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Reduction of lead pollution in groundwater using soil based protective liner bed in land fill pits

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ABSTRACT

Liner provides resistance to pollutant such as lead which seeps into groundwater from the polluted landfill, hence the study of its characteristics is important. Of the various methods to provide better and effective properties of landfill liners, the method of using clay as liner materials has been explored in laboratory scale. The purpose is to overcome the problem and deficiencies of the liners made of Geo-membrane. It is observed that using clay with some amount of admixture like cement, gypsum, lime, bentonite, etc, the concentration of lead at lower portion of membrane is reduced to 89–98%. A mathematical treatment of the phenomenon has been developed. The experimental result shows satisfactory agreement with the model.

Keywords: Ground water contamination; Liner; Lead poisoning; Clay; Admixture

1. Introduction

Landfill is a source of the hazardous material. Over a period of time, these enter the groundwater and pollute it. This in turn becomes source of health hazard. Therefore it is essential to prevent such contamination such as that due to lead. One of the ways to do so is to use a liner that prevents the seepage of the pollutants to enter groundwater. So to dispose of any hazardous waste to a landfill, liner is used which protects the landfill as it provides a barrier to fluid movement. The overall objective is to limit the discharge of toxic contaminants to groundwater. Liners provide the final line of defuse against groundwater contamination. In industry geo-membrane such as high density polyethylene, flexible polyethylene, poly vinylchloride, polypropylene and geo-synthetic clay liner are used as liner materials for hazardous waste landfill. But the problems to use these materials are:

1. These are very costly, unsuitable for retention of some hydrocarbons and when exposed to sunlight it susceptible to UV attack.
2. There is a possibility of structural cracking in liner material.
3. These are non-biodegradable, so there is a problem for disposal of these liner materials after use.
4. Seepage problem from impoundment represents the greatest potential contamination from surface impoundment and can lead to groundwater contamination [1].

Using these types of geo-membrane materials as liner there is every possibility of contamination of groundwater. To overcome this problem, clay can be used as liner material for the hazardous waste landfill

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as porosity of clay particle is very low and equivalent movement of liquid is very low. Permeability (K) of water through clay is less than 10^{-9} m/s and so the rate of advection transport through clay is negligible. Soil can adsorb some contaminants also. The very low permeability of the clay barrier is expected to lengthen the lifetime of the landfill and slow down the consequent release of contaminants [2–4]. Clay has the property of swelling, plasticity, cohesion and adhesion. Some clay soils have the ability to act as membrane that restricts the passage of charged solutes [5–7]. Such membrane behaviour also results in Chemico-Osmosis, or movement of liquid in response to solute concentration gradient. Both these effects result in reduced solute transport through a soil barrier for waste contaminant [8,9].

For clay used as liner materials there should be certain properties of clay [10,11]. These are:

1. The permeability of soil should be less than 1×10^{-9} m/s for soil liners which are used for hazardous waste, municipal waste and industrial waste landfill.
2. The clay % in a given soil should be higher than 20%, etc.
3. Plasticity index should be >10 and liquid limit should be >30.
4. The thickness of the liners varies from few decimeters to more than 1 m depending on the waste composition.

But clay liners can be attack by the chemical wastes or leachate directly or indirectly. The interaction of soil with the chemical waste, pesticide may attack the double diffuse layer of clay [12–17]. As a result the permeation rate through the liner is increased and the possibility of groundwater contamination is also increased. To overcome this problem, some admixture like gypsum, cement, lime, bentonite, flyash, etc can be used with soil to stabilize the soil particles from chemical attack and to decrease the porosity of soil particles [18–21].

The main objectives of the present work are:

1. To study on the permeability of lead solution through clay and different admixture membrane.
2. To study the permeability through the different thickness of clay–admixture medium.
3. To study on the metal solution permeation rate through the membrane and to choose the better clay – admixture membrane where the permeation rate is low.
4. To develop a simple mathematical model which can describes the phenomenon.

Lead is present in almost all types of waste materials. Lead has adverse effect on environment and human health. If heavy metal like lead comes in contact with ground water, the later gets contaminated. Lead builds up in the body over many years and can cause damage to the brain, red blood cells and kidneys. The greatest risk is to young children and pregnant women.

For the present work, soil was collected from Matla river of Canning, West Bengal and the properties of the soil of Matla river were determined by using mainly the instruments such as pH meter (ELICO), Atomic Absorption Spectrophotometer (AANALYST 200; Perkin Elmer), variable head soil permeability apparatus (Aimil Limited, India), liquid limit apparatus, X-ray diffractometer (Miniflex X-Ray Diffractometer), etc.

