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Studies on the Leachate Characteristics of the Compacted Fly Ash Bed Treated with Lime Column

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Abstract—*This paper entails the effect of lime column on the hydraulic conductivity and leachate characteristics of compacted fly ash bed. In the present experimental investigation, large scale laboratory model of compacted fly ash bed was prepared with a centrally installed lime column simulating a field condition as closely as possible. Samples are collected from different radial directions such as 5cm, 15cm, 25cm and 35cm as well as depths of ash bed such as 10cm, 30cm, 50cm, 70cm and 90cm after 30, 90, 180 and 365 days of curing periods and subjected to different tests such as pH, hydraulic conductivity and leachate analysis. From the test results, it was found that lime column treatment is an effective means of reducing pH, hydraulic conductivity and leachate effluent characteristics of fly ash bed.*

1. INTRODUCTION

The generation of fly ash has been increased considerably. In order to get rid of disposal and dusting problem, this waste material is being used in several construction processes such as structural fills for low lying areas, embankment and subgrade for highways, backfill in retaining structures, mine stowing etc. However, unstabilized fly ash is not suitable for construction works due to low bearing capacity and high compressibility. Therefore, some chemical additives like lime/cement are used to improve the strength and stability of fly ash. Conversely, fly ash contains a number of soluble major and trace elements such as As, Fe, Cd, Hg, Zn, Pb and Cu, etc.There is possibility that leachate emanating from this fly ash bed may contaminate the ground water. Thus, fly ash stabilisation by lime is an excellent method to mitigate the leachate characteristics of fly ash. A good number of literatures are available on the leachate characteristics of ash deposits. Based on several investigations, the pH value of the pore water is one of the factors which governs the concentration of a metal in the leachate The ambience of high alkalinity in the pore fluid of the stabilized fly ash was conducive to the precipitation of some of the metals. The concentrations of Cu, Fe, Mg, Ni, and Zn in the leachate flowing out of the stabilized specimens were below allowable limits of drinking water quality, whereas concentrations of As, Cd, Cr, and Pb were above allowable limits, but below threshold limits [2]. Stabilization of fly ash with proper additives may be one of the promising methods to mitigate the problem of leaching and dusting [1]. The concentration of Calcium in the leachate depends upon the curing period [8]. The concentration of contaminants that leach out depends on the pH of the environment [7]. The hydraulic conductivity and the amount of chemical additives had an inverse relationship together [6]. The strength and durability of fly ash increase due to addition of lime alone or in combination with gypsum and the decrease in hydraulic conductivity is due to reduction in interconnectivity of the pore channels due to formation of hydration products [3]. Class F fly ash stabilized with lime alone or in combination with small percentages of gypsum yields a strong impermeable matrix [4]. The reduction in hydraulic conductivity occurs if lime/gypsum is used as additive and it also depend on curing period [5].

Scanning through the relevant literatures, it is perceived that research works on leachate effluent characteristics of fly ash deposits is not so profound and researchers have tried to reduce the concentration of major and trace elements in leachate without finding out the total concentration of metals of raw fly ash. So in this present investigation, an effort has been made to know the effect of lime column in mitigating the problems of leaching from the fly ash bed. In addition, the total metal concentration of pond ash and their maximum leaching ability were also found out by acid digestion and extraction method respectively in order to get confirmed whether it is in compliance with the specified water quality standards or not.

2. MATERIALS

2.1 Pond Ash

The pond ash used in the experimental work was procured from an ash pond at Rourkela steel plant, Rourkela. The major constituents of pond ash are silica, alumina and iron. Calcium oxide present in the fly ash is 3.2%. So, according to ASTM specification C 618-89 (1992), this ash belongs to a Class F category.

2.2 Lime

The commercially available superior grade quick lime was used to prepare lime column. The purity of lime is 90.2 %.

