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Migration of Chromium Through Black Cotton Soil Amended with Ground Granular Blast Furnace Slag

Srinivasa B.T, Shankara, S. N. Maya Naik, P. V. Sivapullaiah

Abstract: ***The aim of this work is to assess the suitability the locally available black cotton soil amended with industrial waste material such as blast furnace slag in the context of using them as liner materials. The black cotton soil (BCS) and Ground Granulated Blast furnace Slag (GGBS) are mixed in three ratios, 90:10, 80:20 and 70:30 and hydraulic conductivity of these mixtures have been tested using falling head method. The hydraulic conductivity of soil with 30% GGBS is the lowest and satisfies the hydraulic conductivity criteria of 10-7 cm/s or less for liner application. Soil column tests are conducted to determine the transport parameters of chromium through the optimized soil mixture. The transport parameters of chromium through optimized mixture was found to be diffusion coefficient D = 3.9x10-6 cm2/s and retardation factor R = 4.964. BCS with 30% GGBS mixture with a hydraulic gradient of 0.3 and can be used as liner to contain chromium ion as it gives a breakthrough time of more than 100 years for a liner thickness of 1m.***

Keywords: Migration, Heavy metal, Containment, Soil column, Black cotton soil, Ground Granulated blast furnace and Chromium.

I. INTRODUCTION

The disposal of waste through landfilling is the important stage in any waste management system. Under the landfill site a low permeable barrier is laid to retard the leachate and toxic constituents of the solid waste, which are going to be generated at later stages of the waste digestion processes [1]. To construct this important low permeable layer at landfill site, a compacted clay is most preferred as it is easy availability and economically feasible. If any material to be used, for the construction of liner material, then it should have a low permeability and sustainability of that material with leachate produced in the landfill mass. Clays exhibit the property of retardation of leachates as they possesses low permeability and also contain the contaminant cations due to their inherent nature of charged surface. In India, the most of the areas are covered with a few types of soils which are promising as soil liners commonly are Red earth, Brown earth and Black cotton soil. The common ions which are present in the municipal solid waste/industrial solid waste leachate are sodium, calcium, chloride, copper, iron, zinc, lead, nickel and chromium etc [2, 3]. These ions present in the leachate if reaches ground water can causes serious health complications in the locality of landfill area [4, 5]. Most of the literatures on clay materials focused towards the geotechnical aspects, characterization, permeability etc. The literature on the rates of migration of contaminant cations through clay materials (liner materials) and sorption capacity is very scanty. Therefore in this study an effort is made to check the migration rates of cations such as chromium in the compacted amended clayey soils. The liner material is expected to retard the migration of contaminants and lower the rates of migration of ions through the selected clay liners and the additives which can reduce the rates of migration effectively is chosen as amendment for construction of liner [6, 7].

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*Correspondence Author
Srinivasa B.T. Research Scholar, Department of Civil Engineering, BMSCE, Bengaluru India.
Shankara, Department of Civil Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India. E-mail: shankarsamrud@gmail.com
S. N. Maya Naik, Professor, Dept. of Civil Engineering, BMS College of Engineering, Bull Temple Road, Bangalore-560019 India, E-mail ID:: snmcivbmsce@gmail.com
P. V. Sivapullaiah, Pro Vice Chancellor, CMR Uni, Bengaluru Campus, (former Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore-560012) E-mail ID:sivapullaiah@gmail.com

II. CLAY AND GGBS INTERACTION MECHANISM

Clays and soils containing significant amounts of clays are controlled by the type and amount of clay presents in them. The behavior of any particular clay is controlled by its structure. The most common clay minerals present in soils and their properties are summarized in Table 1. Clays with 2:1 minerals are characterized by high surface area, cation exchange capacity and hence high swelling capacity and low hydraulic conductivity. These minerals though they possess good strength loose strength. Generally, soils containing this type of clays such as Indian black cotton soils are suitable for construction of barriers for waste disposable facilities such as landfills.