2. Experimental procedure

2.1. Methods

For the experimental work, 0.025 kg of Matla river soil sample was taken and the lead content present in the sample was determined with the help of Atomic Absorption Spectrophotometer using standard method. After that 2 kg of soil sample was taken in the special type variable Head Permeability apparatus (depth 0.126 m and diameter 0.1 m, diameter of stand pipe = 0.02 m) which operates on the basis of Darcy's law:

$$K = 2.3\frac{aL}{At}(\log H_0 - \log h_1), \quad (1)$$

where K is the coefficient of permeability of the given soil sample, cm/s, a is area of cross-sectional of stand pipe. L is the length of soil sample, h_1 is head of water after a fixed time. A is the area of cross section of soil sample, H_0 is initial head of solution.

For determination of permeability the variable – head parameter was used which consisted of a brass-mould in which soil samples could be compacted or undisturbed samples could be placed. Fine copper-wire mesh and perforated plates were fitted at the top and the bottom of the mould and it was kept in a constant level through. The top was connected to a glass-stand pipe of suitable size. At any instant, the head of water was equal the scale reading plus the difference in elevation of the zero of the scale and the water level in the through. The flow of water was stopped when water level in the stand pipe was failed through a sufficient distance as indicated and the time was noted. Five sets of such independent readings were taken and an average value of the coefficient of permeability coefficient was found out.

For the experiment of lead solution transport through the soil bed, known concentration of lead solution was passed through the stand pipe to the sample chamber (depth 0.126 m long and 0.1 m diameter sample port). At the bottom of the soil chamber, extra chamber arrangement was made (depth 0.10 m and made from Perspex) where solution (transport through the soil layer) transported through the soil chamber was collected. After different time intervals, solution from the Perspex chamber was taken out and lead concentration was measured using Atomic Absorption Spectrophotometer. After 7 d exposure of lead solution on soil membrane, soil samples were taken out from the soil chamber and concentrations of lead present in different layers of soil membrane were extracted and measured using standard method using 2.1.1. Atomic Absorption Spectrophotometer.

Different admixtures were added to the soil and permeated in 0.05 m long and 0.10 m diameter sample port with de-ionized water. Solution of lead was passed through the different soil–admixture liner (Fig. 1). The concentration of metal at the different layers of membrane in the sample port was analysed after 3 d exposure using standard method with the help of Atomic Absorption Spectrophotometer. The different soil admixture beds used [21] were: (a) soil, (b) soil–bentonite mixture bed, (c) soil–gypsum mixture bed, (d) soil–cement mixture bed, (e) soil–lime mixture bed, H was determined by the amount of lime (calcium) contained in soil. pH had been measured by following electrometric method using a digital pH meter (make: Elico Limited, LI 120 / LI 610) after necessary calibration with standard buffers (buffer 4, 9.2, 7).

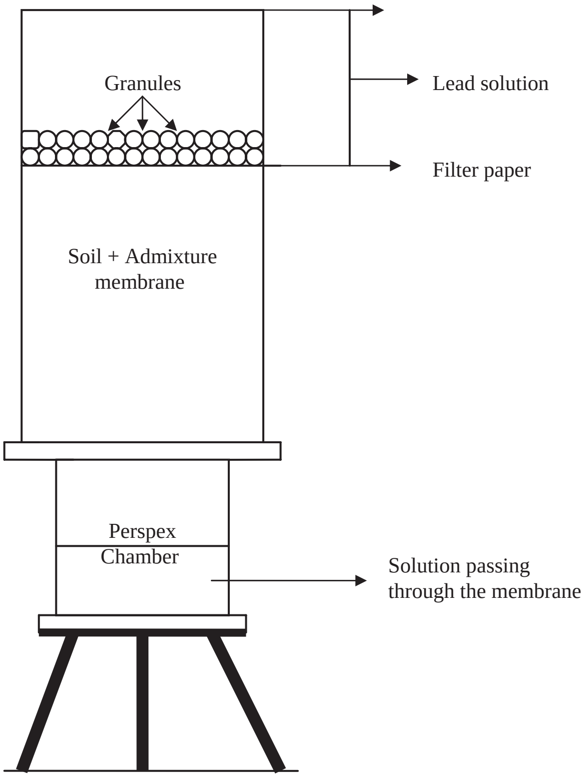

Fig. 1. Experimental set-up.