3. METHODOLOGY

3.1 Preparation of Compacted fly Ash Bed in Test Tank

The test set up for compacted fly ash bed consists of a large circular galvanized iron tank of 105 cm diameter and 120 cm height open at the top with a drainage arrangement at the base (Figure 1).About 1 ton of fly ash sample was taken and compacted to maximum dry density (1.16gm/cc) at optimum moisture content (38.7%). After mixing, the sample was placed in the tank by 10 equal layers and tamped with a large hammer so that the compacted fly ash sample could be placed uniformly throughout the tank.

3.2 Installation of Lime Column

After the elapse of two months, the lime column was installed at the center of the ash bed in the test tank. The quantity of lime required for installing the lime column was 10 kg. The required quantity of lime was taken and it was divided into10 equal parts after placing each part, the layers are tamped with a small hammer. Thus, a lime column of 10 diameter and 100cm height was installed at the middle of the ash beds. During the stabilization period, the test tank was uncovered at the end of every 7 days and a small amount of water each time was added to maintain the hydrated lime in a slurry condition. Sensors were placed inside the tank in order to know the temperature effect of lime migration radially and vertically in the tank after installation of lime column. These are located at a depth of 0.5m from top of the fly ash bed with c/c spacing of 0.1 m.

3.3 Sampling Program

After the specified stabilization periods, the samples are collected to study the improvement in various properties such as pH, permeability and leachate effluent characteristics of the fly ash bed. The samples were collected from four radial distances, i.e. 5cm, 15 cm, 25cm and 35cm and at 5 different depths i.e. 10cm, 30cm, 50cm, 70cm, and 90cm as shown in Figure 3 and Figure 4. For leachate analysis, 5nos of steel hollow pipes of 1cm diameter, length varying from 10 to 90 cm are inserted with c/c spacing of 8 cm at a radial direction of 25 cm from the center of the test tank (Figure 2). In addition, another 4nos of similar pipes having length 50cm are inserted in four different radial distances for collecting leachate samples from a depth of 50cm. In order to collect samples for permeability test, sampling molds having 10cm diameter and 15cm height were used.

3.4 Details of test conducted

***3.4.1 pH Test**:* In order to know the variation of pH in the test tank, water samples are collected from different radial distances and depth of the compacted fly ash bed after specified periods and stored in bottles for pH test. Then it was filtered with Whatman 42 filter paper and tested in a calibrated pH meter.

***3.4.2 Leachate Analysis**:* The total concentration of major and trace elements present in the fly ash is determined by acid analysis according to Environmental Protection Agency (EPA 3050B method). The leachate characteristics of raw fly ash are determined by extraction method (Toxicity Characteristic Leaching Procedure 1311 method). In order to know the leachate effluent characteristics of lime column treated ash, samples are collected from the test tank at various radial distances as well as depths after specified curing periods and the concentration of the elements like Cu, Fe, Ca, Ni, Pb, Cr and Zn were found out by AAS (Perkin Elmer).

***3.4.3 Hydraulic Conductivity**:* The permeability of test specimens was performed according to the procedure prescribed IS: 2720-1987 (Part 36) using a constant head permeameter. In order to know the hydraulic conductivity of stabilized fly ash specimens, the samples were collected from different radial distances as well as different depths after specified days of curing with the help of the sampling tube. Tap water of pH 7.49 was allowed to flow while measuring permeability.

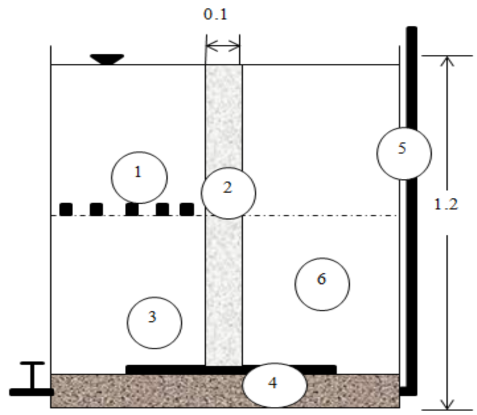

Figure 1. Details of test tank and its components

1-Temperature sensors, 2-Lime column, 3-Base plate, 4-Sandbed, 5-Stand pipe, 6-Fly ash bed