Table 1. The most common clay minerals present in soils [8]

Mineral	Type	CEC [cmol/kg]	Swelling prospective	Specific surface area [m2/g]
Kaolinite clay	1 : 1 (non-swelling)	3 - 15	almost none	5 - 20
Montmorillonite clay	2 : 1 (swelling)	80 - 150	high	700 - 800
Vermiculite clay	2 : 1 (swelling)	100 -150	high	500 - 700
Hydrous Mica clay	2 : 1 (non-swelling)	10 - 40	low	50 - 200

Black cotton soil generally contains sufficient amount of swelling clay – montmorillonite to yield low hydraulic conductivity. But it has high swelling and shrinkage potentials restricting its use directly for liner construction. Hence it properties needs to be modified/stabilization. There are variety of stabilizers but use of waste materials such as GGBS can be considered. The mechanisms of stabilization of soil by pozzolanic stabilizers such GGBS are cation exchange, flocculation of soil particles and pozzolanic reactions products by hydration of GGBS.

On other hand GGBS itself can considered as it can give very good strength after compaction with suitable amount of water. But its hydraulic conductivity will be high. Thus the mixtures of black cotton soil and GGBS can be advantageous for liner construction. The admixture of if properly compacted when properly proportioned it may be good material for liner construction.

Early studies have shown that soils may require about 20% of fly ash. But it was found that soil with about 30% of GGBS yielded low hydraulic conductivity. Though optimization can be done based on several properties, in this study it is given importance to hydraulic conductivity. Further its hydraulic conductivity may further reduce due to filling up of voids by pozzolanic reaction products formed.

III. RESULTS AND DISCUSSION

The black cotton soil (BCS) and Ground Granulated Blast furnace Slag (GGBS) are mixed in three ratios, (90:10, 80:20 and 70:30) and the mixtures were tested for important geotechnical properties. The hydraulic conductivities of all the proportions were determined using Falling Head Method as per ASTM D5856-07. Particular mixture was optimized and selected based on the lowest hydraulic conductivity. It can be seen from the Table 2 that, the hydraulic conductivity of black cotton soil with 30% ground granular blast furnace slag is having the lowest when compared to 10% and 20% of GGBS in BC. Therefore, the 30% GGBS mixture has been considered for the modelling of the chromium transport. The selected mixture was compacted in to column cell and the predetermined concentration of chromium stock solution was passed through the compacted soil column and the effluent volume was measured, filtered, and then filtrates were tested for effluent chromium concentration using Atomic Absorption Spectrophotometer (AAS) thereby the relative ion concentrations were noted at specified pore volumes [9-11]. Graphs have been plotted to get the experimental breakthrough curve (BTC). The column setup involves a Plexiglas cylinder of 10 cm height, 2 cm inner radius and 0.3 cm thick. The schematic diagram of the column experimental set up is shown in Fig. 1.

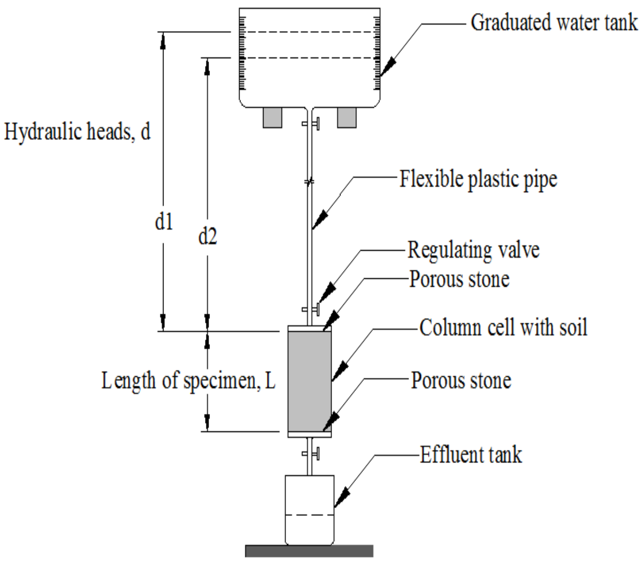

Fig 1 Experimental set up for soil column test.

