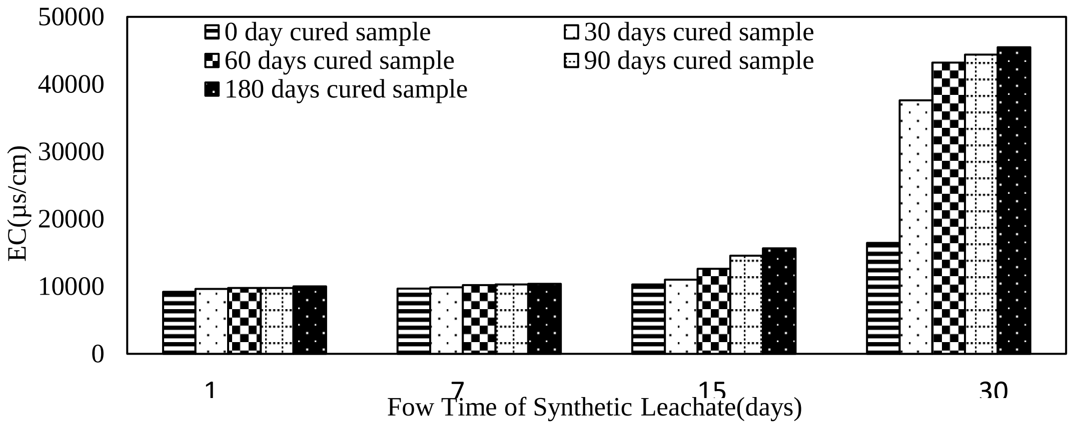


Figure 16 Electrical Conductivity(μs/cm) versus flow period for effluent leachate collected in S7 mix sample

The laboratory-prepared synthetic leachate was used as permeation liquid in the falling head permeability apparatus after 30,60 and 180 days of cured S7 sample. The variation of electrical conductivity value with different flow periods for the S7 sample permeated with synthetic leachate is shown in Figure 16.

Total Dissolved Solids

Total Dissolved Solid was calculated after a continuous flow period of 1 ,7,15, and 30 days with the interrelationship established with Electrical Conductivity (µs/cm) value. Using the established correlation of TDS and conductivity, Total Dissolved solids are to be calculated.

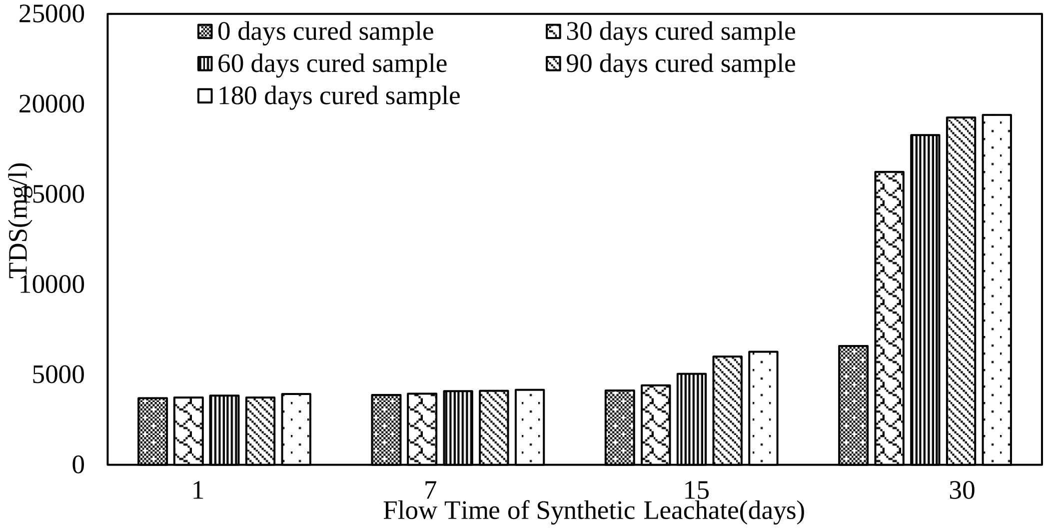


Figure 17 Total Dissolved Solids versus flow period for effluent leachate collected in S7 mix sample

Taking the constant of proportionally as 0.4, the corresponding TDS value for each effluent liquid was determined by multiplying the corresponding electrical conductivity value with a constant of proportionality. The value of TDS showed increased value with a continuous flow period as shown in Figure 17.