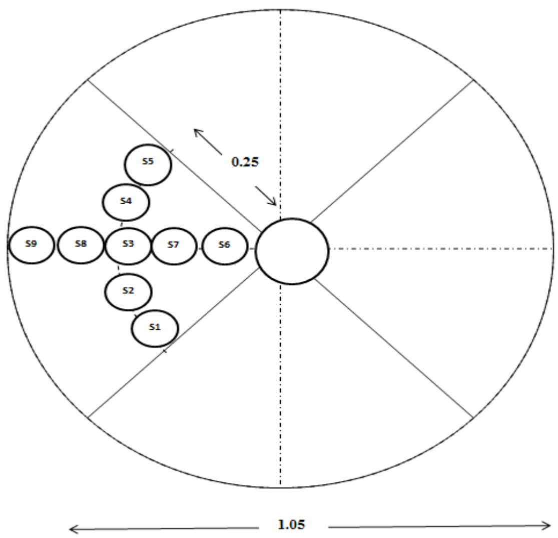

Figure 2. Plan of the test tank showing locations for collection of leachate samples

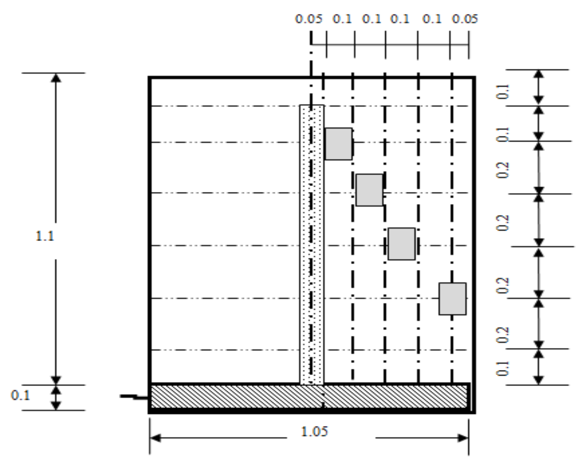

Figure 3. Elevation of the test tank showing locations for collection of samples for determination of hydraulic conductivity

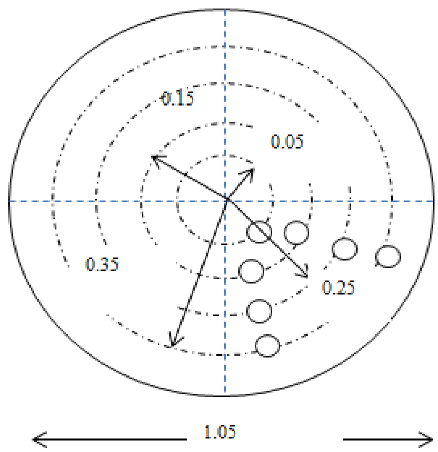

Figure 4. Plan of the test tank showing locations for collection of samples for determination of hydraulic conductivity

4. ALL DIMENSIONS ARE IN MMRESULT AND DISCUSSION

4.1 pH Test

Figure 5 and 6 represent the pH test results of the samples collected from different depths and radial distances of the test tank after 90,180 and 365 days of curing. It is observed that pH value follows a decreasing trend with an increase in radial distance and follows an increasing trend as we move down from the top surface of the fly ash bed. This is due to migration of lime to the periphery of tank. As there is much concentration of lime at the location near to the lime column, so pH value is higher for the samples collected adjacent to the lime column. Similarly, an increasing trend of pH value is obtained with increase in depth from the surface of the tank due to migration of lime. Moreover, it is also observed that the pH value increases with curing period. This indicates that the migration of lime continues even upto 180 days, and the amount of lime migrated is higher than the amount of lime consumed in pozzolanic reaction. This leads to a gradual increase in the pH value. However, beyond 180 days of curing, the pH value is found to be reduced due to participation of more lime in pozzolanic reaction. Further, the migration of lime from lime column towards the peripheral region reduces with time as the hydration products clog the capillary voids.