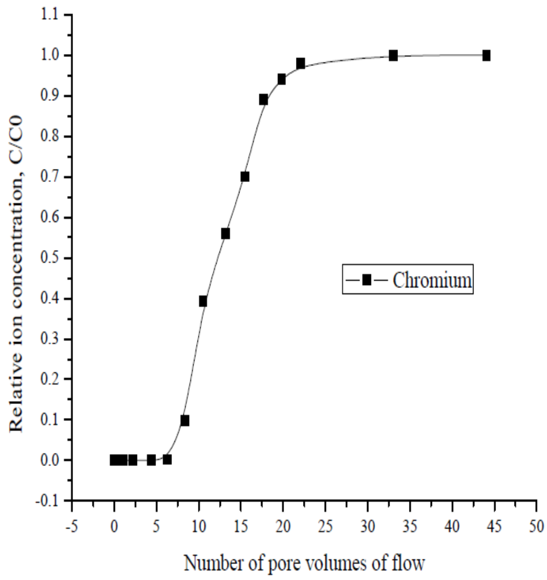

Fig 2 Experimental break through curve of chromium with respect to number of pore volumes for BCS with 30% GGBS

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Table 2 Hydraulic conductivity parameters for different oil mixtures

Soil mixture	Hydraulic gradient (i)	Hydraulic conductivity, cm/s	Darcy's Velocity, cm/s	Porosity (n)	Seepage velocity, cm/s
BCS+10%GGBS	15	1.19673E-06	1.795E-05	0.434	4.137E-05
BCS +20% GGBS	15	8.97565E-07	1.346E-05	0.437	3.081E-05
BCS +30% GGBS	15	5.98388E-07	8.976E-06	0.430	2.087E-05

It can be seen from the Fig 2 that the variation of relative concentration of chromium ion with number of pore volumes of flow. It is observed from the graph that the curve is almost flat up to about 5 pore volumes later the curve rises indicating there is a release of some amount of contamination in the effluent of the soil column experiment. The arrival of C/C0 = 1 is occurring at 27 pore volumes of flow. Thus the BTC shows that chromium is very greatly retarded by BCS with 30% GGBS.

IV. MODELLING OF THE CHROMIUM TRANSPORT IN BCS WITH 30% GGBS

To design the liner system for landfill site, the necessary to assess their rates of migration in the proposed soil liner system. For this it is necessary to understand different contaminant transport processes and the modeling. To select the type of soil and its thickness for a given design period time depends on the rates of contaminant migration of the selected contaminant. To assess the rates of travel of given contaminants it is necessary to understand contaminant transport parameters which are Diffusion coefficient (D) and Retardation factor (R). The concentration of contaminant migrated through porous media/liner system for a predefined time is assessed from theoretically determined breakthrough curves using theoretical Advection-Dispersion Equation (ADE) [6, 12]. Further it is known some of the properties of soils play important part in minimizing the rate of migration of ions. Particular emphasis is given to assess the rates of migration of chromium through commonly available soils as it is one of the common ions present in both industrial and domestic solid wastes in many cities in both developed and developing countries.

Further to avoid environmental concerns of using natural soils it is proposed to use industrial waste themselves as a part of soil barrier system. One of most common industrial waste generated in huge quantities is Blast Furnace Slag. To enable its use as barrier for waste disposal facilities it is necessary to optimize the ratios of soil and GGBS in the barrier system for maximizing the efficiency of the liner for maximizing its retention and to minimize its migration.

