

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Study on Retention Behavior of Heavy Metal Lead Ion on Soil Bentonite Mixture

Sampath Kumar S¹, Megha N Kulkarni², Shilpa S Rathnoji³, P V Sivapullaiah⁴

Research Scholar, Department of Civil Engineering, Manipal Institute of Technology, Manipal Karnataka, India¹

Asst. Professor, Department of Civil Engineering, Nagarjuna College of Engineering and Technology, Bangalore,
India²

Asst. Professor Selection-Grade, Department of Civil Engineering, Manipal Institute of Technology, Manipal
Karnataka, India³

Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, Karnataka, India⁴

ABSTRACT: In this study, it is proposed to obtain breakthrough curves commonly occurring lead ions in any effluents through locally available soil amended with 10% bentonite and determine the diffusion coefficients. The theoretical breakthrough curves of migrating ions in the soil column experiment are generated using mathematical equation applying considering effective diffusion coefficients alone, knowing soil parameters and hydraulic data. These curves are then compared with experimental curves. In cases where the theoretical and experimental breakthrough curve do not match, there would be need to consider other parameter – retardation factor along with diffusion coefficient. Theoretical curves are generated for sets of diffusion coefficient and retardation factor. The sets which give theoretical curve close to experimentally determined breakthrough curves are accepted. Thus it may be possible to bring out the condition for the dominance of diffusion coefficient and retardation factor. Then knowing the values of diffusion coefficient and retardation factor along with soil porosity and hydraulic gradient it is possible to predict the breakthrough times of different ions in the soil. In this work the breakthrough times of lead ion for the soil of 1m and 0.5m are established. The studies can be extended for any ion or soil after establishing diffusion coefficient and retardation for the concerned ions in the selected liner under different hydrological regimes.

KEYWORDS: Column, Effective Diffusion Coefficients, Retardation Factor, Bentonite.

I. INTRODUCTION

The aim of the present study is to investigate the extent of contaminant attenuation of chemical species by specific soil and whether the present retardation equation can successfully predict contaminant transport. These aspects form an important basis for design of clay liners for waste impoundment such as landfills. In order to predict the transport of lead pollutant species, the transport parameters involved in the governing set of equations that describes the transport processes need to be accurately defined. The laboratory column experiments, which can be used to estimate the transport parameters of chemicals species migrating through waste contaminant barriers, are discussed.

1.2 CONTAMINANT TRANSPORT PROCESSES THROUGH SOIL LINER:

It is impossible to practically provide complete containment of leachate generated in a waste Landfill facility. Hence the design of a suitable (either as a primary barrier for municipal waste site or as a backup barrier for hazardous waste) requires an estimation of potential rate of contaminant transport through clay liner of landfill is useful in the design of secure waste storage facility. The following physical and chemical processes usually govern the contaminant transport.

1.2.1 ADVECTION

Advection (convection) is the process by which solutes are transported along with the flowing fluid or solvent. Due to advection, non-reactive solutes travel at an average rate equal to the seepage velocity of the pore fluid

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

1.2.2 DIFFUSION- Diffusion is the transport process in which a chemical or chemical species migrate in response to a gradient in its concentration

1.2.3 DISPERSION - dispersion refers to the spreading and mixing caused by the variation in velocity with which water moves

1.3 DETERMINATION OF DIFFUSION COEFFICIENTS BY COLUMN EXPERIMENT

However, for predicting the effective diffusion coefficients of ionic species of interest using column experiments, a modified form of above equation is used. The column experiment results are commonly reported in terms of number of pore volumes that have passed through packed soil column wherein one pore volume, is the cross sectional area of column(A) times its length(L) times the porosity(n).i.e., ALn .