Moisture content of the sample was determined using certain amount of the collected sediment (about 40 g) was taken and weighed. It was kept for drying until a constant weight was obtained. Then it was cooled and weighed. The moisture content can be calculated as

$$\%\ \text{Moisture} = \frac{\text{Initial weight} - \text{Final weight} \times 100}{\text{Initial weight}}.$$

Instrument used: Tray Drier; Manufacturer: Amalgamated Suppliers, Kolkata; Range: 30–460°C.

The plastic limit is the water content, in percent, at which the soil passes from a plastic state to a brittle state. It is the limiting water content between the plastic and semi-solid state. At the plastic limit, the soil begins to crumble while being rolled into a 3 mm diameter thread (Made by Shambhavi Impex, India).

For liquid limit determination of soil, 48 g of the thoroughly mixed soil fines (i.e. the material passing the 0.425 mm sieve) were weighed out and transferred to a porcelain dish. Distilled water was added by means of a burette and the moist material was then thoroughly mixed for 10 min with a spatula. The liquid limit device was then operated at a speed which results in two taps per second being applied to the soil, until the lower parts of the faces of the two soil portions had flowed together and made contact across a distance of about 10 mm. The number of taps required to close the groove across this distance was recorded and a sample of approximately 2–3 g, representative of the total thickness of the layer, was transferred to a tarred weighing bottle (or other suitable container) for the determination of its moisture content. The loss in mass was the mass of water which is then expressed as a percentage of the oven-dried mass of soil. The moisture content of the soil was expressed as a percentage of the mass of the oven-dried soil and is calculated.

The % of clay, silt, sand present in samples was analysed by hydrometric Method (Wet Analysis procedure). The analysis was based on Stoke's law according to which fine particles from suspension in a liquid settle at different rates according to their sizes, the coarser settling more quickly than the finer. The percentage finer N can be computed from

$$N = \frac{G}{G-1}\frac{V}{W_s}C\,(r - r_w)\,100\,\%.$$

where G is specific gravity of solids, V is volume of suspension (1 l), W_s is unit weight of water at temperature (usually 20°C), C is hydrometer calibration, r is hydrometer reading in suspension, r_w is hydrometer reading in water (at same temperature as suspension).

Metals present in soil samples were extracted from soil using fixed amount of nitric acid and hydrochloric acid following standard methods and concentrations of the corresponding metal solutions were determined using atomic absorption spectrophotometer in mg/L level [22].

Instrument used: Atomic Absorption Spectrometer; Manufacturer: Perkin-Elmer.

For determination of total dissolved solid present in the solution a beaker was dried and weighed (a_1) and then 20 ml sample was taken on it through a filter paper. The beaker was dried above 102°C and cooled and again weighed (a_2). From the difference, total dissolved solids were calculated in %.

2.2. Mathematical modeling of the problem

Let a liquid in which metallic compound has a concentration of C_0 be placed over the top of the bed. Initially the bed being dry, the concentration, C, at depth x is zero, i.e, at $t = 0$, $C = 0$. x is length of the membrane = [L], k_1 is coefficient of permeability = [L/T] (sssuming constant or different type of soil–admixture medium), ρ is density of soil = [M/L^3], t = time, in sec = [T]

The process may be written as:

$$f(\Delta C, x, k_l, \rho, t) = 0 \tag{2}$$

$$\text{where } \Delta C = \text{Concentration difference} = (C_0 - C), \tag{3}$$

Total number of variables: $n = 5$, number of fundamentals units, $j = 3$, number of repeating variables = 3, number of dimensionless groups, $i = 5 - 3 = 2$.

Solving the dimensions of all the parameters and taking assumption that coefficient of permeability through out the experiment is constant the dimensionless groups are derived, and the dimensionless groups are:

$$\Pi_1 = \frac{C_0 - C}{\rho} \quad \& \quad \Pi_2 = \frac{k_1 t}{x} \tag{4}$$

So, the final equation derived from the Buckingham Π Theorem is:

$$\frac{C_0 - C}{\rho} = f\left(\frac{k_l t}{x}\right). \tag{5}$$

3. Results and discussions

The experimental results are given in Figs. 2–3 and Table 1.

From Fig. 2, it is observed that concentration of lead is decreasing as the soil layer thickness is increasing. The concentration of lead is reduced from 85% to 99.28% from upper to lower level of the liner membrane. The lead concentration of the solution collected at the bottom of the sample port for the first experiment is found as 0.321 mg/L which is very low and the reduction % from upper level is 99%. The reason of this phenomenon is that a large amount of lead ion is adsorbed by the soil layer of the upper portion of the soil chamber and as a result the concentration of lead transported through the layer of the soil membrane is decreased gradually.