V. THEORETICAL MODEL

In order to get the theoretical BTC of the optimized mixture, the geotechnical properties tested in the laboratory and appropriate advective and diffusive parameters are require to be listed in the beginning of the modelling process. Once the data are given to the POLLUTEv7 program in the order breakthrough curve will be generated through the Advection-Dispersion Equation (ADE). The input data that are to be given to the POLLUTEv7.13 software are General

data such as Darcy's velocity soil column height etc., Layer data including geotechnical properties, number of division of the layer, diffusion coefficient, retardation factor etc. Boundary conditions such as source of contamination etc. and Run parameters consisting appropriate time steps depending on the soil height [13, 14]. In Table 2 and Table 3, the parameters which are used for the chromium transport in BCS with 30% GGBS has been presented.

The comparative analysis between the experimental BTC and that of theoretical BTC generated using POLLUTEv7 program have been done. It is to be noted that the theoretical BTC has been generated with measured/known set of hydraulic conductivity (HC), density and porosity and assumed diffusion coefficient and retardation factors. For the set of assumed values of diffusion coefficient and retardation factors with which the theoretical curve matched closely with experimental curve are taken as the transport parameters for chromium in the selected mixture. Fig 3 shows the matching of the experimental and theoretical breakthrough curves.

VI. DESIGN OF BCS WITH 30% GGBS SOIL LINER TO RETARD CHROMIUM

Knowing the transport parameters of the ion, density of the compacted soil admixtures and its HC the rates of migration of chromium for any thickness can be calculated. Then it is possible to design the thickness of the liner material for any given ion for any desired period can obtained. The data available on hydraulic conductivity presented in table 1 aided to select the appropriate soil mixture combination for the purpose of modelling. The BTC's, under different hydraulic gradients for given compacted soil mixture, the diffusion coefficient and retardation factor are found through modelling with POLLUTEv7 program for a liner thickness of 1m. The data used to design the liner thickness under different hydraulic gradients are presented in the table 4.

Table 3 Data required in the modelling process

Input parameter	GGBS 30+BCS 70
Advective Diffusive Transport mechanism, Hydraulic gradient = 15 (100 ppm Cr solution)	
Darcy's Velocity, cm/s	8.976E-06
Dry density, g/cc	1.55
Porosity	0.43
Distribution coefficient	1.1 ml/g
Diffusion coefficient, cm^2/s	$3.9x10^{-6}$

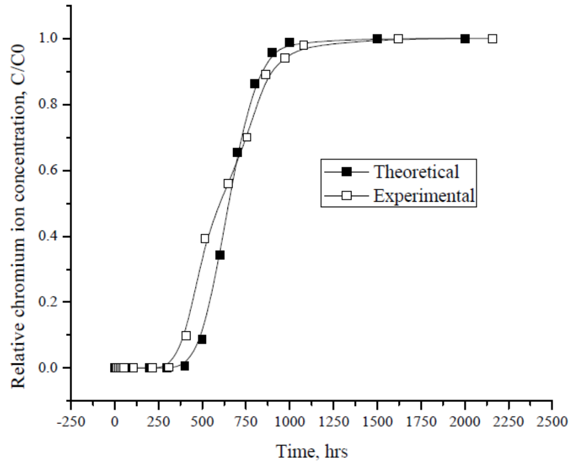

Fig 3 Matching of the experimental and theoretical breakthrough curves

Table 4 Data required to build the model in POLLUTE V7.13 program

Input parameter	GGBS 30+BCS 70
Advective Diffusive Transport mechanism, Hydraulic gradient = 1 (Cr solution)	
Darcy's Velocity, cm/s	5.98388E-07
Dry density, g/cc	1.55
Porosity	0.43
Distribution coefficient	1.1 ml/g
Diffusion coefficient, cm^2/s	$3.9x10^{-6}$