Total number of pore volum U is the total discharge divided by value of one pore volume

$$U = \frac{vnAt}{ALn} = \frac{vt}{L}$$

Thus with these definitions, the one dimensional approximate Ogata-Banks equation can be rearranged as:

$$\frac{C}{C_o} = \frac{1}{2} \left[\operatorname{erfc} \left(\frac{1 - U}{2 \sqrt{UD_e / vL}} \right) \right]$$

$$J_{0.84} = \left[\frac{(U-1)}{U^{1/2}} \right] \quad \text{when } \frac{C}{C_o} = 0.84$$

$$J_{0.16} = \left[\frac{(U-1)}{U^{1/2}} \right] \quad \text{when } \frac{C}{C_o} = 0.16$$

$$D_e = \frac{vL}{8} [J_{0.84} - J_{0.16}]^2$$

1.4 RETARDATION FACTOR

The migration of contaminants caused by the movement of chemicals dissolved in the water is described by the retardation factor. Attenuation of leachate contaminant species is one of important criteria for the choice of landfill liner(Drury,1997). The retardation factor for any particular chemical includes all the interactions between the many chemical species and the solid surfaces of the porous media. These interaction tend to retard the migration of the chemical behaviors need to be known.

Retardation factors, R_f , can be determined in flow experiment where R_f for particular species in the ratio of solution velocity to the contaminant velocity. The retardation factor for that species is given by (Bouwer, 1991)

$R_f = \frac{V_{gw}}{V_{sp}}$ Where V_{gw} is the velocity of the water and V_{sp} is the velocity of the contaminant species

1.4.1 Analytical solutions to One Dimensional Contaminant Transport Equations

Method used to solve the one dimensional governing equation, analytical methods are widely used for calculating the contaminant migration The best known analytical solution for concentration C at time t and depth x beneath the surface of a barrier, which is assumed to be infinitely deep and subject to a constant surface concentration, C_o (Ogata 1970) is represented by

$$\frac{C}{C_o} = \frac{1}{2} \left[\operatorname{erfc} \left(\frac{R_f x - vst}{2 \sqrt{(DetR_f)}} \right) + \exp \left(\frac{R_f v_s x}{D_e} \right) \operatorname{erfc} \left(\frac{R_f x + vst}{2 \sqrt{(DetR_f)}} \right) \right]$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

II. DETAILS EXPERIMENTAL

In order to predict the transport of lead pollutant specie, the transport parameters involved in the governing set of equations that describes the transport processes need to be accurately defined. The laboratory column experiments, which can be used to estimate the transport parameters of chemicals species migrating through waste contaminant barriers

2.1 Influent Reservoir; It consists of a tank made of polyethylene with two openings. One at the top for transferring the synthetic source solution of interest into it and the other at the bottom to allow it to migrate through the soil specimen.

2.2 Column Assembly; The column assembly consists of Plexiglas cylinder of 11-cm long, 4-cm inner dia and 1 cm thick wall. The Plexiglas cylinder is attached to the base plate, which houses a porous stone as shown in the Fig 3. The soil specimen of 4cm dia and 10 cm height is compacted into the Plexiglas cylinder in three equal layers using a screw jack to ensure uniform compaction for the entire specimen. Once the soil sample was in place, one more set of porous stone are placed at the top and capped with top plate as shown in the figure.

2.3 Effluent Collector; It consists of a jar covered at the top to avoid evaporation of collected leachate. The effluent collected in the collector is monitored regularly.

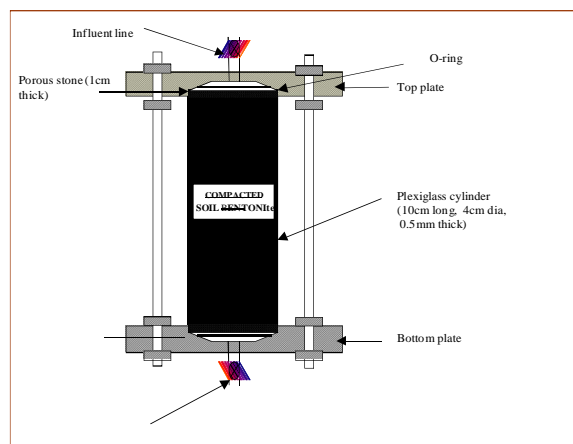


Fig.3.1 Components Of Experimental Set-Up Of Column Soil Test

III. EXPERIMENTAL PROCEDURE

3.1 Preparation of Soil Sample and Compaction

The oven dried soil is mixed with necessary amount of water separately as to prepare samples of required density. The details of experiment condition of soil specimen with source solutions are presented in Table 3.1. The soil is then compacted to required density by dividing the soil into 3 equal parts by weight and then, each part is compacted into plexglas cylinder,