It is observed from Figs. 3 and 6 that the concentration of lead is reduced from upper level to lower level when different admixture is mixed with soil. The reason behind the result is that admixture mixed with soil decreases the porosity of soil particles and strengthens the soil by cementing the porosity. So the resistance to flow of lead solution is increases. It is observed that lead has the binding effect with soil. So the permeation rate through soil–admixture become low. It is observed that soil–cement admixture gives the better result than other admixture. The reason behind is that cement particles decrease the soil porosity due to their cementing effect with soil, strengthening the soil from flocculation and so as a result permeability through the soil–cement mixture is decreased. In case of gypsum, due to this cementing effect, permeation rate is decreased. But due to the presence of calcium ion in gypsum permeation rate of solution is increased as calcium ion can diffuse through the double diffuse layer of soil particle. Due to this combined opposite effect, the permeation rate through soil–gypsum admixture liner is somewhat higher than soil–cement mixture. In case of lime, due to presence of calcium ion in lime permeation rate through the soil–lime admixture is increased. Bentonite is also a good alternative as admixture, but due to the properties of cracking of bentonite in absence of solution, permeation rate can be increased after some time period. It is observed that soil itself is a better liner material for hazardous waste landfill and if some amount of admixture like cement is added with it and used as liner material, it will be better alternative for reduction of lead ion effect to protect groundwater.

Using experimental data and mathematical expression (5), it is observed that in case of concentration difference of lead ion with layer thickness (in Fig. 4) the nature of the curve is straight-line and correlation coefficient R^2 is very high (0.974). So the predicted