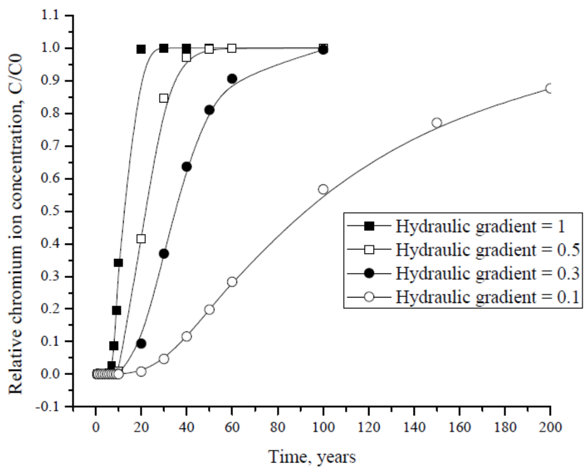

Fig 4 Break through curves for a liner of 1m thickness at varied hydraulic gradient

In the Fig 4 the variation of relative chromium ion concentration with time with advective diffusive transport in black cotton soil containing 30% GGBS mixture for various hydraulic gradients has been shown. It is observed that the variation in breakthrough times are small at lower C/C0 (relative concentration,) changes gradually and spreads steadiness at C/C0 of 1.0 for hydraulic gradients 1, 0.5, and 0.3, but at the same time when hydraulic gradient is reduced to 0.1, the breakthrough time rapidly increases to 100 years at C/C0 of 0.7. It can be concluded that this mixture attains better performance when hydraulic gradient is lower. But if the hydraulic head increases due to leachate built-up the thickness of liner needs to be increased.

VII. Conclusions

Based on the results presented in this Chapter and on the analysis of the same the following conclusions can be drawn:

The order of hydraulic conductivity variation with respect to selected GGBS-BCS mixtures were in the order GGBS30<GGBS20<GGBS10 where GGBS refers Ground Granular Blast Furnace Slag and the number refers to the percentage in the mixture.

The set of values D = 3.9x10-6 cm2/s and R = 4.964, satisfied to match the theoretical breakthrough curves with the experimental curves and are taken as the transport parameter for the ion through the selected liner material.

With D = 3.9x10-6 cm2/s and R = 4.964 and measured HC, porosity and dry density of the mixture the BTCs under hydraulic gradients (1, 0.5, 0.3 and 0.1) on compacted 30% GGBS-BCS mixture have been obtained through POLLUTEv7 software for a liner thickness of 1m.

BCS 30% GGBS mixture with a hydraulic gradient of 0.3 and can be used as liner to contain chromium ion as it gives a breakthrough time of more than 100 years for liner thickness of 1m.

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AUTHORS PROFILE

Srinivasa BT received his M.Sc. Engineering by research in the field of Environmental Engineering in the year 2019. Currently he is working as Executive Engineer in PWD, Bangalore, India.

Dr. Shankara received his Ph.D in Civil Engineering from Visvessaraya Technological University,-Belagavi in 2015. He has published about 15 papers in international journals. Currently he is working as Assistant Professor in the department of Civil Engineering Amrita School of Engineering, Bangalore, India.

Dr. Maya Naik received his Ph.D from Indian Institute of Science, Bangalore in 2003. He has published many papers in national and international journals.
He is working in the area of Environmental Geo technique particularly Contaminant Transport Through soil liner. Currently he is working as Professor in the department of Civil Engineering, BMS College of Engineering, Bangalore, India.

P.V. Sivapullaiah has done his Ph. D from Indian Institute of Science, Bangalore in 1977. Since then he served in the department of Civil Engineering, and retired as Professor in the year 2016 after 38 years of service of active service. He has taught and worked in the area of Environmental Geotechnics; Waste Management, Soil Stabilisation; Ground Improvement. He has 23 students for Ph. D formally and associated with many more informally. He is a member of several professional bodies. He has served as editor of many journals. He has worked for many sections committees for many universities. He has published more than 280 technical papers in the national and international journals, special volumes and conference proceeding, Chapters in books. He worked on several funded projects and challenging consultancy projects. He has organized several conferences, seminars and workshops. He has received several awards/ He delivered several keynote/invited lectures including IGS annual lecture. He has widely travelled both in India and abroad Presently he is serving as Pro Vice Chancellor CMR University. Prior to that he served as Pro Vice Chancellor, GITAM university. He has introduced several innovative practices as an academic administrator.