3.2 Monitoring the effluent leachate

The desired solution is passed through the column. The volume of the effluent that comes out of the column with time was monitored at regular intervals and the concentration of ions measured. The interval selected varied with flow rate. The test is terminated once effluent concentration reaches influent concentration ($C=C_0$).

3.3 Chemical analysis of leachate

The chemical Analysis was performed by using AAS instrument. Dilution were made to bring the concentration into instrument range.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

IV. MATERIALS AND METHODS

4.1 Clayey Soil

Clayey soil obtained from Mundur dumpsite in Bangalore was used in this study. The samples were collected by open excavation from a depth of 1 meter from natural ground. The soil was dried and passed through IS 452-micron sieve. The soil so obtained has clay content of 62%. The cation exchange capacity of soil is about 31meq/100 g.

4.2 Bentonite Used:

Bentonite procured from Indian Institute from Bangalore was used in the present study. Bentonite is a natural clay mineral and is found in many places of the world it belongs to 2:1 clay family the basic structure in it is composed of two tetrahedrally coordinated sheets of silicon ions surrounding a sandwiched octahedrally coordinated sheet of aluminum ions. It has excellent sorption properties and possesses sorption sites available within its interlayer space as well as on the outer edges

V. DETERMINATION OF EFFECTIVE DIFFUSION COEFFICIENTS

The column method is used to calculate transport parameter and its is most preferred and is described here. This soil column test, traditionally known as leaching column test and has been used to study the adsorption and migration of contaminants through clay barriers. Firstly steady state flow is established through the soil sample by using distilled water in source reservoir. After steady state fluid has been established, the fluid in the influent reservoir is changed to a solution to a known and constant concentration (C_0) of particular chemicals constituents. The concentration (C) in the effluent reservoir is measured as the data are reduced in the form of break through curves, the breakthrough curves are modelled using analytical solutions and hence the, Diffusion coefficient can be calculated by knowing C , C_0 , v , L . This section describes some of the more common procedures, which have been used to calculate the transport parameters.

5.1 Ogata Bank's Method

In this method a plot of relative concentration versus time or number of pore volume are plotted from the plot the time ($t_{0.16}$) corresponding to $C/C_0 = 0.16$ and time ($t_{0.84}$) corresponding to $C/C_0 = 0.84$ are obtained using these values and knowing the thickness of soil (L) and knowing the value of velocity, effective diffusion coefficient is calculated as follows:

Where, $U=vt/L$

5.2 Time Lag Method

In this method, the total amount of diffusion substance per cross sectional area, Q_t is plotted versus time and determining the values for the intercept, T_L then diffusion coefficient, D , is calculated from the equation,

$$T_L = \frac{L^2}{6D}$$

5.3 Root - Time Method

In this method, the time corresponding to relative concentration of 0.1 (90% equilibrium) is obtained from the breakthrough curve of the species. Then diffusion coefficient, D , is calculated using the equations,

$$D = \frac{0.2436 L^2}{t_{90}}$$

VI. ION MIGRATION IN SOIL BENTONITE MIXTURE BASED ON DIFFUSION COEFFICIENT ONLY

From the fig. 6.1 it is clear that the effect of variation in diffusion coefficient of iron obtained by different methods on breakthrough curves is marginal and none of the curves are close to the experimental curve. Thus the breakthrough time for lead with diffusion coefficient from theoretical curves for $C/C_0 = 392$ is 1250 hrs; the breakthrough time obtained experimentally from is 1666 hrs. It is clear that the theoretical breakthrough time is occurring earlier than the experimental breakthrough times.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

