



## Compact soil liner membrane as a potential alternative technology to wastewater treatment

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### ABSTRACT

Of the various methods available for providing better and effective treatment of wastewater, the method of using compact liner membrane prepared from bentonite, cement, lime, gypsum etc with clayey soil was explored in the laboratory scale experiments. The primary purpose of the liner membrane was to isolate the wastewater contents and, therefore, to protect the soil and ground water from pollution. Low porosity, slow diffusive transport, high adsorption of cations, and plasticity / swelling is some of the interesting properties of clay which makes it desirable as a liner membrane material. The metal concentration of wastewater passing through the compact liner were found to be below permissible limit and the metal concentration reduced to 87%, 96.33%, 90.4 % and 99% for zinc, copper, cadmium and lead respectively from their original concentration in wastewater. The present findings suggest that compact liner membrane can be used as a potential alternative technology to wastewater treatment.

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### Introduction

When a body of water is adversely affected due to the addition of large amount of materials to the water, water pollution is occurred. When water is unfit for its use, water is considered as polluted. Water pollution [1-3] is not a problem that only takes nature's beauty away, but it also sabotages the living environment for all organisms. The poisonous substances that can be found in waters may cause a harsh lack of oxygen for these aquatic organisms causing them to eventually die out. This pollution would also severely infect water with different types of bacteria and diseases, and this water that we drink and wash may be polluted. Therefore, the disadvantages of water would gradually transfer to us, causing horrible illnesses as well as other miserable conditions.

Hazardous waste is the type of waste that makes it dangerous or potentially harmful to human health and the environment. Due to its quantity, concentration, or physical, chemical, or infectious characteristics may:

- Pose a substantial present or potential hazard to human health or the environment when it will be used improperly treated, stored or disposed of, or otherwise mismanaged; or
- Cause or contribute to an increase in mortality, or an increase in irreversible or incapacitating illness.

The liner membrane [4] is an impermeable membrane which is laid down under the engineered landfill sites and its function is to prevent toxic leachate permeating down into the underlying aquifers or nearby rivers causing spoiling of the local water. The primary purpose of the liner system is to isolate the landfill contents from the environment, groundwater and, therefore, to protect the soil and ground water from pollution originating generally in the landfill.

If hazardous waste or leachate is disposed without any proper arrangement of landfill, the landfill and the groundwater will be contaminated through the hazardous chemicals present in waste. So to dispose any hazardous waste to a landfill, liner is used which protects the landfill as it is a barrier to fluid movement. The overall objective is to limit the discharge of toxic contaminants to groundwater and so liner is the final line of defense against groundwater contamination. To protect the ground water from landfill contaminants, clay liners is the simple liner among the various types of liner.

Clay minerals are the most important components of soil and can be turned fine grain particles when crushed and pulverized or plastic material when wetted or hard when dried [5-7]. On firing soil can be converted to rock line mass. Clay is a term which is used to describe a group of hydrous phyllosilicate of aluminium that are typically less than two micrometer in diameter. Clays are distinguished from other small particles present in soils by their small size, flake or layered shape, affinity for water and tendency toward high plasticity. Clay minerals are composed of two basic building blocks of Silicon-Oxygen Tetrahedron ( $\text{Si}_2\text{O}_5^{2-}$ ) and Aluminium Octahedral (Gibbsite sheet)  $\text{Al}(\text{OH})_6^{3-}$ . Low porosity, slow diffusive transport, high adsorption of cations, and plasticity / swelling etc are the interesting properties of clay. Some clay soils have the ability to act as membrane that restricts the passage of charged solutes also. 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 [8-21].

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For using clay as liner materials, the standard criteria are:

- i. The clay % in a given soil should be higher than 20% etc.
- ii. Plasticity index should be >10 and Liquid limit should be >30.