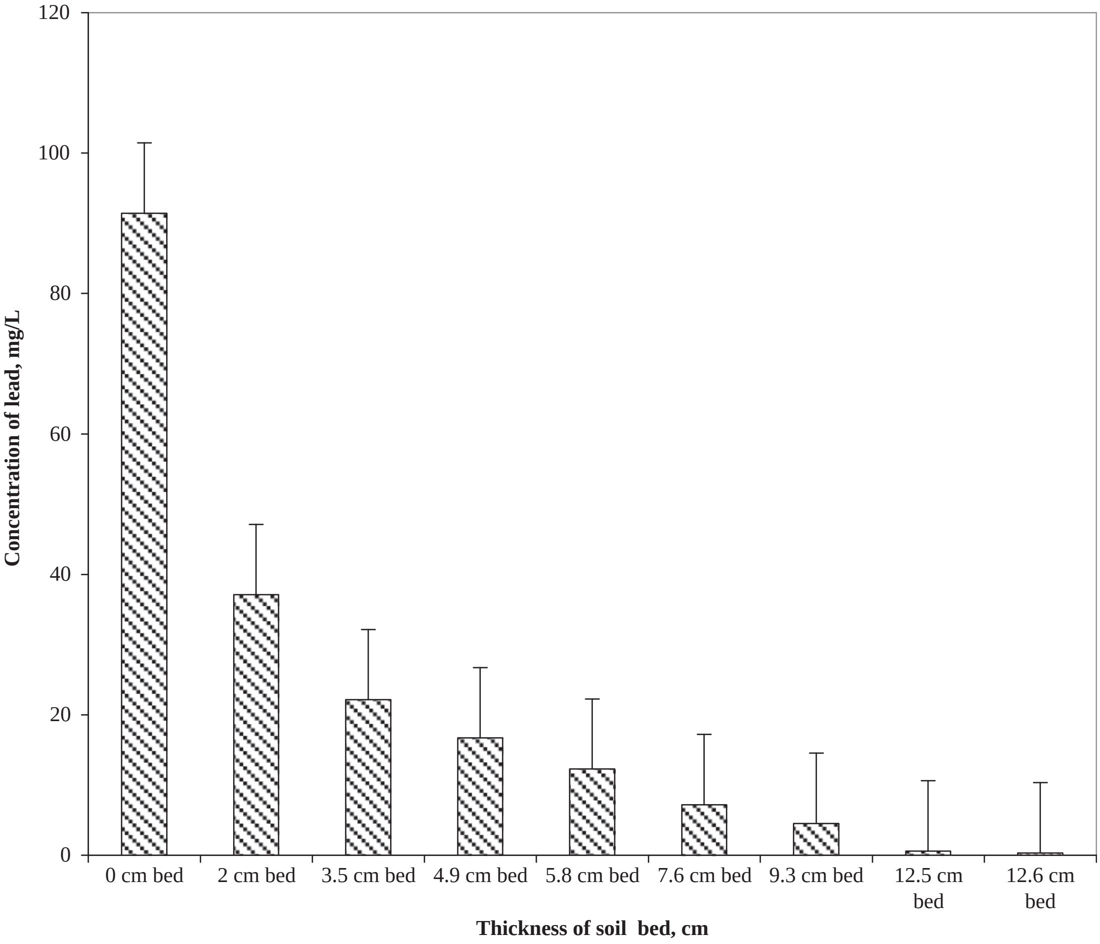

Fig. 2. Lead concentration along the different layer the soil membrane.

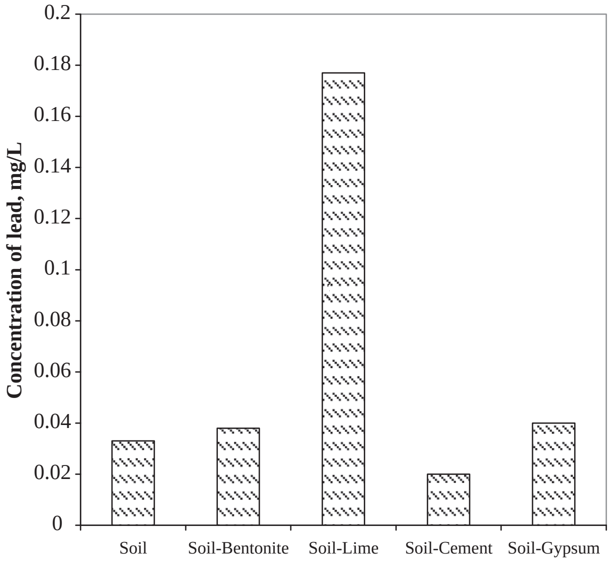

Fig. 3. Concentration of lead solution at perspex chamber passing through the different soil–admixture medium.

mathematical method is valid for the transport of lead ion through the different layer of soil membrane.

From Fig. 5, it is observed that the experimental concentration data are almost same as the theoretical concentration data. So, the derived simple mathematical model equation approach describes the phenomenon satisfactorily.

From Fig. 7, it is observed that using Buckingham Π method, the concentration from experimental results and concentration from theoretical results are almost same. So, the simple mathematical approach describes the phenomenon satisfactorily for different soil–admixture membrane also.

4. Conclusion

The present investigation is a systematic study on the reduction effect of lead on soil and groundwater beneath the waste landfill. It is revealed from the experimental and mathematical model that if soil can be used as liner materials, then effect of lead ion can

Table 1
Properties of soil collected from Matla river for the experiment

Properties	Value	Method/Instrument of measurement
Soil pH	7.49	pH meter
Moisture content	26.1142%	Tray drier
Conductivity, µs/cm	227	Conductivity meter
Liquid limit	48	Liquid limit devices, AASHTO T-89-00 (2004)
Plastic limit	24	Plastic limit apparatus AASHTO T-90-00 (2004)
Plasticity index	24	-
Permeability, m/s	1.08×10^{-9}	Permeability apparatus
Clay %	27	Sedimentation process
Silt %	68	Sedimentation process
Sand %	5	Sedimentation process
Quartz	45%	X-ray diffraction
Illite	25%	X-ray diffraction
Feldspar	5%	X-ray diffraction
Kaolinite	5%	X-ray diffraction
Montmorillonite	5%	X-ray diffraction
Chlorite	10%	X-ray diffraction

be reduced to above 90%. As the layer thickness of soil is increasing, the concentration of lead is decreased from upper to lower level of soil bed. Concentration of lower aqueous solution passing through the soil membrane is very low and it is observed that if soil is used as liner material, groundwater contamination due to lead ion can be reduced to above 90%. As industrial waste materials can have chemical effect on soil particles (due to