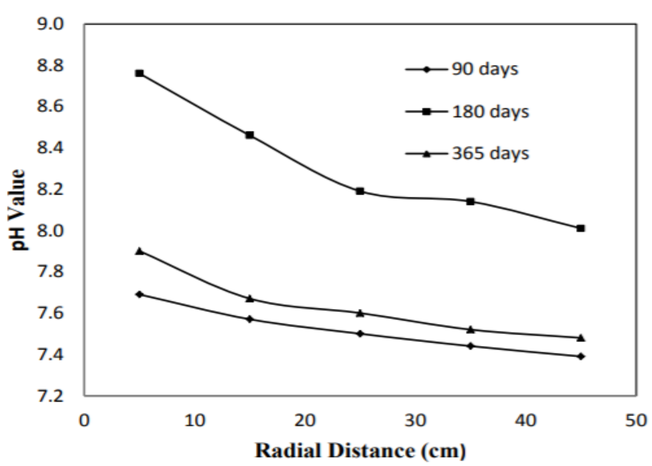

Figure 5. Variation of pH value with radial distance

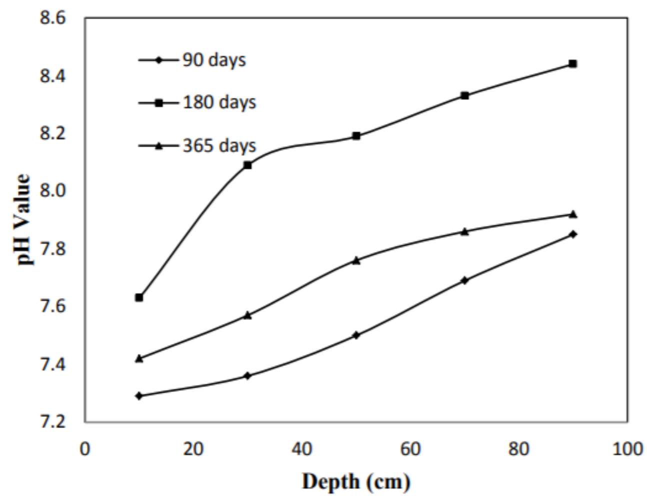

Figure 6. Variation of pH value with depth

4.2 Hydraulic Conductivity

Figure 8 and 9 shows the hydraulic conductivity results of pond ash specimens collected after 180 and 365 days curing period and it was found to be less than the hydraulic conductivity of virgin pond ash which is $4.25X10^{-5}$ cm/sec. During the early period of stabilization (30 days of curing) no particular trend has been observed in hydraulic conductivity value (not shown in this paper). However, as the curing period increases, the hydraulic conductivity follows a decreasing trend as with increase in depth (Figure 7 and8) and also a reduced value is obtained in the samples collected adjacent to the lime column .This is due to the uneven migration of lime from lime column to the surrounding. As there is much concentration of lime at the location near to the lime column, so hydraulic conductivity is lesser for the samples collected adjacent to the column whereas the hydraulic conductivity is more for the samples collected at a remote area from the lime column. The reduced value of hydraulic conductivity is obtained due to the participation of lime in hydration reaction and formation of hydration products like C-S-H gel which cause reduction of void space and in the interconnectivity of pore channel. In addition, it is also observed that as the curing period increases, a marginal reduction in hydraulic conductivity occurs in all the layers of compacted fly ash bed. This indicates that the hydration reaction becomes even more stronger with a higher curing period, which causes the generation of more amount of hydration products and hence reduction in hydraulic conductivity.