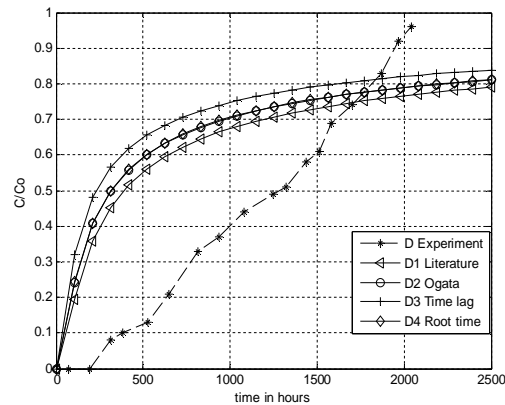


Fig. 6.1 Comparison of theoretical breakthrough curves obtained using different diffusion coefficients with experimental curve for Lead ion.

There is considerable difference in the nature of curves while the theoretical curve indicates piston flow, the experimental curve indicates presence of attenuation/ retardation process. This shows that the effective diffusion coefficient alone, as calculated by different methods, is not adequate to describe breakthrough curves. This also indicates that the effective diffusion coefficient as calculated by different methods is not fully accounting all the retardation processes that may occur while the lead ion is migrating through soil.

VII. ROLE OF RETARDATION FACTOR IN THE PREDICTION OF EXPERIMENTAL BREAKTHROUGH CURVES OF IONS IN SOIL

Fig.7.1 shows the theoretically obtained breakthrough curves, using diffusion coefficients obtained by different methods, with retardation factor selected on trial and error for lead ion along with experimental curve. From the figure is clear that all the theoretical curves agree reasonably well with the experimental curve except ogata bank's method. However some variation in the diffusion coefficients, even though the same retardation factor is used. Thus the breakthrough time for lead ion with any diffusion coefficient from theoretical curves for $C/C_0 = 0.5$ varies in the range of 1200 to 1700 hrs; and the actual breakthrough time obtained by experimental curve is 1300 hrs. Relatively the curves obtained using diffusion coefficient obtained by Root time method is closer to the experimental breakthrough curve.

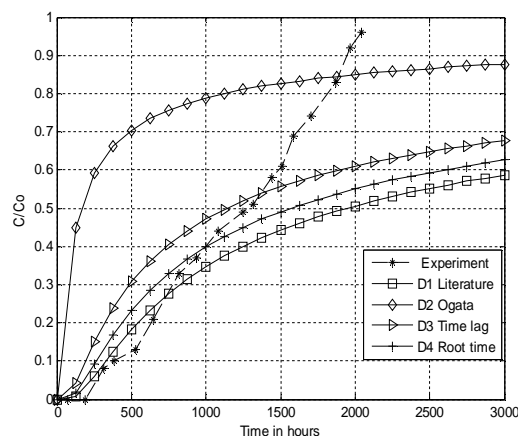


Fig. 7.1 comparison of theoretical breakthrough curves obtained using retardation factor and different diffusion coefficients with experimental curve for lead ion

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Compared to the theoretical curves obtained without retardation factor, the theoretical curves with retardation factor shows considerable variation between $C/C_0 = 0.5$ and 1.0. this is due to difference in the nature of breakthrough curves. The curves exhibit lesser characteristics of piston flow. The theoretical curves obtained without retardation factor (fig.6.1) showed earlier breakthrough time, whereas the curve in this case showed not only higher breakthrough times but also nearer to the experimental value.

VIII. RATE OF MIGRATION OF IONS IN SOIL BENTONITE LIRER

8.1 Migration of Lead Ion Considering only Diffusion Conditions

Fig 8.1 shows the variation of relative concentration with time for lead ion using respective diffusion coefficient and with retardation factor in soil bentonite mixture for lead contaminating fluid and considering 1 m as thickness of the liner breakthrough occurred at about 580 years for lead ion.