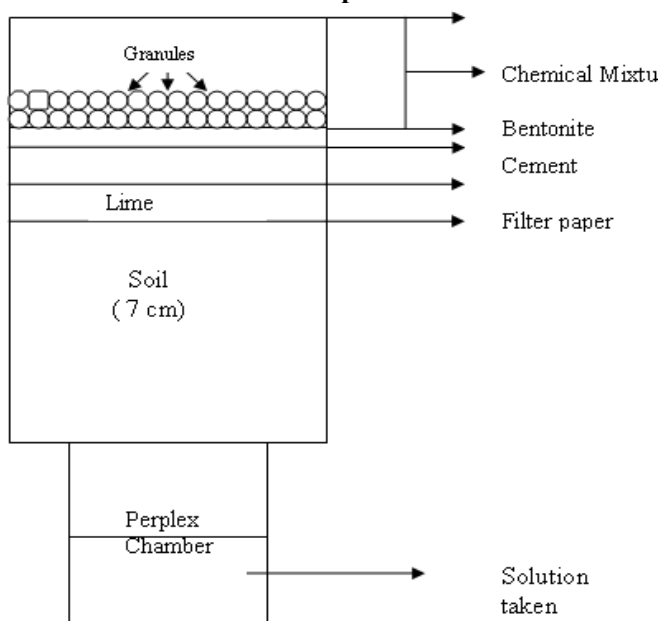
The problems of using clay liners are diffusion, desiccation, leakage through clay liner etc. As a consequence, the concentrated chemicals inside a landfill tend to move steadily through the bottom of the clay liners. Clay liner can also be affected by the chemical wastes or leachate directly or indirectly. The interaction of soil with the chemical waste may attack the double diffuse layer of clay. 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 are used with soil and compact soil – admixture liner [22 – 24] is prepared to stabilize the liner from chemical attack and to decrease the porosity of soil particles. If different admixture materials like cement, lime, bentonite etc are mixed with this soil it is observed that soil – cement mixture act as better liner materials than other soil – admixture medium [24].

In the present study, clayey soil was collected from river of Matla, West Bengal, India and physical - chemical properties of the soil was determined using standard methods in laboratory scale [24]. Compact soil – admixture membrane was prepared using different admixtures with soil and the efficiency of the liner is verified. The overall objective of the work was to assess the compact liner effectivity for treatment of hazardous waste water.

### Experimental

The soil was collected from the river of Matla and is air dried for 24 hours at 110<sup>0</sup> C. The air dried soil was mixed with a fixed amount of water to saturate the soil and was used as liner materials for the further experiment.

**Figure 1: Schematic representation of the experimental setup**



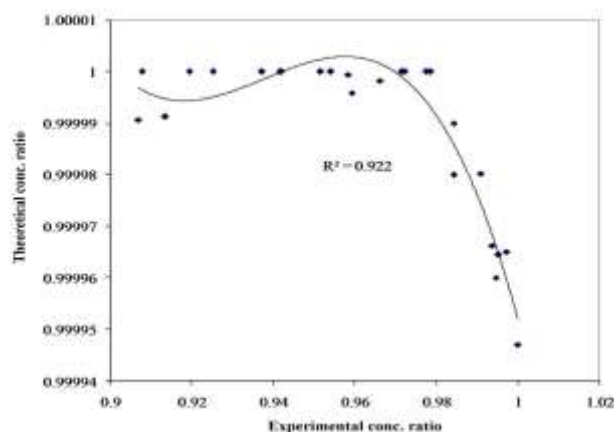
Soil was air dried, crushed and to it admixture was added separately. Distilled water was added to the mixture to the ultimate optimum water content. The sample bed was prepared from different layers of soil – admixtures medium. The composite layers were made of soil (7 cm), soil with 10% cement (of 1.5 cm height), soil with 10% bentonite (of 1.5 cm height) and soil with 10% lime (of 1.5 cm height), i.e. total

height of composite liner was 11.5 cm from lower to upper level respectively. The gravels particles were placed on the compact liner. The gravel particles were taken to tighten the soil membrane from flocculation in presence of solution. All the specimens were permeated in 15 cm long and 10 cm diameter sample port and permeated first with water. The mixture solution was placed over the soil liner and the solution was passed through the membrane. The solution passing through the compact liner membrane was collected at the perspex chamber and analysed using standard procedure. The different layers were used above soil liner [Figure 1]. The reasons for using the different layer are as follows:

**Soil – Lime mixture:** lime was also a good admixture for the purpose. Acidic waste can be neutralized in presence of lime over soil liner. The acidic wastes had better effect on soil membrane than basic or neutralized membrane. So, soil – lime mixture was chosen as upper layer for the compact liner medium.

**Soil – Bentonite mixture:** the permeability through soil - bentonite layer was very low than that of soil liner. So the metal and suspended particles transportation through the compact liner can be reduced.