Analysis of Karl Pearson's Coefficient of Correlation

In this study statistical package (IBM SPSS STATISTICS 20) was used. As multiple variables are there, bivariate analysis having a two-tailed test was carried out. The result gave Pearson's correlation coefficient value for the interrelationship between two sets of variables [4].

Table 4. Pearson correlation analysis of sample S7 permeated with synthetic leachate

		CT	FT	pH	TDS	EC	$K_{S.L}$
CT	Pearson Correlation	1					
	Sig. (2-tailed)						

FT	Pearson Correlation	.000	1				
	Sig. (2-tailed)	1.000					
pH	Pearson Correlation	.397	.827**	1			
	Sig. (2-tailed)	.083	.000				
TDS	Pearson Correlation	.196	.837**	.889**	1		
	Sig. (2-tailed)	.408	.000	.000			
EC	Pearson Correlation	.200	.840**	.892**	1.000**	1	
	Sig. (2-tailed)	.397	.000	.000	.000		
K	Pearson Correlation	-.596**	-.010	-.431	-.244	-.244	1
	Sig. (2-tailed)	.006	.967	.058	.301	.300	

**. Correlation is significant at the 0.01 level (2-tailed).

CT. Curing Time(days), FT. Flow time(days), $K_{S.L.}$ Coefficient of permeability of S7 sample permeated in synthetic leachate (cm/sec)

Table 4 illustrates the result of the analysis done in SPSS software. According to Table 4, in the effluent leachate sample, pH was well correlated with EC. Flow time(days) was well correlated with TDS, EC, and pH. Flow Time showed a significant positive correlation of 0.840 with Electrical Conductivity and an almost negligible correlation of 0.010 with a coefficient of permeability when synthetic leachate is permeated. The result of curing time and permeability correlation indicates that curing time is negatively and significantly correlated with the Coefficient of permeability.

Conclusions

The results of the experimental investigation to assess the potential of stabilized Pond ash as landfill bottom liner material showed the following conclusions.

- Stabilization of pond ash with lime and gypsum overcame the limitations of inadequate permeability of Pond Ash and proved to be a stable material to be used as landfill liner. Coefficient of Permeability value of the specimens indicated that with acetic acid solution permeability was observed to be less for all the curing periods when compared with values for permeation with water, methanol solution and synthetic leachate solution. The synthetic leachate did not have an adverse effect on the permeability of stabilized pond ash. The treated pond ash is compatible with the synthetic leachate used and met the minimum possible permeability value of $1x10^{-7}$ cm/sec after 90 days of curing period
- S7 sample after being treated with synthetic leachate showed increase in pH value of effluent sample with curing time and continuous flow period of leachate poured from the head of tank in the falling head permeability apparatus. The pH value of effluent from 180 days cured sample after 30 days of flow period was found to be 8.88 which was within permissible limit of standard mode of disposal for inland surface water.

- Higher porosity leads to lesser Electrical Conductivity value. Higher EC value indicates greater packing of soil to avoid seepage of leachate. Electrical Conductivity increased from 9215 µs/cm to 16480 µs/cm for 1 and 30 days of synthetic permeation when S7 sample was uncured. After 180 days of curing and 30 days of a continuous flow of leachate in falling head permeability apparatus, the conductivity was found to be 45480 µs/cm.
- High conductivity will eventually develop high TDS. High TDS is not necessarily unhealthy rather the hazardous minerals emanating from leachate caused various health hazard. It is expected that with decrease in permeability and increase in TDS, the minerals coming out of effluent solution will minimize decreasing the capillary voids in pond ash liner.
- A significant positive Pearson's correlation of 0.889 has been observed between TDS and pH value whereas a significant negative correlation of 0.596 was observed between curing time and coefficient of permeability value

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