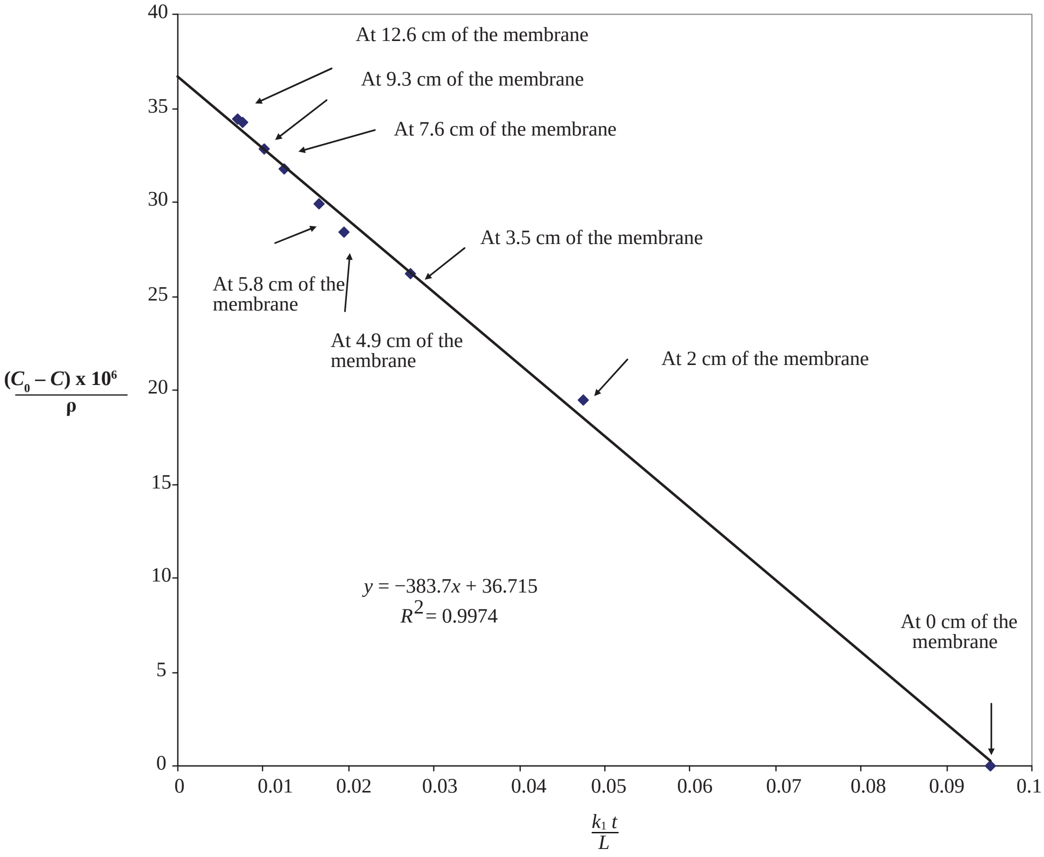

Fig. 4. Concentration difference of lead ion with thickness of soil bed using mathematical equation.

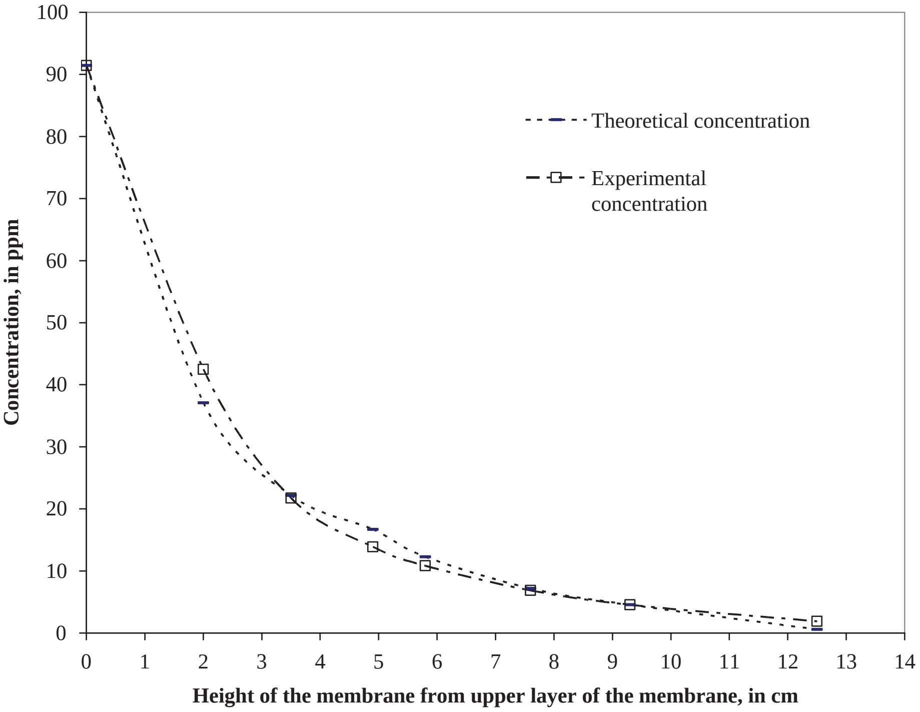

Fig. 5. Comparison of theoretical vs experimental concentration of soil membrane using Buckingham theorem.