**Figure 2: Plot of experimental versus theoretical concentration ratio of Lead ions passing through the compact membrane at different time intervals.**



**Soil – Cement mixture:** From the literature [21-24], it was observed that cement was the best material which can resist the effect of waste chemical attack on soil liner, permeability through soil - cement mixture was also very low. So the chemical waste passing through bentonite liner can not pass through the soil - cement liner.

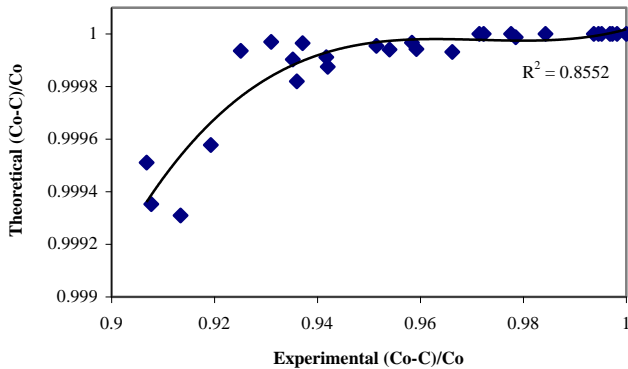
**Soil :** After passing through above four different layer, the remaining waste was passed through soil liner.

The composition of waste water solution was 31.5% Lead nitrate, 21.88% Cadmium chloride, 22.58% zinc sulphate, 24.04% copper sulphate by weight percentage. The wastewater passing through the composite liner was collected at a Perspex chamber below the sample port. As the amount of sample passing through the composite liner was very low, 100 ml distilled water is kept at the Perspex chamber and sample was collected and analysed.

The concentration of metal passed through the compact membrane was extracted using standard procedure and measured using Atomic Absorption Spectrophotometer (Model: AANALYST 200, Perkin Elmer]. The metal ion passing through the above mentioned soil bed was collected till 109 days to a Perspex chamber where a fixed amount of deionized water was

kept. The various properties of the solution at Perspex chamber like concentration, chemical oxygen demand, total solid, pH etc were determined using standard methods.

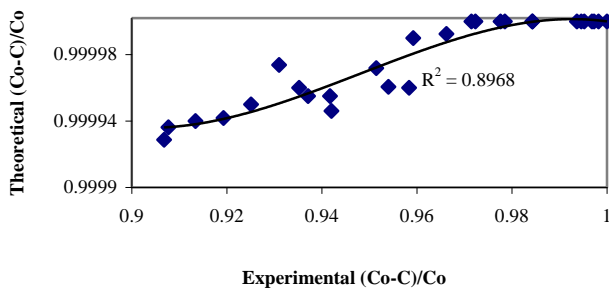
Figure 3: Experimental and theoretical concentration ratio of cadmium ions passing through the comoaact membrane at different times.



Permeability of the soil can be determined on the basis of Darcy's law for flowing of solution through soils. For it the variable – head parameter was used. The steps for using the Variable – head permeameter are:

- The stand pipe was filled with water and the stop cock at the top of the permeameter was closed after the expulsion of all the air from the rubber tube and connecting pipe.
  - Soil was saturated with water for 24 hours.
  - The standpipe was filled with water and clamp was released.
  - The flow of water was stopped when the water level in the stand pipe falls through a sufficient distance and time was noted.
  - Five sets of independent readings were taken and coefficient of Permeability, k was found out.
- 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).

Figure 4: Experimental and theoretical concentration ratio of copper ions passing through the compact membrane at different times.



Moisture content of the sample was determined using certain amount of the collected sediment (about 40gm) was taken and weighed. It was kept for drying in a tray drier (Manufacturer: Amalgamated Suppliers, Kolkata) until a constant weight was obtained. Then it was cooled and weighed. The moisture content can be calculated as-

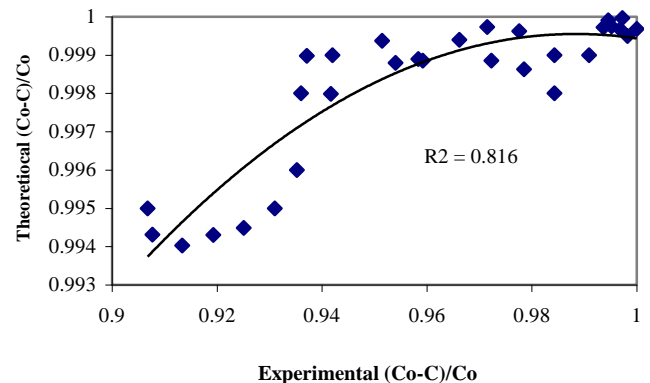
$$\% \text{ Moisture} = \frac{(\text{Initial weight}-\text{Final weight}) \times 100}{\text{Initial weight}}$$

The plastic limit was the water content, in percent, at which the soil passes from a plastic state to a brittle state. It was 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 grams 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 minutes with a spatula. In order to facilitate mixing, the water should be added in small quantities. 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 10mm. The number of taps required to close the groove across this distance was recorded and a sample of approximately 2 to 3 grams, 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 was then expressed as a percentage of the oven-dried mass of soil.