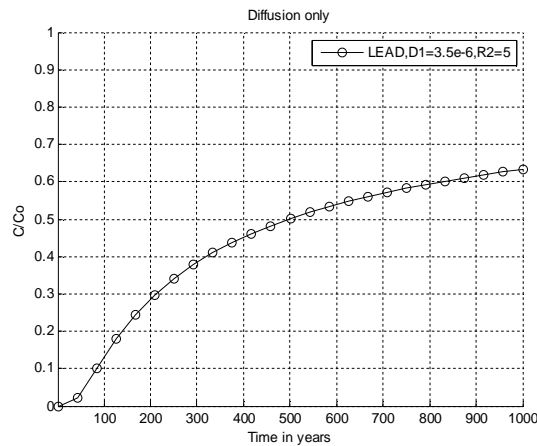


Fig.8.1 Variation of relative concentration with time for Lead ion considering diffusion only

The breakthrough time for any relative concentration can be obtained in any soil. The curve showing the variation of breakthrough time of lead ion in soil bentonite mixture with respect to relative concentration in the particular soil.

8.2 Migration of Lead Ion Considering both Advection-Diffusion Conditions

Fig.8.2 shows the variation of depth of arrival of C/C_0 of 0.5 front for Lead ion with 1 m thickness of liner considering both advection and Diffusion. It can be seen that the breakthrough concentration for lead ion reaches bottom of Soil Bentonite liner of 1 m thickness of about nearly 210 years.

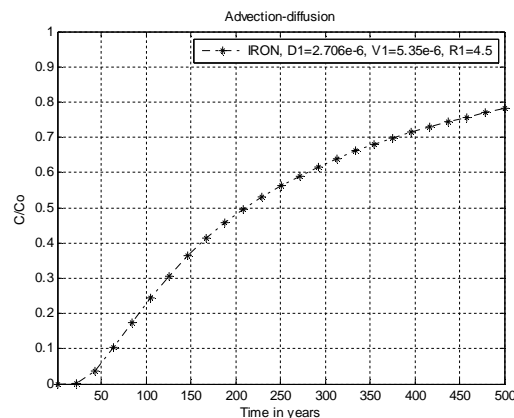


Fig.8.2 Variation of relative concentration with time for Lead considering both Advection-diffusion

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Comparing the breakthrough times obtained in case of diffusion alone (fig 7.1) the breakthrough times are reduced considerably in the present case. Considerable reduction in breakthrough time occur due to advection in soil bentonite for lead ion.

Fig.8.2 shows the variation of depth of arrival of C/C_0 of 0.5 front for Lead ion with 0.5 m thickness of liner considering both advection and Diffusion. It can be seen that the breakthrough concentration for lead ion reaches bottom of Soil Bentonite liner of 0.5 m thickness within 100 years.

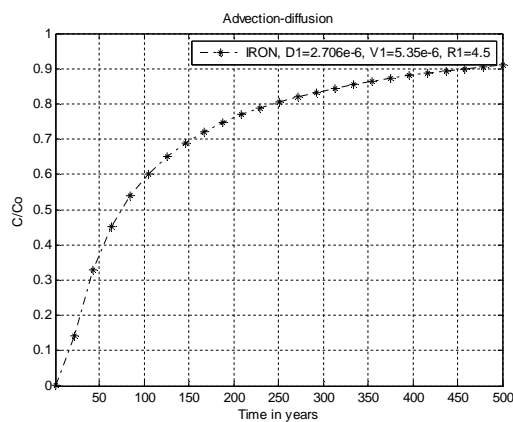


Fig.8.3 Variation of relative concentration with time for Lead ion considering both Advection-diffusion for 0.5m thickness of liner.

Comparing the breakthrough times obtained in case of Advection-Diffusion for 1 m thickness (fig 7.1) the breakthrough times are reduced considerably in the present case. Considerable reduction in breakthrough time occur due to reduction in thickness of the soil Bentonite liner soil for lead ion.