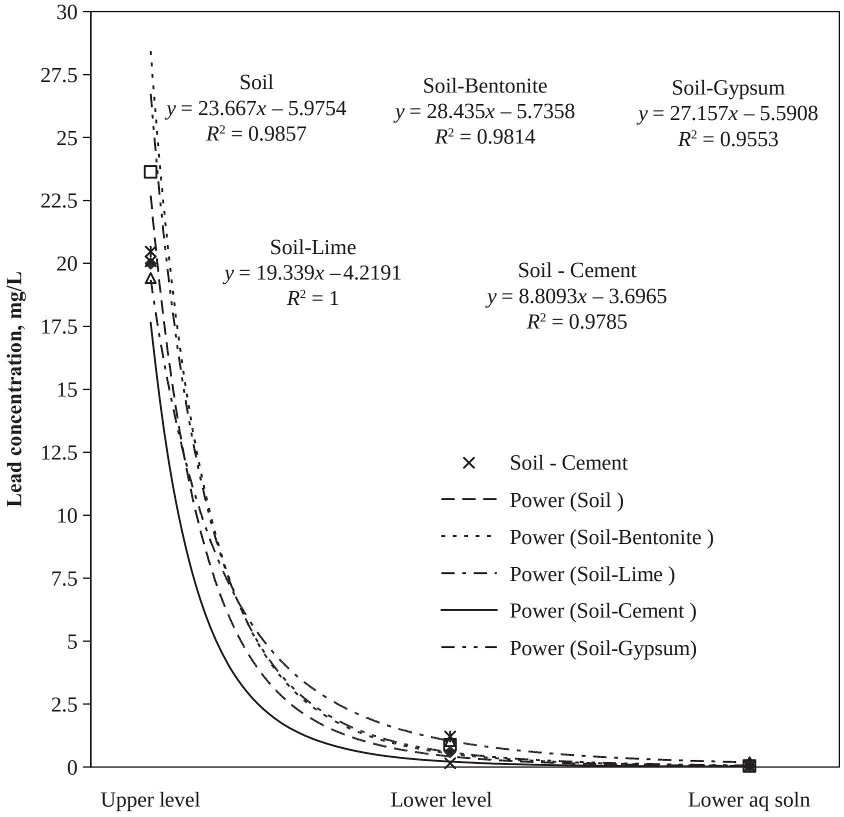

Fig. 6. Lead concentration at different level of soil–admixture medium.

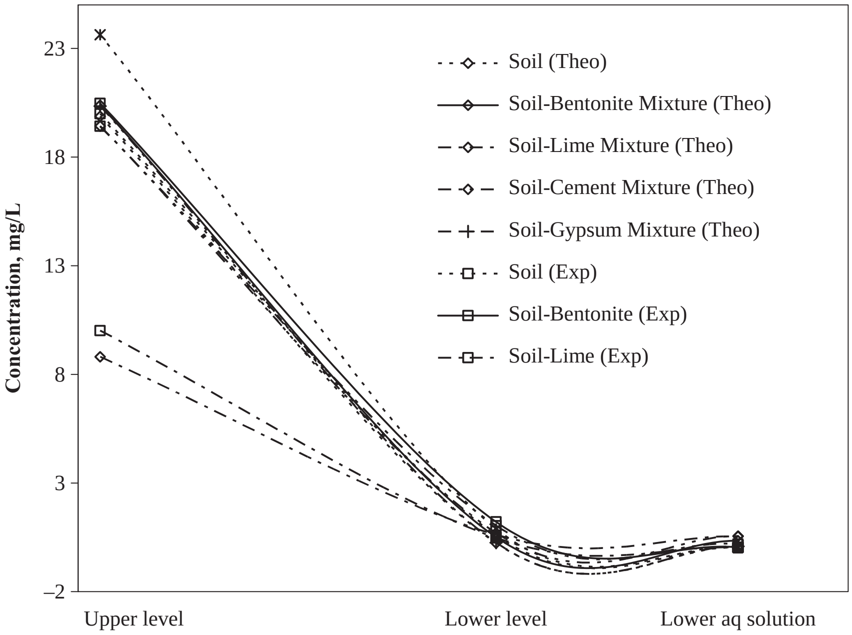

Fig. 7. Concentration from different soil–admixture membrane using Buckingham Π theorem.

presence of different heavy metals present with lead), soil–cement mixture liner is best alternative for this purpose as cement particles decrease the porosity of soil mixture due to the cementing effect and heavy metals have no effect on cement particles.