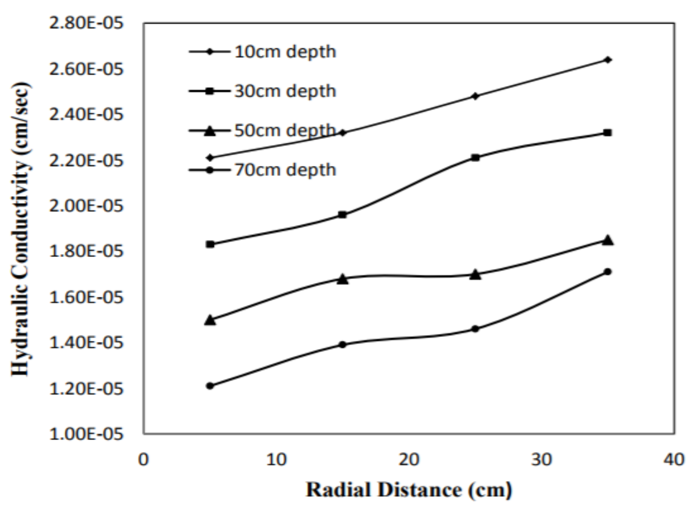

Figure 7. Variation of hydraulic conductivity with radial distance on 180 days curing

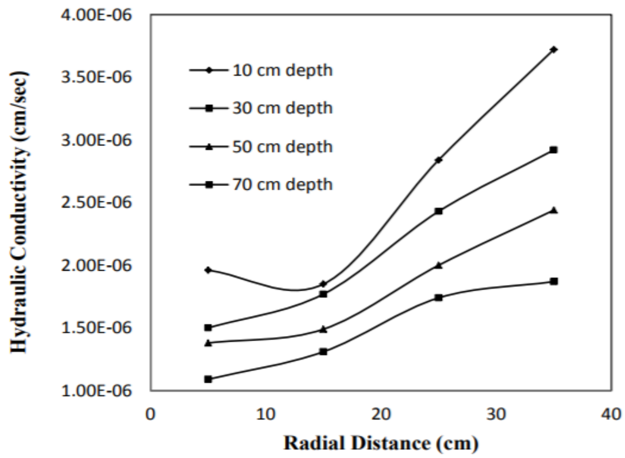

Figure 8. Variation of hydraulic conductivity with radial distance on 365 days curing

Table 1. Allowable and threshold limits of concentration of metals in drinking water

IS-10500(1992)	Concentration of metals (mg/l)						
	Ca	Cu	Fe	Pb	Cr	Ni	Zn
Allowable limit	200	1.5	0.3	0.1	0.05	0.02	5
Threshold limit	20000	150	30	10	5	2	500

Table 2. Concentration of metals in leachate sample of raw fly ash

Samples	Concentration of metals (mg/l)						
	Ca	Cu	Fe	Pb	Cr	Ni	Zn
N1	46.409	1.543	23.350	1.699	2.464	1.48	2.172
N2	35.219	0.06	0.057	0.325	1.875	0.159	0.315

Table 3. Concentration of metals in leachate on 180 days curing

Samples	Concentration of metals in leachate (mg/l)						
	Ca	Cu	Fe	Pb	Cr	Ni	Zn
S1	87.995	0.029	0.017	0.94	ND	0.44	ND
S2	88.02	0.028	0.015	0.077	ND	0.043	ND
S3	88.686	0.025	0.008	0.074	ND	0.037	ND
S4	88.581	0.021	0.006	ND	ND	0.029	ND
S5	88.886	0.014	ND	ND	ND	0.01	ND
S6	89.183	0.011	ND	ND	ND	0.02	ND
S7	88.897	0.023	0.001	ND	ND	0.033	ND
S8	88.267	0.032	0.014	ND	ND	0.059	ND
S9	88.232	0.034	0.017	0.073	ND	0.08	ND