Figure 5: Experimental and theoretical concentration ratio of zinc ions passing through the compact membrane at different times.



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 ppm (mg/l) level ( Model: AANALYST 200, Perkin Elmer)

The concentration of metal passed through soil bed through different height as well as the metal concentration at the lower portion of the membrane (as aqueous solution) was extracted using standard method and concentration was determined using Atomic Absorption Spectrophotometer. The Total solid, pH etc characteristics of the aqueous solution were also determined using standard methods.

Considering bed of soil of constant thickness x and permeability  $k_1$ , a mass balance was set up in which concentration C is dependent on time, t. 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. The resulting 1<sup>st</sup> order differential equation is as follows:

$$V \frac{dC}{dt} = Ax \left[ \frac{k_1 (C_0 - C)}{x} \right] \text{----- (1)}$$

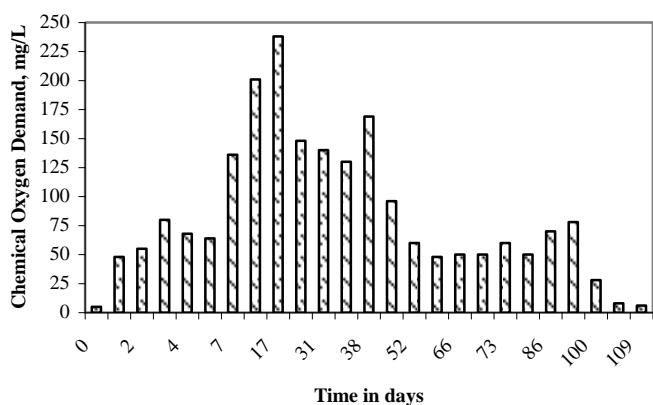
where, A is the cross sectional area of the bed, x is the thickness of the bed and  $k_1$  is the coefficient of permeability of the sample which depends on sample ion composition and soil properties, V = volume of the soil bed.

With the initial concentration so given, the solution is given below:

$$\frac{(C_0 - C)}{C_0} = \exp\left(-\frac{k_f t}{x}\right) \quad \text{----- (2)}$$

The properties of the clayey soil which was used for the experiment were: pH of the soil was 7.49, clay % was 27, moisture content was 26%, liquid limit was 48, plastic limit was 24, plasticity index was 24, permeability was  $0.99 \times 10^{-9}$  m/sec. It was observed that the properties of soil fulfill the properties of liner materials as the clay % was 27% (>20%), permeability was low, plasticity index was greater than 10%, and liquid limit was also greater than 30% [25, 26].

**Figure 6: Chemical Oxygen Demand of the solution passing through the compact membrane and collected at perspex chamber**



## Results and Discussion

Concentration of different metals at the Perspex chamber after 109 days of experiment are: lead: 0.01 ppm, cadmium: 0.55 ppm, copper: 0.3 ppm, Zinc: 0.28 ppm. The concentrations of all the metals passing through the prepared liner have been shown in Table [1]. It is observed that the metal concentration and all the other parameters increases first and after some certain time period, the parameters are decreased. After a certain time period, it is observed that by addition of metal solution at the upper layer of the compact liner, the concentration of the solution at the Perspex chamber is not increased so much. So addition of metal solution at the upper layer of the liner have less effect on the solution collected at Perspex chamber at that time. It is also observed that the metals concentration passing through the liner and collected at the Perspex chamber are below permissible limit.