IX. CONCLUSIONS

From the current research the following major conclusions are as follows:

1. Determining the diffusion coefficient of an ion experimentally is an important step for the calculation of rates of migration of ions.
2. Diffusion coefficients is sensitive to the method of determination, Generally, diffusion coefficient obtained from Root-Time Method is lower and is matching with the literature value.
3. It is clear that prediction of breakthrough curve considering diffusion alone is not sufficient, hence there is a need to consider retardation factor too.
4. To obtain the values for retardation factor required, the breakthrough curve of ions in soil bentonite mixture using both the ions and different diffusion coefficients as determined above, are generated and compared with experimental breakthrough curves.
5. The evaluation is done both with and without Advective flow condition.
6. Breakthrough times will be more if we design appropriate thickness of liner.

REFERENCES

1. Mor, S., Ravindra, K., Visscher, A.D., Dahiya, R.P., Chandra, A., 2006. Municipal solid waste characterization and its assessment for potential methane generation: a case study. *Journal of Science of the Total Environment* 371 (1), 1–10.
2. S. S. Tahir, R. Naseem, (2004) Removal of Cr(III) from tannery wastewater by adsorption onto bentonite clay *Separation and Purification Technology* 53 (2007) 312–321.
3. E. Eren, B Afsin (2008) An investigation of Cu (II) adsorption by raw and acid activated bentonite: A combined potentiometric thermodynamic, XRD, IR, DTA study. *Journal of hazardous material* 151, 682-691.
4. A Dube et.al. (2001) Adsorption and migration of heavy metals in soils. *Journal of environmental studies*. Vol 10, No.1, 1-10

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

5. Syed Abu Sayeed Mohammed., Maya Naik., Adsorption Characteristics of Metals in Aqueous Solution by Local Materials with Additives as Liners for Waste Containment Facilities, *Journal of Water and Environment Technology*, Japan, 8(1), 2010, pp 29 – 50. doi:10.2965/jwet.2010.29
6. Tuncer B. Edil A review of aqueous-phase VOC transport in modern landfill liners Professor of Civil & Environmental Engineering and Geological Engineering, University of Wisconsin-Madison, 1415 Engineering Drive, Madison, WI 53705, USA *Waste Management* 23 (2003) 561–571
7. Qian, Xuede; Koerner, Robert M. and Gray, Donald H. (2002) "Geotechnical Aspects of Landfill Design and Construction", in Michigan Department of Environmental Quality, Waste Management Division, USES, pp. 399-4379
8. ASTM., (2004) International American Standard Testing Method D3987 –85 (reapproved 2004), 'Standard test Method for shake extraction of solid waste with water', USA.
9. ASTM., (2001), International American Standard Testing Method D4646 –87 (reapproved 2001), 'Standard test Method for 24-h Batch – Type Measurement of Contaminant Sorption by Soils and Sediments.', USA.
10. Rajasekhar C, Sridharan A , Pandian NS, Effect of Lime on the heavy metals ions
11. retention characteristics of Fly Ash, International Symposium on Natural hazards and Environmental Geotechniques, Bangkok 1995 pp 1-9.
12. MayaNaik (2003), Influence of Diffusion Coefficient and retardation factor in contaminant transport through soil liners, PhD thesis, Indian Institute of Science, (IISc), Bangalore.
13. Syed Abu Sayeed Mohammed, Maya Naik. Syed Tanveeruddin , Influence of additives on the retention of metal ions in a soil of Bangalore, India. *Ambiente & Agua – An Interdisciplinary Journal of Applied Science.*, Brazil, 4 (1), 2009, pp 20 - 36. doi:10.4136/ambi-agua.71
14. Bowders, J.J., et al 1987 stabilised fly ash for use as low permeability barriers. Wood, R.D. (ed.), Proc. Conf. on geotechnical practice for waste disposal; Geotechnical special publication No. 13, ASCE Wood R. D (ed.), New York, pp 320-333.