Table 4.Concentration of metals in leachate on 365 days curing

Samples	Concentration of metals in leachate (mg/l)						
	Ca	Cu	Fe	Pb	Cr	Ni	Zn
S1	41.535	0.007	ND	ND	ND	0.027	ND
S2	40.270	0.005	ND	ND	ND	0.022	ND
S3	39.767	0.004	ND	ND	ND	0.019	ND
S4	38.172	0.003	ND	ND	ND	0.011	ND
S5	32.688	0.002	ND	ND	ND	ND	ND
S6	35.113	0.001	ND	ND	ND	0.015	ND
S7	38.155	0.002	ND	ND	ND	0.018	ND
S8	39.012	0.005	ND	ND	ND	0.37	ND
S9	40.724	0.006	ND	ND	ND	0.5	ND

Note: S1, S2, S3, S4, S5 are the leachate samples collected from same radial distance that is at 25cm but with varying depth of 10cm, 30cm, 50cm, 70 cm and 90cm respectively, whereas S6, S7, S8, S9 are the samples collected from same depth ,that is 50cm but at different radial distances of 5cm, 15cm, 25cm and 35cm respectively. N1 denotes the sample prepared from acid digestion of raw fly ash and N2 denotes the extracted leachate sample of raw fly ash {liquid-solid ratio (L/S)=10)}. ND denotes " Not detected".

4.3 Leachate Analysis

The leachate analysis results of sample collected on 180 days and 365 days curing are given in Table 3 and Table 4 respectively. It shows that concentration of elements in the leachate sample collected from the test tank is much lower than the leachate sample extracted from raw fly ash (Table 2). It also shows that at early period of curing the concentration of Ca is more whereas in the longer curing period, i.e at 365 days, the concentration of Ca gradually reduces. This is because during initial stage of the curing period the pozzolanic reaction is slow and the unreacted lime leached out very easily. However, at the longer curing period the concentration of calcium decreases due to participation of lime in pozzolanic reaction. It is also observed that the concentration of Ca in sample follows an increasing trend in the sample collected at same radial distances but varying depth in the order of S1<S2<S3<S4<S5 due to migration of lime in downward direction, whereas the concentration of Ca in samples follows a decreasing trend in the samples collected at the same depth but different radial distance in the order of S6>S7>S3>S8>S9 due to lesser migration of lime at greater radial distance from the lime column. It is also observed from the results that the concentration of major and trace elements in the leachate sample collected adjacent to the lime column is lesser than that of the sample collected at the periphery of the test tank. This is due to the migration of lime from the lime column towards the periphery resulting in higher pH value near the lime column and lower pH value at a remote area from lime column which provides an unfavorable alkaline medium for metal precipitation. Similarly, as with increase in depth from the top surface of the fly ash bed , the concentration of the element decreases due to downward movement of the lime from the lime column. Moreover, it is observed with increase in curing period, the concentration of elements in the leachate decreases. This is due to the formation of hydration product such as C-S-H gel which encapsulates the elements and prevents leaching. So this confirms that addition of lime plays a pivotal role in reducing the concentration of elements and with higher curing period the concentration of element reduces even more. The concentration of all the elements was found to be less than threshold limit of IS-10500 (Table 1) water quality standard.

5. CONCLUSIONS

From the experimental investigation, it is found that the concentration of metals majorly depend on two factors pH and hydraulic conductivity. The pH value of the samples was found to be more at the location adjacent to the lime column and less in the sample collected at remote area from the lime column. An increasing trend of pH value is obtained with increase in depth from the top surface of the fly ash bed. This is due to migration of lime towards periphery and downward direction, thus providing an alkaline medium in reducing the solubility of the toxic metals. With higher curing period the hydraulic conductivity value was found to be decreased vertically due to migration of lime and formation of C-S-H gel which clogs the pores and decreases the capillary voids, thus, preventing the leachate from contaminating the ground water. From the leachate analysis, the concentration of other metals is below the threshold limit of IS-10500. Thus, lime treatment was found to be effective in reducing the hydraulic conductivity and concentration of the metals coming out of the compacted fly ash specimens.

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