Due to soil- lime mixture layer, the acidic materials present in wastewater sample will be neutralized. After passing through the soil – lime mixture medium, waste water is passing through soil – bentonite mixture medium. Bentonite itself has a very lower permeability than soil as clay% in bentonite is higher than other type of soil. So the heavy metals bind through soil - bentonite mixture level and the rest of the waste is contact with the soil – cement mixture. Soil with cement mixture decreases the porosity of the soil by cementing the pore space of soil and as a result it increases the strength of liner. So, the rest of the heavy metals passing through the soil – bentonite mixture are restricted to transport through the soil – cement mixture medium. After passing through the soil – cement mixture, the rest of the waste is passing through the soil layer of 7 cm thickness.

From the experimental results [Table 2], it is observed that the concentrations of metal ions are decreased from upper level to lower level of compact liner. For lead ion it is 99.5%, for cadmium it is 90.4%, for copper it is 96.33% and for zinc it is 87.65 %. As the metal ions cannot passed through the compact liner made of different soil – admixture medium, the % reduction of metal ions are greater than 87%. As the metal ions adsorbed by the clay – admixture membrane, the concentration of the metal passing through the compact membrane is lower than the original concentration of the metals.

Using material balance equation and from Figure [2-5], it is observed that in case of different metal ions, the nature of the curves for the compact soil-admixture are same in nature and regression coefficients for all the curves are very high (0.923 >0.8). As binding rates of lead with soil is very high, the lead particles bind with soil – admixture bed and the transport of the metal through the soil – admixture bed is low [Figure 2]. In case of cadmium ion, the regression coefficient for the compact soil – admixture is also high (0.855 >0.8) [Figure 3]. In case of copper ion, the regression coefficient for the compact soil – admixture is also high (0.897 >0.8) [Figure 4]. In case of zinc ion, the regression coefficient for the compact soil – admixture is also high (0.816 >0.8) [Figure 5]. As the ionic radii of zinc is lower than other metals and binding effect (mainly adsorption) of zinc with soil is lower, it can permeate through the double diffuse layer of the liner and as a result the permeation rate through the soil membrane is higher than that of the other metals. As a result zinc metal can permeate through the soil membrane higher than other metals, but from experimental results it is observed that the concentration of solution passing through the membrane is below permissible limit. From Table 1 and Figures it is observed that chemical oxygen demand [Figure 6], total dissolved solids [Table 1], salinity [Table 1] of the aqueous solution collected at Perspex chamber increases when the metal concentration increases and parameters decreases as metal concentration decreases.

## Conclusion

From the experimental study using different admixtures with clay it is observed that using clay with different admixture the effect of heavy metals of wastewater can be reduced from 50 -90% than the waste original concentration of metals. Using the admixture like cement, bentonite, lime etc with soil, and the soil porosity is densified. As a result permeability of waste water through the membrane decreases, attack of metal ions on soil liner and on groundwater contamination is minimized. Soil is easily available and the amount of cement, bentonite, lime require for the membrane is very low only 5 - 10% of the original soil sample. So, the preparation cost of the membrane is very low than the membrane prepared from geotextile or geomembrane. So it can be concluded that the compact soil – admixture membrane can be used as liner materials for the treatment of wastewater.

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**Table 1: Characteristics of wastewater collected at perspex chamber**

Sample (mL)	Time (days)	TDS (ppm)	TS (ppm)	pH
100	0	200	985	6.87
100	1	567	1340	7.33
100	2	491	1280	7.0
100	3	681	1850	7.16
100	6	313	1070	6.97
100	7	431	987	7.08
100	10	649	1540	7.14
100	17	1820	3500	7.63
100	24	2001	2900	7.72
100	31	565	1510	7.03
100	32	1280	2950	7.52
100	38	800	1645	7.42
100	46	602	1165	7.64
100	47	542	1215	7.07
100	52	870	2400	7.75
100	55	602	1165	7.35
100	60	542	1815	7.52
100	66	659	1191	7.57
100	67	450	1091	7.11
100	73	340	780	7.48
100	74	398	485	7.08
100	79	216	471	7.14
100	86	412	625	2.11
100	93	228	525	3.51
100	100	176	460	7.74
100	109	91	425	7.99

**Table 2: % Reduction and concentration of different heavy metal ions at the different layers of compact membrane**

<i>Position of soil liner</i>	<i>Pb (mg kg<sup>-1</sup>)</i>	<i>Cd (mg kg<sup>-1</sup>)</i>	<i>Cu (mg kg<sup>-1</sup>)</i>	<i>Zn (mg kg<sup>-1</sup>)</i>
Upper level	886	614	1483	590
Lower level	3.76	58.98	54.44	72.85
% of reduction	99.51	90.39	96.33	87.65