References

[1] J.H Huddleston: How soil properties effect groundwater vulnerability to pesticide contaminants, www.agcomm.ads.orst.edu, FM 8559 October 1996.

[2] P. Corser and M. Cranston, Geosynthetic Design of Performance, Proceeding – Vancouvver Geotechnical Society, Vancouver, B.C, May 24, pp. 11–16, 1999.

[3] D.E. Daniel, Predicting hydraullic conductivity of clay liners, J. Geotech. Eng., 110 (2) (1984) 285–300.

[4] C.H. Benson, D.E. Daniel and G.P. Boutwell: Field performance of compacted clay liners, J. Geotech. Geoenviron. Eng.,. 125 (5) (1999) 390–402.

[5] R.N. Collins, F. Merrington, M.J. Mclaughlin and J.L.Morel, Organic ligand and pH effects on isotopically exchangeable Cd in polluted soils, Soil Sci. Amend. J. (67) (2003) 112–121.

[6] Thorton et al., Attenuation of landfill leachate by clay liner materials in laboratory columns, Waste Manag. Res., (1) (2001) 70-88.

[7] K.R. Rowe, M. ASCE, J.R. Booker, 1-D pollutant migration in soils of finite depth, J. Geotech. Eng, ASCE., 111(4) (1885) 479–497.

[8] R.W. Grimshaw, The chemistry and physics of clays and allied ceramic materials, Ernest Benn Limited. Fourth Edition, London, pp. 29–34, 1971.

[9] W.D. Kemper and J.B. Rollins: Osmotic Efficiency Coefficients across Compacted Clays, Soil Physics, Proceedings of Soil Science Society of America, pp. 529–534, 1966.

[10] C.H. Benson and D.E. Daniel, Minimum thickness of compacted soil liners: I. stochastic models, J. Geotech. Eng., 120 (1) (1994) pp. 129–152.

[11] C.H. Benson and D.E. Daniel, Minimum thickness of compacted soil liners: II. analysis and case histories, J. Geotech. Eng., (120) (1) (1994) 153–172.

[12] F. Fernandez and R.M. Quigley, Hydraullic conductivity of natural clays permeated with simple liquid hydrocarbons, Can. Geotech. J. 22 (1985) 205–215.

[13] R.W. Gillham, M.J.L. Robin and D.J. Dytynyshyn, Diffusion of nonreactive and reactive solutes through fine-grained barrier materials, Can. Geotech. J. 21 (1984) 541–550.

[14] F.S. Barone, E.K. Yanful, R.M. Quigley and R.K. Rowe, Effect of multiple contaminant migration on diffusion and adsorption of some domestic waste contaminants in a natural clayey soil, Can. Geotech. J., 26 (1989), 189–198.

[15] R.L. Johnson, J.A. Cherry and J.F. Pankow, Diffusive contaminant transport in natural clay: A field example and implications for clay-lined waste disposal sites, Environ. Sci. Technol., 23 (3) (1989) 340–348.

[16] C.D. Shackelford, D.E. Daniel and H.M. Liljestrand, Diffusion in inorgamic chemical species in compacted clay soil, J. Contam. Hydrol., 4 (1989) 241–273.

[17] M.A. Estévez, E.L. Periago, E.M. Carballo, J.S. Gándara, J.C. Mejuto and L.G. Rıo, The mobility and degradation of pesticides in soils and the pollution of groundwater resources, J Agric. Ecosyst. Environ., 123 (2008) 247–260.

[18] E. Kalkana and S. Akbulut: The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners, Eng. Geol., 73 (2004) 145–156.

[19] G.P. Broderick and D.E. Daniel, Stabilizing compacted clay against chemical attack, J. Geotech. Eng. ASCE, 116 (10) (1900) 1549–1567.

[20] S. Comeau and M.A.Caissie, Liner construction using tills composed of weekly cemented particles, Proceedings 3rd International Congress on Environmental Geotechnics, Lisbon, Portugal, pp. 77–82, 1998.

[21] P. Saha, S. Datta and, S.K.Sanyal, Hazardous Waste Pollution Prevention Using Clay With Admixture, Clean-Soil, Air, Water, Wiley InterScience, Volume 36, Issue 2, pp. 230 – 238, 2008.

[22] M.L.Jackson, Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd., New Delhi, 2nd edition, pp.57–262.